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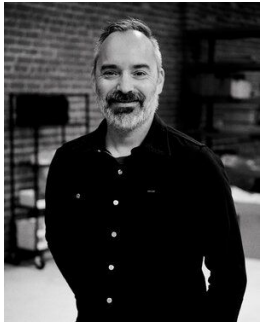
Democratizing Mobile Manipulation

Aaron Edsinger, Ph.D.
Co-founder & CEO

Charles Kemp, Ph.D.
Co-founder & CTO

Founding Team



Aaron Edsinger, Founder & CEO

- Founder Meka Robotics and Redwood Robotics
- Former Director of Robotics, Google
- PhD MIT CSAIL
- Built Meka and Redwood Robotics and sold to Google
- World expert on design for robot manipulation

Charlie Kemp, Founder & CTO

- Associate Professor, Georgia Tech
- Founder & Director of the Healthcare Robotics Lab
- PhD MIT CSAIL
- World expert on assistive mobile manipulation

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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.

Georgia Tech

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Outline

Stretch Design

Stretch Community

Collaboration with Prof. Rogers

Live Demo

Pitch Competition

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Stretch Research Edition

“Beautifully Simple, Clever Robot Design”

- IEEE Spectrum

Hardware & Software Platform

- $19,950 for a complete mobile cobot
- Lightweight (51lb)
- Slender & Compact
- Contact Sensitive
- Open Source Code
- Python & ROS

The Design of Stretch

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Cornell University

We gratefully acknowledge support from the Simons Foundation and member institutions.

arXiv.org > cs > arXiv:2109.10892

Search... All fields Search

Help | Advanced Search

Computer Science > Robotics

[Submitted on 22 Sep 2021]

The Design of Stretch: A Compact, Lightweight Mobile Manipulator for Indoor Human Environments

Charles C. Kemp, Aaron Edsinger, Henry M. Clever, Blaine Matulevich

Mobile manipulators for indoor human environments can serve as versatile devices that perform a variety of tasks, yet adoption of this technology has been limited. Reducing size, weight, and cost could facilitate adoption, but risks restricting capabilities. We present a novel design that reduces size, weight, and cost, while still performing a variety of tasks. The core design consists of a two-wheeled differential-drive mobile base, a lift, and a telescoping arm configured to achieve Cartesian motion at the end of the arm. Design extensions include a 1 degree-of-freedom (DOF) wrist to stow a tool, a 2-DOF dexterous wrist to pitch and roll a tool, and a compliant gripper. We justify our design with mathematical models of static stability that relate the robot's size and weight to its workspace, payload, and applied forces. We also provide empirical support by teleoperating and autonomously controlling a commercial robot based on our design (the Stretch RE1 from Hello Robot Inc.) to perform tasks in real homes.

Comments: 6 pages plus references, 7 figures
Subjects: **Robotics (cs.RO)**
Cite as: arXiv:2109.10892 **[cs.RO]**
(or arXiv:2109.10892v1 **[cs.RO]** for this version)

Submission history

From: Henry M. Clever [view email]
[v1] Wed, 22 Sep 2021 17:56:51 UTC (11,297 KB)

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[The Design of Stretch: A Compact, Lightweight Mobile Manipulator for Indoor Human Environments](), Charles C. Kemp, Aaron Edsinger, Henry M. Clever and Blaine Matulevich, arXiv, 2021.

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Building Brains for Bodies, Rodney A. Brooks and Lynn Andrea Stein, MIT AI Lab Memo 1439, August 1993.

The first Roomba from 2002.
Almost 20 years ago!

Millions of Roombas Sold vs. Year

Bodies and Brains Working Together

- Body matched to ecological niche
  - Small footprint
  - Circular and flat
  - Giant contact sensor
  - Easy for people to pick up and move
- Brain matched to the body
  - Haptic sensing as primary modality
  - Change direction on contact
  - Wall following
  - Spiraling

“Viewed as a geometric figure, the ant’s path is irregular, complex, and hard to describe. But its complexity is really a complexity in the surface of the beach, not the complexity in the ant.”

Herbert Simon,
The Sciences of the Artificial, 1969

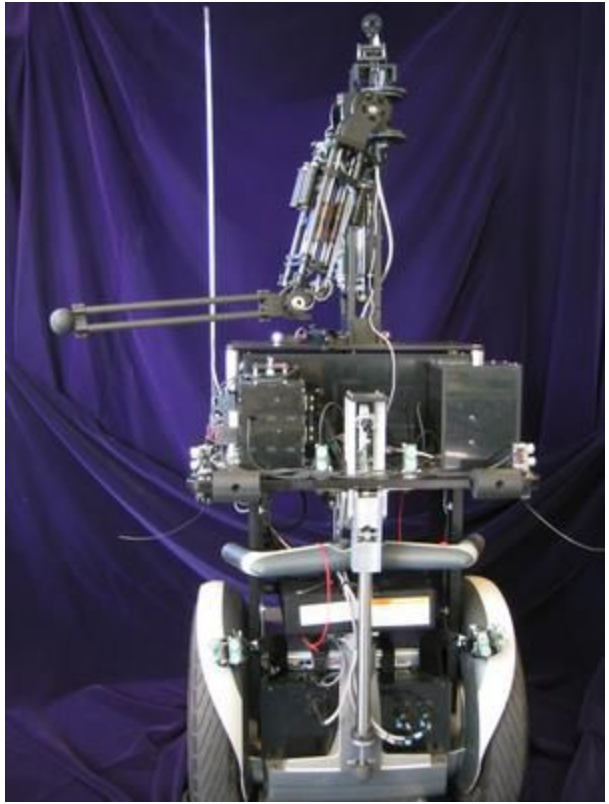
Photo Credit:
Andreas Dantz
Roomba, first attempt
Taken on April 14, 2013
https://www.flickr.com/photos/szene/8649326807/in/pool-roomba/

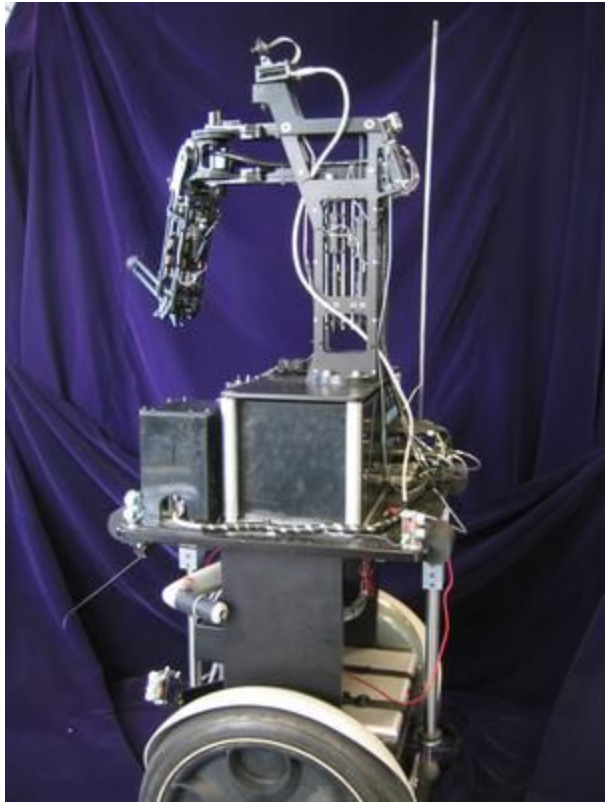
What is the Roomba of mobile manipulation?

What body for **indoor** mobile manipulation in homes and workplaces?

- Flat smooth surfaces
- Visible from human head height
- Reachable by human arms
- Children, older adults, and pets

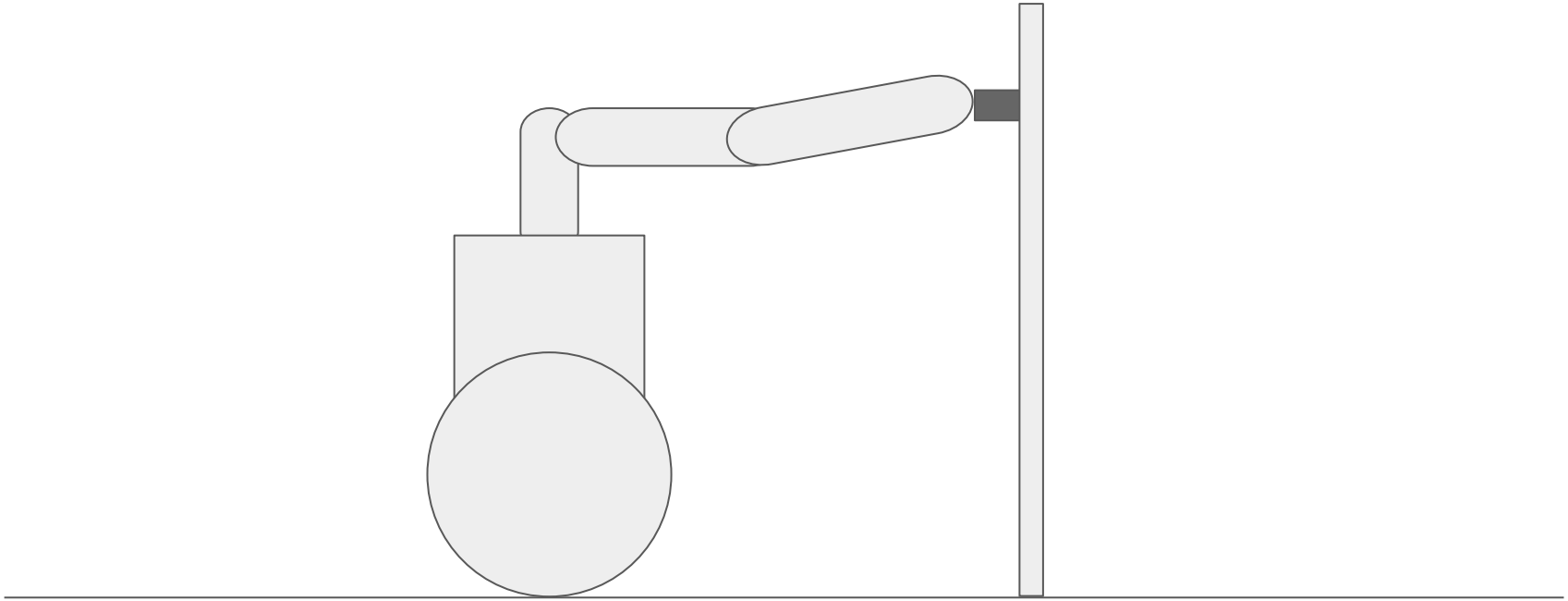
?



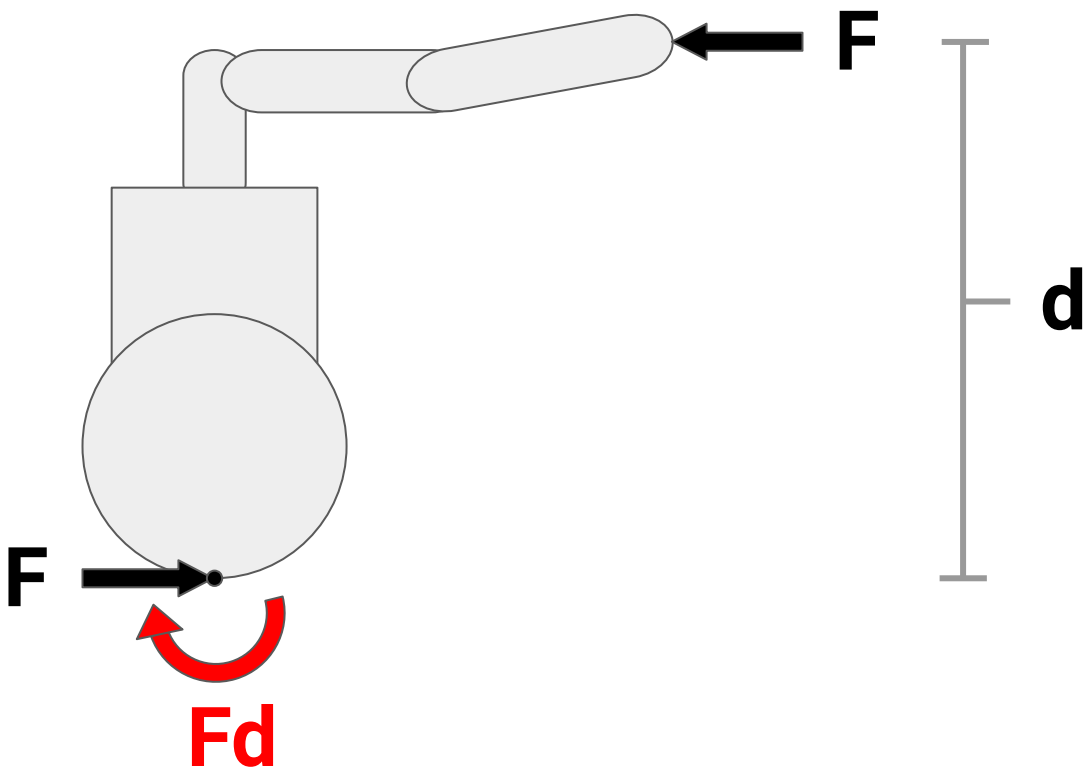


Sensing and Manipulating Built-for-Human Environments, **Rodney A. Brooks**, Lijin Aryananda, **Aaron Edsinger**, Paul M. Fitzpatrick, **Charles C. Kemp**, Una-May O'Reilly, Eduardo Torres-Jara, Paulina Varshavskaya and Jeff Weber. International Journal of Humanoid Robotics, Vol 1, Number 1, pages 1-28, 2004.

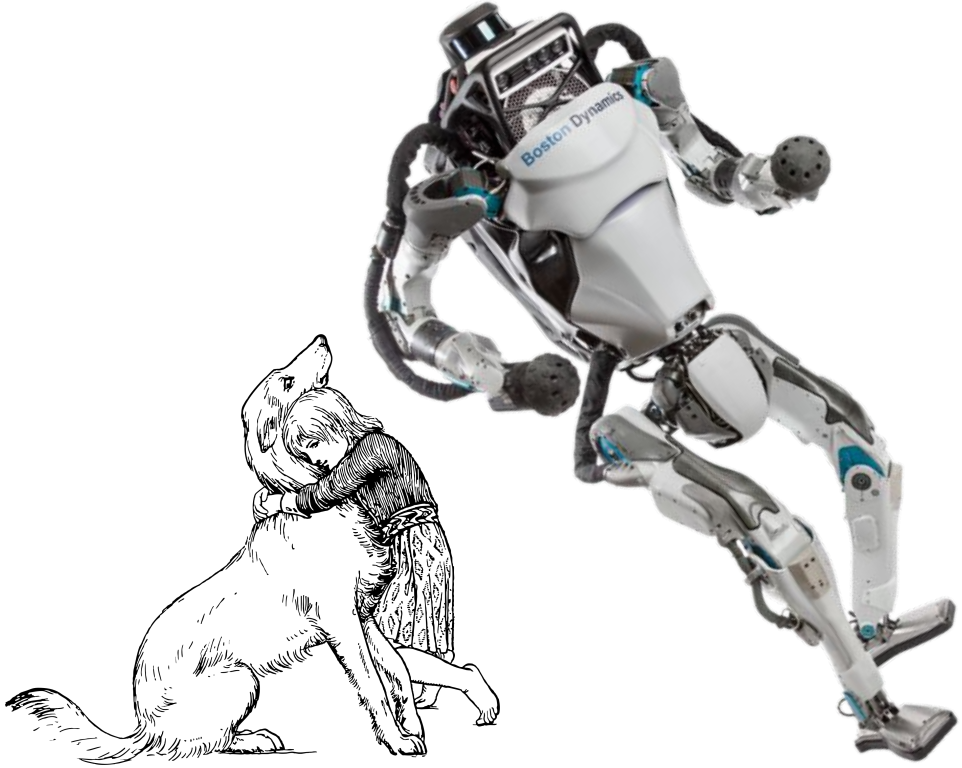
Momentary Problem when Balancing on Wheels



Momentary Problem when Balancing on Wheels



It Just Takes One Fall

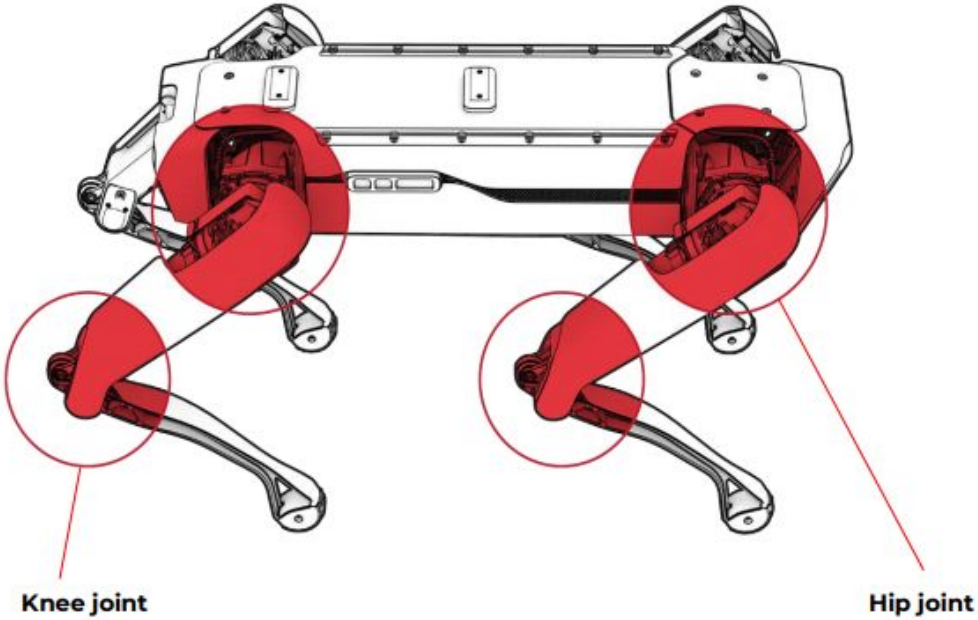


CSAIL

What about quadrupeds?

Pinch Points

Spot's joints can pinch fingers and other body parts and entangle loose clothing, long hair, and jewelry.



BostonDynamics

SPOT INFORMATION FOR USE

V1.0 - Original Instructions

https://www.bostondynamics.com/sites/default/files/inline-files/spot-information-for-use-en.pdf

Dynamic Stability Risks

Spot will always try to keep balance. This may result in high-acceleration motion of the legs

WARNING

Failure in locomotion could happen unexpectedly and could result in de-energization of the robot's actuators.

A failure event may cause loss of stability and potential hazards associated with a fall or tipping over.

Always keep a separation distance of 2 m

BostonDynamics

SPOT INFORMATION FOR USE

V1.0 - Original Instructions

https://www.bostondynamics.com/sites/default/files/inline-files/spot-information-for-use-en.pdf

What is the Roomba of mobile manipulation?

My Lab’s Initial Answer (EL-E)

- 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

Georgia Tech

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.

Georgia Tech

Mobile Manipulators Can Provide Meaningful Assistance

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

Georgia Tech

Georgia Tech's Prototype
March 2017

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

2016	2017		2018	2019	2020

Georgia Tech

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3 years
8 versions
tested in Charlie's home

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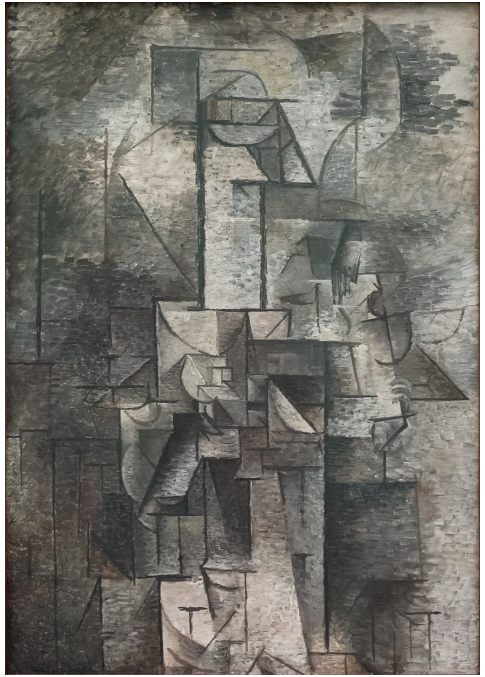
Small, Lightweight, Affordable & Capable

- Static stability constrains capabilities
  - narrower, taller, longer, lighter ⇒ lower payloads & forces
- Degrees of Freedom
  - 4 DOF: minimal proximal actuation for Cartesian end-of-arm motion and base mobility
  - + 1 DOF wrist for stowing tools & planar dexterity
  - + 2 DOF optional wrist accessory for additional dexterity
- Dimensions matched to human environments
  - The human form deconstructed and reassembled (*robotic cubism*)

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

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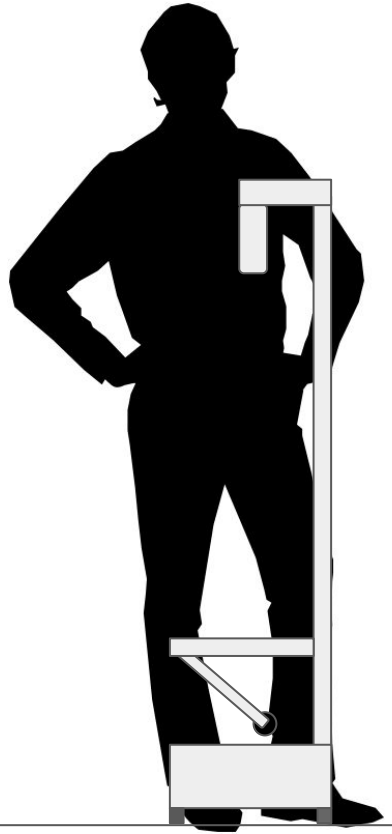
< 50th Percentile Hip Width



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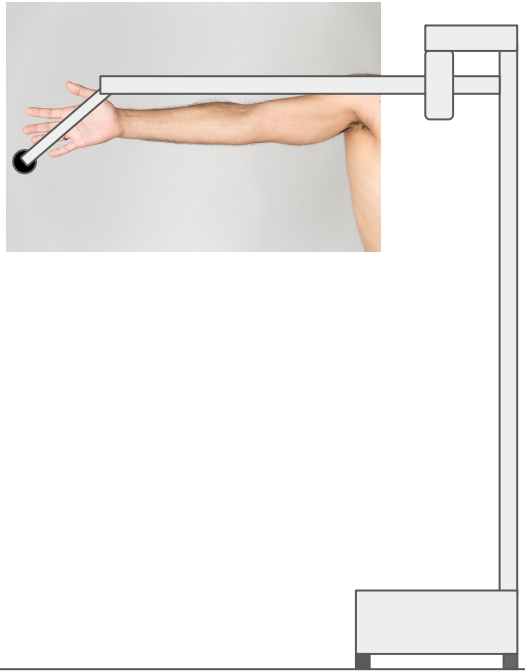
50th Percentile Arm Length



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Reaches 36” Countertops

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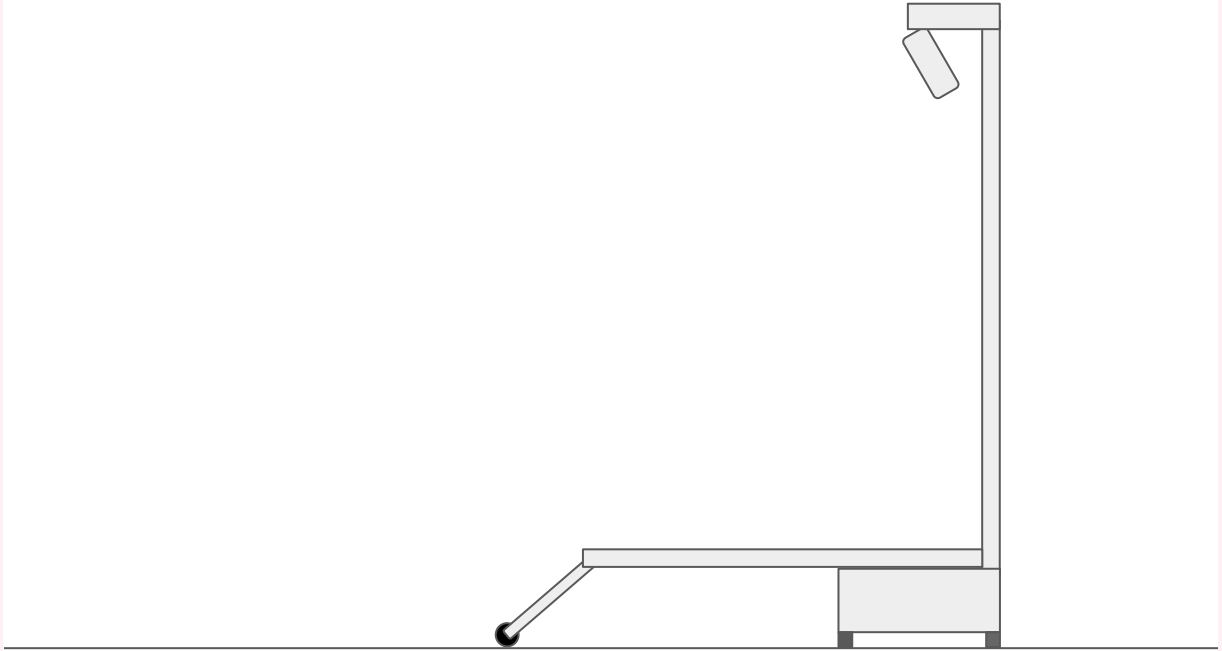
Reaches the Floor



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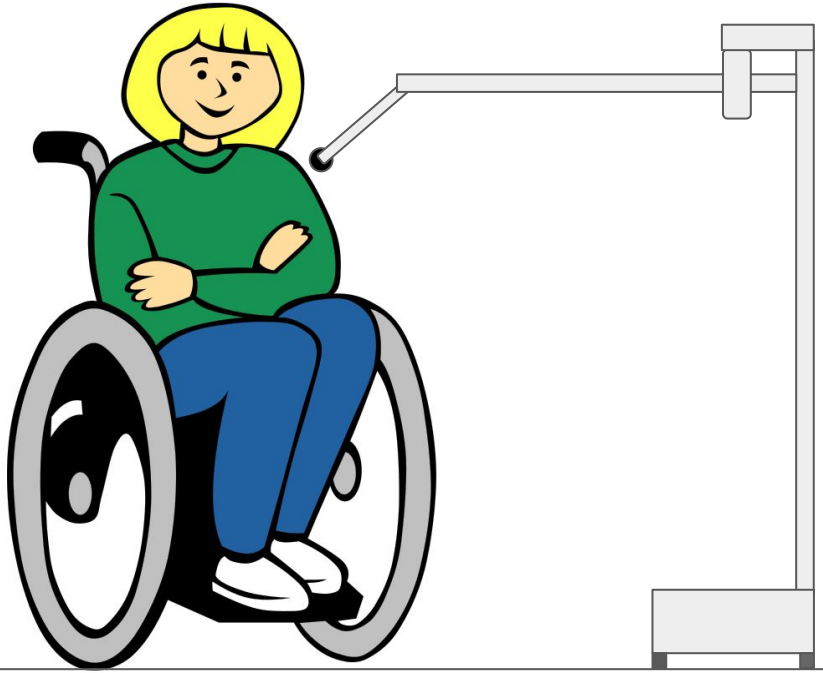
95th Percentile Shoulder Height for Wheelchair Users



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23 kg (51 lb)

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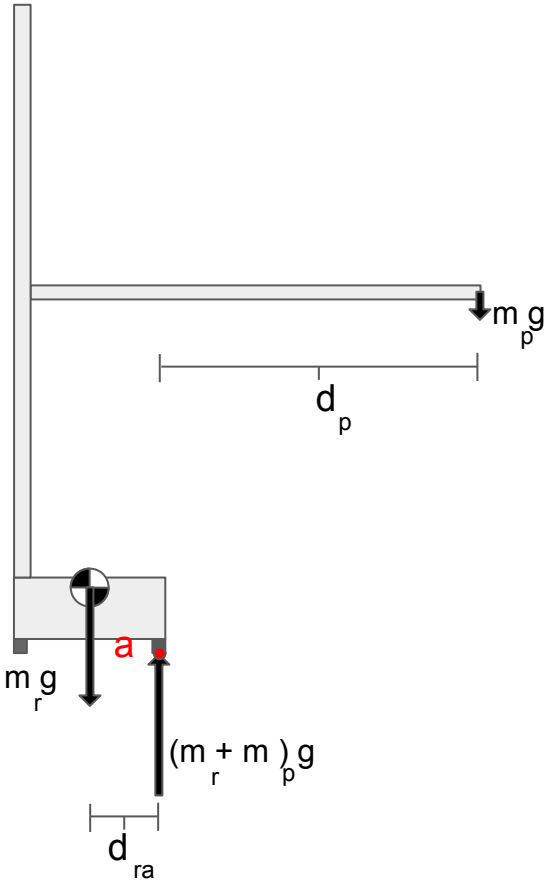
Tipping from Payload



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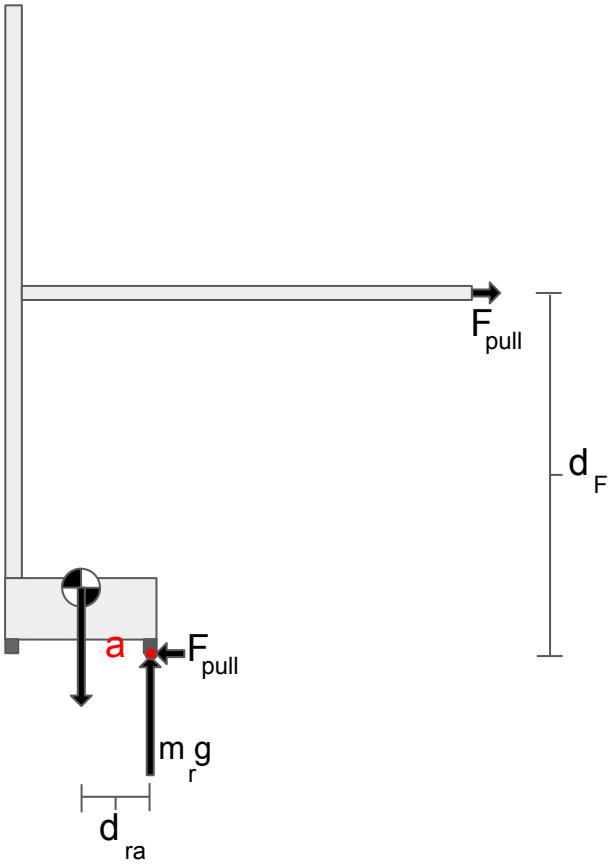
Tipping from Pulling



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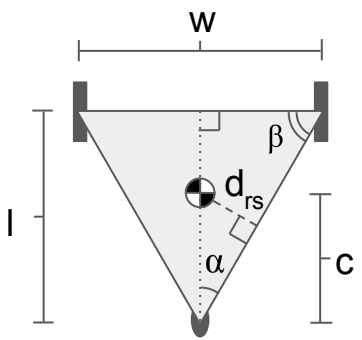
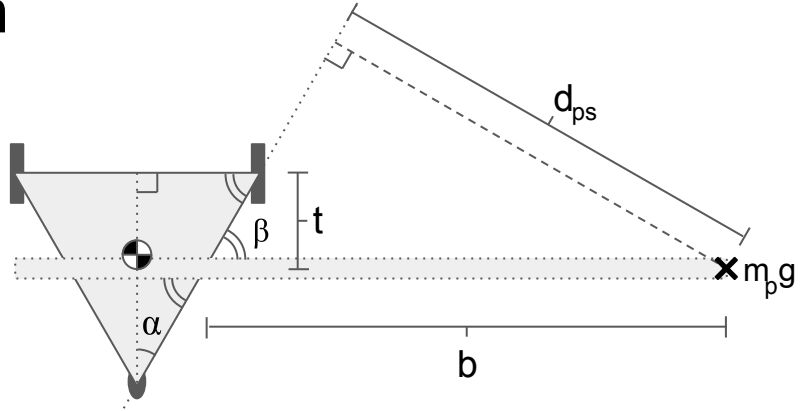
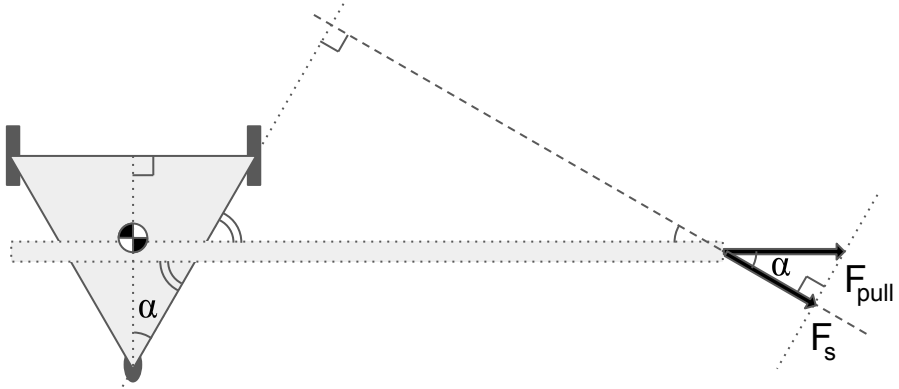
Triangular Support Polygon



Moment Arm (d_{rs}) for the Robot's Center of Mass



Moment Arm (d_{ps}) for the Payload



Tipping Component (F_s) of the Pulling Force

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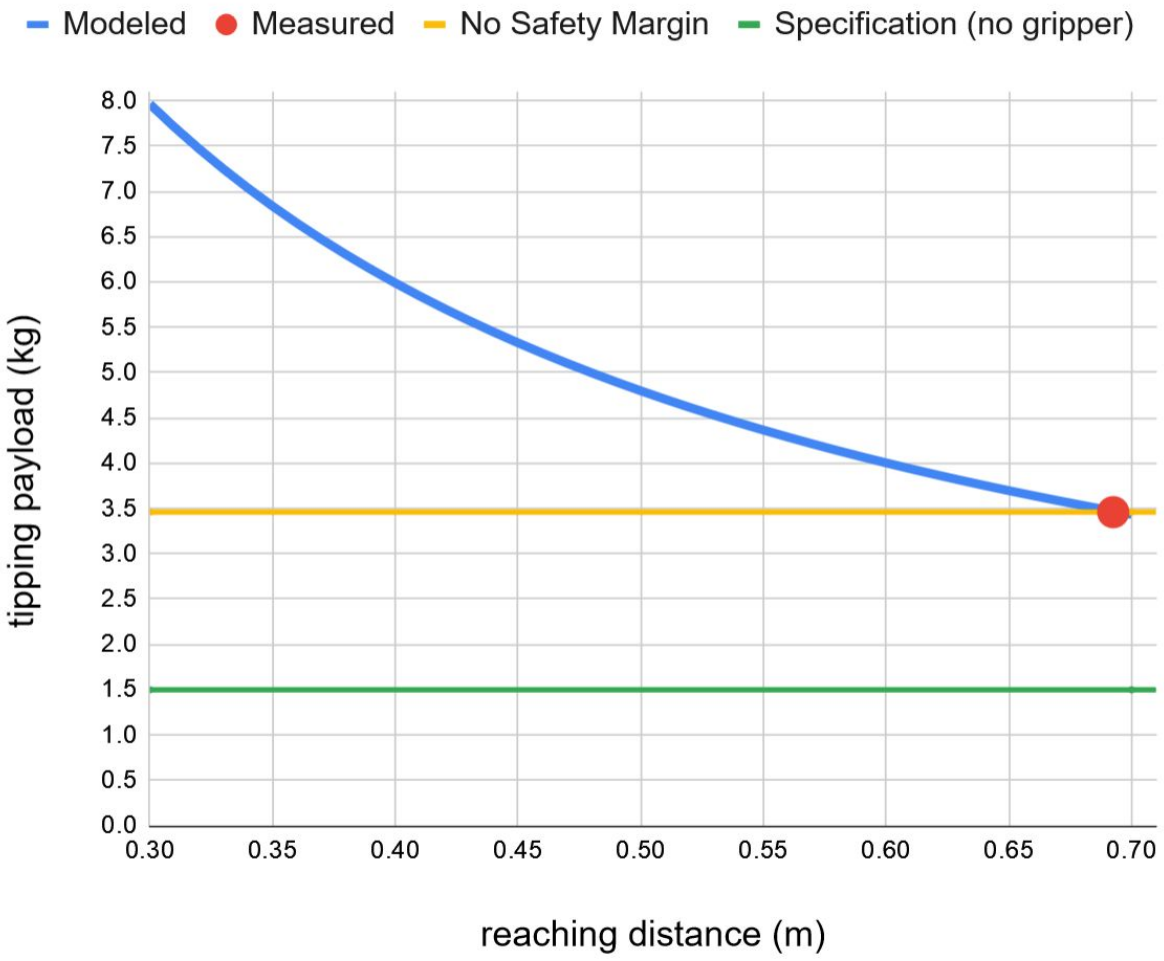
Maximum Payload with Gripper



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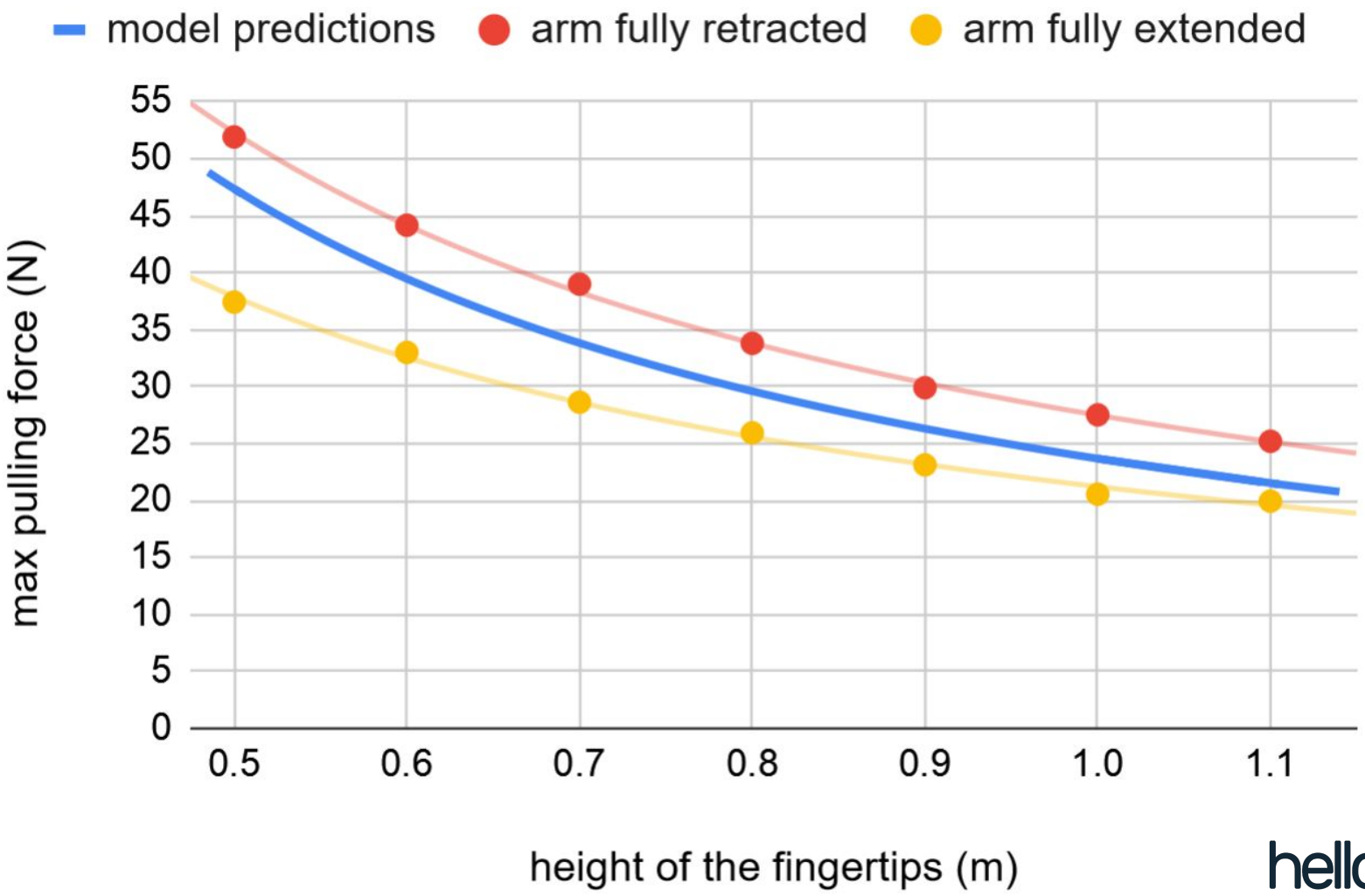
model predictions
arm fully retracted
arm fully extended
max pulling force (N)
55
50
45
40
35
30
25
20
15
10
5
0
0.5
0.6
0.7
0.8
0.9
1.0
1.1
height of the fingertips (m)

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Community is our Priority

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Successful Launch in July 2020

IEEE SPECTRUM Topics Reports Blogs Multimedia

Automaton | Robotics | Home Robots

14 Jul 2020 | 4:01 GMT

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

RBR 50 INNOVATION AWARDS

BBC Sign in Home News Sport Reel Wo

NEWS

Home | Prince Philip | Coronavirus | Video | World | US & Canada | UK | Busines

Tech

Research robot helps with housework and other news

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Our North Star

Robots that improve life for everyone.

It will take time.

We can’t do it alone.

Let’s build the future together

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AUBURN UNIVERSITY
avanade
Carnegie Mellon University
THE UNIVERSITY OF CHICAGO
UNIVERSITY OF Cincinnati
Cornell University
Georgia Tech
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN
JOHNS HOPKINS UNIVERSITY
Microsoft
Massachusetts Institute of Technology
NYU
OSAKA UNIVERSITY
Pacific University Oregon
PICKNIK
R4H
Rensselaer
RICE
robust AI
ROCOS
Sandia National Laboratories
UC San Diego
UNIVERSITY OF CALIFORNIA SANTA CRUZ
UCLA
UMASS LOWELL
umbrella research
VIAM
UNIVERSITY of WASHINGTON
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON
Yale

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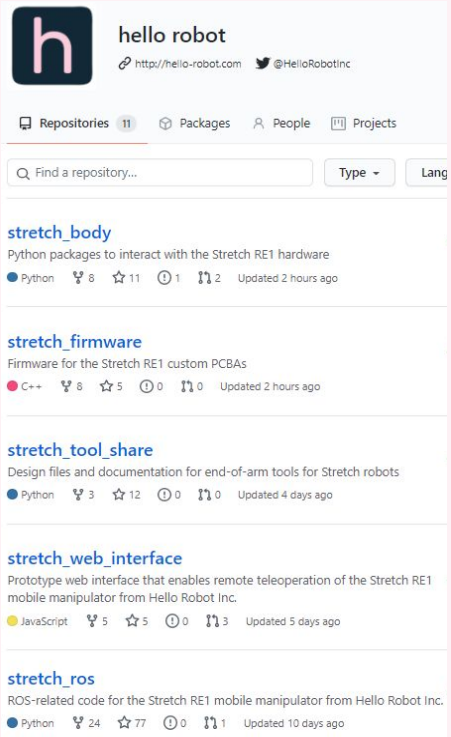
Transparency & Openness

Simple Pricing
hello-robot.com

Open Source & Open Development
github.com/hello-robot

Open Hardware Accessories
github.com/hello-robot/stretch_tool_share

Open Forum
forum.hello-robot.com



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Human Fusions at ANA Avatar XPRIZE Semifinals

Prof. Veronica Santos from UCLA

http://humanfusions.org/ana-avatar-xprize.html

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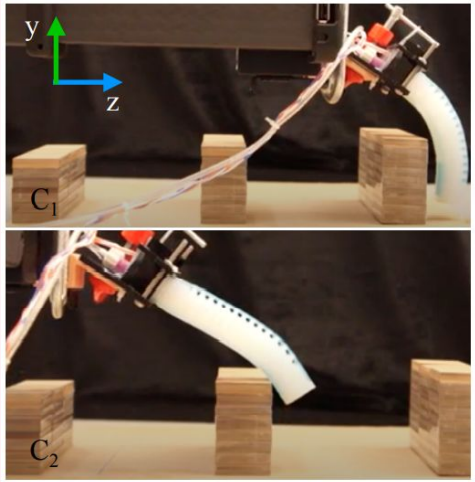
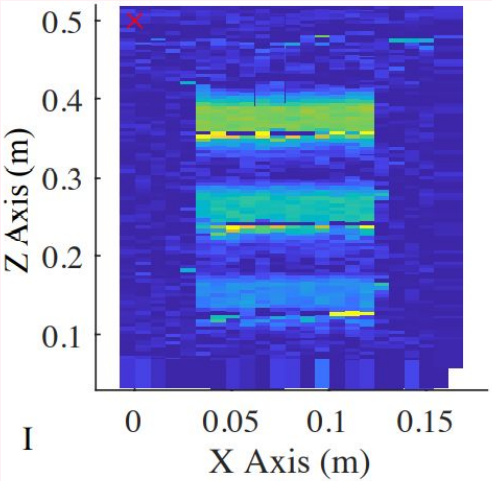
Soft Robotics at UC Santa Cruz

Megan Boivin, PhD





Boivin, Megan. "Study of Kinesthetic Feedback Control for Compliant Proprioceptive Touch for Soft Robotic Finger-Like Actuators." **PhD dissertation**, University of California, Santa Cruz, 2021.

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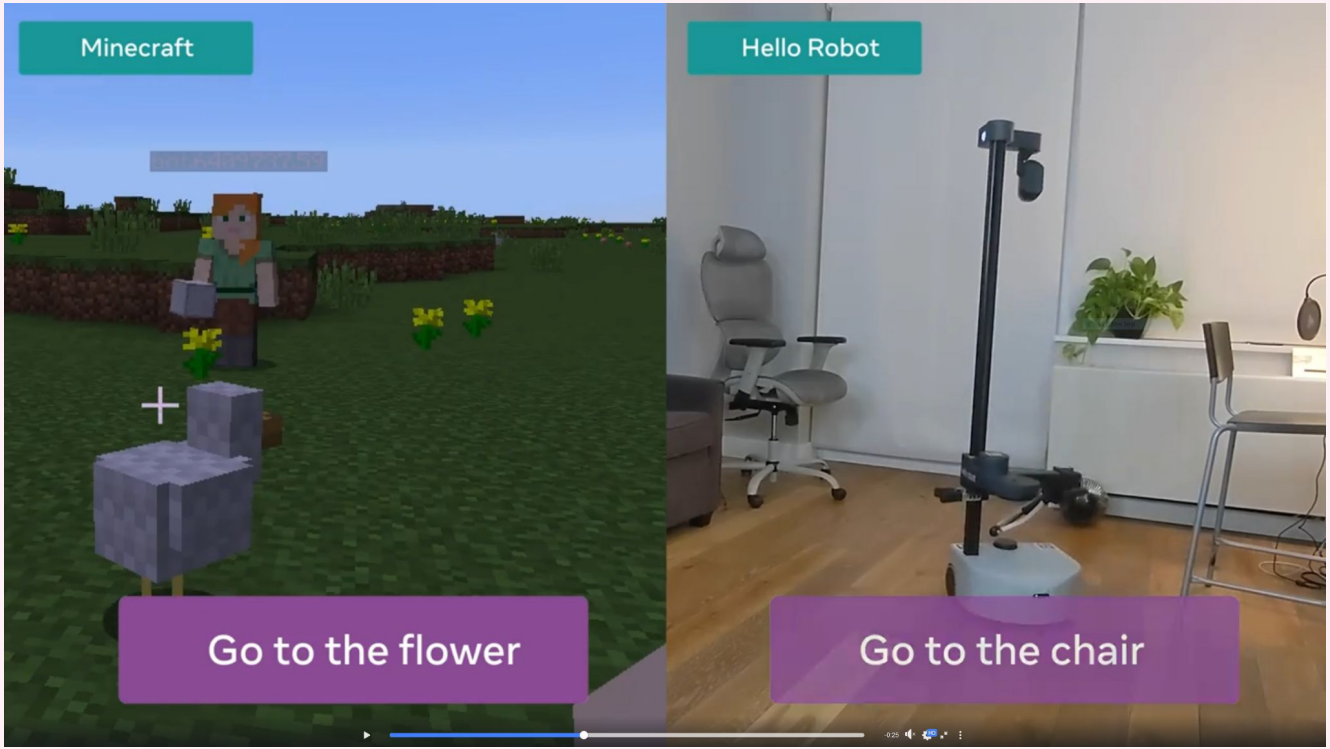
Droidlet from Facebook



https://ai.facebook.com/blog/droidlet-a-one-stop-shop-for-modularly-building-intelligent-agents

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Assistive Robotics at the University of Washington

21 people, **including 3 people with disabilities**, remotely operated Stretch

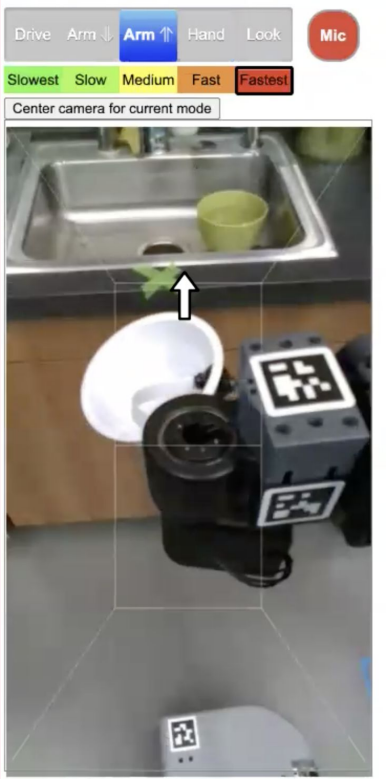
Cabrera, Maria E., Tapomayukh Bhattacharjee, Kavi Dey, and Maya Cakmak. "An Exploration of Accessible Remote Tele-operation for Assistive Mobile Manipulators in the Home." In *2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN)*, pp. 1202-1209. IEEE, 2021.

Maru Cabrera
Assistant Professor
UMass Lowell

Tapo Bhattacharjee
Assistant Professor
Cornell University

Kavi Dey
Research Intern
Seattle Academy

Maya Cakmak
Associate Professor
University of Washington



UW's open source web interface, which significantly improved Hello Robot's original version.

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Other Community Contributions

Nathan Wright

UMass Lowell, Computer Science undergrad

Octomap and RTabMap for Stretch now in official repository!
https://github.com/hello-robot/stretch_ros/pull/37

Nick Walker

University of Washington, Computer Science PhD Student

Improved PID gains for Gazebo simulation
https://github.com/hello-robot/stretch_ros/pull/40

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Collaboration with Prof. Wendy Rogers

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Timeline of our Collaboration

2010: Profs. Rogers & Kemp begin collaborating

2020, April: Prof. Rogers buys early robot (first 10)

2020, April: Start of regular meetings

2021, Sept: NIH awards SBIR

A human factors analysis of the Stretch mobile manipulator robot

Authors: Travis Kadylak[1], Megan A. Bayles[1], Leonardo Galoso[1], Maxwell Chan[1], Harshal Mahajan[1], Charles C. Kemp[2], Aaron Edsinger[2], Wendy A. Rogers[1]

[1]*University of Illinois Urbana-Champaign*
[2]*Hello Robot Inc.*

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Occupational Therapy Doctoral Project

Pacific University Oregon

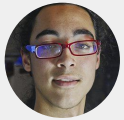
Vy Nguyen

R4H

Henry & Jane Evans

University of Washington 1861

Maya Cakmak



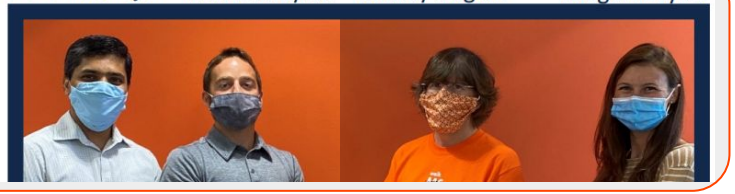
Kavi Dey

Cornell University Founded A.D. 1865

Tapo Bhattacharjee

University of Illinois Urbana-Champaign

Harshal Mahajan Travis Kadylak Wendy Rogers Megan Bayles



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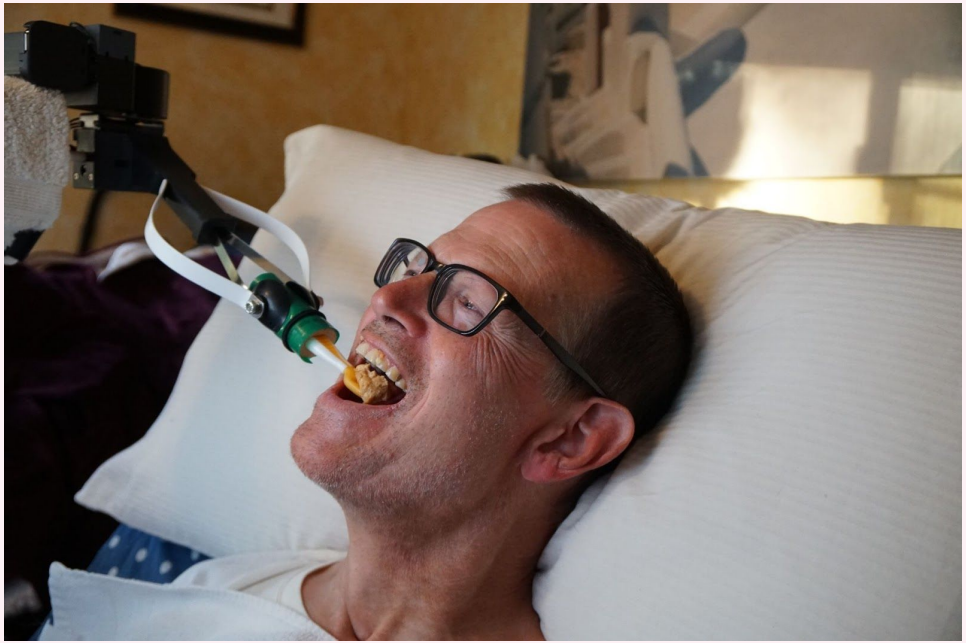
Elliston Franks

Charlie Kemp

Blaine Matulevich

Binit Shah

Stretch provides meaningful assistance



Stretch provides meaningful assistance

Live Demo of the Stretch RE1

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TechSAge presents

Seeking creative solutions to support people aging with disabilities

STRETCH ROBOT PITCH COMPETITION

in collaboration with Hello Robot and P&G

Open to all majors (undergrad & grad) at the University of Illinois Urbana-Champaign

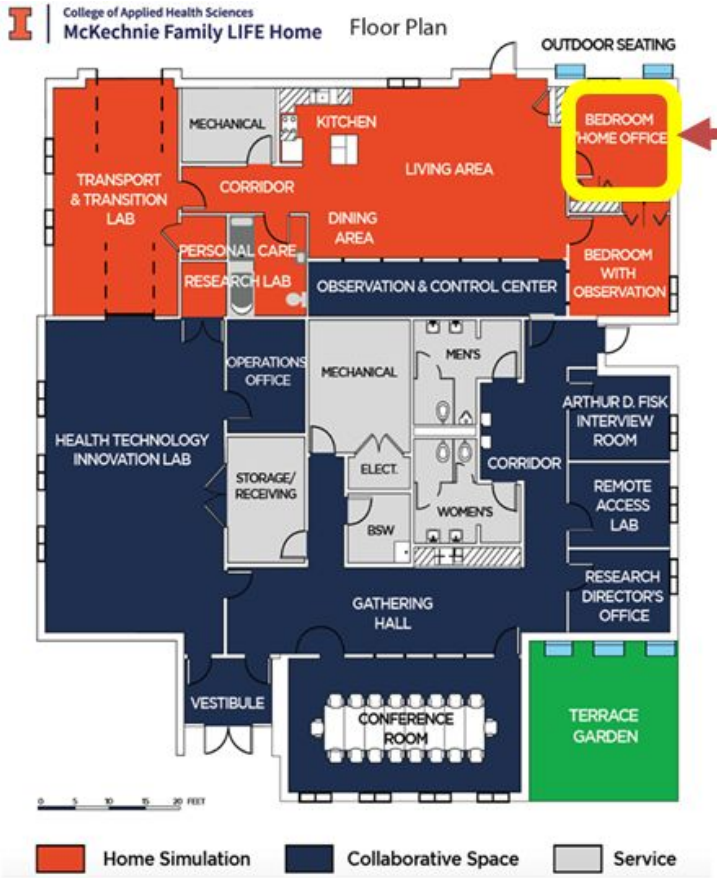
- Cash prizes & more!
- Submission Requirements: 2 page proposal & pitch video (< 3 minutes)
- Deadline: November 19, 2021
- Contact us: techsage@illinois.edu
- For complete details, visit: https://rebrand.ly/Stretch-Robot-Comp

Stretch Robot Pitch Competition!

(*Encouraging an Inclusive Future*)

rebrand.ly/stretch-robot-comp

Stretch in the McKechnie Family LIFE



Stretch's Bedroom

rebrand.ly/stretch-robot-comp

Questions?

Learn more at
hello-robot.com

Extra Slides


Teleoperated 4x


Teleoperated 6X Speed

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

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

$$F_{pull/push} = \frac{23.68 Nm}{h}$$

$$m_{payload} = \frac{1}{0.0014 + 0.414\, D}\, kg$$

$$m_{payload} = 3.47\, kg$$

Title

Hello Robot: Democratizing Mobile Manipulation

Abstract

Mobile manipulators have the potential to improve life for everyone, yet adoption of this emerging technology has been limited. To encourage an inclusive future, Hello Robot developed the Stretch RE1, a compact and lightweight mobile manipulator for research that achieves a new level of affordability. The Stretch RE1 and Hello Robot's open approach are inspiring a growing community of researchers to explore the future of mobile manipulation. In this talk, we will present the Stretch RE1 and the growing community and ecosystem around it. We will present our exciting collaboration with Professor Wendy Roger's lab and provide a live demonstration of Stretch. Finally, we will be announcing the Stretch Robot Pitch Competition -- a collaboration with TechSage and Proctor and Gamble -- where students have the opportunity to generate novel design concepts for Stretch that address the needs of individuals aging with disabilities at home.