My Work with Stretch at Georgia Tech

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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.

Citation for Stretch

https://arxiv.org/abs/2109.10892

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

ICRA 2022 [48] with minor corrections

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

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

***Abstract*— 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 supporting 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 anthropometry and mathematical models of static stability. We also provide empirical support from teleoperating and autonomously controlling a commercial robot based on our design (the Stretch RE1 from Hello Robot Inc.) to perform tasks in real homes.**

I. INTRODUCTION

Mobile manipulators for indoor human environments have the potential to serve as versatile devices that perform a variety of useful tasks. Examples include assisting people with disabilities [1]–[6], retrieving and delivering objects [7]–[13], cleaning [14]–[16], organizing [17]–[19], laundry [20], [21], exercise [22], and entertainment [23]–[25]. To date, mobile manipulators have primarily been used in robotics research labs. Widespread use in homes and offices has yet to be realized, and use in industrial spaces is nascent.

We posit that reduced size, weight, and cost will improve adoption of this emerging technology. Larger size increases a robot's swept volume, limiting options for collision free navigation and manipulation. Greater mass worsens the consequences of collisions and falls. Larger and heavier robots are more difficult to transport and manually reposition. Higher cost makes applications infeasible and deters production.

Our primary objective was to create a compact, lightweight, and affordable mobile manipulator capable of performing a variety of useful tasks within indoor human environments. Static stability becomes a dominant concern, since reducing weight and base size reduces the stably achievable workspace and loads [26]. Reducing the scale of mobile manipulators can make tasks infeasible [27]–[32], so we developed a novel design matched to indoor use with better scaling properties [33], [34].

Henry M. Clever is with the Georgia Institute of Technology (GT), Atlanta, GA., USA. He was supported in part by NSF GRFP Grant DGE1148903. Aaron Edsinger and Blaine Matulevich are with Hello Robot Inc. (HRI), Martinez, CA, USA. They were supported in part by NIH Award R43AG072982. Charles C. Kemp is with GT and HRI. He owns equity in and works part time for HRI. He and Henry Clever receive royalties from GT for sales of the Stretch RE1 due to a licensing agreement with HRI. ***Please note that issued and pending patents cover the Stretch RE1.***

Fig. 1. The Stretch RE1 from Hello Robot Inc. teleoperated to hand an object to Dr. Aaron Edsinger in a real home.

To balance competing objectives, we used mechanical models and iterative design. For each iteration, we created a prototype robot and tested it with a variety of real tasks. From October 2016 to July 2017, we created and tested two prototype robots in the Healthcare Robotics Lab at Georgia Tech [35]. From August 2017 to May 2020, Hello Robot Inc. created a sequence of eight prototype robots with tests in a real home in Atlanta, Georgia, USA.

Robot	Width	Weight	Price
Stretch RE1 by Hello Robot	34 cm	23 kg	~$20,000
HSR by Toyota [36], [37]	43 cm	37 kg	N.A.
Fetch by Fetch Robotics [38], [39]	51 cm	113 kg	~$100,000 [40]
TIAGo Steel by PAL Robotics [41]	54 cm	70 kg	~$56,000 [42]
PR2 by Willow Garage [43]–[45]	67 cm	220 kg	$400,000

TABLE I

The resulting product, the Stretch Research Edition 1 ("Stretch RE1" or "Stretch"), is significantly smaller, lighter, and less expensive than prior mobile manipulators with comparable capabilities (see Fig. 1 and Table I). Within this paper, we present the design of Stretch, justify it, and provide empirical evidence for its efficacy.

II. THE DESIGN OF STRETCH

We created a minimalist design for mobile manipulation in indoor human environments. The Roomba robotic floor cleaner by iRobot served as an inspirational example due to its minimalist design and wide adoption. iRobot began selling the Roomba in 2002 and sold over 1 million robots by late 2004 [46]. This success was due in part to the Roomba's compact, lightweight, and low-cost design for autonomous floor cleaning in homes. These characteristics were achieved by matching the Roomba's body, sensors, and computation to the task and environment [47].

A. The Structure of Indoor Human Environments

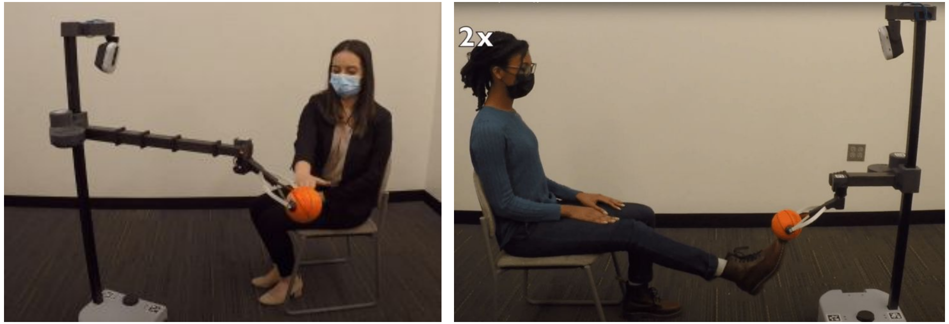
Indoor human environments have Cartesian structure with horizontal planes and vertical surfaces, including floors,

Project-based Class with Open Materials

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

Teaching Award
Student Recognition of Excellence in Teaching:
Class of 1934 CIOS Honor Roll

Now a research project in my lab!



Rehabilitation Game

*Madeline Beatty, **Matthew Lamsey**, Zexuan Liu, Arjun Majumdar, and Kendra Washington*

Hydration Assistance via Water Delivery

Zach Shaefer, Miles Macero, Hannah Paterson, Kendra Dawson, & Naveen Balaji N

Fall Assistance using Remote Teleoperation

Aparna Subramaniam, Mark Putman, Jeremy Collins, Stuart Song, Prathic Sundararajan

Manipulating Blankets via Physics Simulations

https://github.com/RCHI-Lab/bodies-uncovered

Kavya Puthuveetil, Charles C. Kemp, and Zackory Erickson, [Bodies Uncovered: Learning to Manipulate Real Blankets Around People via Physics Simulations](). IEEE Robotics and Automation Letters (RA-L), 2022.

Reaching Body Locations

https://github.com/Healthcare-Robotics/BodyPressure

Robotic Control
(unpublished)
Matt Lamsey
Naveen Balaji

Henry M. Clever, Patrick Grady, Greg Turk, Charles C. Kemp, BodyPressure – Inferring Body Pose and Contact Pressure from a Depth Image, IEEE Transactions on Pattern Analysis and Machine Intelligence, 2022.

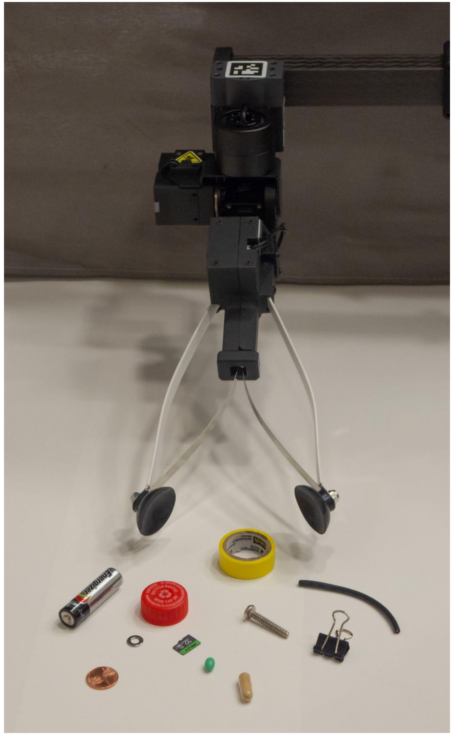
Visual Pressure Estimation and Control

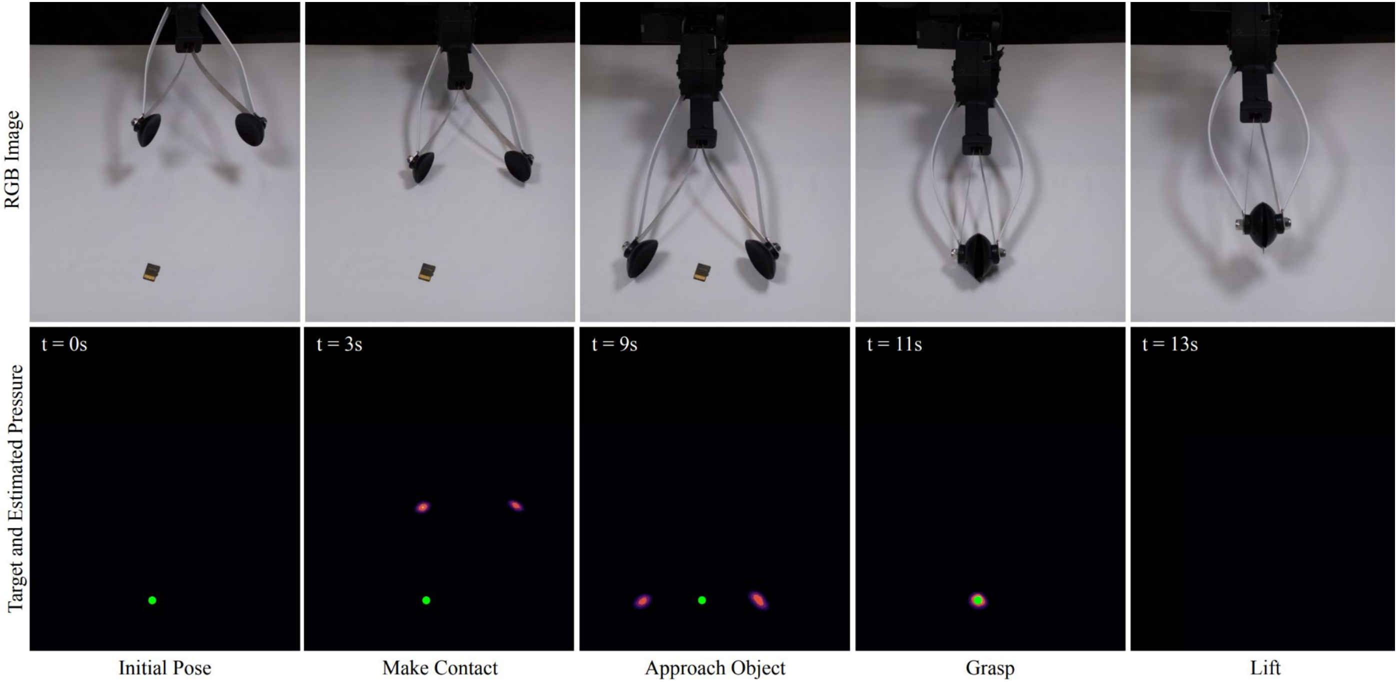
https://arxiv.org/abs/2204.07268

Patrick Grady, Jeremy A. Collins, Samarth Brahmbhatt, Christopher D. Twigg, Chengcheng Tang, James Hays, Charles C. Kemp, Visual Pressure Estimation and Control for Soft Robotic Grippers, preprint on arXiv, 2022.

Visual Pressure Estimation and Control

https://arxiv.org/abs/2204.07268





Patrick Grady, Jeremy A. Collins, Samarth Brahmbhatt, Christopher D. Twigg, Chengcheng Tang, James Hays, Charles C. Kemp, Visual Pressure Estimation and Control for Soft Robotic Grippers, preprint on arXiv, 2022.