Haptic Sensing for Assistive Robots

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Haptic Sensing for Assistive Robots

- Quick overview of assistive robotics
- Data-driven models of forces
- Whole-arm tactile sensing
- Thermal tactile sensing

Healthcare Robotics Lab

http://healthcare-robotics.com

Health-Related Physical Assistance

- People with motor impairments, injuries and illnesses would often benefit from physical assistance.
- Today in the US alone
  - >15,000 with ALS [1]
  - ~290,000 with a spinal cord injury [2]
  - ~14,000,000 aged 65 years and older have a severe disability [3]

[1] Paul Mehta, M. D. "Prevalence of Amyotrophic Lateral Sclerosis—United States, 2012–2013." MMWR. Surveillance Summaries 65 (2016).
[2] Singh, Anoushka, et al. "Global prevalence and incidence of traumatic spinal cord injury." Clin Epidemiol 6 (2014): 309-331.
[3] Brault, Matthew W. "Americans with disabilities: 2010." Current population reports 7 (2012): 0-131.
[image] http://www.nurseuncut.com.au/how-stressed-are-you/

Types of Tasks

- **Activities of Daily Living (ADLs)**
  - Feeding, toileting, transferring, dressing, and hygiene
  - Predictive of ability to live independently
  - Manipulation near the person's body

- **Instrumental Activities of Daily Living (IADLs)**
  - Housework, food preparation, taking medications, …
  - Manipulation of objects in the environment

In 2010 in the US alone, ~12,000,000 "aged 6 years and older … needed assistance with one or more ADLs or IADLs" [1]

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

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[images] found on the internet and used without permission

Robotic Opportunities

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

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

Assistive Robots

- Robotic Prostheses
- Robotic Orthoses / Exoskeletons
- Wheelchair Mounted Robot Arms
- Desktop Robots
- *Mobile Manipulators*

DEKA Arm by DEKA

MySpoon by SECOM

JACO by Kinova

HAL by Cyberdine

Potential Benefits of Mobile Manipulators

- Operate independently from user
- No don/doff
- Assist diverse end users
- Mass market product

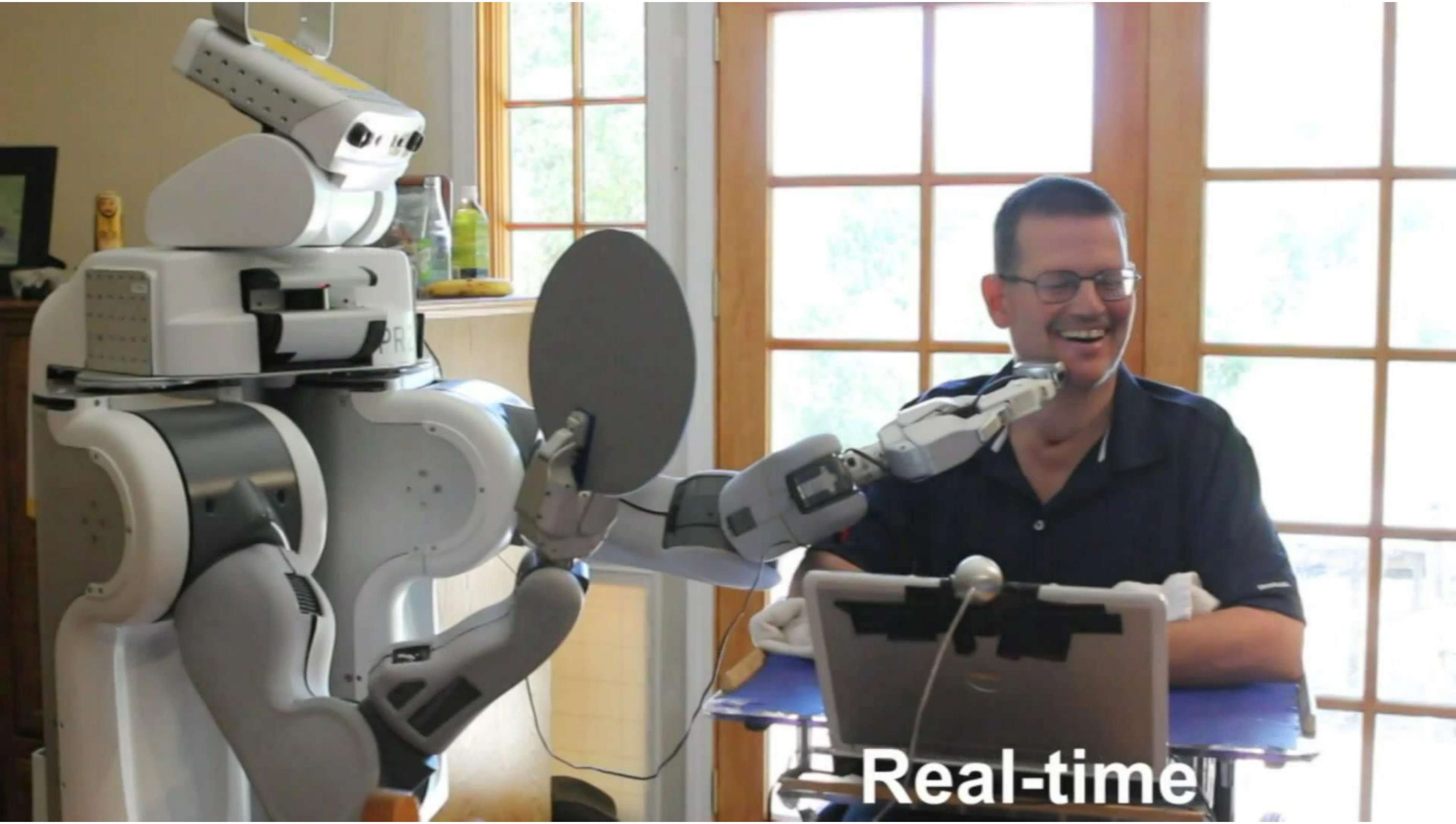
[image] from Willow Garage

Our Data Suggest that Many People will be Open to Assistance from Mobile Manipulators

- Over 200 participants in studies about assistive mobile manipulation
- Most studies with representative end-users
  - Older adults
  - Nurses
  - Able-bodied participants (mock generic patients)
  - People with severe motor impairments

[Image] Chih-Hung King, Tiffany L. Chen, Zhengqin Fan, Jonathan D. Glass, and Charles C. Kemp, *Dusty: An Assistive Mobile Manipulator that Retrieves Dropped Objects for People with Motor Impairments*, Disability and Rehabilitation: Assistive Technology, 2011.

Hai Nguyen, Matei Ciocarlie, Kaijen Hsiao, and Charles C. Kemp, *ROS Commander (ROSCo): Behavior Creation for Home Robots*, IEEE International Conference on Robotics and Automation, 2013.

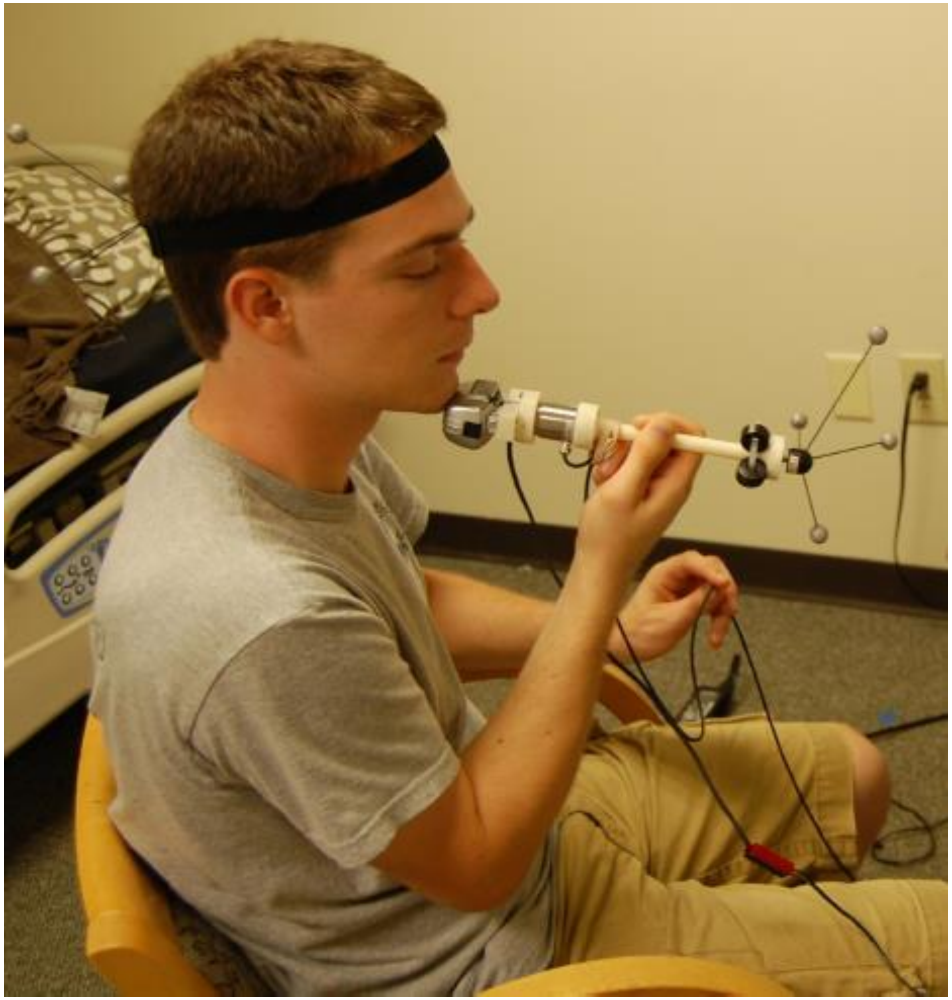


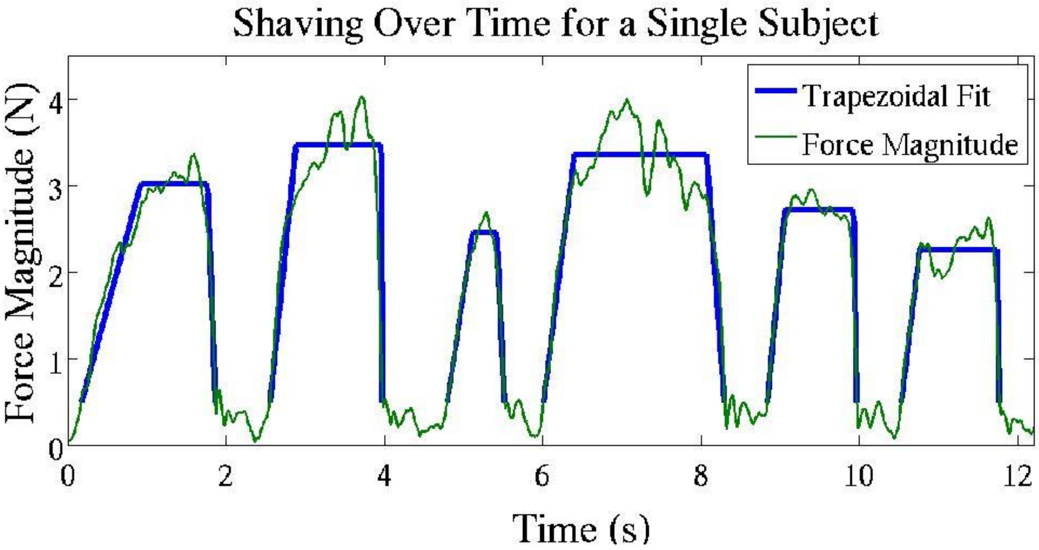
Kelsey Hawkins, Phillip M. Grice, Tiffany L. Chen, Chih-Hung King, and Charles C. Kemp, *Assistive Mobile Manipulation for Self-Care Tasks Around the Head*, 2014 IEEE Symposium on Computational Intelligence in Robotic Rehabilitation and Assistive Technologies, 2014.

How can haptic sensing help?

Data-Driven Models of Forces for Robot-Assisted Tasks

Data-driven Models for Robot-Assisted Shaving

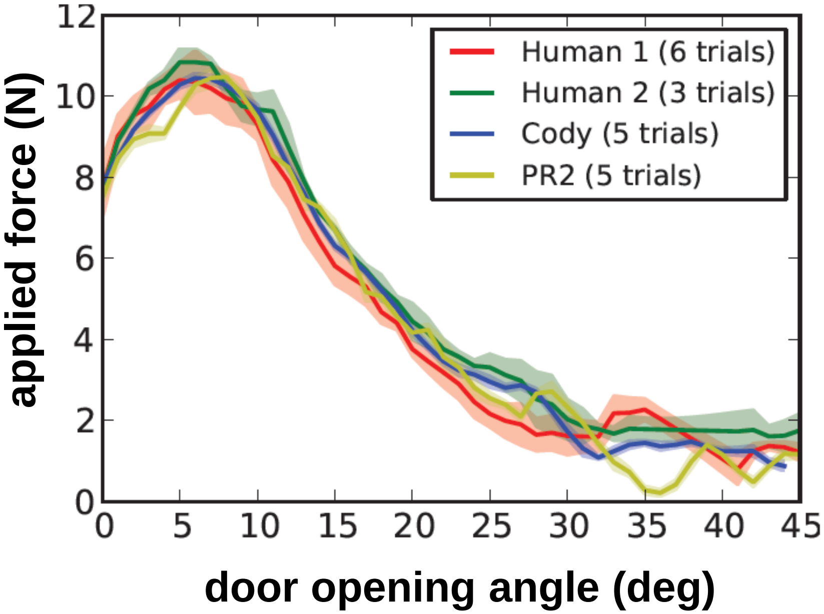




Statistics for the Target Force of Shaving Strokes	
Maximum	8.2 N
First Quartile	2.7 N
Median	1.9 N

Kelsey Hawkins, Chih-Hung King, Tiffany L. Chen, and Charles C. Kemp, *Informing Assistive Robots with Models of Contact Forces from Able-Bodied Face Wiping and Shaving*, IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), 2012.

Data-driven Models for Robot-Assisted Door Opening



Advait Jain and Charles C. Kemp, *Improving Robot Manipulation with Data-Driven Object-Centric Models of Everyday Forces*, Autonomous Robots, 2013.

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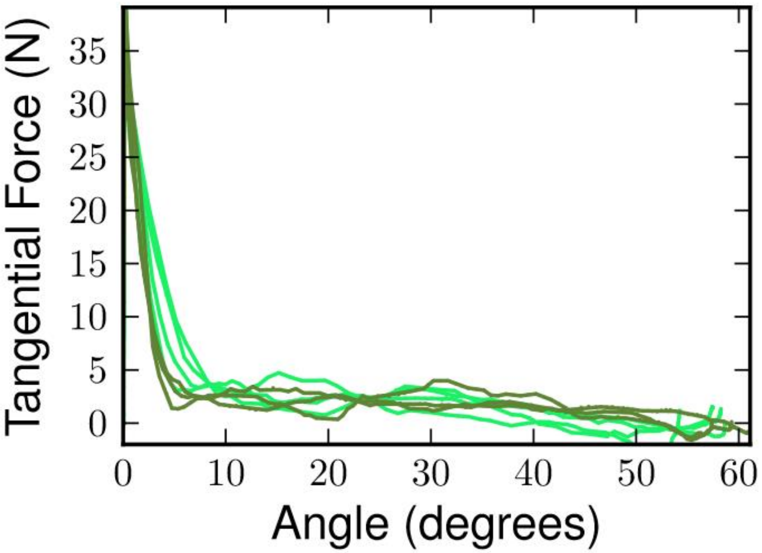
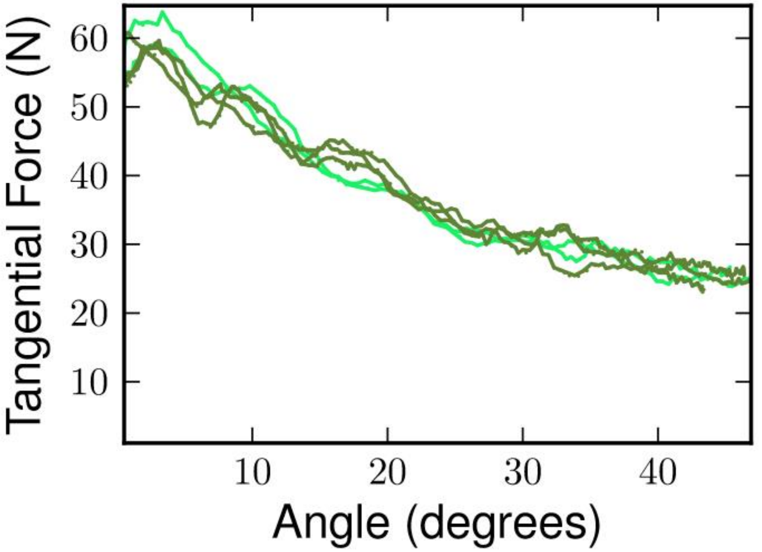
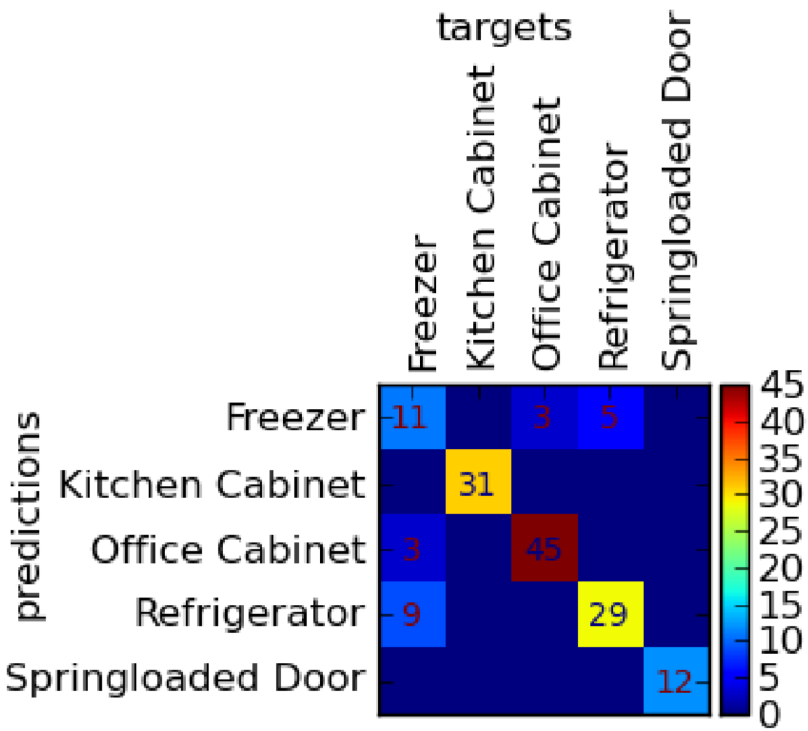
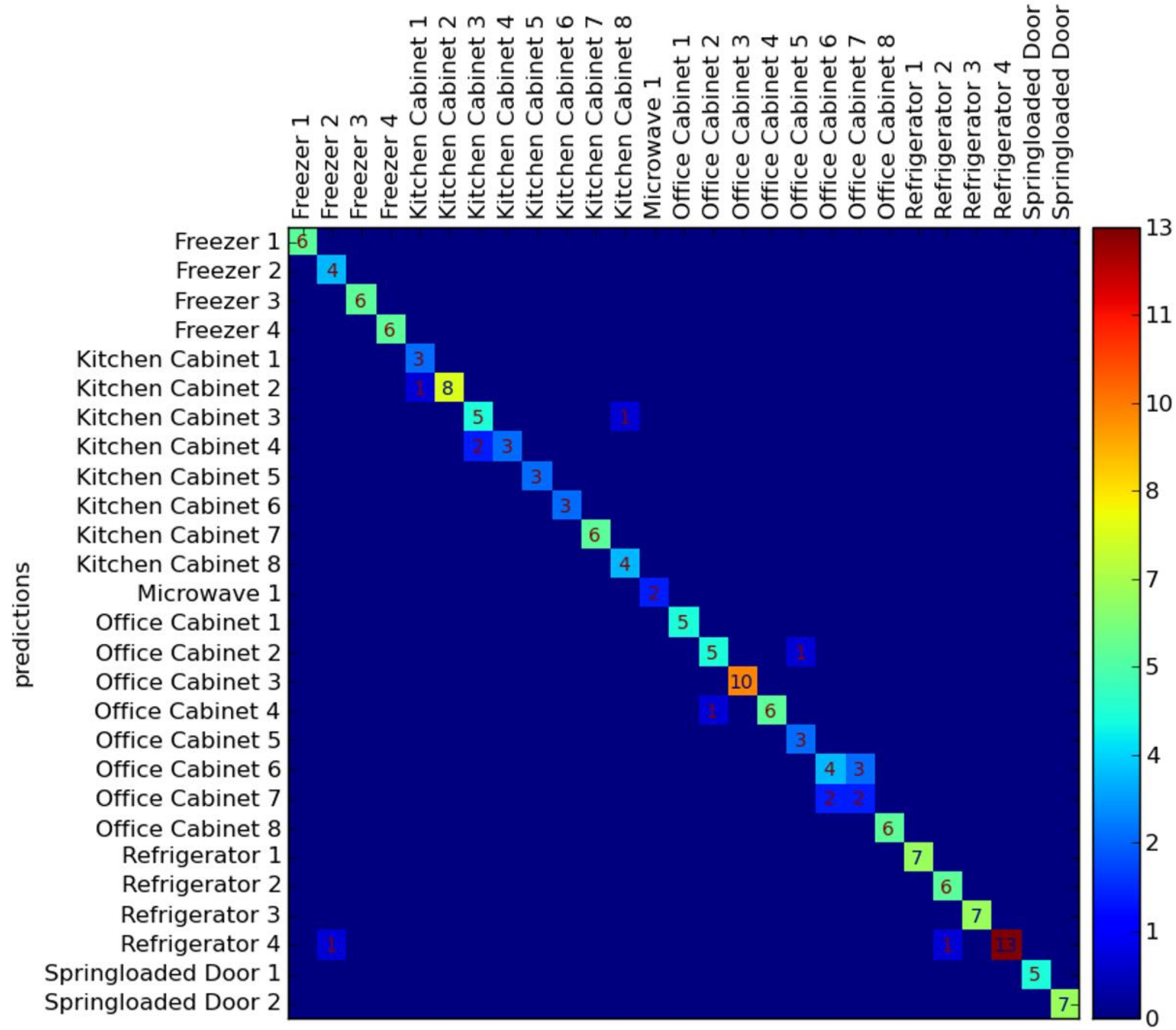




Advait Jain and Charles C. Kemp, *Improving Robot Manipulation with Data-Driven Object-Centric Models of Everyday Forces*, Autonomous Robots, 2013.

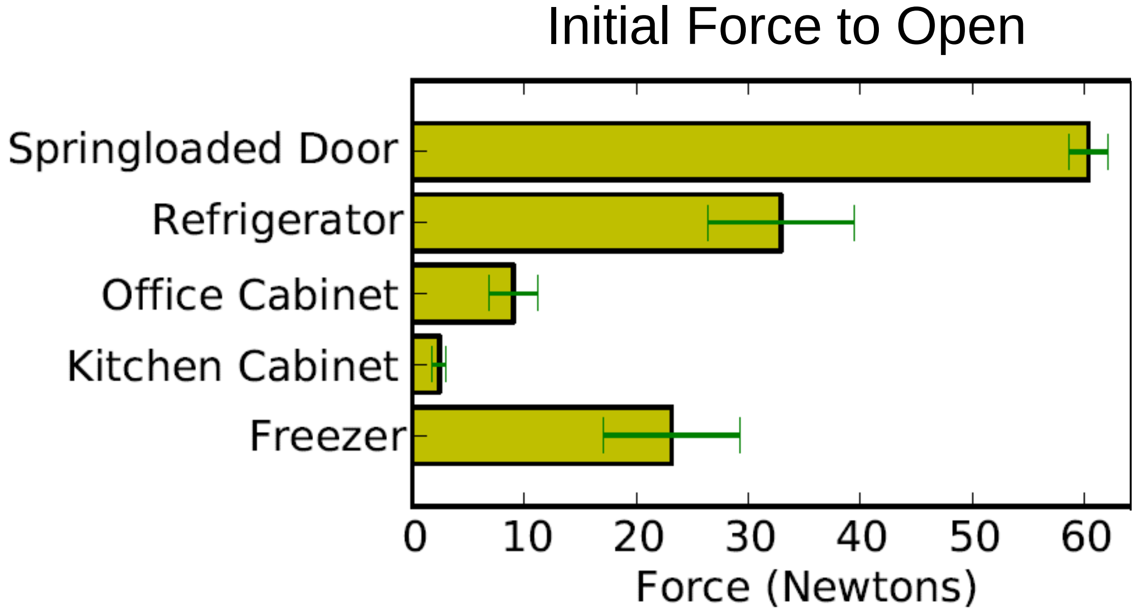
Recognition of Categories and Instances





Advait Jain and Charles C. Kemp, *Improving Robot Manipulation with Data-Driven Object-Centric Models of Everyday Forces*, Autonomous Robots, 2013.

Aggressive, Timid, or Smart?



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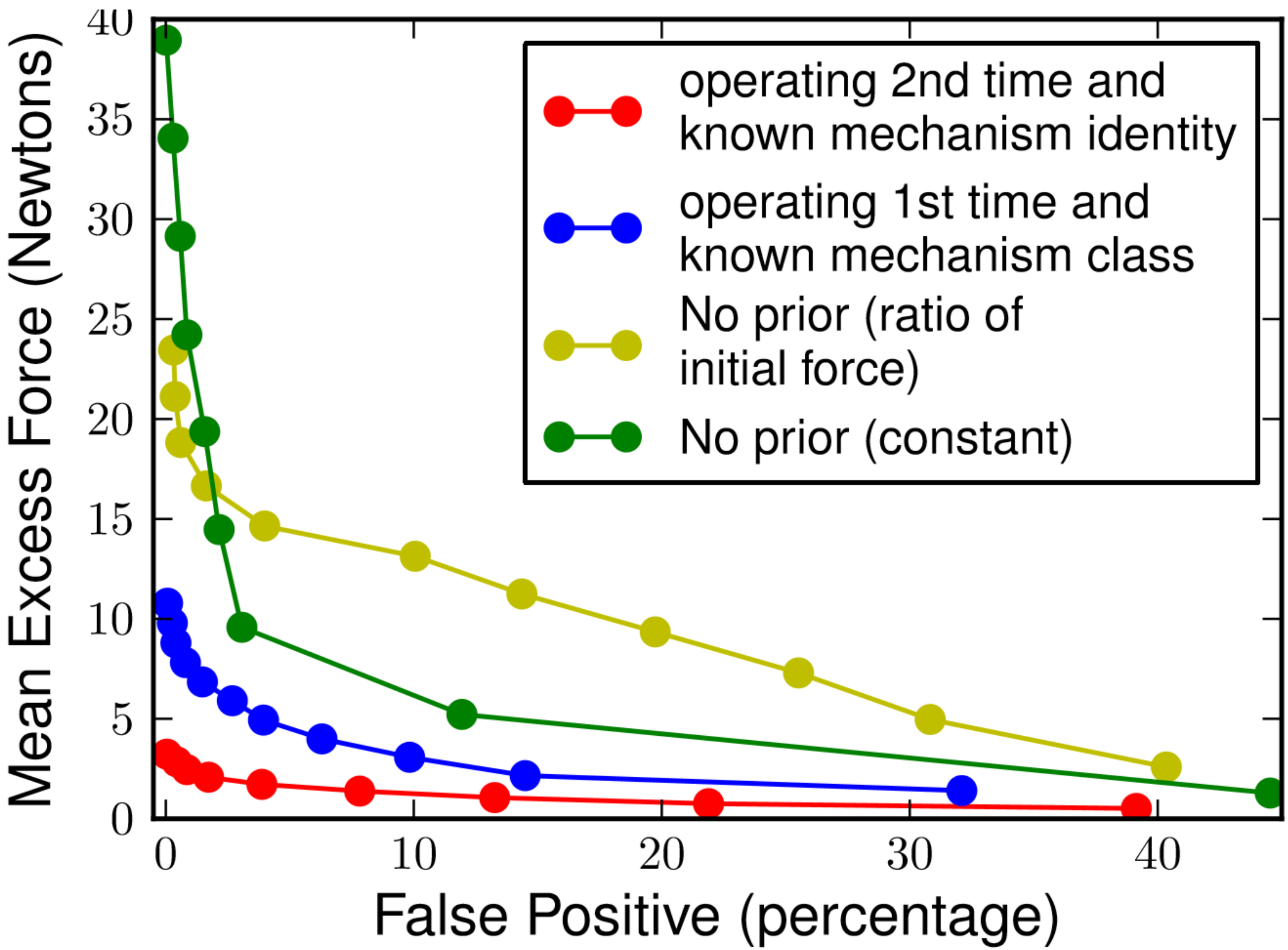
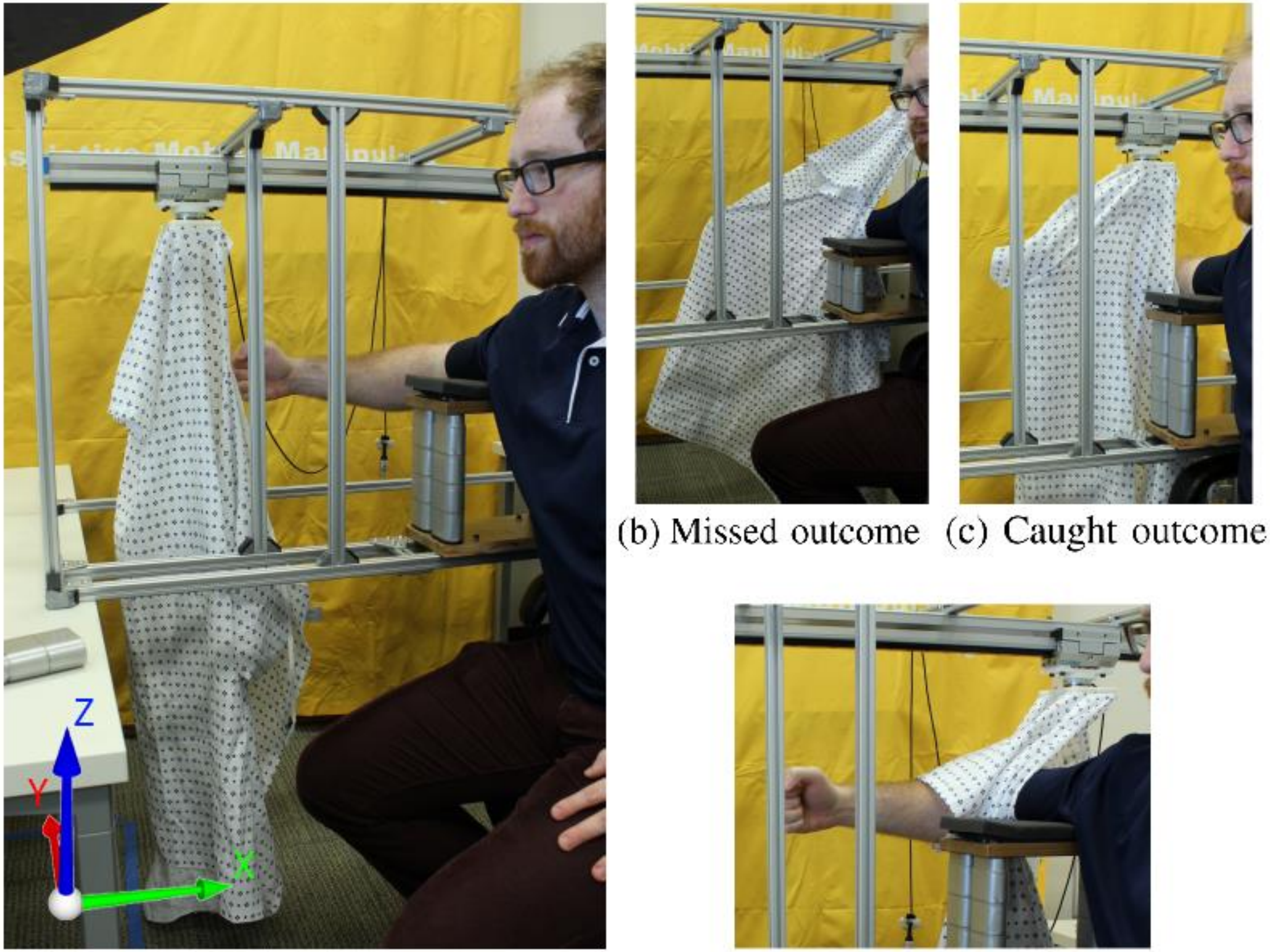


Advait Jain and Charles C. Kemp, *Improving Robot Manipulation with Data-Driven Object-Centric Models of Everyday Forces*, Autonomous Robots, 2013.

Data-Driven Models for Robot-Assisted Dressing



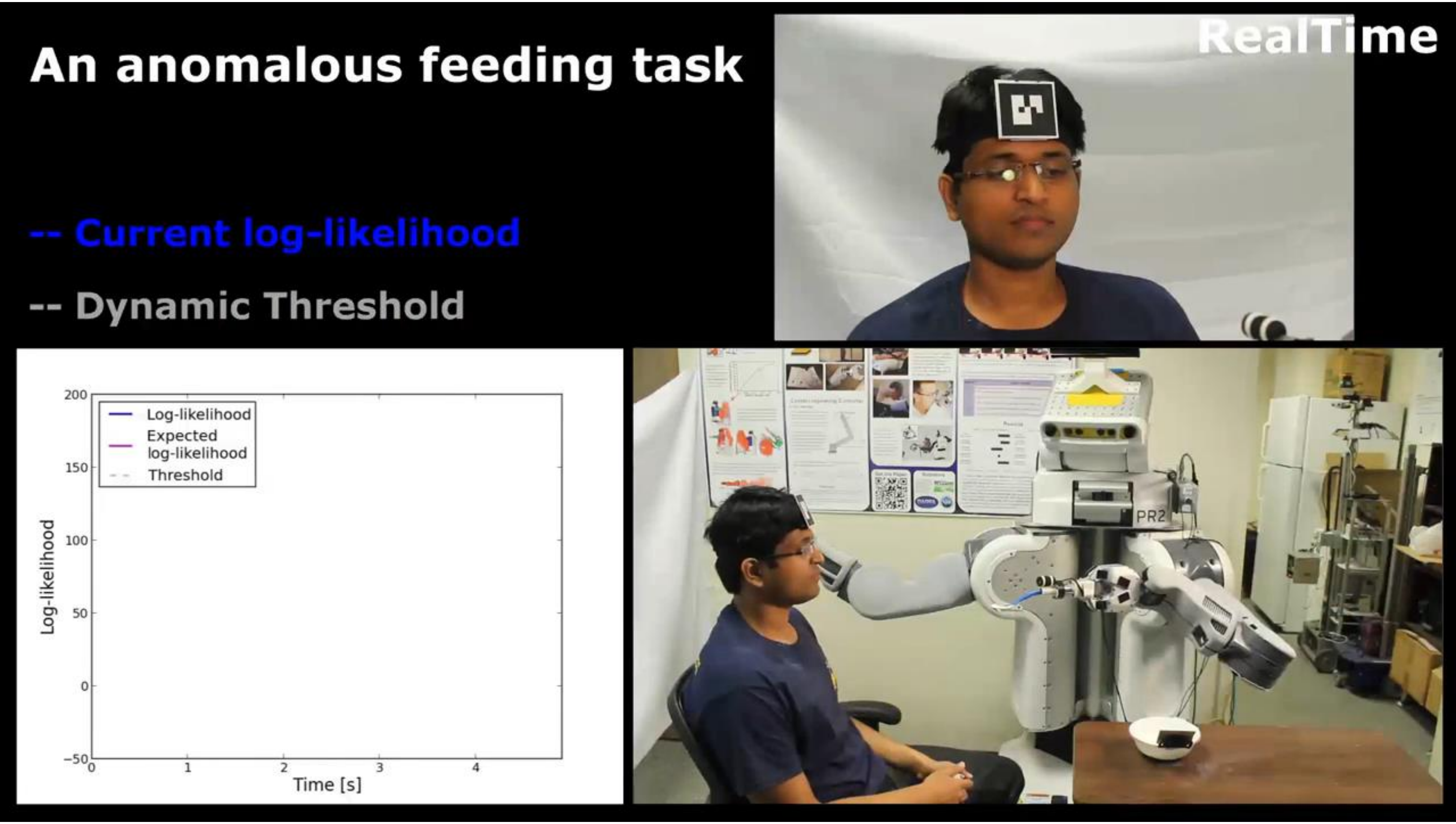
(a) Starting condition

(b) Missed outcome

(c) Caught outcome

(d) Good outcome

Ariel Kapusta, Wenhao Yu, Tapomayukh Bhattacharjee, C. Karen Liu, Greg Turk, and Charles C. Kemp, *Data-Driven Haptic Perception for Robot-Assisted Dressing*, IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), 2016.



Daehyung Park, Zackory Erickson, Tapomayukh Bhattacharjee, and Charles C. Kemp, *Multimodal Execution Monitoring for Anomaly Detection During Robot Manipulation*, IEEE International Conference on Robotics and Automation (ICRA), 2016.

Data-Driven Models of Forces for Robot-Assisted Tasks

- Common sense about forces during tasks
  - Detect anomalies and unsafe situations
  - Recognize object instances and classes
  - Infer task-relevant state
- Forces are useful for sharing
- Data collection challenge
  - Handheld device
  - Human participants

Whole-Arm Tactile Sensing

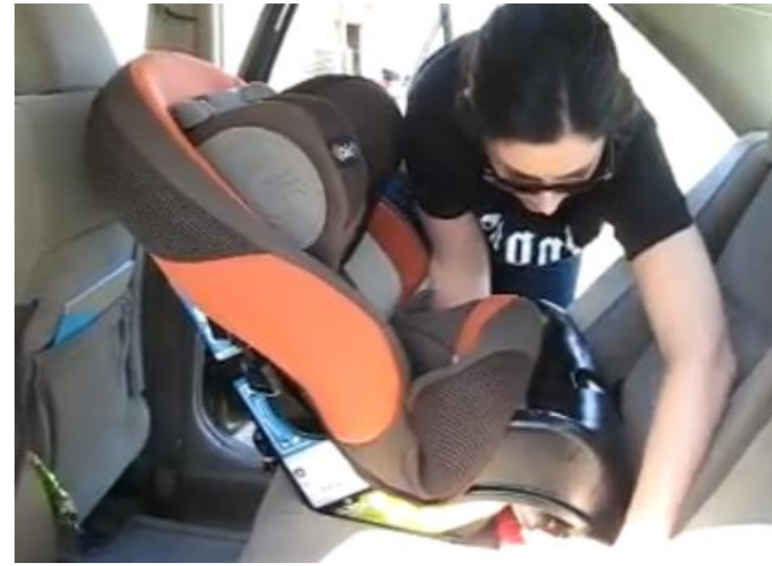
Dominant Strategy for Robotic Manipulation has been to **Avoid Contact**

- Between the robot’s arm and **the world**
- Between the robot’s arm and **other parts of its body**
- Between the robot’s arm and **people**

Contact with the World is Common

Reaching a high shelf

Tying a rope to a pole



Installing a car seat

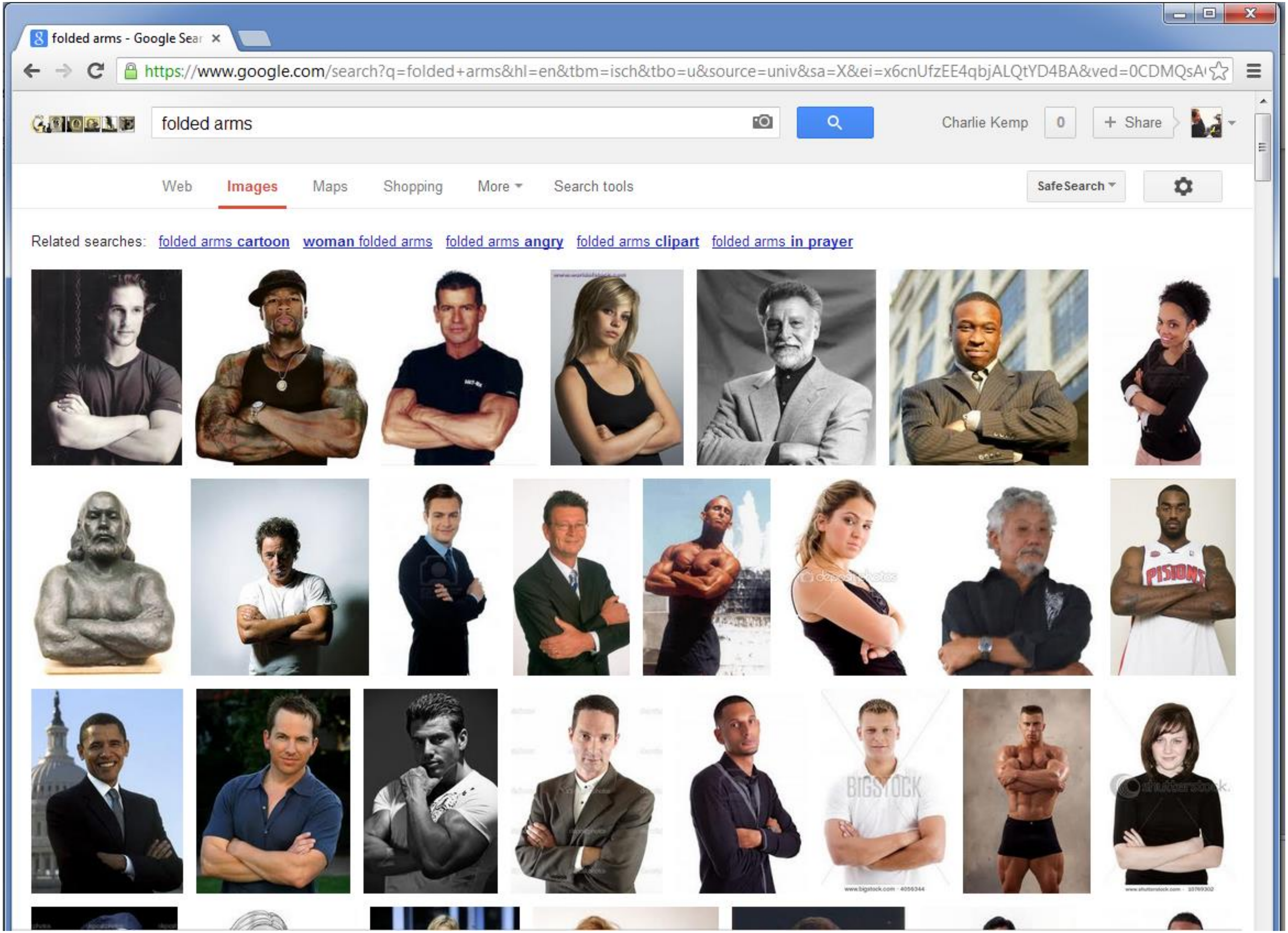
Cleaning a car trunk

Plumbing

Carrying boxes

[images] found on the internet and used without permission

Self-contact is Common

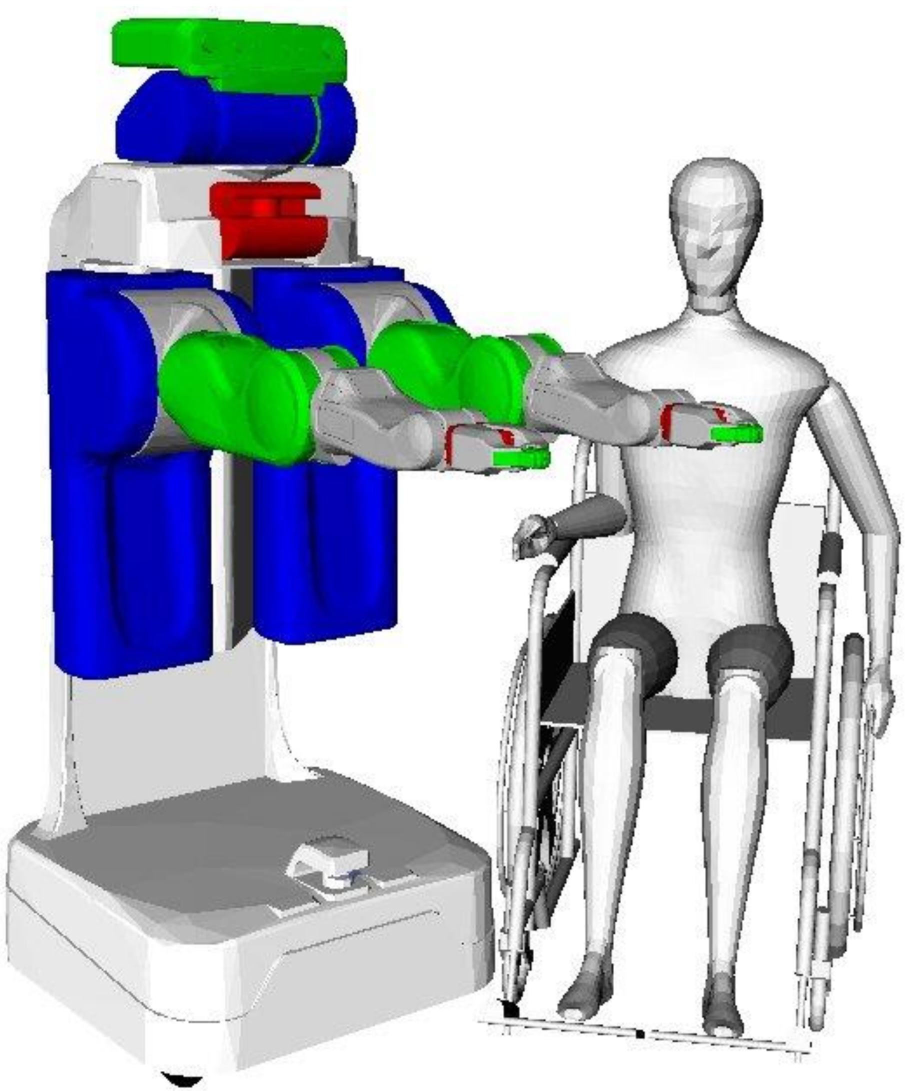


[image] Results of Google search performed by Charles C. Kemp

Contact with People is Common
(e.g., when providing assistance)

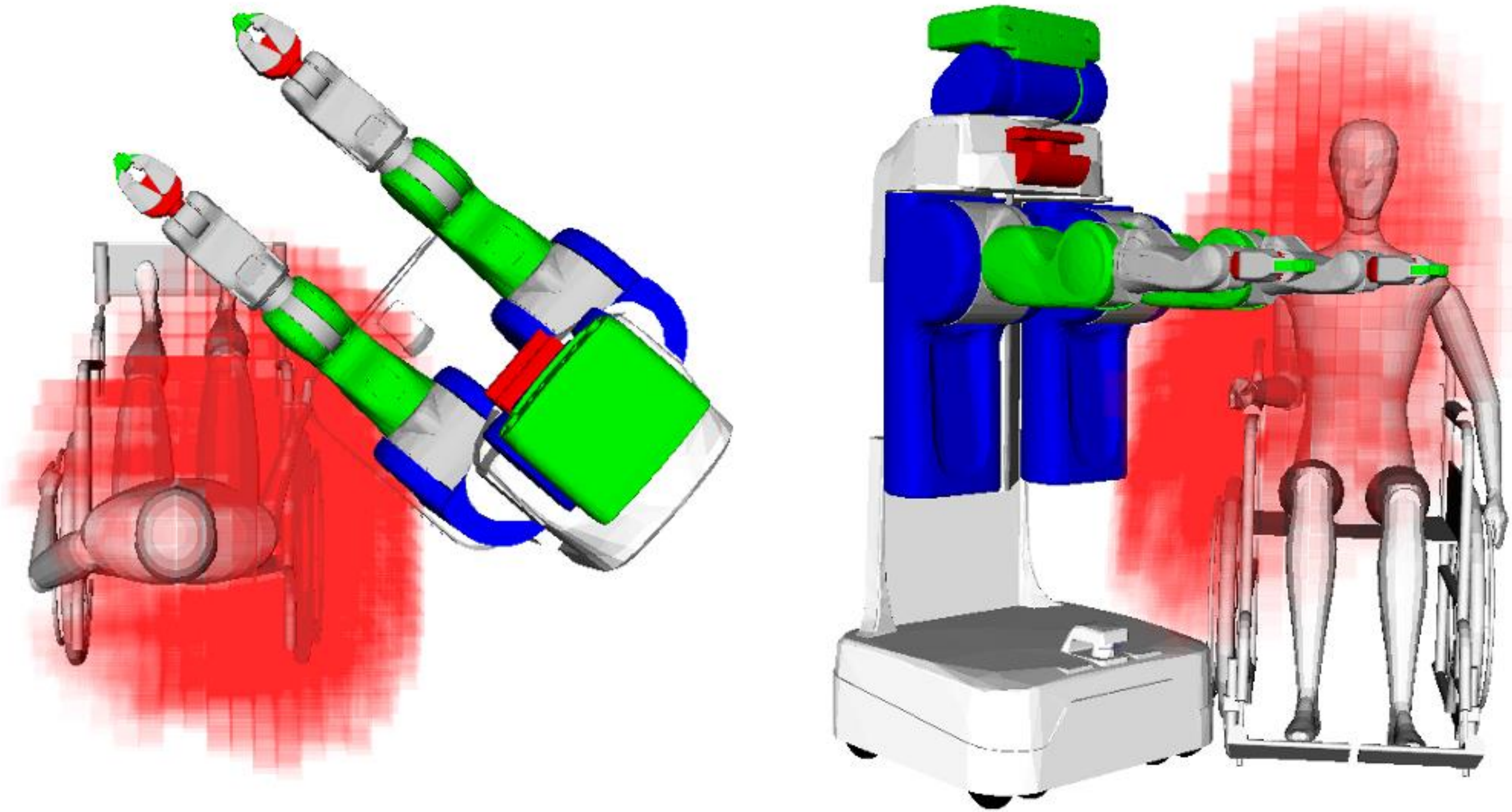
[images] found on the internet and used without permission

Geometric Simulation to Investigate Value of Contact



Phillip M. Grice, Marc D. Killpack, Advait Jain, Sarvagya Vaish, Jeffrey Hawke, and Charles C. Kemp, *Whole-arm Tactile Sensing for Beneficial and Acceptable Contact During Robotic Assistance*, 13th International Conference on Rehabilitation Robotics (ICORR), 2013.

Unreachable End Effector Poses with Safety Margin of 4cm



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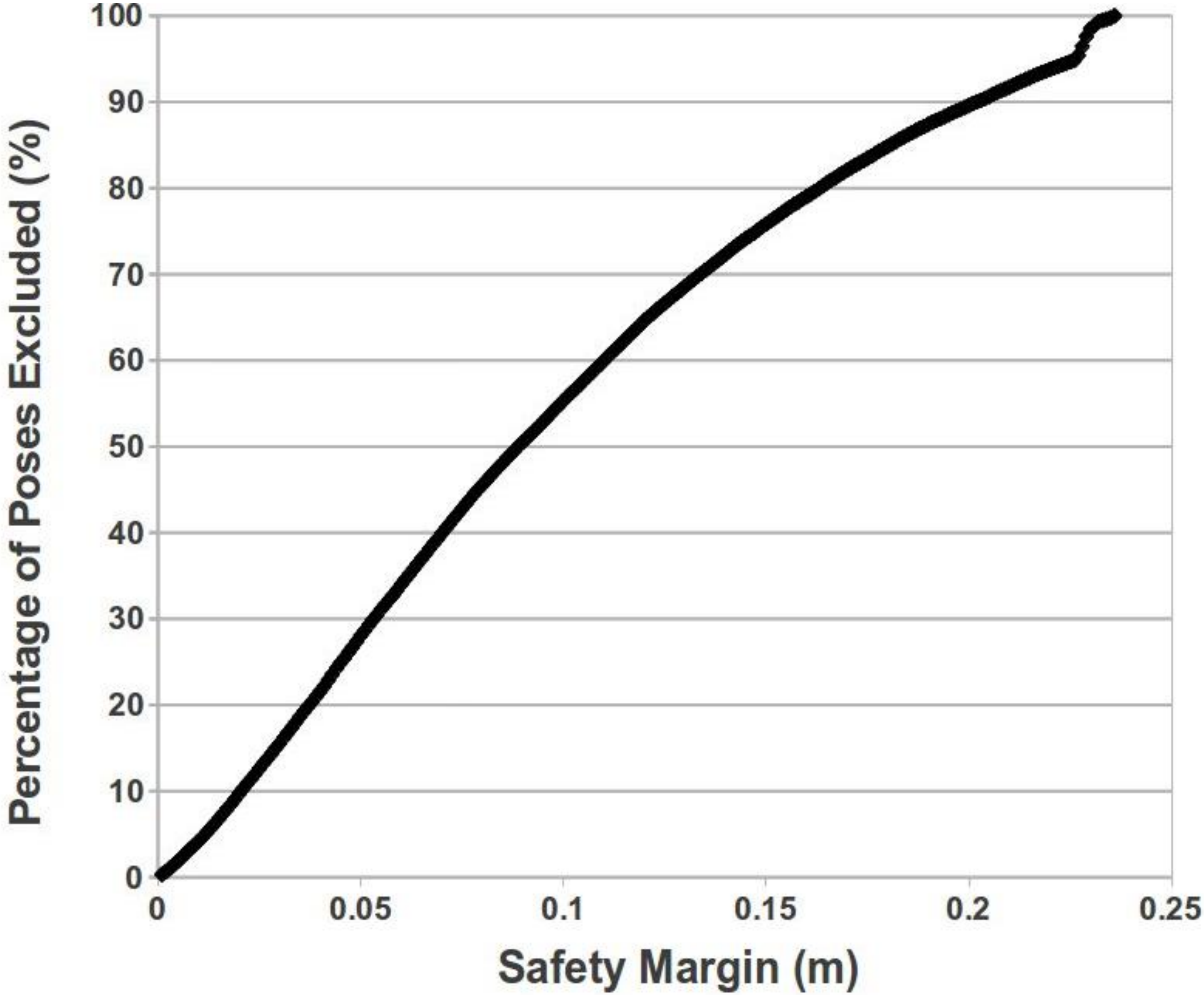

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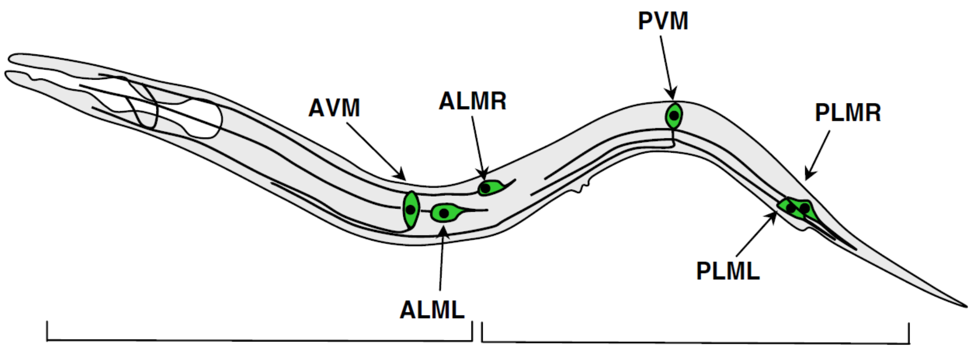
Controllers that Allow Contact

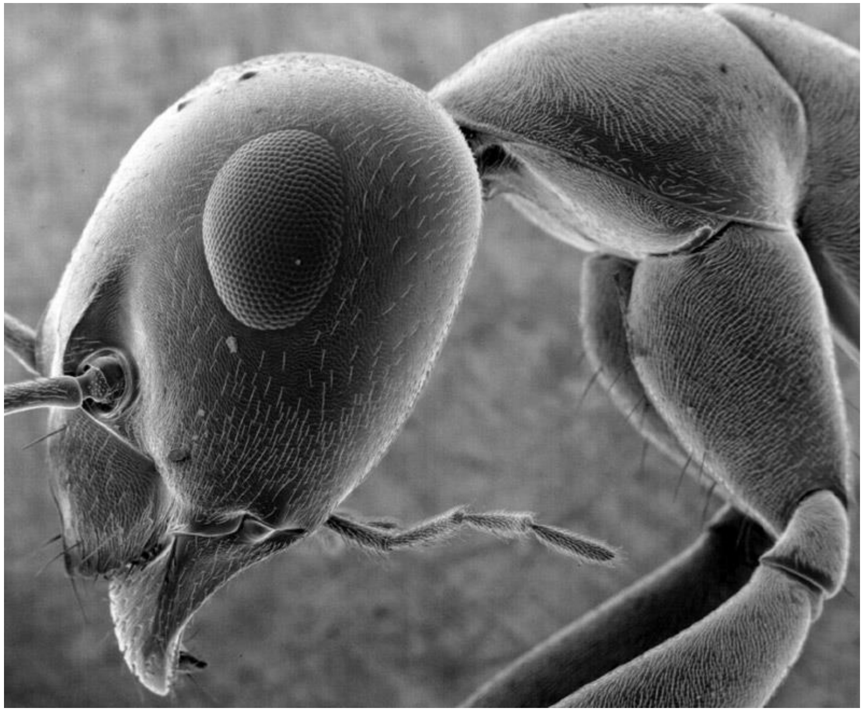
- Assume
  - Low contact forces have no associated penalty
  - The robot has
    - Low-stiffness compliant joints
    - Whole-arm tactile sensing

Advait Jain, Marc D. Killpack, Aaron Edsinger, and Charles C. Kemp, *Reaching in clutter with whole-arm tactile sensing*. The International Journal of Robotics Research, 32.4 (2013): 458-482.

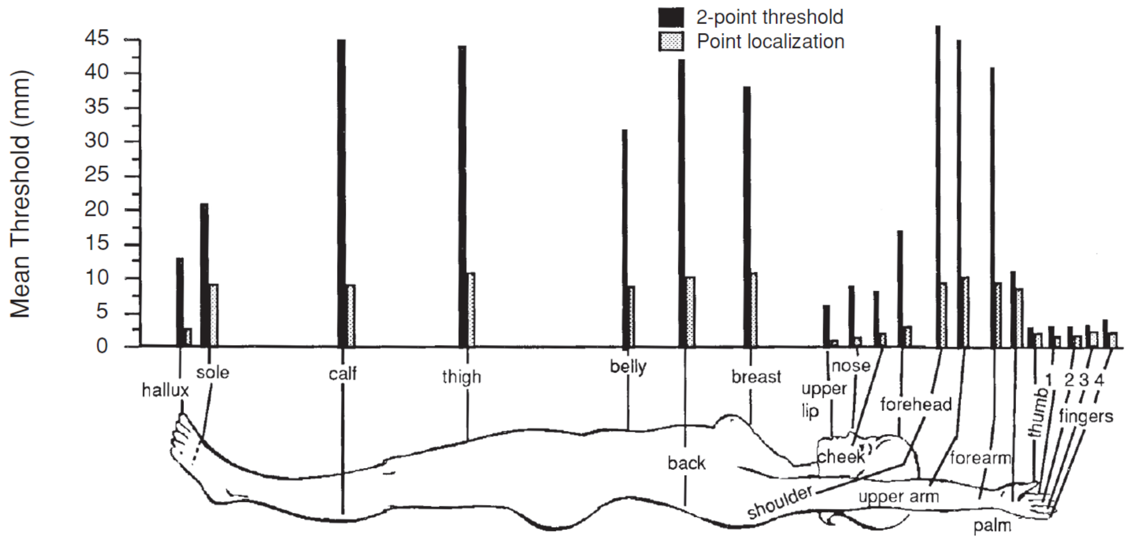
Whole-body tactile sensing is everywhere.



Nematode (~mm)



Ant (~cm)



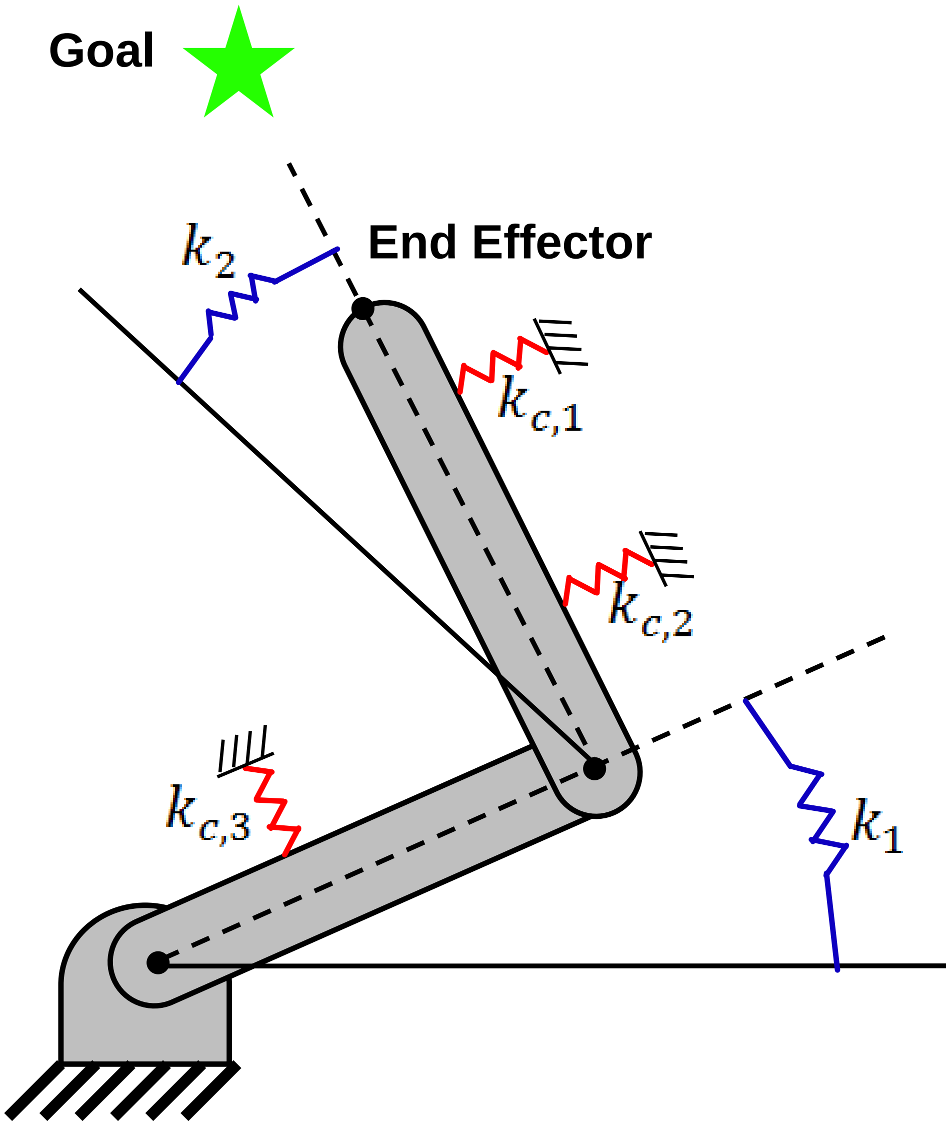
Human (~m)

[image of nematode] Bianchi L, *Mechanotransduction: Touch and feel at the molecular level as modeled in caenorhabditis elegans*. Molecular Neurobiology 36(3): 254–271, 2007.
[image of ant] from the Dartmouth College Electron Microscope Facility, http://remf.dartmouth.edu/images/insectPart3SEM/source/31.html
[image of human] Lederman, Susan J., and Roberta L. Klatzky. *Haptic perception: A tutorial*. Attention, Perception, & Psychophysics 71.7, 1439-1459, 2009.

Quasistatic Model Predictive Control

At each time step

- Generate quasi-static model
- Use quadratic programming to find a change to the equilibrium angles of the joints that
  - Minimizes the predicted distance to the goal
  - Subject to constraints on predicted contact forces



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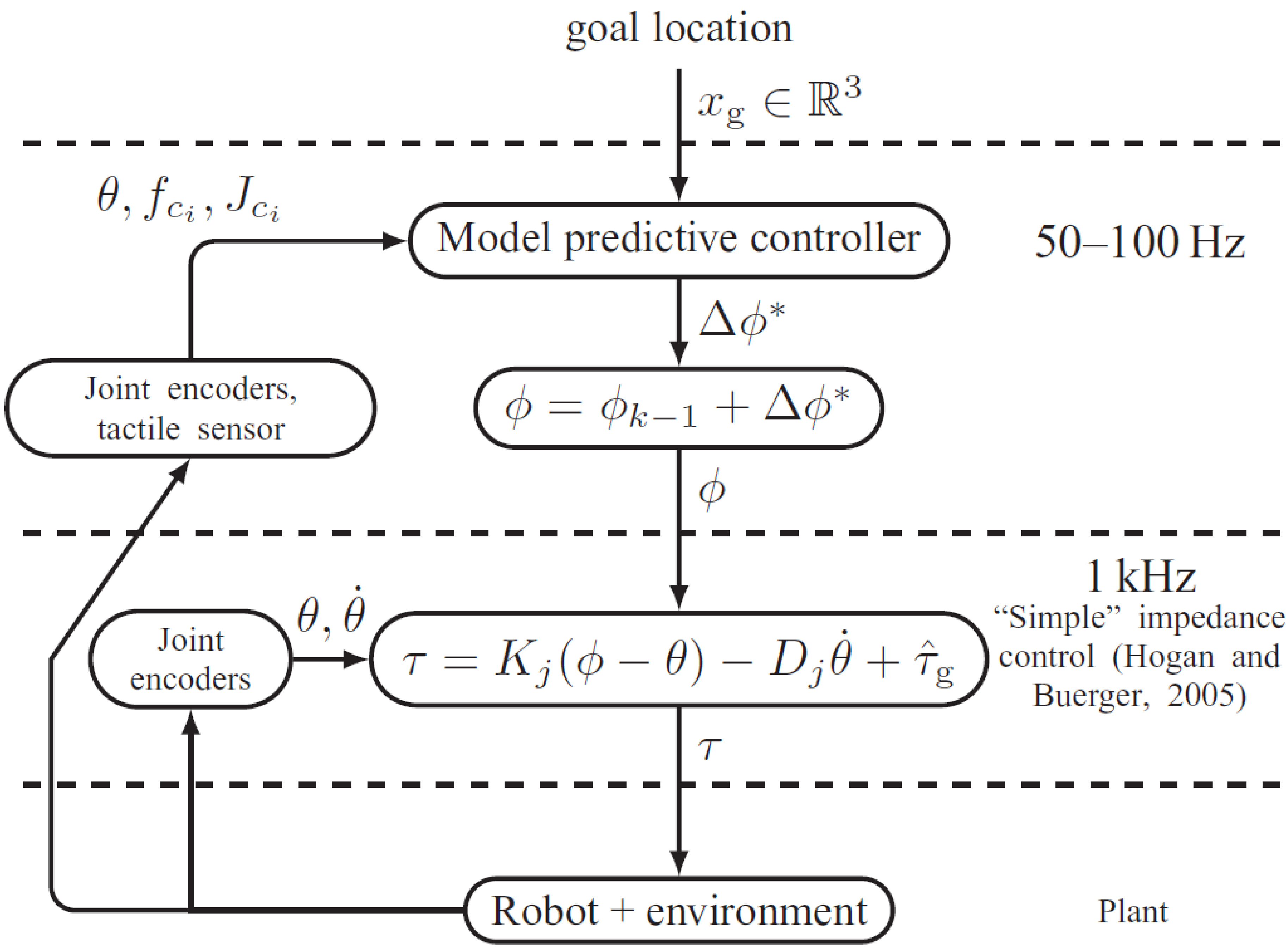

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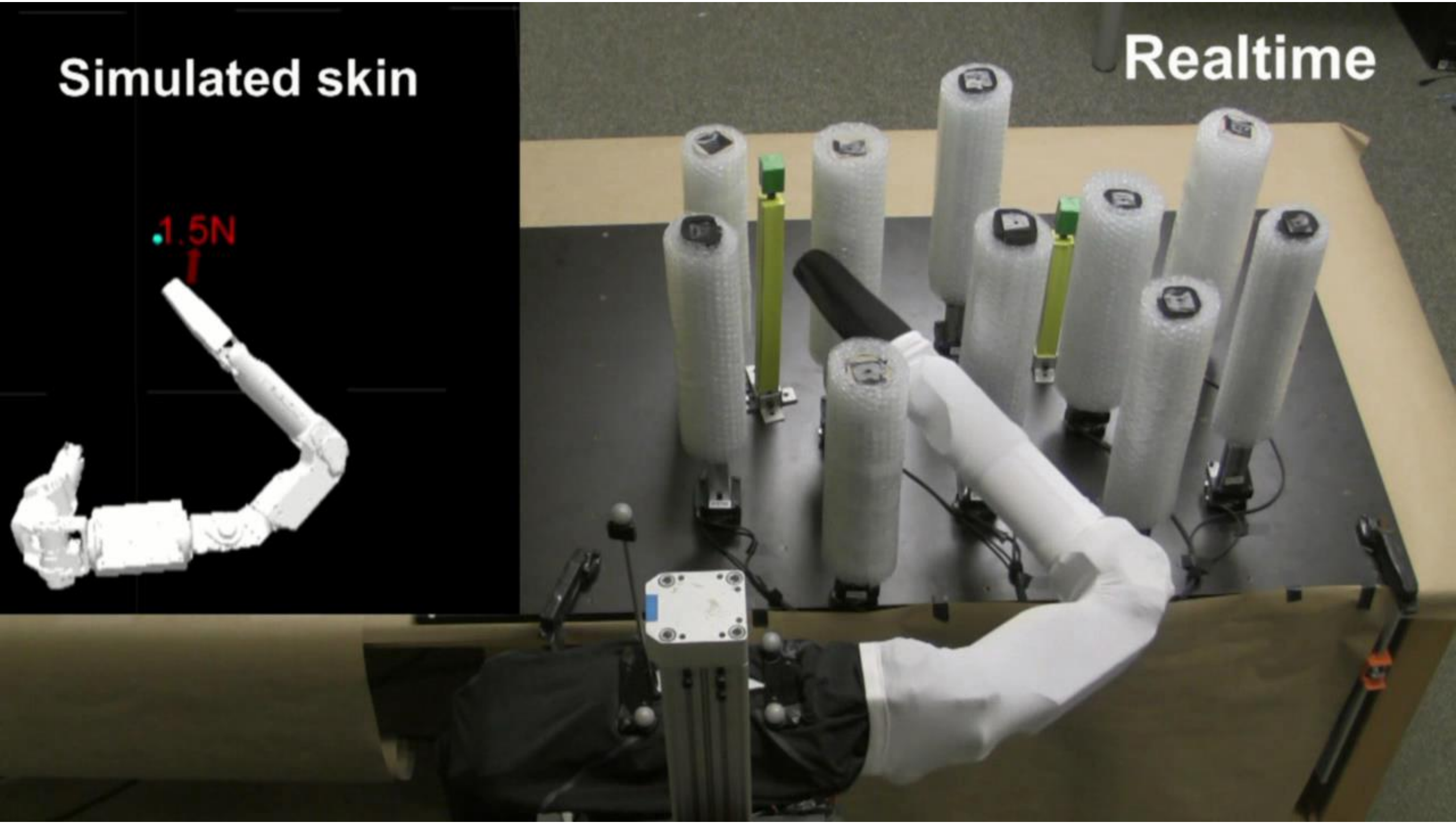

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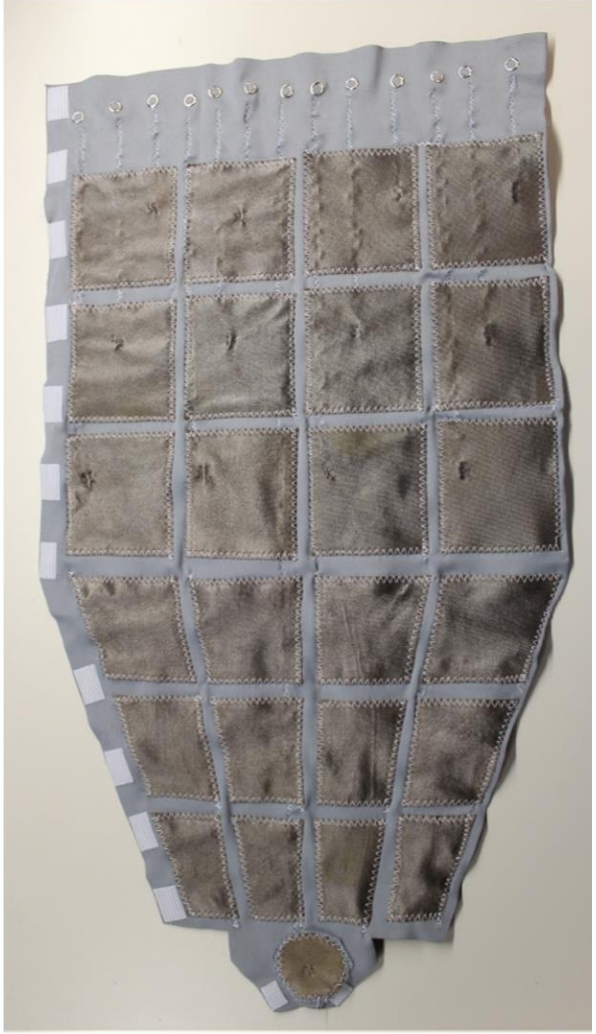
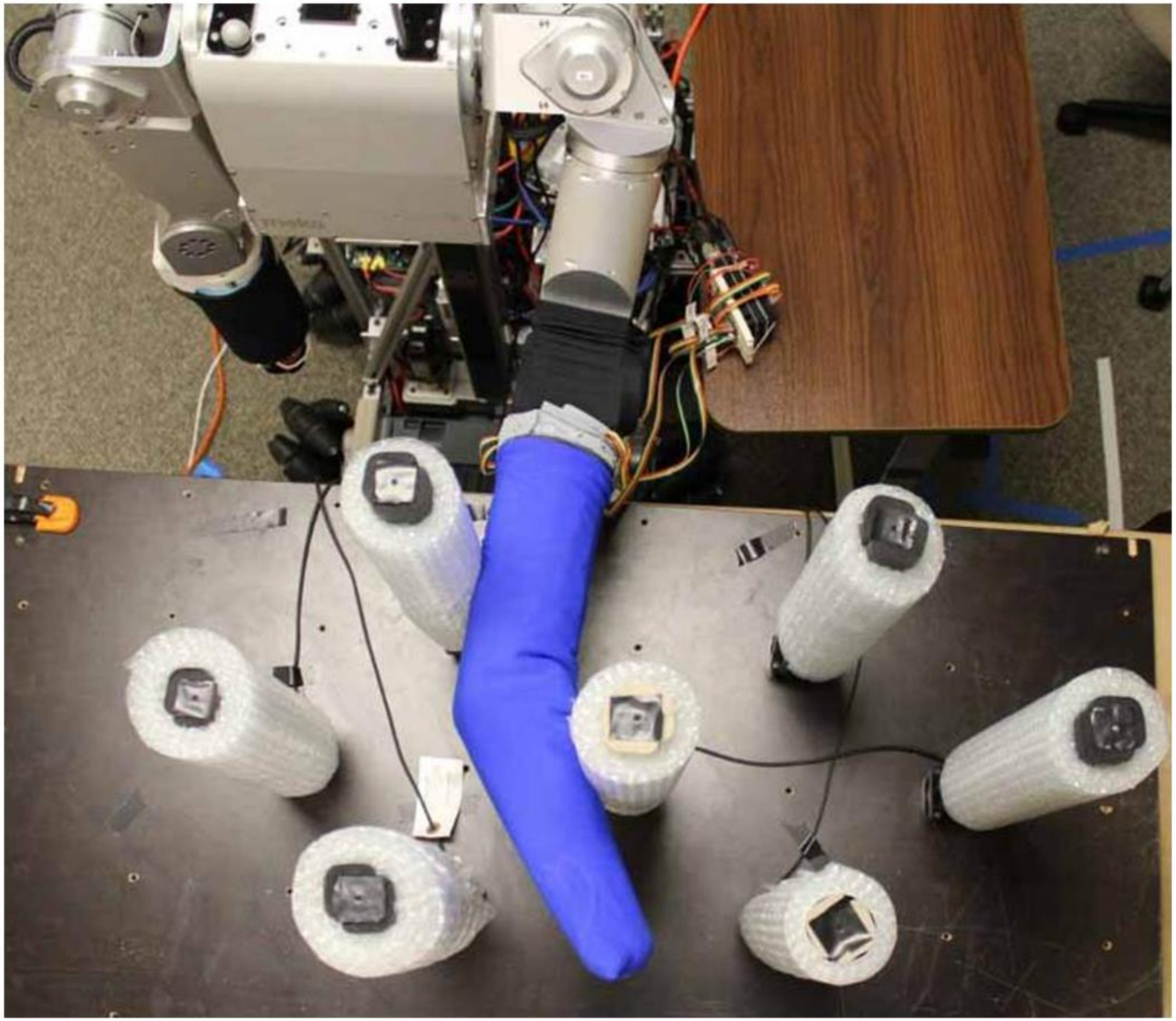
Marc D. Killpack, Ariel Kapusta, and Charles C. Kemp, *Model predictive control for fast reaching in clutter*, Autonomous Robots, 2015.

Contact at the Joints

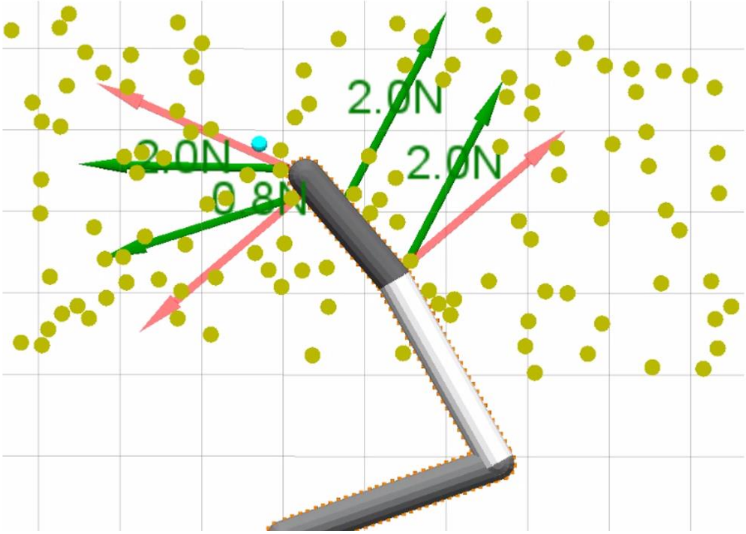


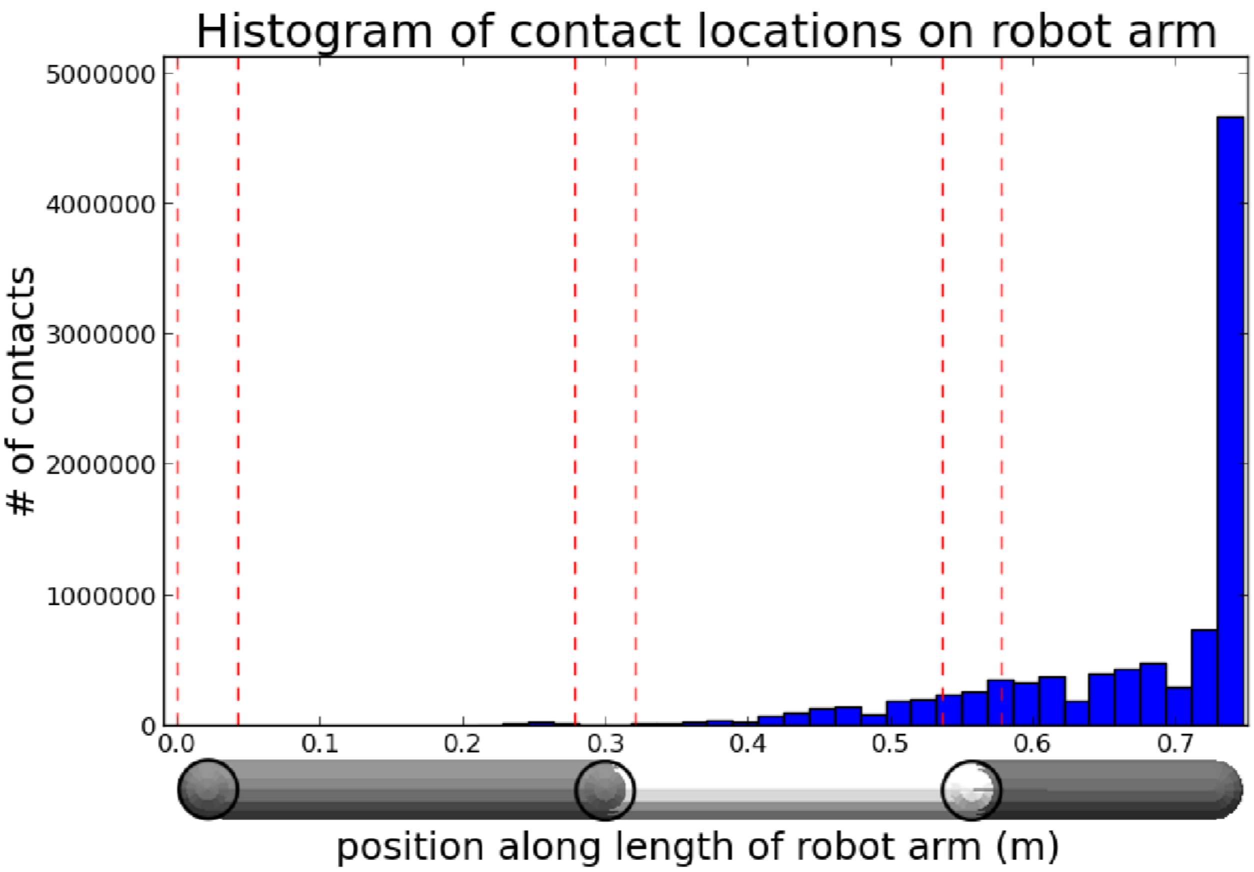


Tapomayukh Bhattacharjee, Advait Jain, Sarvagya Vaish, Marc D. Killpack, and Charles C. Kemp, *Tactile Sensing over Articulated Joints with Stretchable Sensors*, IEEE World Haptics Conference (WHC 2013), 2013.

Contact at the Joints

Reaching Task





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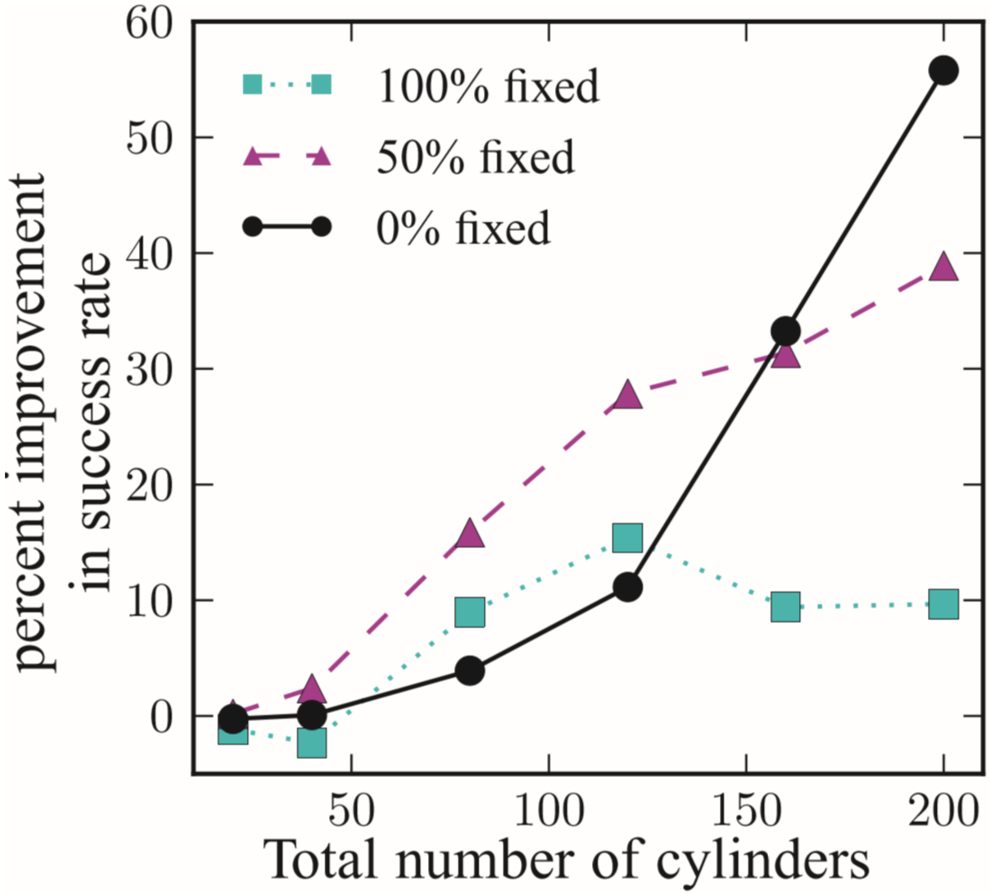
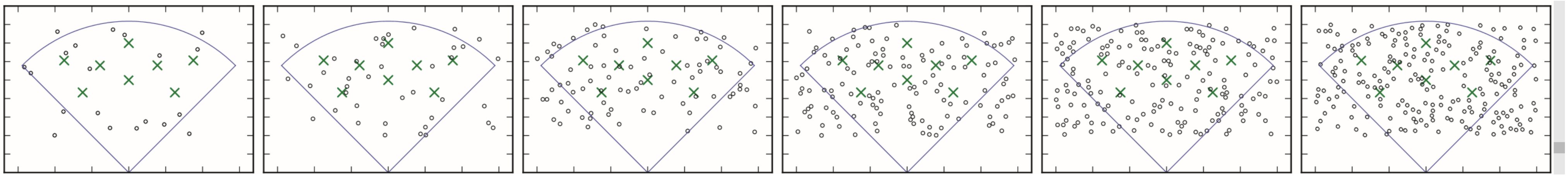
Higher success rate with tactile sensing compared to per-link force-torque sensing

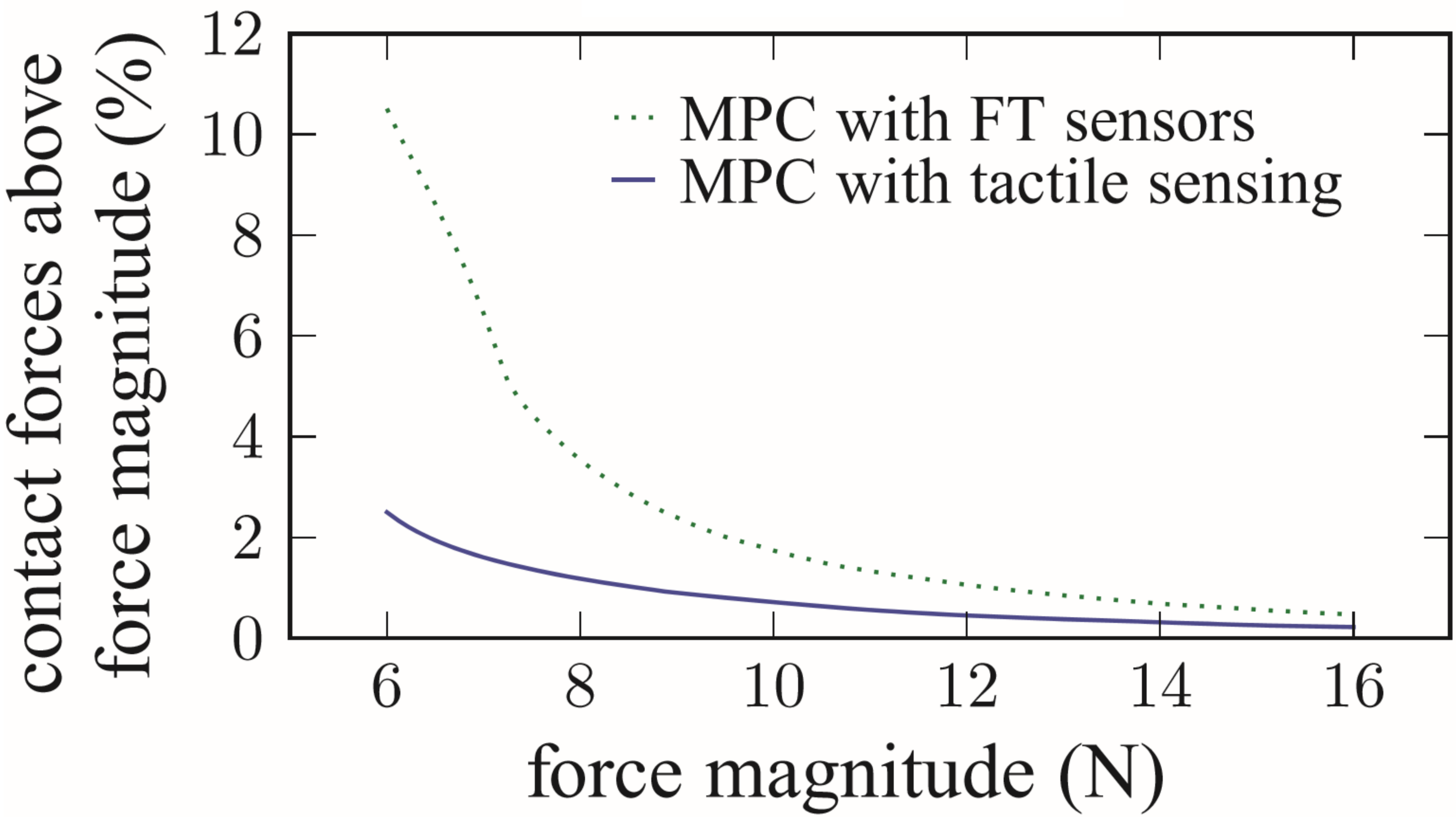


64,800 trials in simulation



Advait Jain, Marc D. Killpack, Aaron Edsinger, and Charles C. Kemp, *Reaching in Clutter with Whole-Arm Tactile Sensing*, The International Journal of Robotics Research (IJRR), 2013.

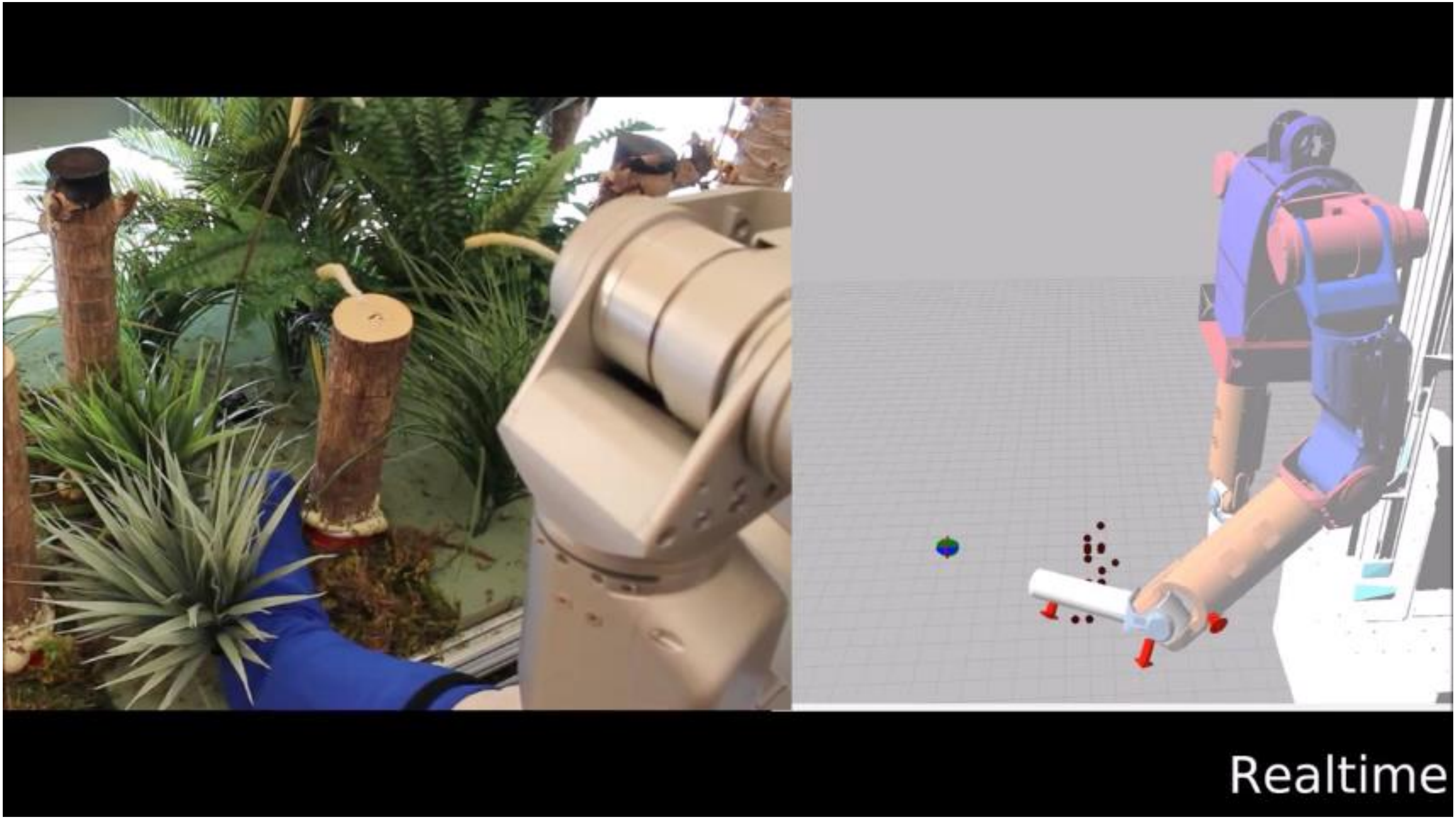
Higher contact forces with per-link force-torque sensing



attempt to keep force <= 5N

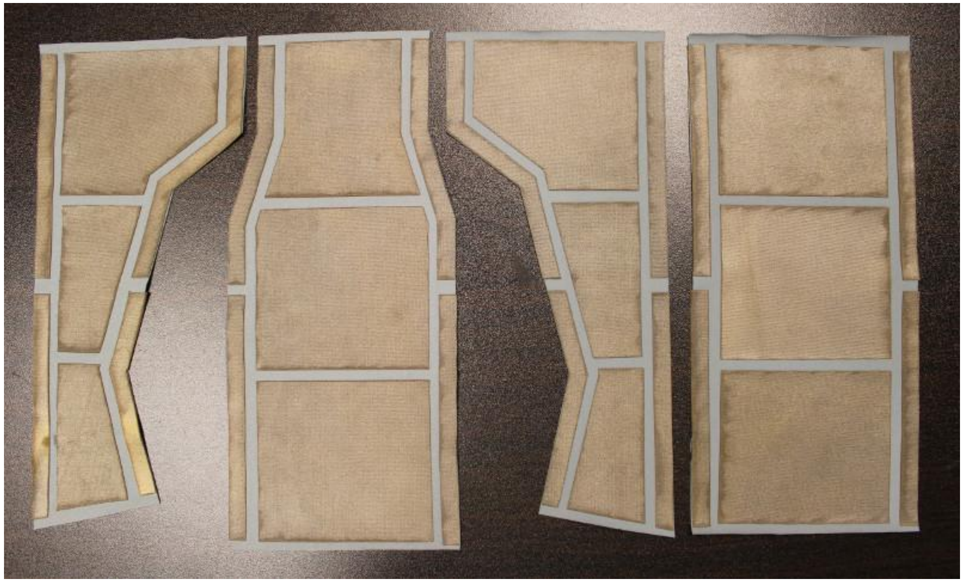
Advait Jain, Marc D. Killpack, Aaron Edsinger, and Charles C. Kemp, *Reaching in Clutter with Whole-Arm Tactile Sensing*, The International Journal of Robotics Research (IJRR), 2013.

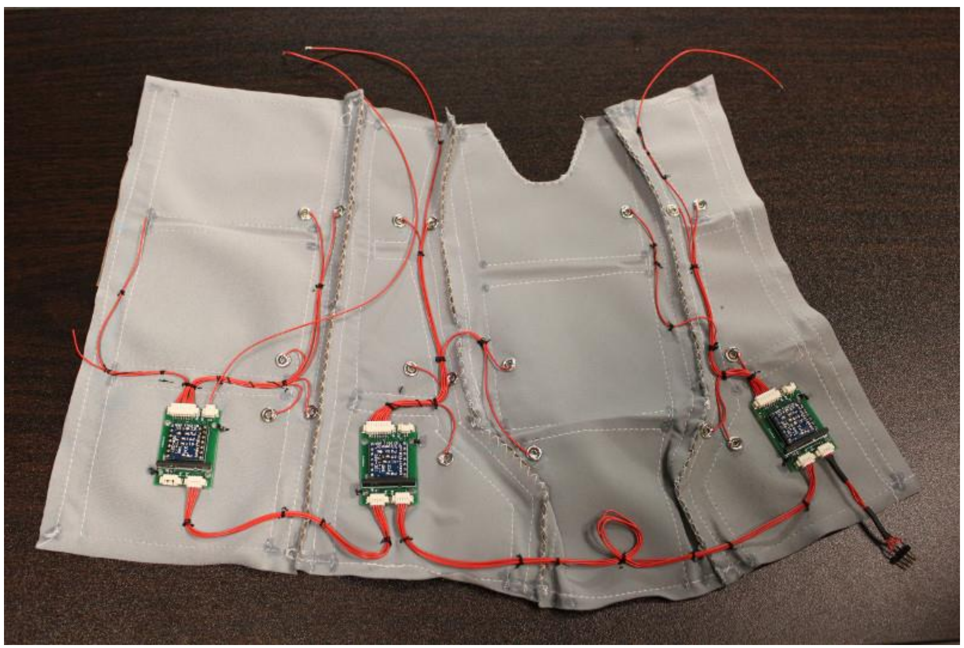
Real-time Haptic Mapping

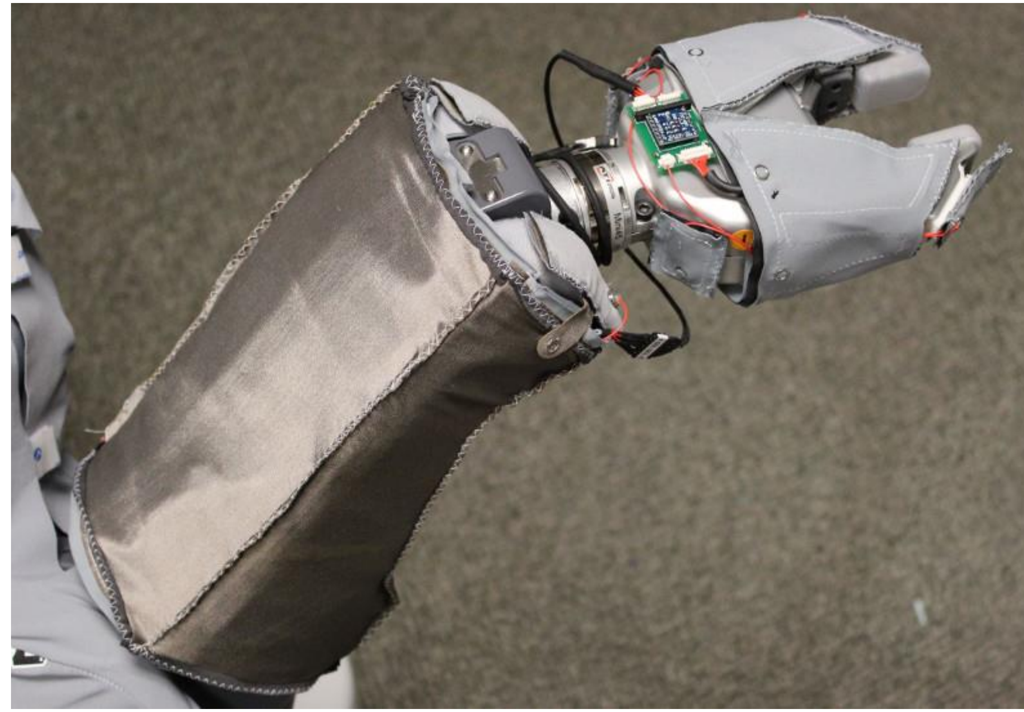


Tapomayukh Bhattacharjee, Phillip M. Grice, Ariel Kapusta, Marc D. Killpack, Daehyung Park, and Charles C. Kemp, *A Robotic System for Reaching in Dense Clutter that Integrates Model Predictive Control, Learning, Haptic Mapping, and Planning*, IROS 2014 workshop: 3rd Workshop on Robots in Clutter: Perception and Interaction in Clutter, 2014.

Stretchable Fabric Tactile Sensors

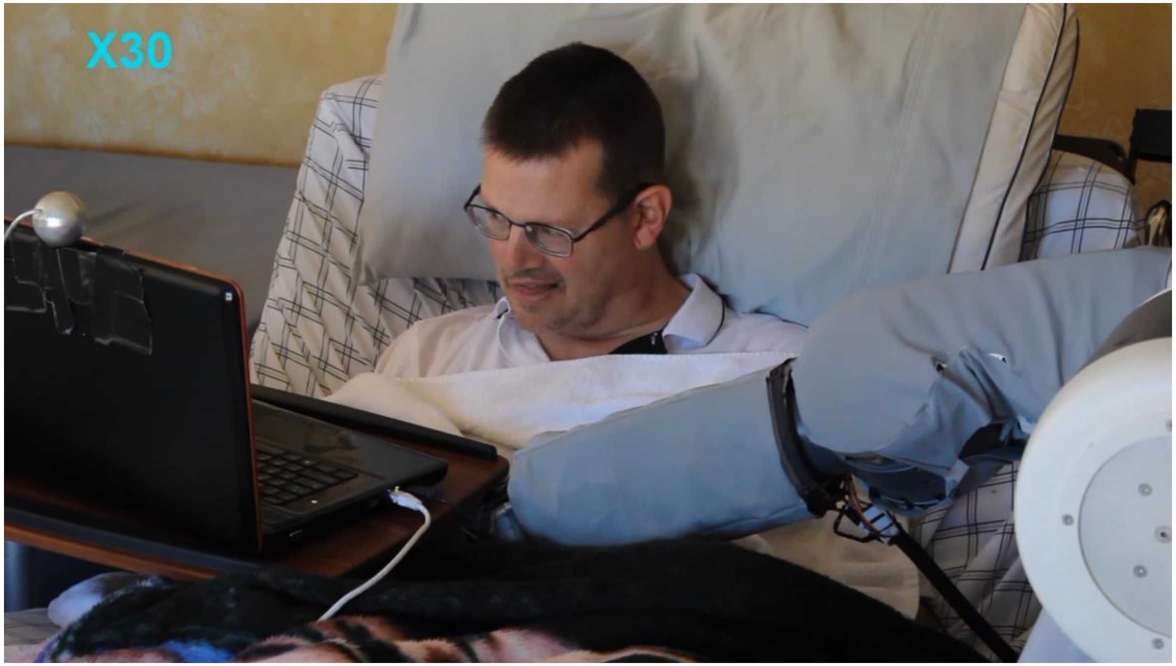


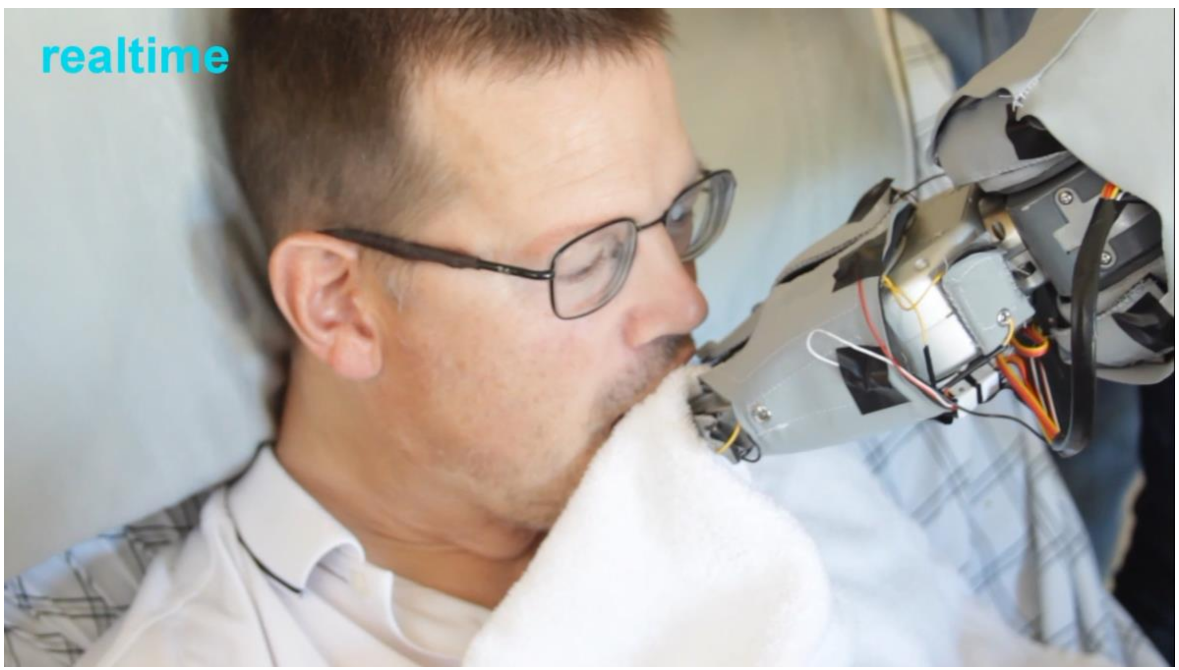




- **41 discrete tactile sensor elements (taxels)**
  - 3 on upper arm
  - 22 on forearm
  - 16 on the gripper
- **Open hardware**

Phillip M. Grice, Marc D. Killpack, Advait Jain, Sarvagya Vaish, Jeffrey Hawke, and Charles C. Kemp, *Whole-arm Tactile Sensing for Beneficial and Acceptable Contact During Robotic Assistance*, 13th International Conference on Rehabilitation Robotics (ICORR), 2013.





Picking Up a Cloth and Wiping Face in Bed

Phillip M. Grice, Marc D. Killpack, Advait Jain, Sarvagya Vaish, Jeffrey Hawke, and Charles C. Kemp, *Whole-arm Tactile Sensing for Beneficial and Acceptable Contact During Robotic Assistance*, 13th International Conference on Rehabilitation Robotics (ICORR), 2013.

Grasping and Pulling up a Blanket in Bed

Phillip M. Grice, Marc D. Killpack, Advait Jain, Sarvagya Vaish, Jeffrey Hawke, and Charles C. Kemp, *Whole-arm Tactile Sensing for Beneficial and Acceptable Contact During Robotic Assistance*, 13th International Conference on Rehabilitation Robotics (ICORR), 2013.

Henry Evans's Original Comments

During the tests:

"It is very compliant"

"**I like it.**"

"I think it's a good safety feature because **it hardly presses against me** even when I tell it to."

"It really feels safe to be close to the robot."

A week after the tests:

"Skin

Overall awesome

Feels VERY safe

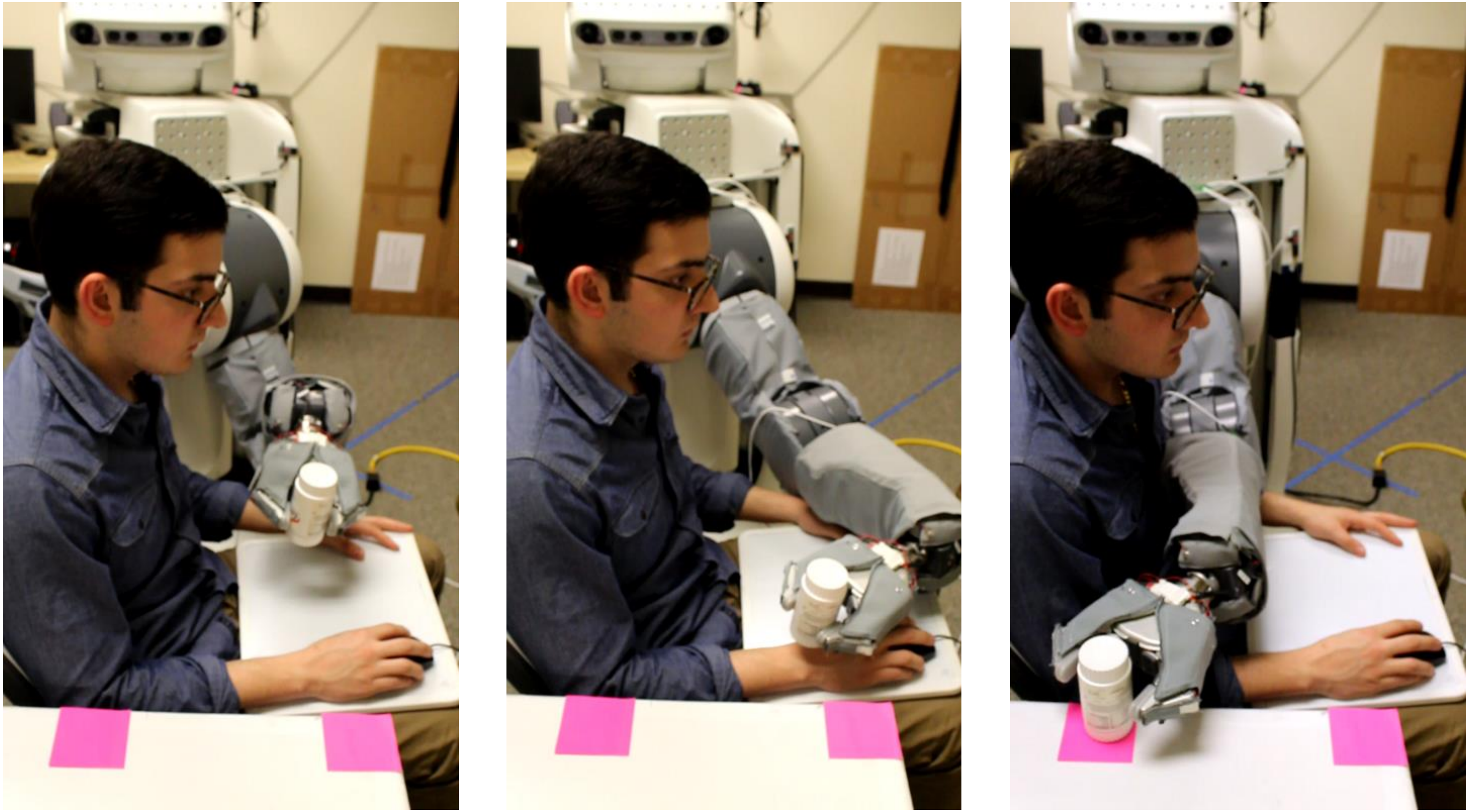
Faster than motion planning

It just wriggles around obstacles"

"DEFINITELY keep developing this !"

Phillip M. Grice, Marc D. Killpack, Advait Jain, Sarvagya Vaish, Jeffrey Hawke, and Charles C. Kemp, *Whole-arm Tactile Sensing for Beneficial and Acceptable Contact During Robotic Assistance*, 13th International Conference on Rehabilitation Robotics (ICORR), 2013.

Will contact be acceptable to others?



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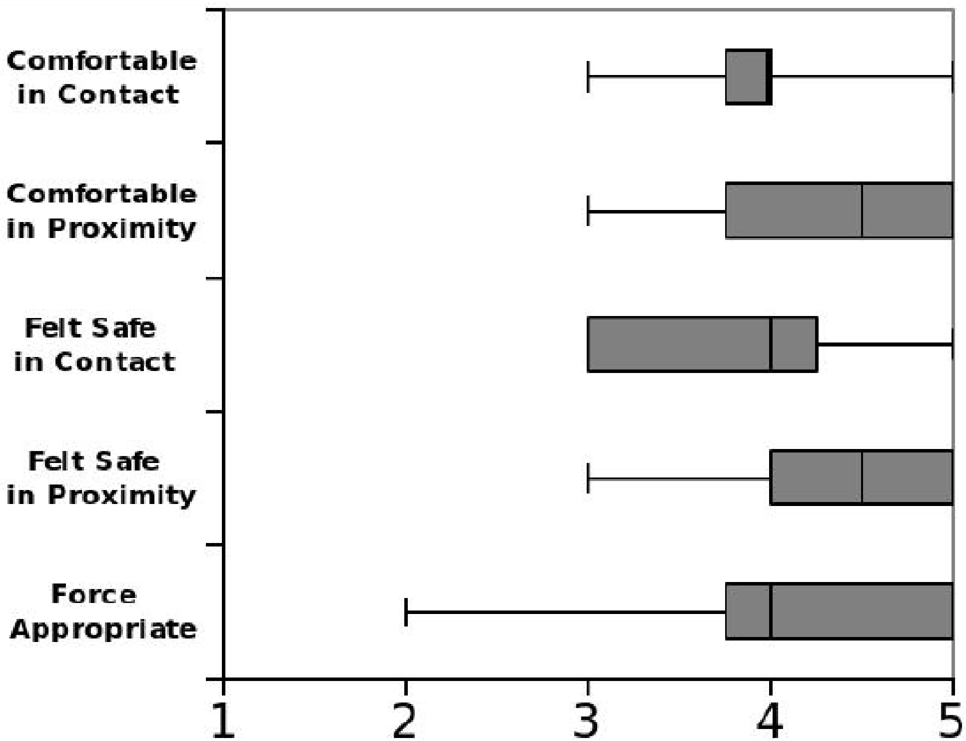
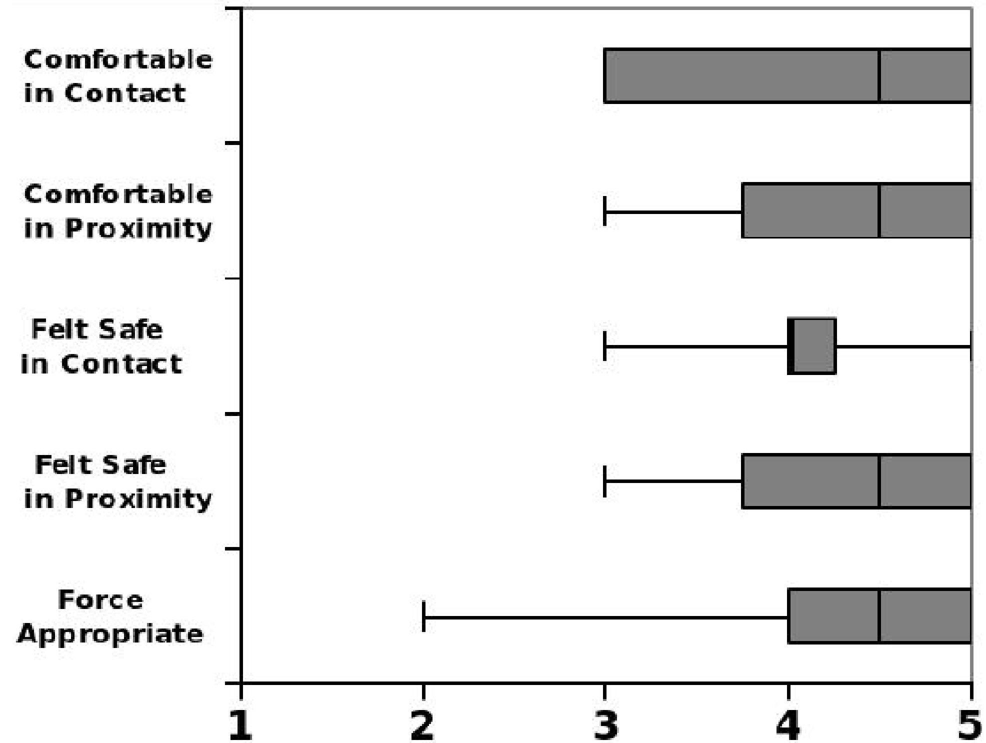
8 Able-bodied Participants



Away Condition



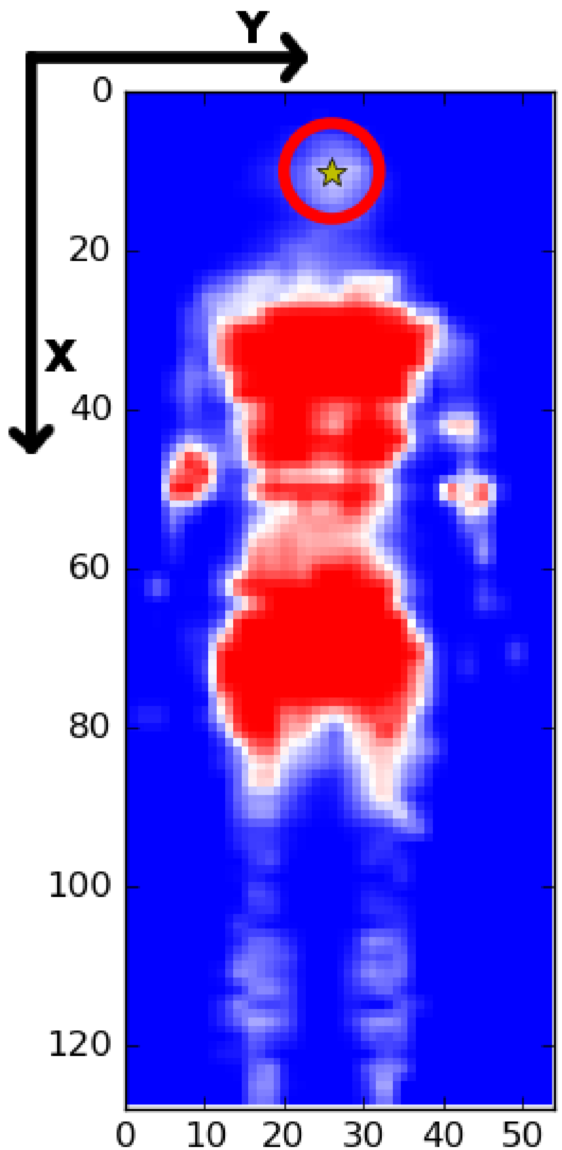
Near Condition

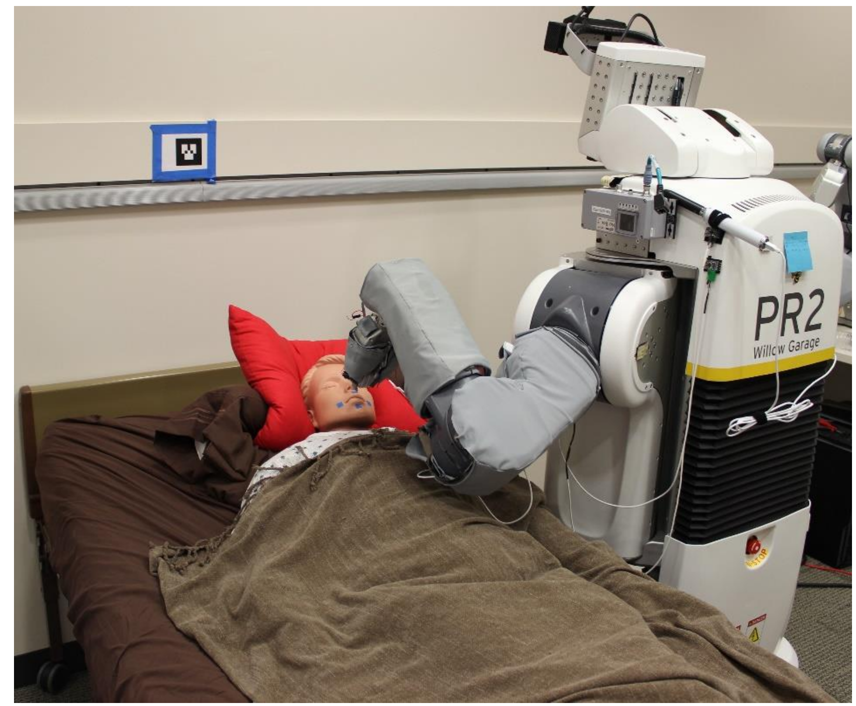
1: Strongly Disagree, 2: Disagree, 3: Neither Agree nor Disagree, 4: Agree, 5: Strongly Agree

Phillip M. Grice, Marc D. Killpack, Advait Jain, Sarvagya Vaish, Jeffrey Hawke, and Charles C. Kemp, *Whole-arm Tactile Sensing for Beneficial and Acceptable Contact During Robotic Assistance*, 13th International Conference on Rehabilitation Robotics (ICORR), 2013.

Whole-Body Tactile Sensing for Unconventional Robots

Perceptual Collaboration Between Robots





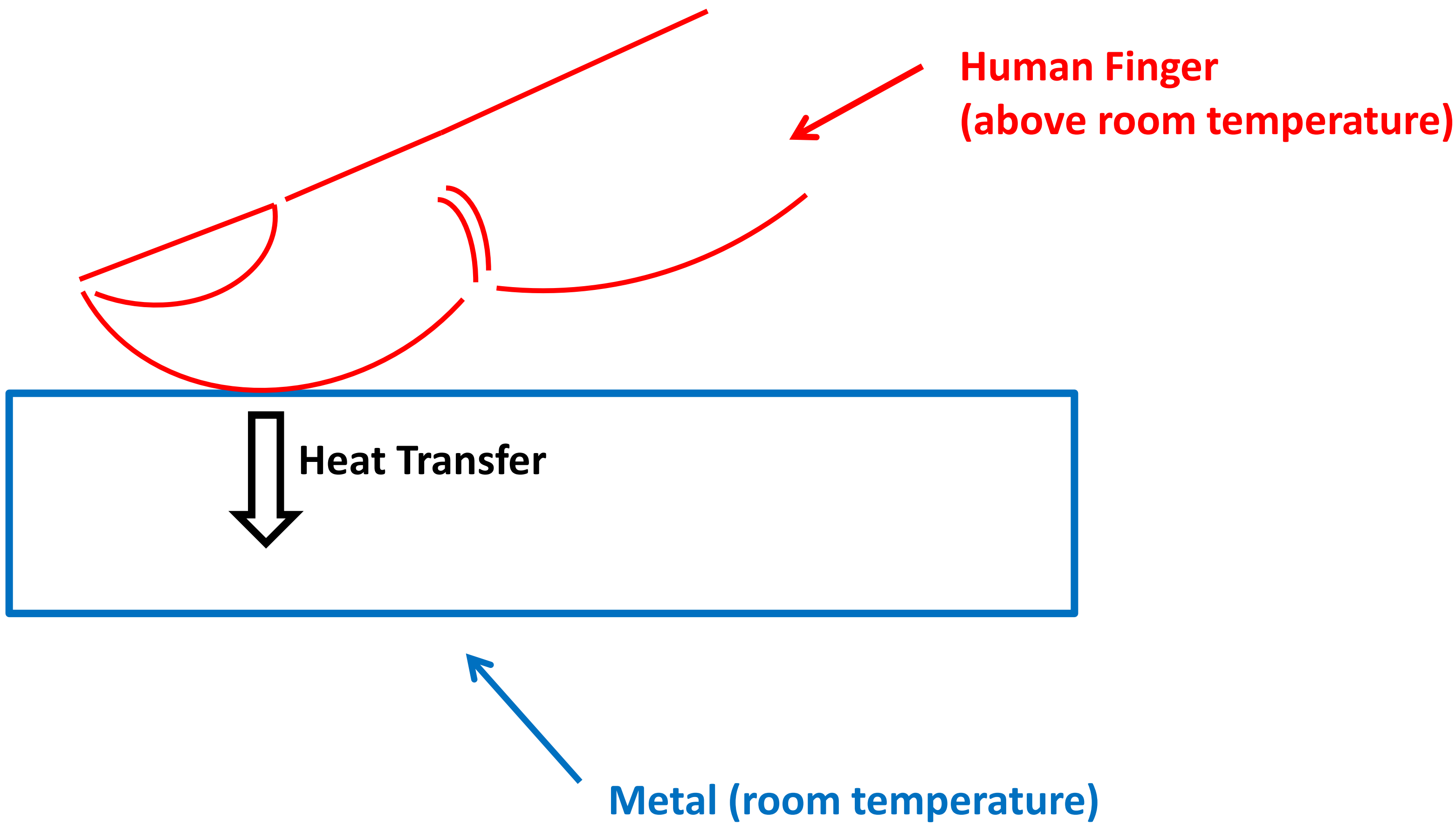
Ariel Kapusta, Yash Chitalia, Daehyung Park, and Charles C. Kemp, *Collaboration Between a Robotic Bed and a Mobile Manipulator May Improve Physical Assistance for People with Disabilities*, RO-MAN 2016 Workshop on behavior adaptation, interaction and learning for assistive robots (BAILAR 2016), 2016.

Whole-Arm Tactile Sensing

- Reach locations in clutter while keeping forces low
  - Reaching around the human body
  - Outperformed per-link force-torque sensing
- Challenge
  - Immature technology for large area tactile sensing
- Permitting contact
  - Makes more poses reachable
  - Reduces line of sight sensing requirements
  - Creates opportunities to sense through touch (e.g., incidental contact)

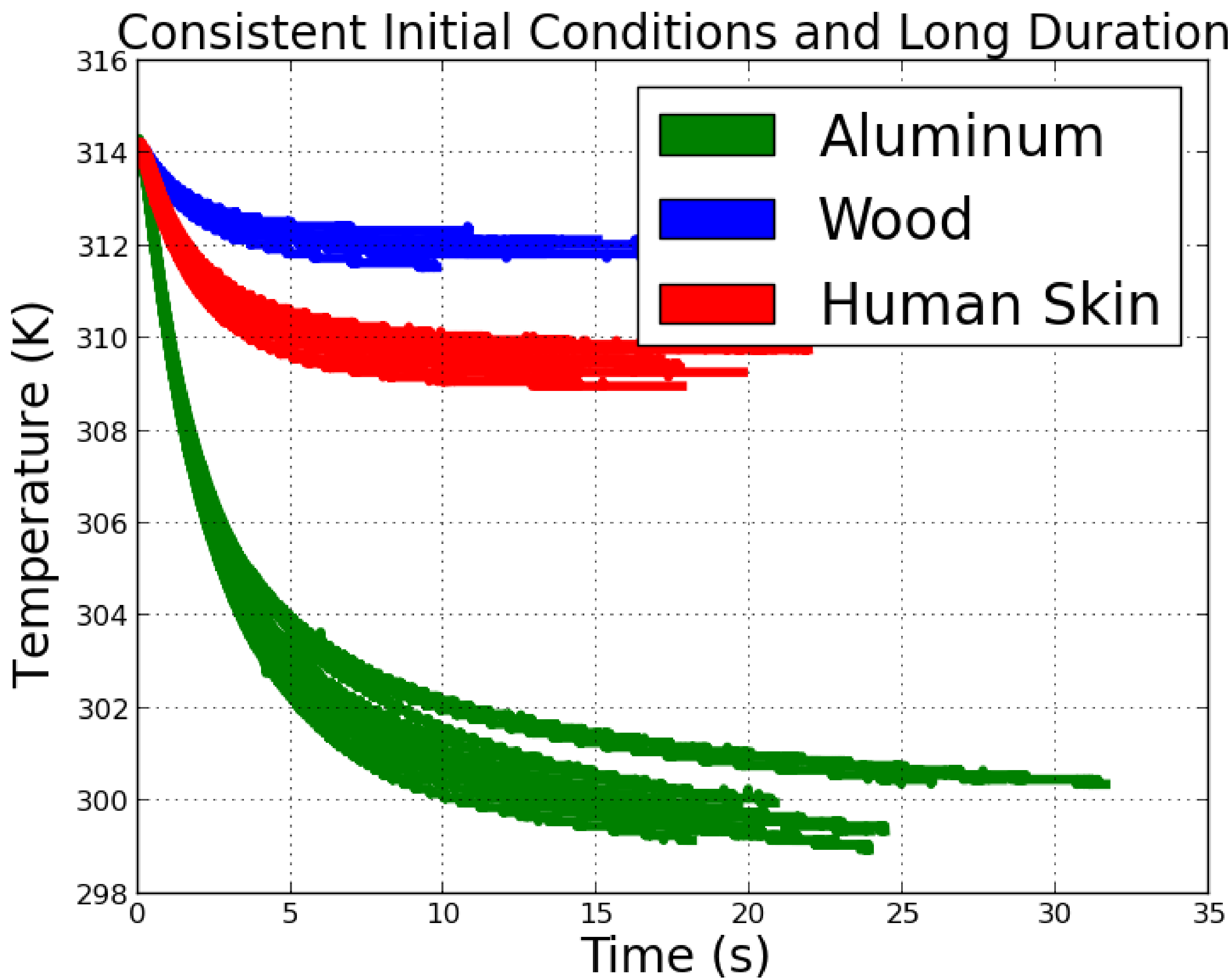
Thermal Tactile Sensing

Active Thermal Sensing



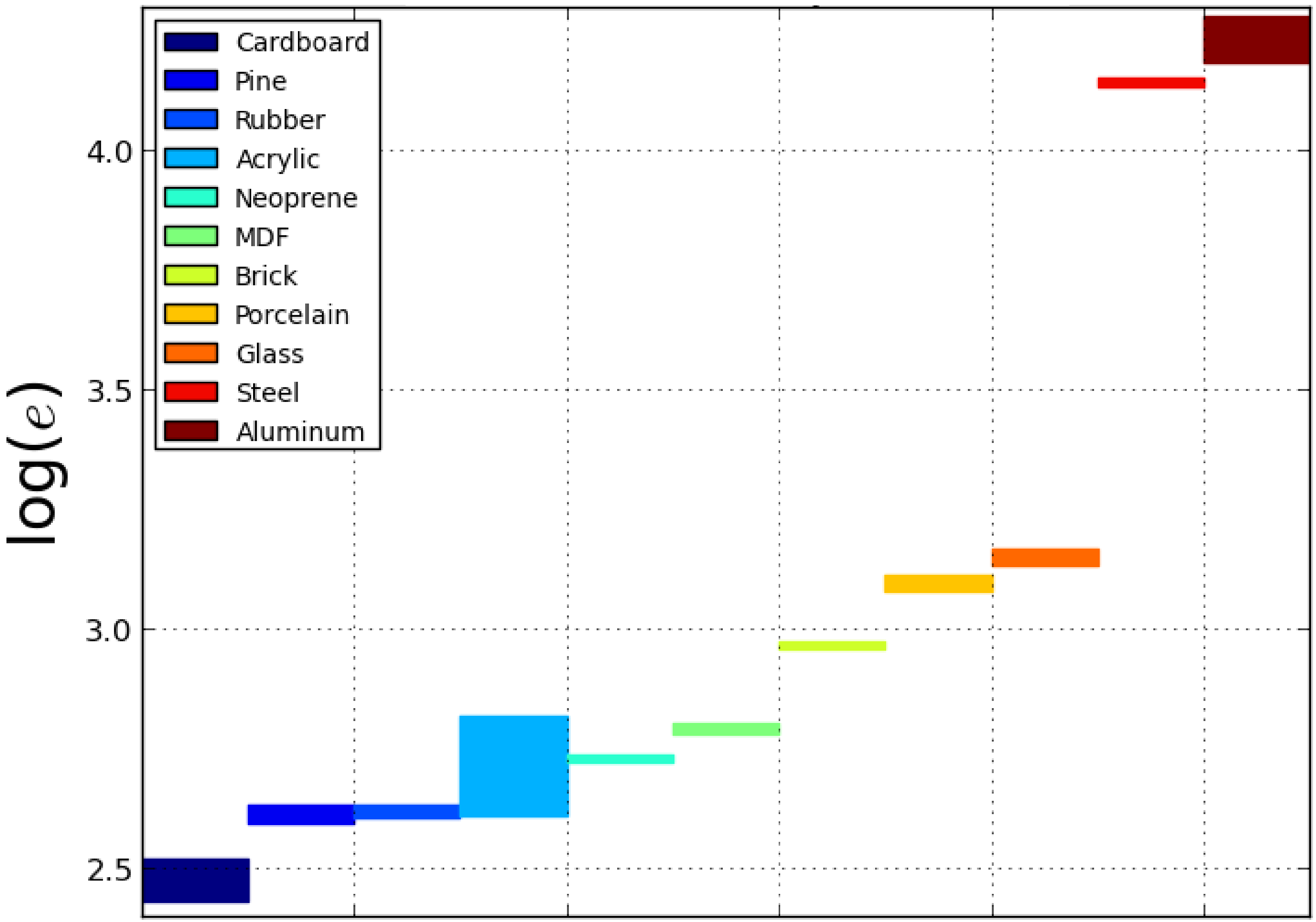
Tapomayukh Bhattacharjee, Joshua Wade, and Charles C. Kemp, *Material Recognition from Heat Transfer given Varying Initial Conditions and Short-Duration Contact*, Robotics Science and Systems (RSS), 2015.

Active Thermal Sensing



Tapomayukh Bhattacharjee, Joshua Wade, and Charles C. Kemp, *Material Recognition from Heat Transfer given Varying Initial Conditions and Short-Duration Contact*, Robotics Science and Systems (RSS), 2015.

Thermal Effusivity



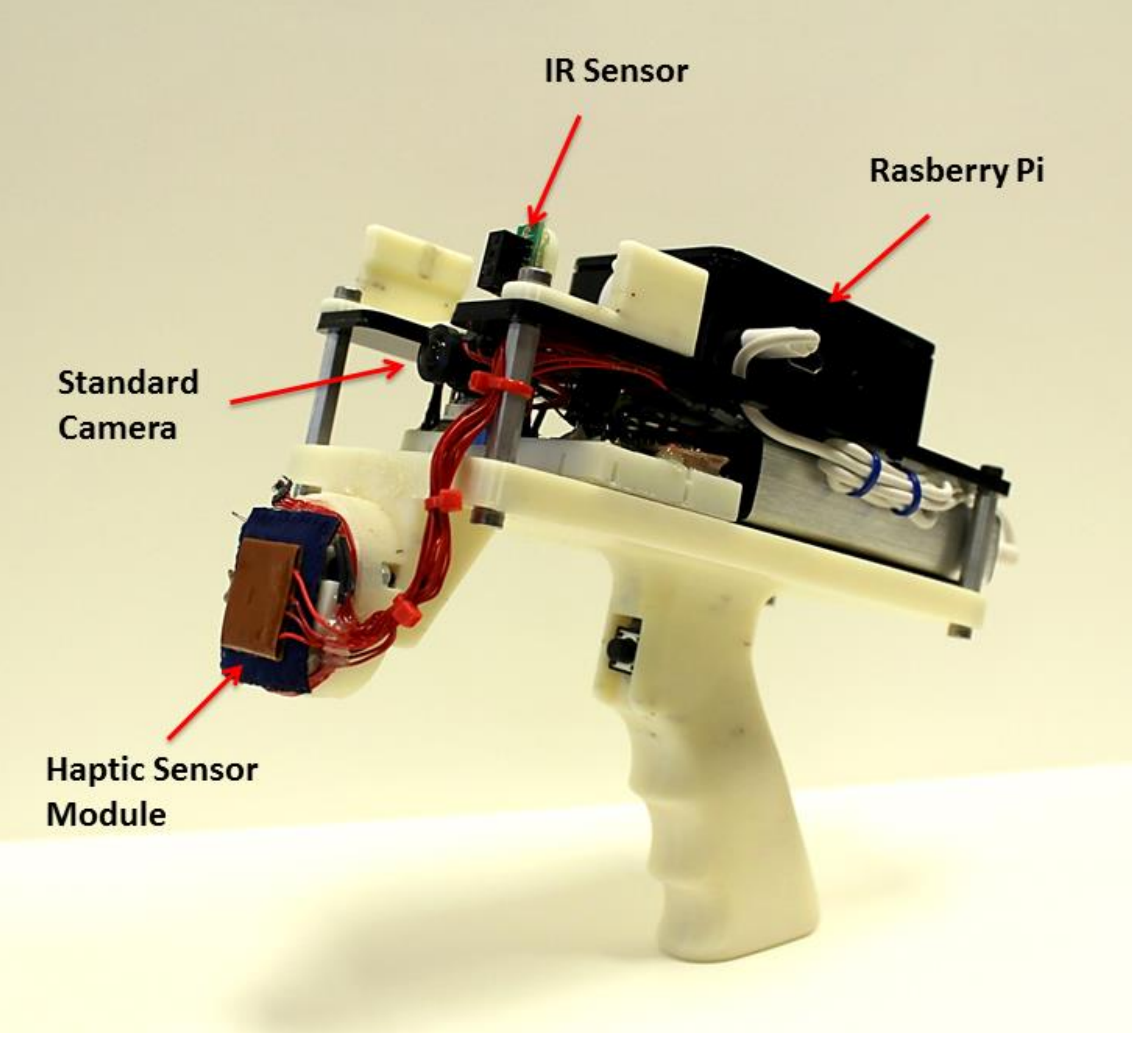
Tapomayukh Bhattacharjee, Joshua Wade, and Charles C. Kemp, *Material Recognition from Heat Transfer given Varying Initial Conditions and Short-Duration Contact*, Robotics Science and Systems (RSS), 2015.

Passive Thermal Sensing

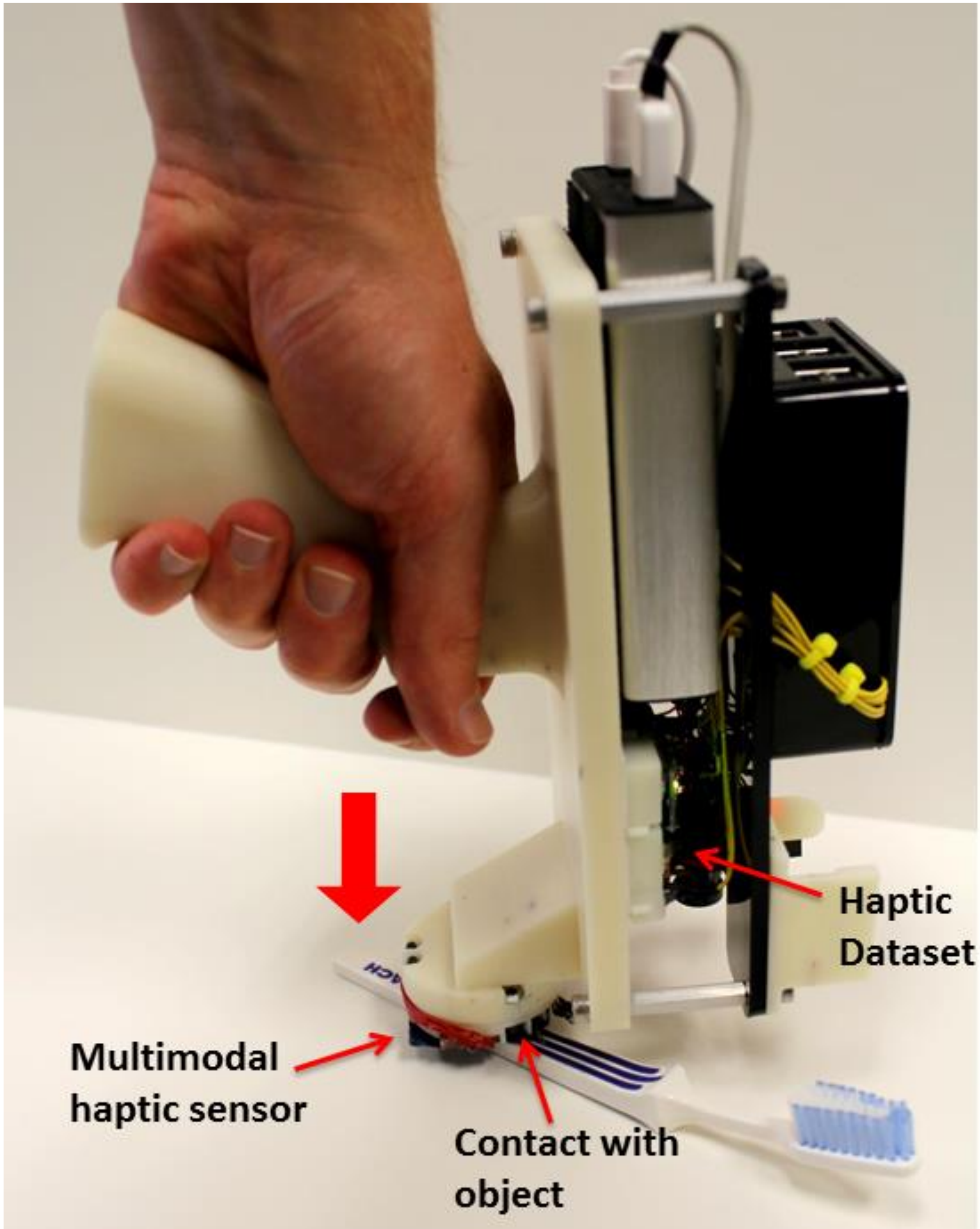
[image] found on the internet and used without permission

Tapomayukh Bhattacharjee, Joshua Wade, Yash Chitalia, and Charles C. Kemp, *Data-Driven Thermal Recognition of Contact with People and Objects*, IEEE Haptics Symposium, 2016.

Data-Driven Thermal Recognition



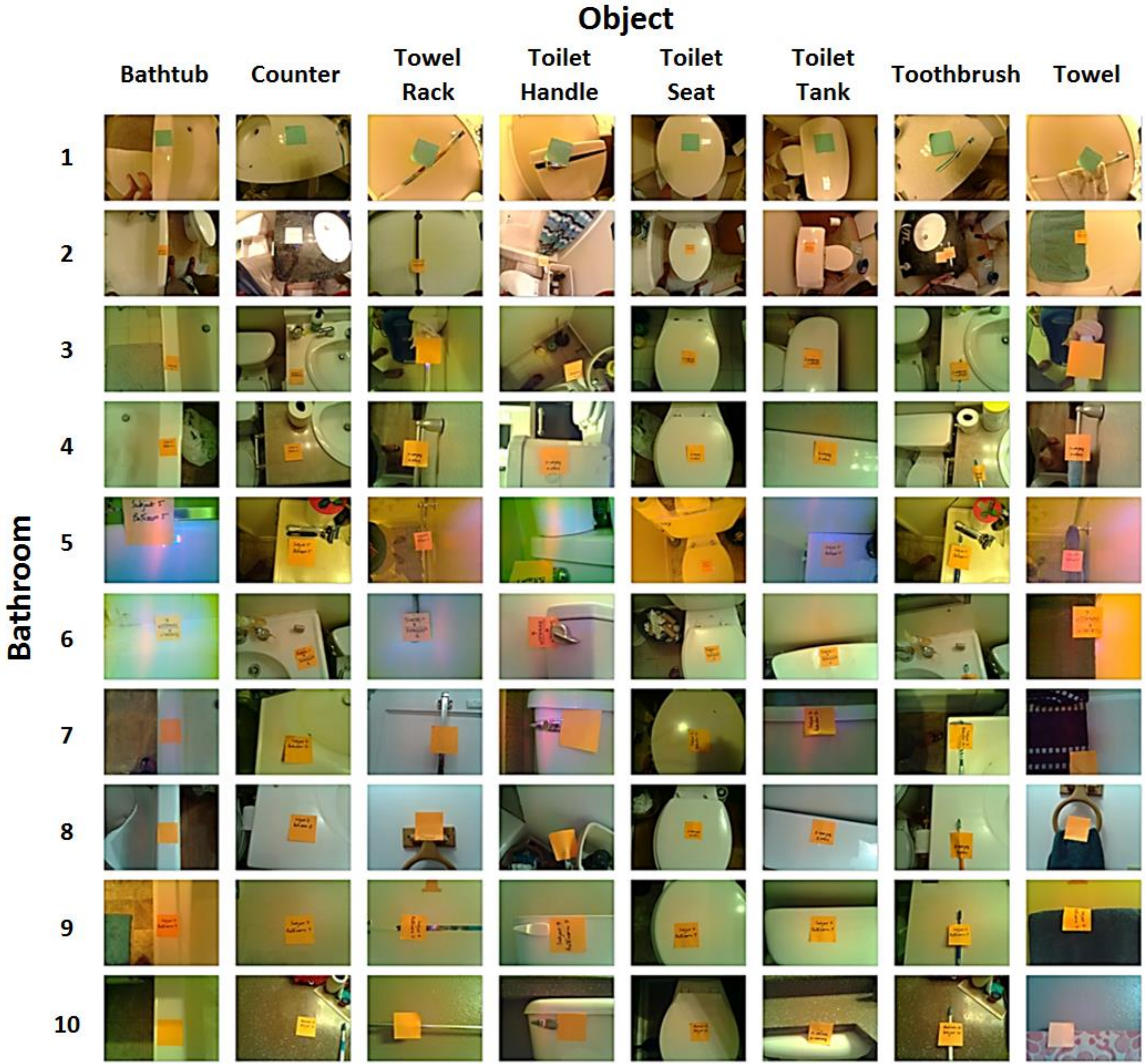
Tapomayukh Bhattacharjee, Joshua Wade, Yash Chitalia, and Charles C. Kemp, *Data-Driven Thermal Recognition of Contact with People and Objects*, IEEE Haptics Symposium, 2016.



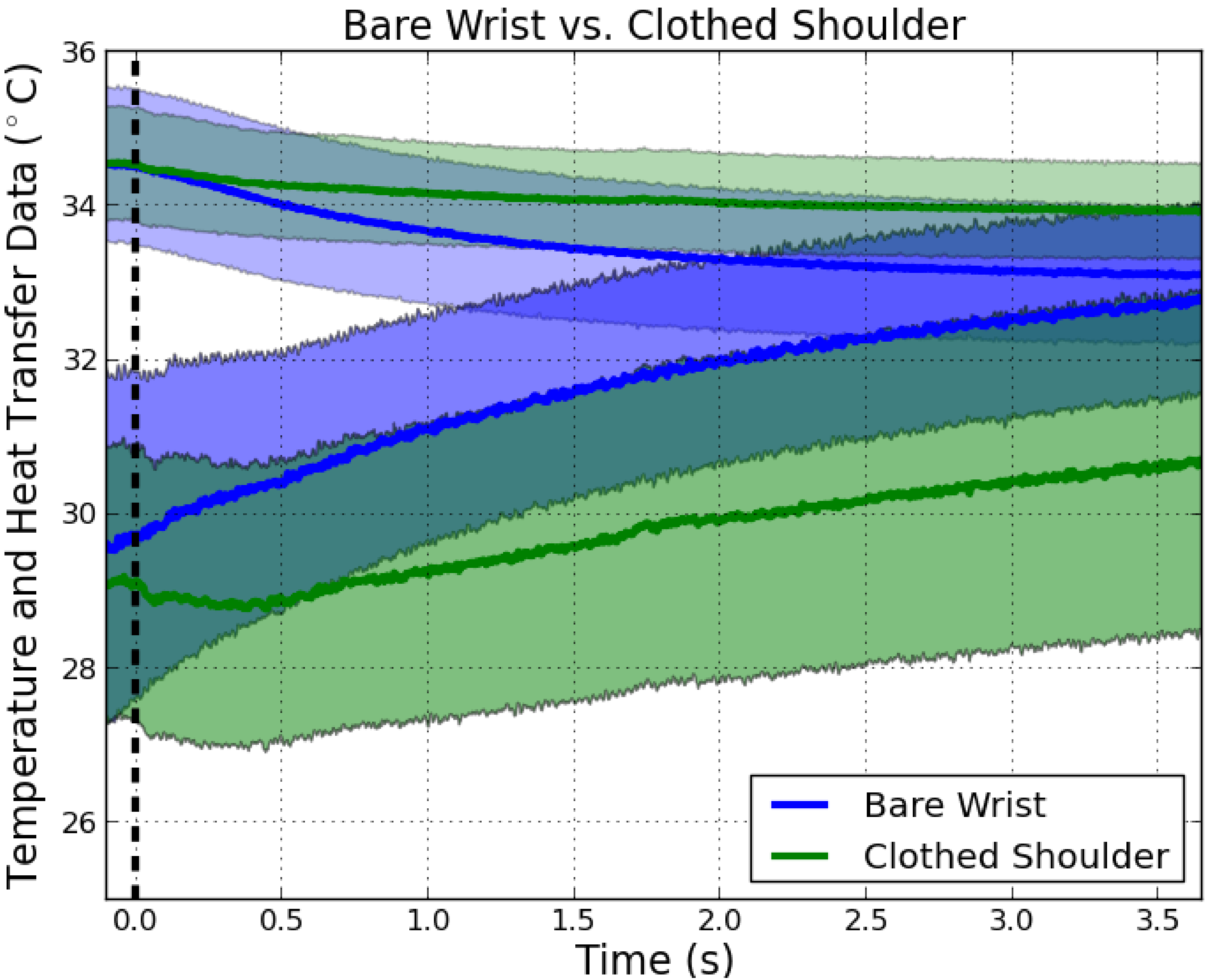
1. Wrist

3. Shoulder

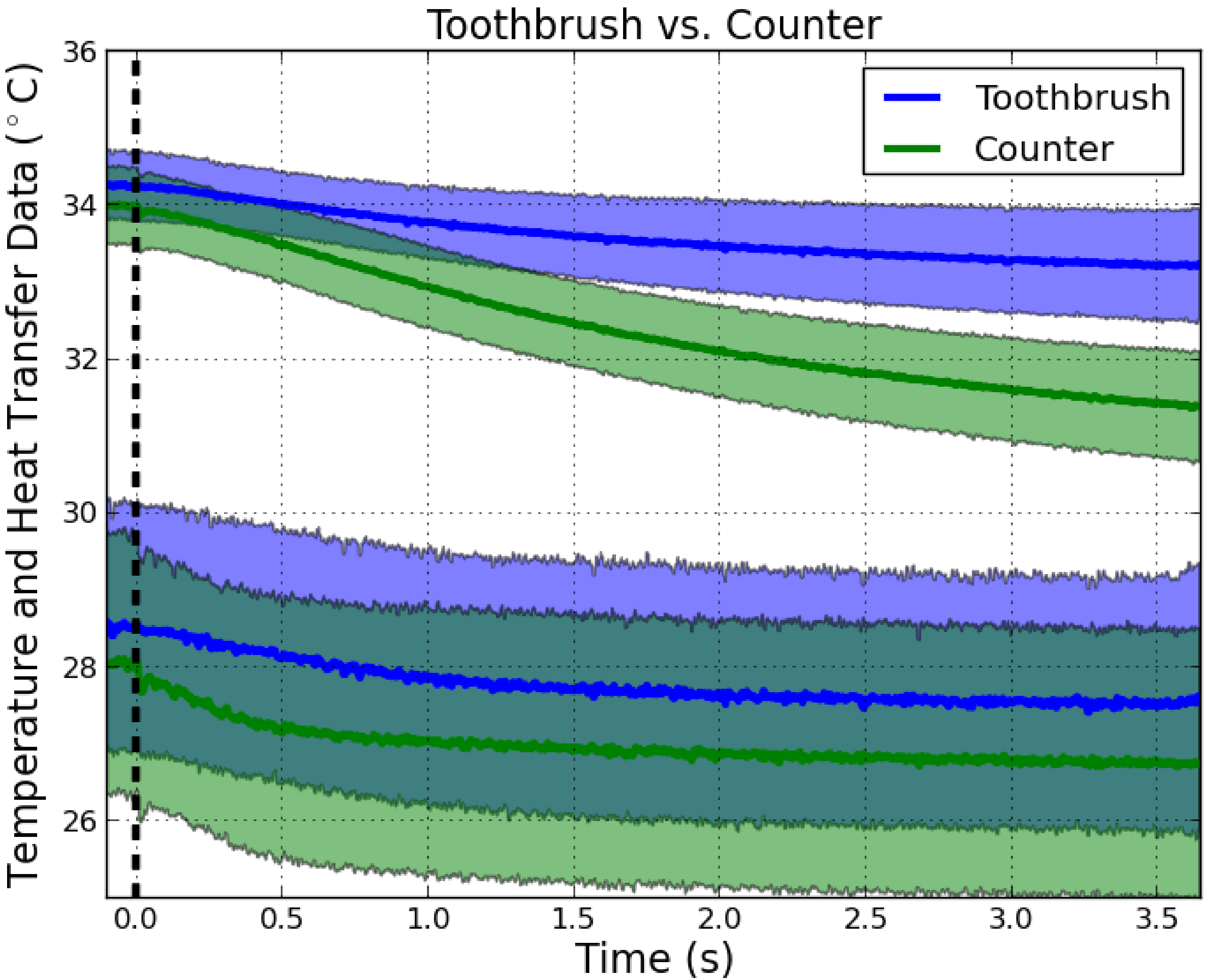
Tapomayukh Bhattacharjee, Joshua Wade, Yash Chitalia, and Charles C. Kemp, *Data-Driven Thermal Recognition of Contact with People and Objects*, IEEE Haptics Symposium, 2016.



Tapomayukh Bhattacharjee, Joshua Wade, Yash Chitalia, and Charles C. Kemp, *Data-Driven Thermal Recognition of Contact with People and Objects*, IEEE Haptics Symposium, 2016.



Tapomayukh Bhattacharjee, Joshua Wade, Yash Chitalia, and Charles C. Kemp, *Data-Driven Thermal Recognition of Contact with People and Objects*, IEEE Haptics Symposium, 2016.

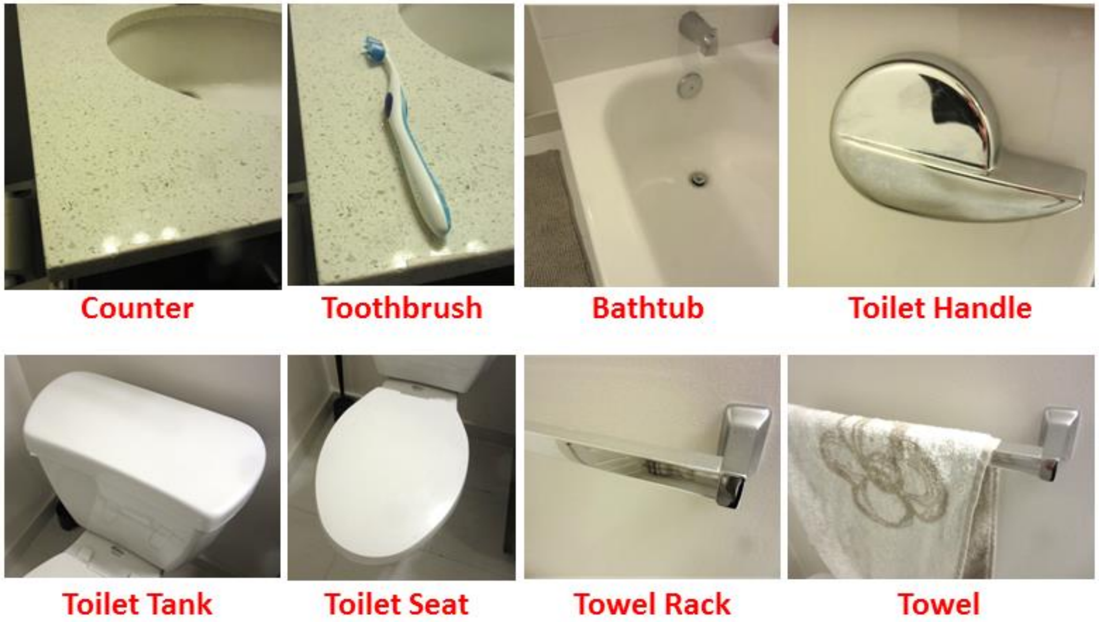


Tapomayukh Bhattacharjee, Joshua Wade, Yash Chitalia, and Charles C. Kemp, *Data-Driven Thermal Recognition of Contact with People and Objects*, IEEE Haptics Symposium, 2016.

Passive thermal sensing performed best for humans vs. objects

98.75% with 3.65s of contact

Vs.



[images] found on the internet and used without permission

Tapomayukh Bhattacharjee, Joshua Wade, Yash Chitalia, and Charles C. Kemp, *Data-Driven Thermal Recognition of Contact with People and Objects*, IEEE Haptics Symposium, 2016.

Passive & active thermal sensing together performed best for objects vs. objects

92.14% : generalizing to new locations in same environment
84% : generalizing to different environments
with 3.65s of contact



[images] found on the internet and used without permission

Tapomayukh Bhattacharjee, Joshua Wade, Yash Chitalia, and Charles C. Kemp, *Data-Driven Thermal Recognition of Contact with People and Objects*, IEEE Haptics Symposium, 2016.

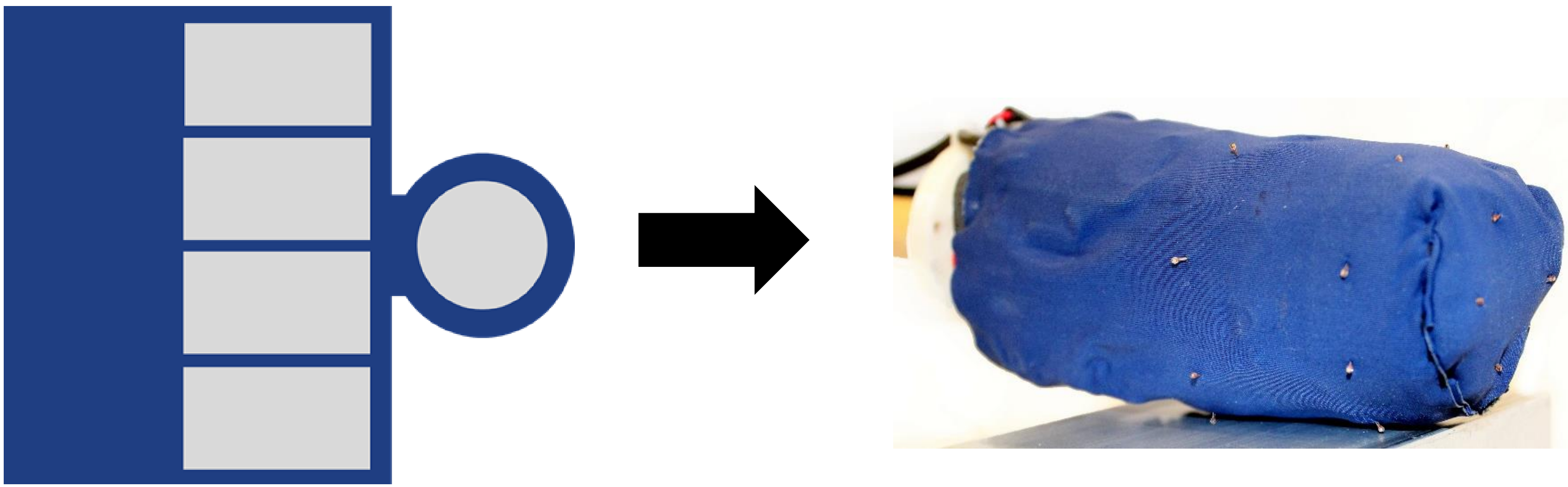
Force and **Thermal** Sensing with a **Fabric-Based** Skin

A Prototype with 5 multimodal taxels :

Force, Active Thermal, and Passive Thermal

Joshua Wade, Tapomayukh Bhattacharjee, and Charles C. Kemp, *Force and Thermal Sensing with a Fabric-based Skin*, IROS Workshop on See, Touch, and Hear : 2nd Workshop on Multimodal Sensor-based Robot Control for HRI and Soft Manipulation, 2016.

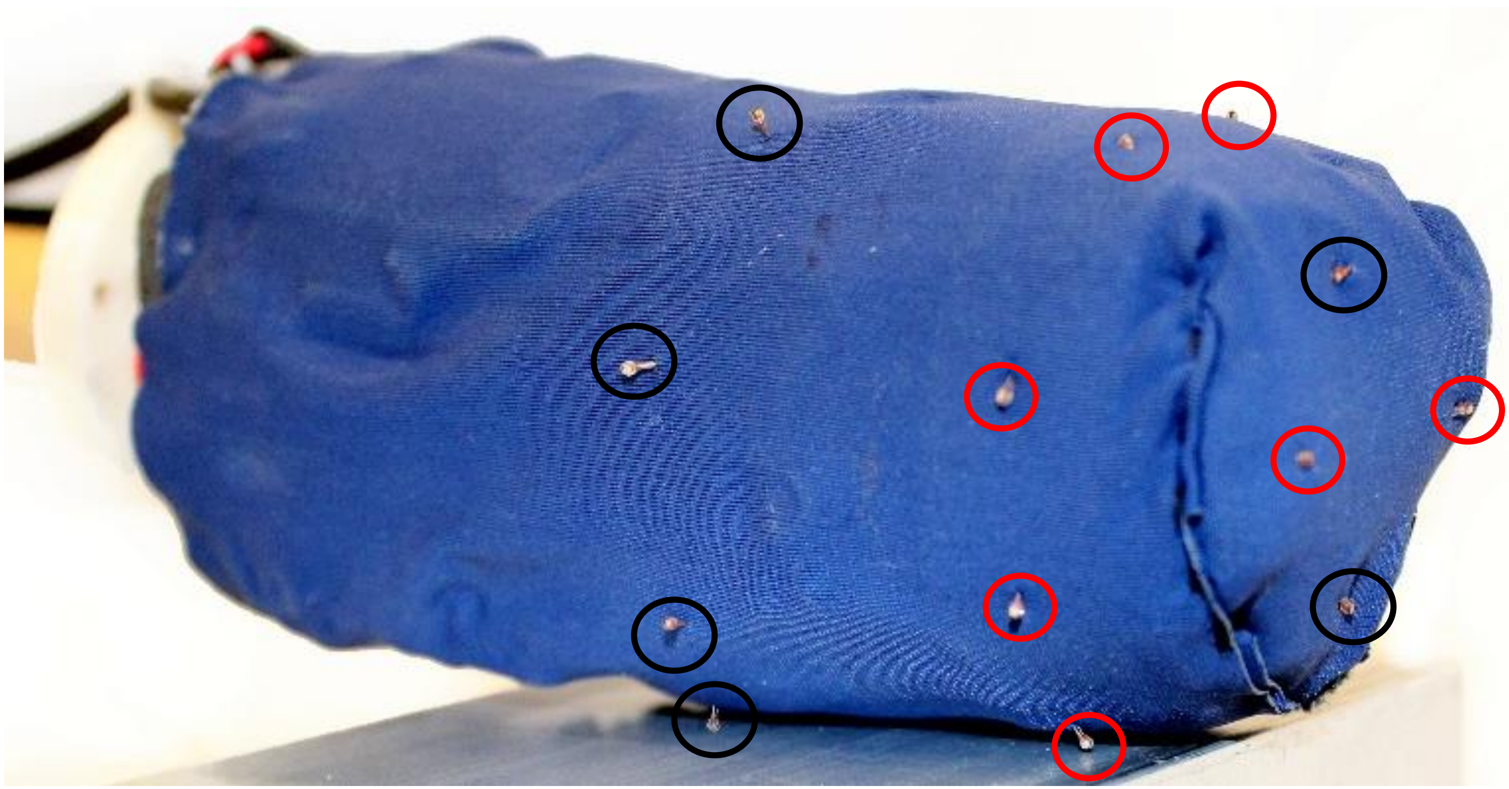
A Prototype with 5 Multimodal Taxels



5 Force Sensing Taxels

Joshua Wade, Tapomayukh Bhattacharjee, and Charles C. Kemp, *Force and Thermal Sensing with a Fabric-based Skin*, IROS Workshop on See, Touch, and Hear : 2nd Workshop on Multimodal Sensor-based Robot Control for HRI and Soft Manipulation, 2016.

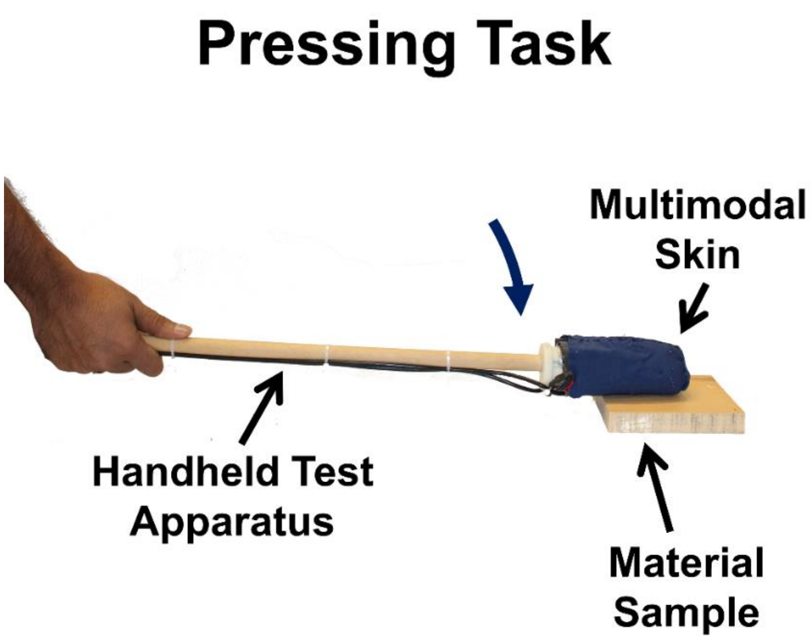
A Prototype with 5 Multimodal Taxels

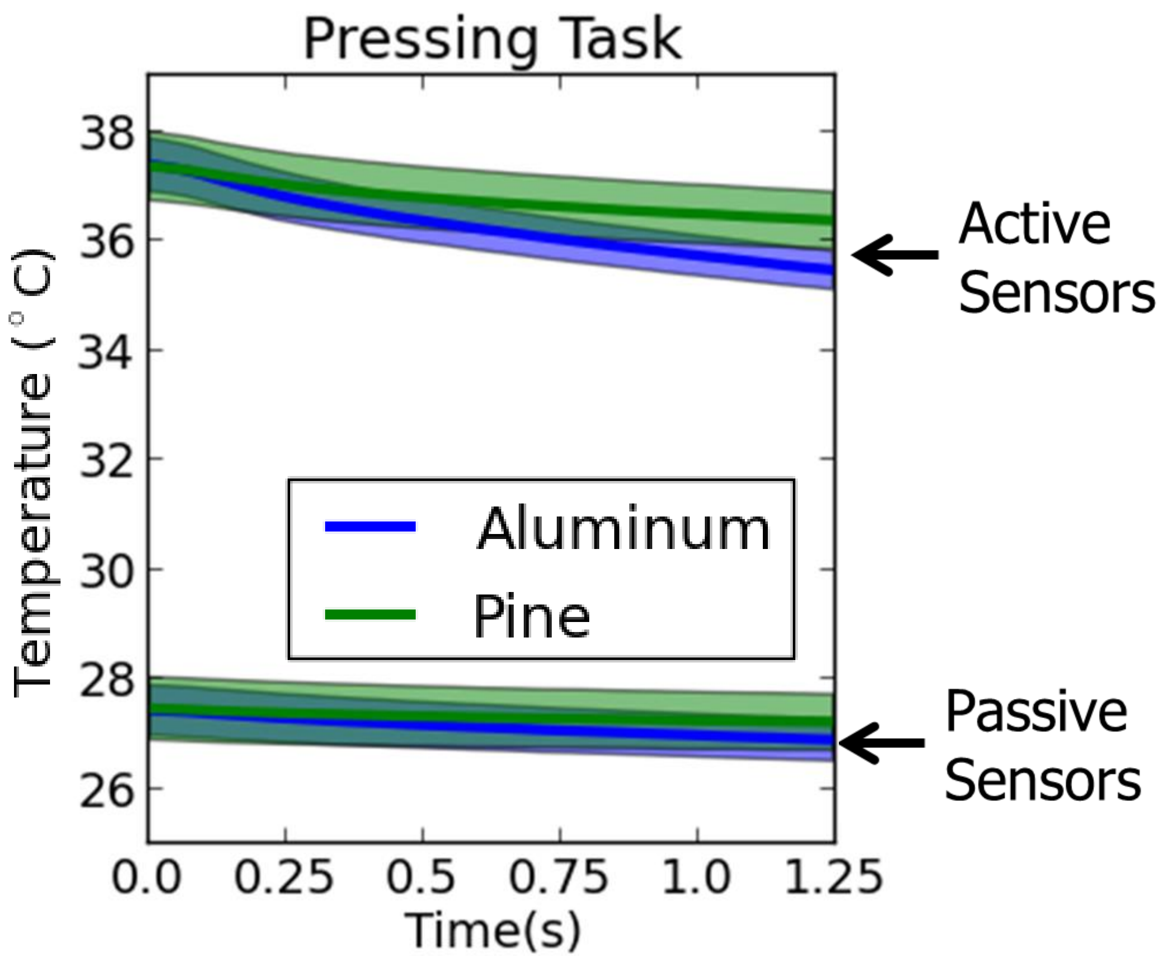


- ○ **10 Actively Heated Thermistors**
- ○ **10 Passive Thermistors**

Joshua Wade, Tapomayukh Bhattacharjee, and Charles C. Kemp, *Force and Thermal Sensing with a Fabric-based Skin*, IROS Workshop on See, Touch, and Hear : 2nd Workshop on Multimodal Sensor-based Robot Control for HRI and Soft Manipulation, 2016.

Experiments : Representative Manipulation Task 1

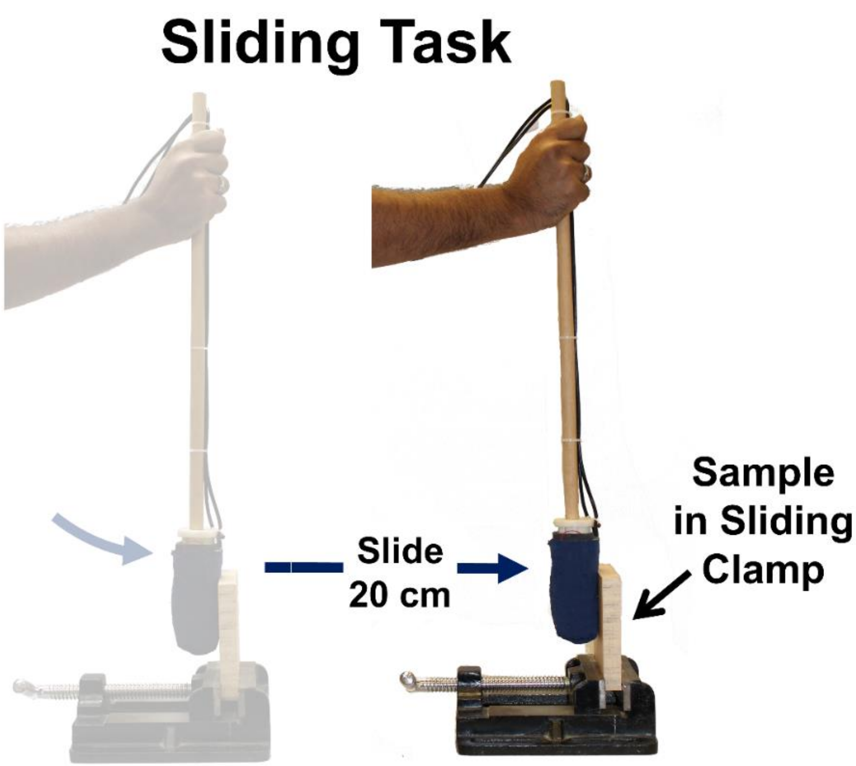


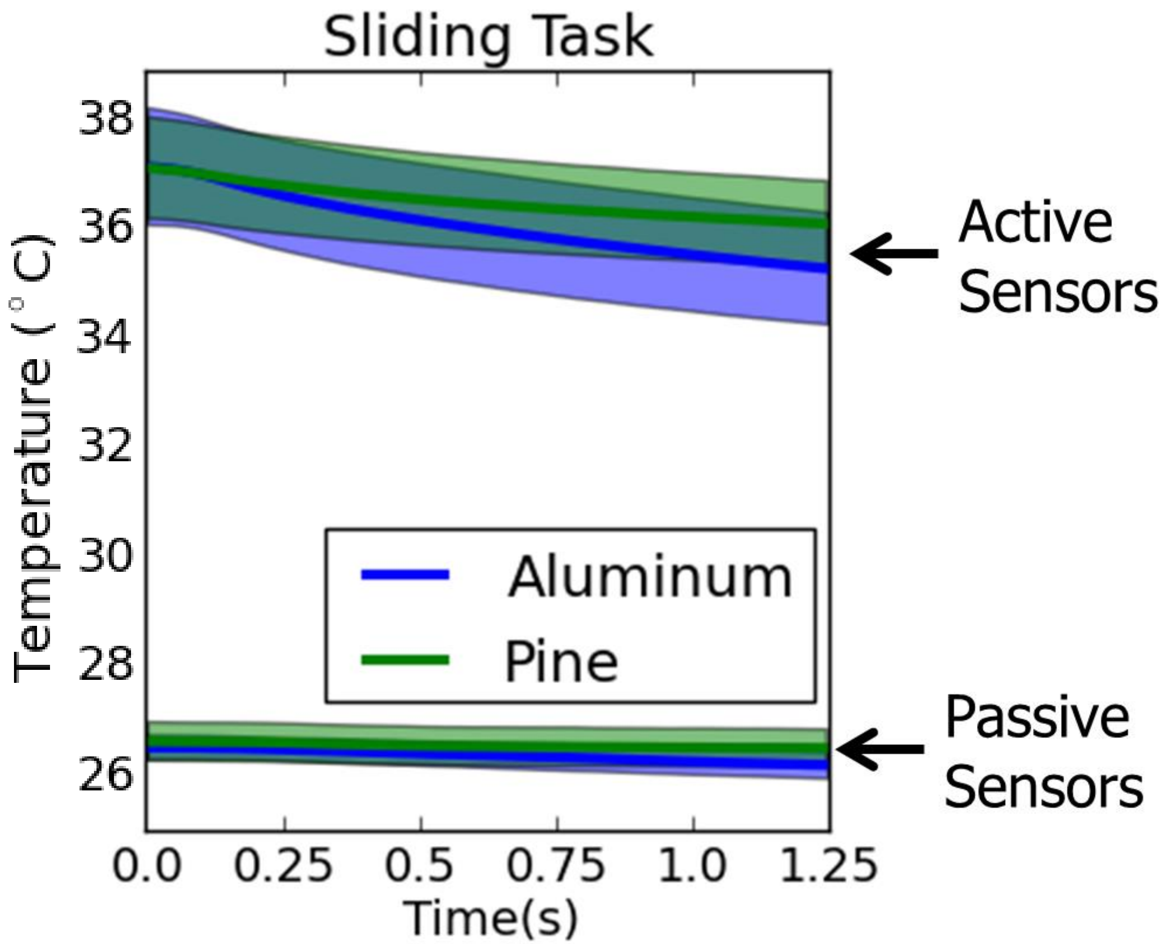


Distinguish between Aluminum and Pine

Joshua Wade, Tapomayukh Bhattacharjee, and Charles C. Kemp, *Force and Thermal Sensing with a Fabric-based Skin*, IROS Workshop on See, Touch, and Hear : 2nd Workshop on Multimodal Sensor-based Robot Control for HRI and Soft Manipulation, 2016.

Experiments : Representative Manipulation Task 2



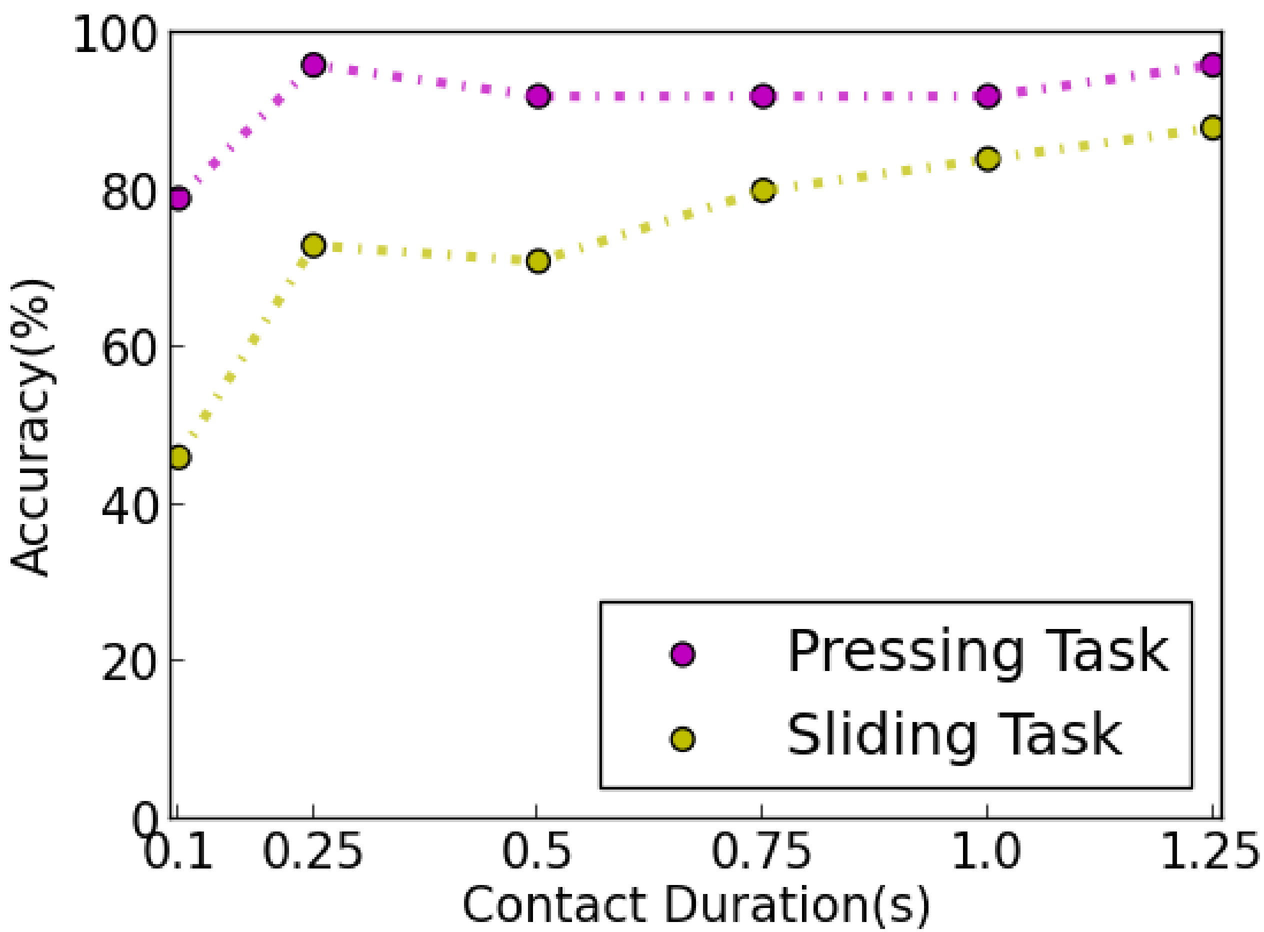


Distinguish between Aluminum and Pine

Joshua Wade, Tapomayukh Bhattacharjee, and Charles C. Kemp, *Force and Thermal Sensing with a Fabric-based Skin*, IROS Workshop on See, Touch, and Hear : 2nd Workshop on Multimodal Sensor-based Robot Control for HRI and Soft Manipulation, 2016.

Results : Aluminum vs. Pine

Contact Duration(s)	Recognition Accuracy: Pressing Task	Recognition Accuracy: Sliding Task
0.25	**96%**	73%
1.25	**96%**	**88%**



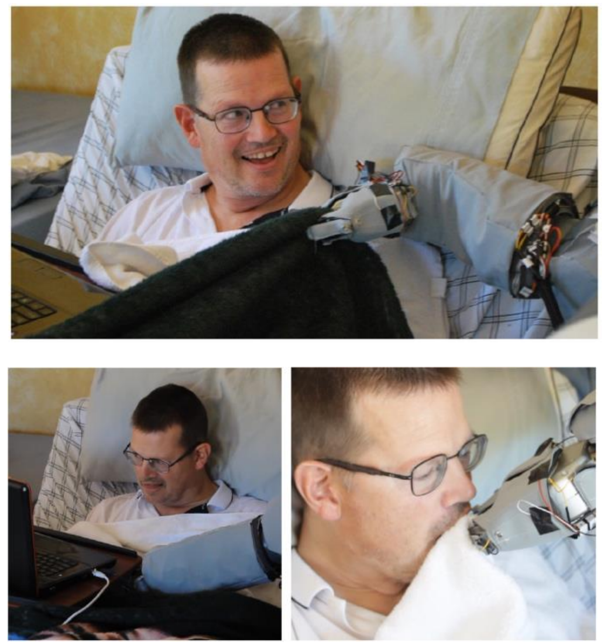
Joshua Wade, Tapomayukh Bhattacharjee, and Charles C. Kemp, *Force and Thermal Sensing with a Fabric-based Skin*, IROS Workshop on See, Touch, and Hear : 2nd Workshop on Multimodal Sensor-based Robot Control for HRI and Soft Manipulation, 2016.

Thermal Tactile Sensing

- Less sensitive to contact mechanics than force sensing
- Recognize contact with
  - Materials with distinct effusivities
  - Human body
  - Task-relevant objects
- Challenges
  - Time to heat up
  - Time for heat to transfer

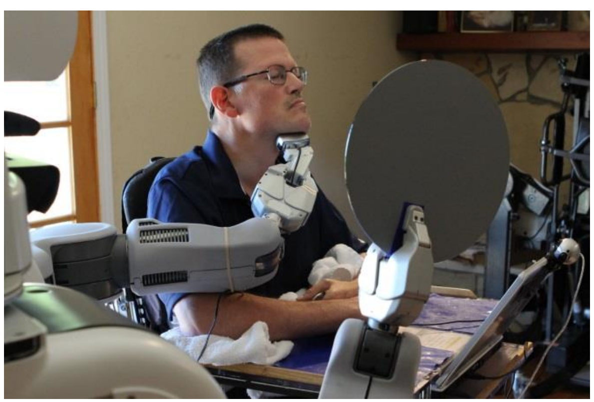
Assistive mobile manipulation at home is feasible for people with severe motor impairments using conventional interfaces.

General purpose robot from Willow Garage used in this research.



Henry pulls up a blanket and wipes his face for himself while in bed at home using a robot with intelligent tactile sensing.

Henry operates devices in his house for himself with autonomous robot actions.



Henry shaves himself at home using a web-based application for shaving.

Henry Evans is severely impaired due to a brainstem stroke. He operates the robot using a mouse pointer that he controls using motion of his head and his fingers via an off-the-shelf head tracker and mouse buttons.

(Research was performed as part of the collaborative Robots for Humanity project.)

Haptic Sensing for Assistive Robots

Haptic Sensing	Capability	Assistive Tasks
Data-driven models of forces	Common sense about forces	shaving, door opening, dressing, feeding
Whole-arm tactile sensing	Reach locations in clutter	Reach locations around the human body
Thermal tactile sensing	Recognize contact with task-relevant categories	human vs. environment, toothbrush vs. counter, tactile foreground vs. tactile background

[images] found on the internet and used without permission

Credit

Many thanks go to the students, postdocs, collaborators, participants, and colleagues who made this work possible.

To learn more, please visit:

http://healthcare-robotics.com

GRADUATING SOON!

Tapo Bhattacharjee

Phil Grice