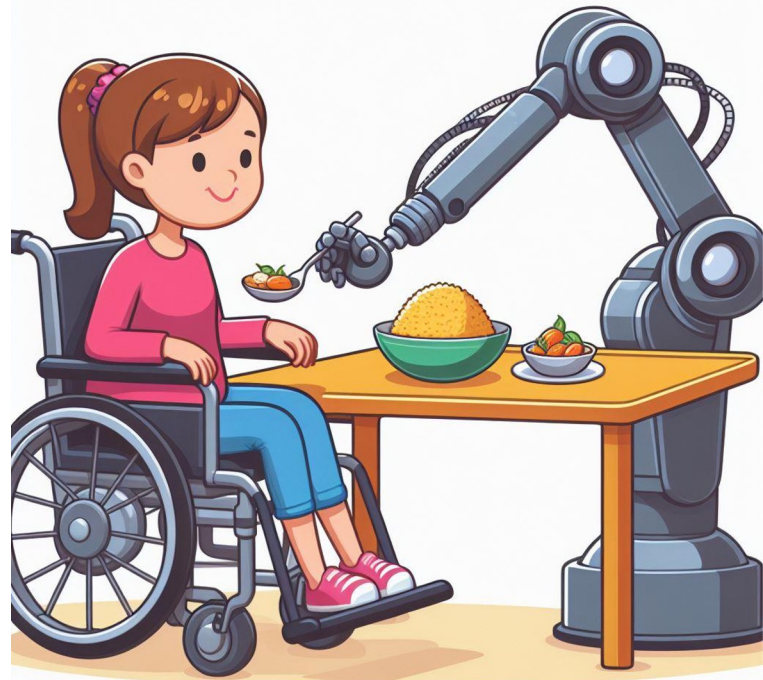


Towards In-Home Deployments of Physically Assistive Robots: Insights from Robot-Assisted Feeding for People with Motor Impairments



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2025-01-24



W
UNIVERSITY of
WASHINGTON

Think about a recent enjoyable meal experience.

What made it meaningful?





“Sometimes I wait little longer to ask [my caregiver] for a bite or a drink because it might mess up a conversation. It's definitely something that's always in the back of my mind while eating socially... Sometimes I find that I'm not eating or barely eating at all because I'm a little self-conscious of interrupting a conversation.” (P2)



**1.8 million
Americans need
assistance eating***



1x

* as of 2010

Theis, Kristina A., et al. "Which one? What kind? How many? Types, causes, and prevalence of disability among US adults." *Disability and health journal*. (2019)

Deployable Robot-assisted Feeding (RAF)



generalize across users usable without researcher intervention generalize across environments

How can we develop a **deployable** robot-assisted feeding system that enables **any*** user, in **any*** environment, to feed themselves a **meal of their choice[†]**, while **aligning with their preferences?**

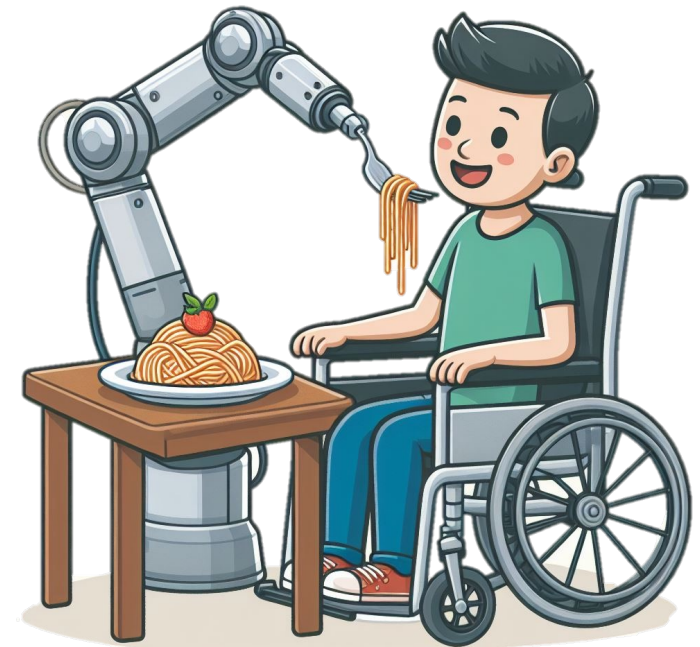
customizable generalize across foods

* “any” = North Star.
 Demonstrate it with “multiple”

[†] that can be acquired with
 a single arm using a fork

Roadmap

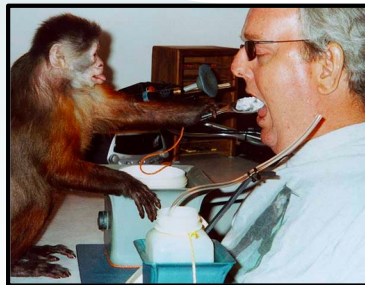
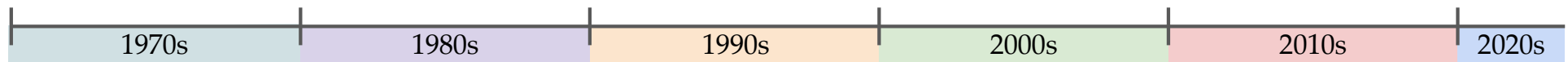
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2. Robot-Assisted Feeding Overview
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4. RQ2: Generalizing Bite Acquisition
5. RQ3: Developing a Deployable System
6. Evaluations & Lessons Learned



Self-feeding has been a research goal since the 1970s

Commercial

Research



monkey service animals, 1977

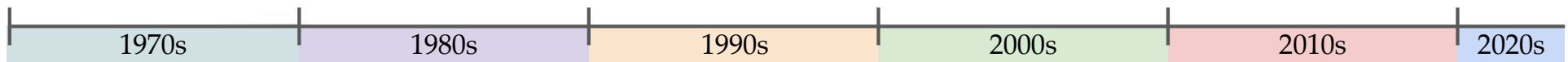
Hien, Emmanuelle, and Bertrand L. Deputte. "Influence of a capuchin monkey companion on the social life of a person with quadriplegia: an experimental study." *Anthrozoös*. (1997)

[Envisioning Access: Our Past](#)

Self-feeding has been a research goal since the 1970s

Commercial

Research



Morewood
Spoon Lifter,
1974



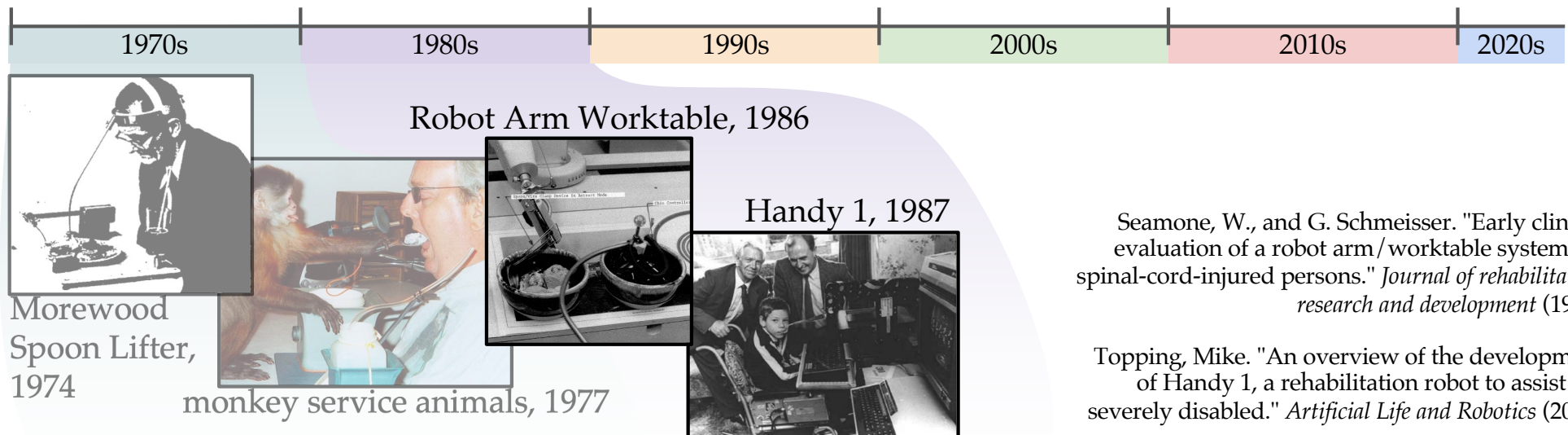
monkey service animals, 1977

Philips, G. N. "Feasibility Study for Assistive Feeder".
Southwest Research Institute. (1986)

Self-feeding has been a research goal since the 1970s

Commercial

Research



1970s-80s: Deployments & Clinical Evaluations

The staff reported that most individuals who were shown the original spoon lifter were negative towards gadgets and preferred to have someone feed them. However, one C₄ level quadriplegic subject was able to functionally feed himself a complete meal using the device. This subject requested permission to take the device home, and arrangements were made for him to do so. He continued to use it in the home situation for almost three years. This individual found it necessary to put Reston Foam under the front of the head band to relieve the pressure against his forehead and to help to keep the head band from slipping. The staff at this center made the initial suggestions that were incorporated in the modified feeder, and this subject's spoon lifter was modified. The staff also reported that the subject had to have good trunk balance in order to use the feeder and that the motor would stall if food was stuck to the bottom of the spoon.

Progress — Through December 1984, 20 male quadriplegics between 21 and 60 years of age at evaluation had been involved in the evaluation in three geographical areas, i.e., Baltimore-Washington, Richmond, and Cleveland. They ranged from five to 26 years between time of injury and evaluation. The levels of injury ranged from C-2 to C-5. Individual accumulations of time actually working with the equipment ranged from one hour to over 100 hours; 316 meals were eaten by these individuals using the Robot Arm. Among the nine quadriplegics who tested the equipment at the Richmond VAMC, seven indicated that they found the equipment gratifying to use, especially for self-feeding. Among the seven

Robot Arm Worktable (1980s):

- 20 people with quadriplegia
- Environments: family home, nursing home, hospital

Morewood Spoon Lifter (1970s):

- 16 veterans with spinal cord injuries
- 3 year home deployment

Seamone, W., and G. Schmeisser. "Early clinical evaluation of a robot arm/ worktable system for spinal-cord-injured persons." *Journal of rehabilitation research and development* (1985)

Philips, G. N. "Feasibility Study for Assistive Feeder". *Southwest Research Institute*. (1986)

Commercial translation in 1990s-2000s

Commercial

Winsford Feeder, 1990s



Research

1970s

1980s

1990s

2000s

2010s

2020s

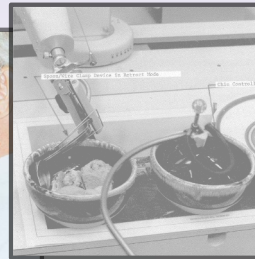


Morewood
Spoon Lifter,
1974



monkey service animals, 1977

Robot Arm Worktable, 1986



Handy 1, 1987



Harwin, William S., Tariq Rahman, and Richard A. Foulds. "A review of design issues in rehabilitation robotics with reference to North American research." *IEEE Transactions on Rehabilitation Engineering* (1995)

[Winsford Feeder Brochure \(2011\)](#)

Commercial translation in 1990s-2000s

Commercial

Winsford Feeder, 1990s



Neater Eater, 1990s



Research

1970s

1980s

1990s

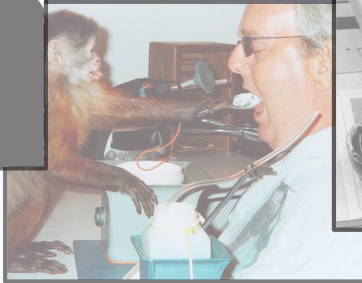
2000s

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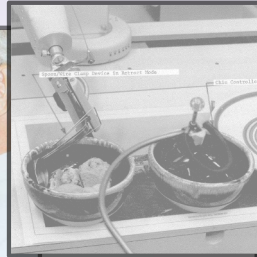


Morewood Spoon Lifter, 1974



monkey service animals, 1977

Robot Arm Worktable, 1986



Handy 1, 1987



Michaelis, J. "Mechanical methods of controlling ataxia." *Bailliere's Clinical Neurology* (1993)

[Neater Eater](#)

Commercial translation in 1990s-2000s

Commercial

Winsford Feeder, 1990s



Neater Eater, 1990s



Bestic, 2004



Research

1970s

1980s

1990s

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2010s

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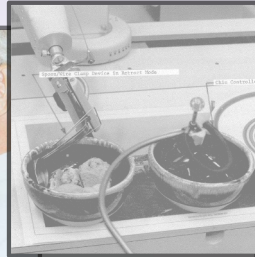


Morewood Spoon Lifter, 1974



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Robot Arm Worktable, 1986



Handy 1, 1987



Lindborg, Ann-Louise, and Maria Lindén. "Development of an Eating Aid-From the User Needs to a Product." *pHealth* (2015)

[Bestic AB \(Youtube\)](#)

Commercial translation in 1990s-2000s

Commercial

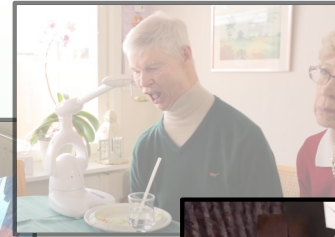
Winsford Feeder, 1990s



Neater Eater, 1990s



Bestic, 2004



Obi, 2009



Research

1970s

1980s

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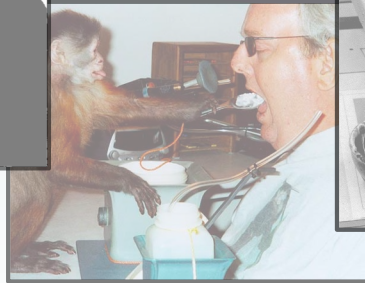
2000s

2010s

2020s

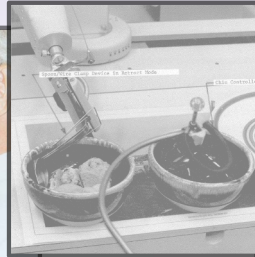


Morewood Spoon Lifter, 1974



monkey service animals, 1977

Robot Arm Worktable, 1986



Handy 1, 1987



Artman, Dar, et al. "[New Obi Robotic Dining Device a Breakthrough for People Living with Physical Challenges.](#)" (2016)

[MeetObi](#)

1990s-2000s: Is Robot-Assisted Feeding Solved?

- **Strengths** of Commercial Systems*:
 - Independently eating a full meal
 - Increased feelings of confidence
 - Improved posture
- **Shortcomings** of Commercial Systems*:
 - Only able to acquire limited foods
 - Acquiring too little food
 - Dropping food
 - Requiring users to hold head in stationary position



* citations in dissertation

Modern Robot-assisted Feeding Research, 2010s-

Commercial

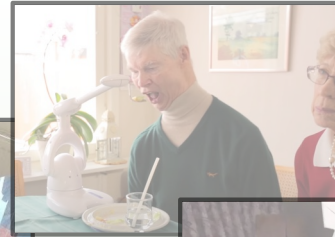
Winsford Feeder, 1990s



Neater Eater, 1990s



Bestic, 2004



Obi, 2009



Herlant, Laura V.
"Algorithms, implementation,
and studies on eating with a
shared control robot arm".
(2016)

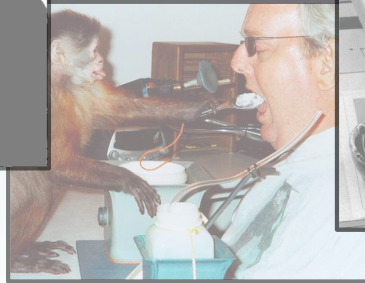
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1970s



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Spoon Lifter,
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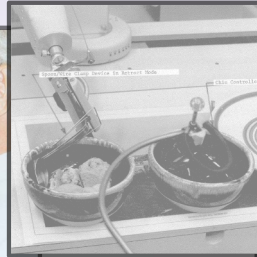
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2000s

Personal Robotics Lab, 2010s



2010s

2020s

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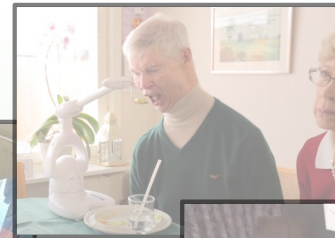
Winsford Feeder, 1990s



Neater Eater, 1990s



Bestic, 2004



Obi, 2009



Park, Daehyung, et al. "Active robot-assisted feeding with a general-purpose mobile manipulator: Design, evaluation, and lessons learned." *Robotics and Autonomous Systems* (2020)

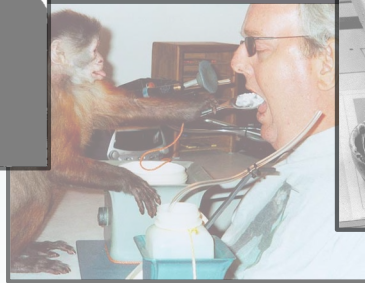
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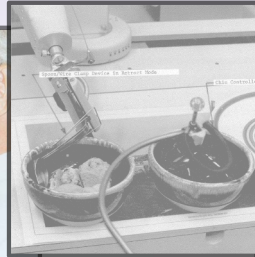
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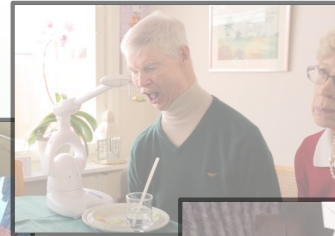
Winsford Feeder, 1990s



Neater Eater, 1990s



Bestic, 2004



Obi, 2009



Jenamani, Rajat et al. "Robot-assisted Inside-mouth Bite Transfer using Robust Mouth Perception and Physical Interaction-Aware Control". (2024)

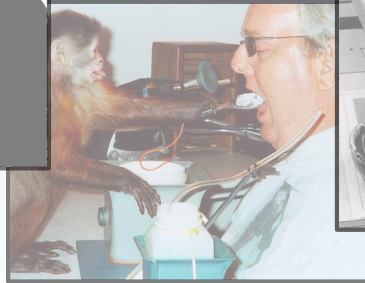
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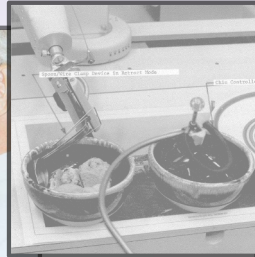
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Kemp Lab, 2010s

2020s



EmP RISE, 2021

Modern Robot-assisted Feeding Research, 2010s-

Commercial

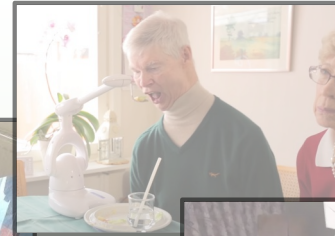
Winsford Feeder, 1990s



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Obi, 2009



Nguyễn, Vy. "Increasing Independence with Stretch: A Mobile Robot Enabling Functional Performance in Daily Activities". (2021)

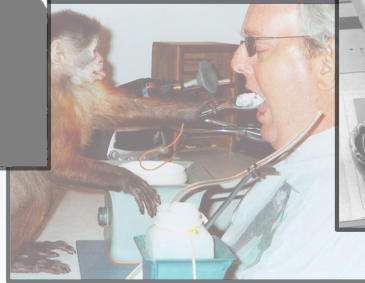
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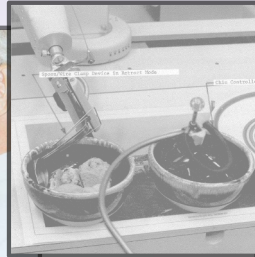
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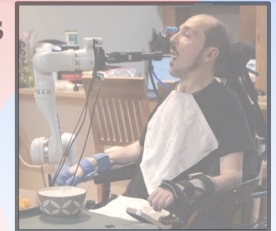


2000s

Personal Robotics Lab, 2010s



2010s



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Hello Robot, 2021



Kemp Lab, 2010s



Modern Robot-assisted Feeding Research, 2010s-

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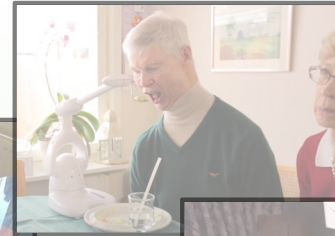
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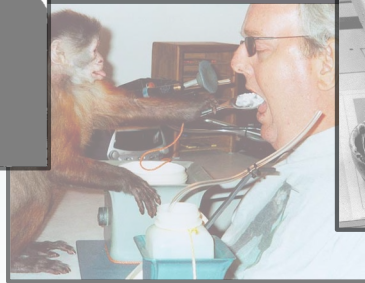
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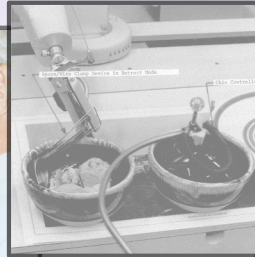
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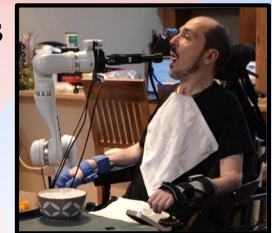


2000s

Personal Robotics Lab, 2010s



2010s



EmP RISE, 2021

2020s

Hello Robot, 2021



Kemp Lab, 2010s



Modern Robot-assisted Feeding Research, 2010s-

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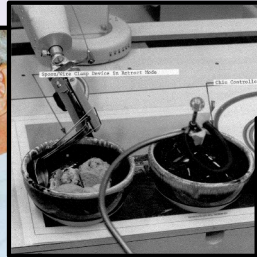
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Kemp Lab, 2010s

2010s



EmP RISE, 2021

2020s



Hello Robot, 2021

Our Robot-assisted Feeding System

24

Bite Acquisition



Bite Transfer



Back View

P3

Real-Time (1x)

Community-Based Participatory Research (CBPR)



Tyler Schrenk

- Entire research process is grounded in and accountable to community needs and priorities
- **Community Researchers (CRs):** equal team members throughout the process, from ideation to dissemination
- Academic & community researchers each bring unique skills, expertise, and **lived experience** to the table
- Learn from each other
- Long-term partnership

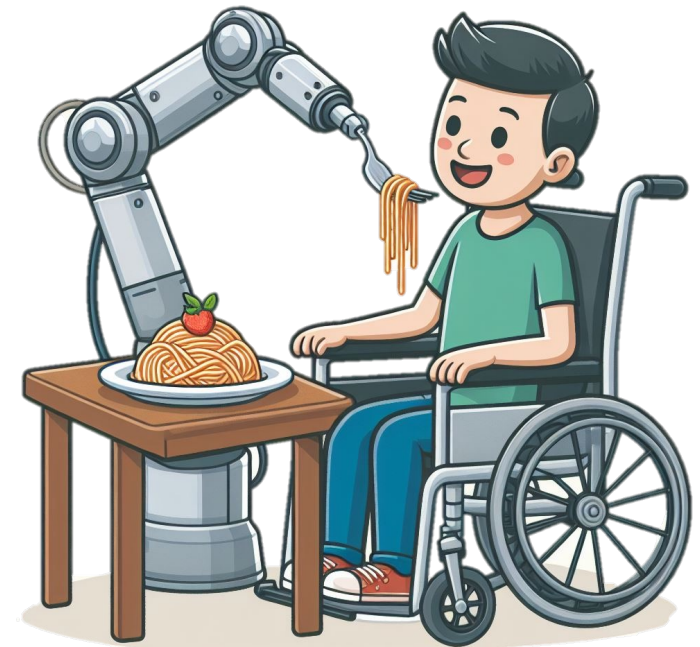
Israel, B. A., Schulz, A. J., Parker, E. A., & Becker, A. B. "Review of community-based research: assessing partnership approaches to improve public health". *Annual review of public health*. (1998)



Jonathan Ko

Roadmap

1. Motivation
2. Robot-Assisted Feeding Overview
3. RQ1: Users' Needs Assessment
4. RQ2: Generalizing Bite Acquisition
5. RQ3: Developing a Deployable System
6. Evaluations & Lessons Learned



RQ1: What challenges do users face during dining, and how can a robot-assisted feeding system address them?

Nanavati, Amal*, Patrícia Alves-Oliveira*, et al. "Design principles for robot-assisted feeding in social contexts." *HRI*. (2023)
Best Design Paper Award 🏆

Method

- Remote, semi-structured interviews led by community researcher
- n=10 participants
- Study stages:
 - Discuss current dining routines
 - Watch social dining videos showcasing various robot features
 - Discuss participants' thoughts
- Thematically analyzed participant quotes





CHALLENGES OF CURRENT SOCIAL DINING



SELF-CONSCIOUSNESS

A. "There are sometimes people who are not used to seeing the situation, they **stare and make you feel uncomfortable.**" (P4)

B. "I end up doing the open mouth [cue] with caretakers... Which **I don't love doing** if I'm out at a restaurant, just **sitting there with my mouth open.**" (P9)

C. "Nobody can feed me better than my parents. So if I want to eat with others, I for sure need one of them. And sometimes **you can't really go with parents to some events.**" (P10)

D. "I'd have to tell [my caregiver] how to do things. 'Not that much', 'Little more', personal cues and directions. **It would just take up all the conversation.**" (P1)



PRESSURE

E. "If a caregiver's holding a fork in front of my face... **I feel like it's pressuring...** [I need to] rush to chew and then take the next bite." (P9)

F. "If I want to eat to the point where I don't feel hungry, it would take 4 times longer than them. I don't want that to happen, so I need to eat less, and **when I get back home I need to eat again.**" (P10)



BURDEN

G. "I feel like **the other person doesn't eat comfortably** because they have to be feeding me and then they have to take a bite." (P2)

H. "When I'm around friends, sometimes I feel a bit bad. I have to keep [saying], 'mom, can I have a bite of my food?' **It's a distraction to get someone to remember me.**" (P9)

Caregiver Variability

Caregivers feed differently (e.g., bite size, eating pace, etc.)

Participants feel self-conscious about interrupting a conversation to instruct their caregiver

Participants don't feel comfortable bringing some caregivers to some social interactions.

Participants want
consistent customization

Design Principles

CUSTOMIZATION



The robot should be adaptable to contexts and user needs.

INCLUSIVITY



The robot should accommodate a user's impairments.

CONTROL



The robot should defer high-level decision making to the user.

MINIMALISM



The robot should be compact and part of the user's assistive tech ecosystem.

SUBTLETY



The robot should be discrete and unnoticeable.

RELIABILITY



The robot should be consistent and error-free.

INTEGRATION



The robot should integrate meal tasks beyond feeding.

INTERACTIVITY



The robot should be able to interact with others.

Design Principles: Reliability

A.

"If it can't get it on the first try, it's still on the plate, **[the food's] not on me**. If it drops it on the way that would be worse." (P1)

B.

"If it was at a soccer game where [my wife] was sitting next to me, the side-resting position could **be in her way, in front of her face**." (P8)

C.

"I want everyone to just see me, not **see me behind a feeding device**." (P9)

RELIABILITY



The robot should be consistent and error-free.

Design Principles: Control

D.

"When it's something as delicate as 'if this messes up I can get impaled,' it would be good to have a **backup safety mechanism.**" (P8)

F.

"For me, I don't mind the robot doing a lot of the thinking, with the exception of **selecting what food I eat.**" (CR)

E.

"I'm not too fond of [automatic bite initiation]. It's restrictive. By **giving the robot the command,** you are controlling the robot." (P6)

CONTROL



The robot should defer high-level decision making to the user.

Design Principles: Customizability

G.

“In a perfect world, I'd be able to choose **how much food it gives to me** [in a bite]. Choking is a huge hazard.” (P8)

H.

“**If the table is noisy**, then [I'd use] mouth open. **If it's not too noisy**, then [I'd use] verbal.” (P6)

I.

“Every person is different. **The way we sit, the way we eat**, we have our own positions and height. This robot, they'd have to customize it.” (P3)

CUSTOMIZATION



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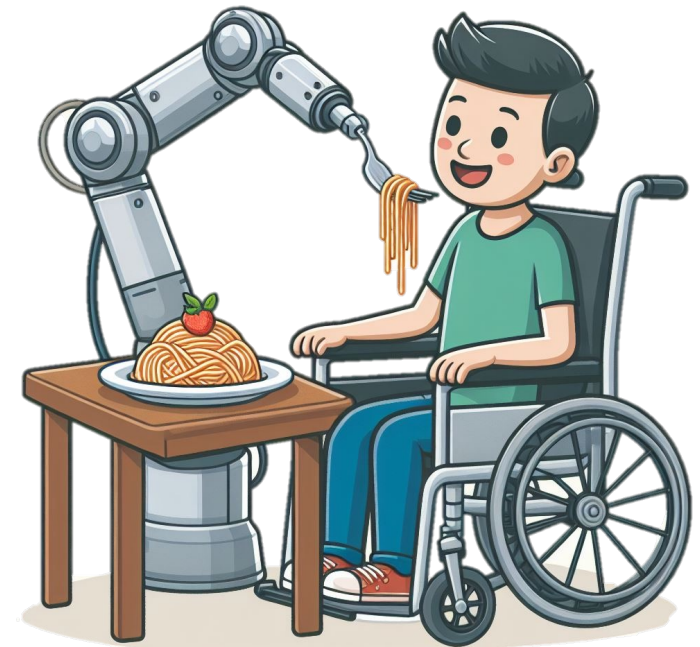
INTERACTIVITY



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Roadmap

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How can we develop a **deployable** robot-assisted feeding system that enables **any*** user, in **any*** environment, to feed themselves a **meal of their choice[†]**, while **aligning with their preferences?**

generalize across users

usable without researcher intervention

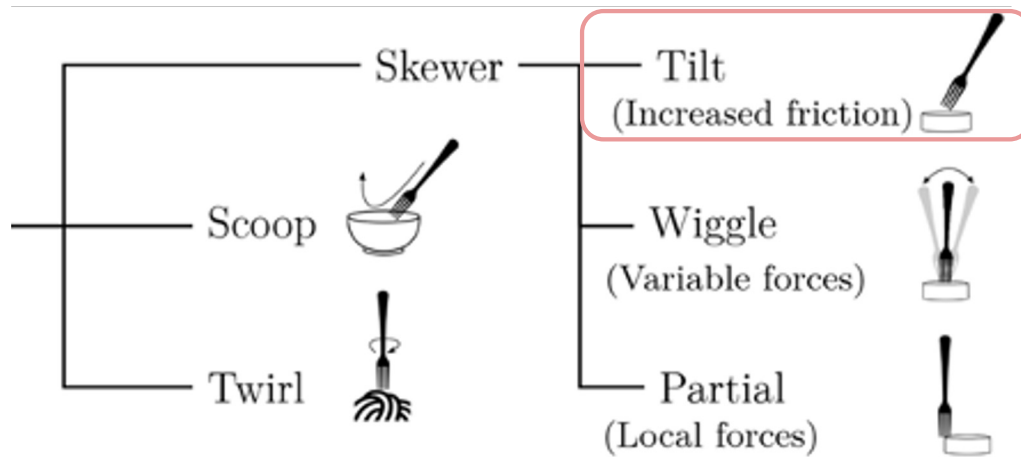
generalize across environments

customized

generalize across foods

RQ2: How can a robot-assisted feeding system reliably acquire the large variety of food items users may want to eat?

Bite Acquisition: Past Work



Bhattacharjee, Tapomayukh, et al. "Towards robotic feeding: Role of haptics in fork-based food manipulation." *IEEE Robotics and Automation Letters* (2019)

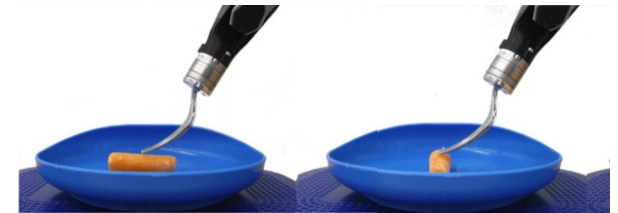
Vertical
(VS)



Tines
Vertical
(TV)

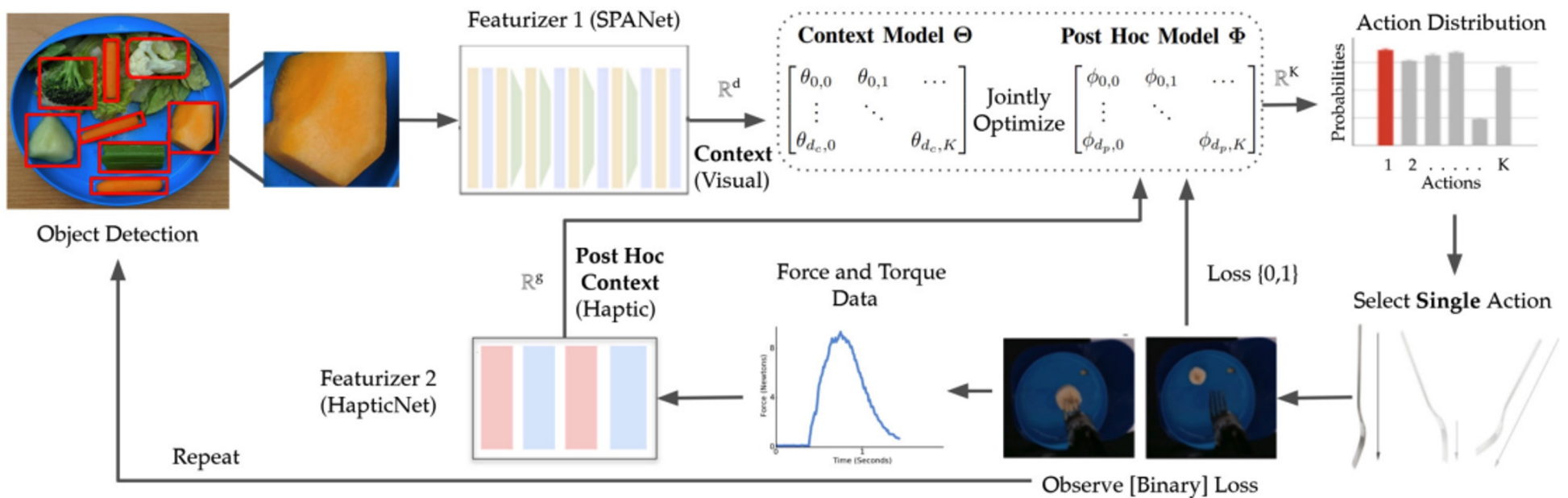


Angled
(TA)



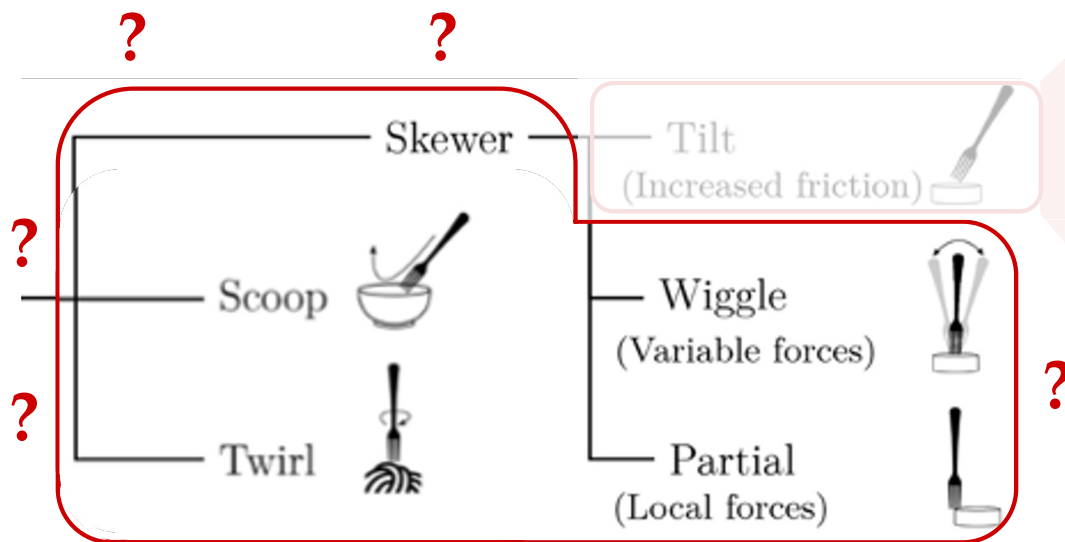
Feng, Ryan, et al. "Robot-assisted feeding: Generalizing skewering strategies across food items on a plate." *The International Symposium of Robotics Research*. (2019)

Bite Acquisition: Past Work



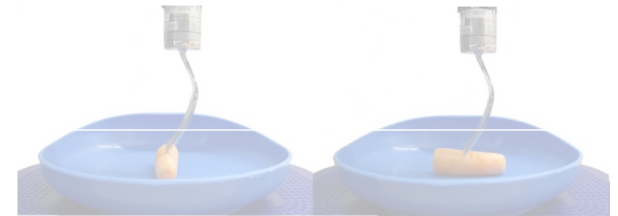
Gordon, Ethan K., et al. "Leveraging post hoc context for faster learning in bandit settings with applications in robot-assisted feeding." *IEEE International Conference on Robotics and Automation (ICRA)*. (2021)

Bite Acquisition: Past Work



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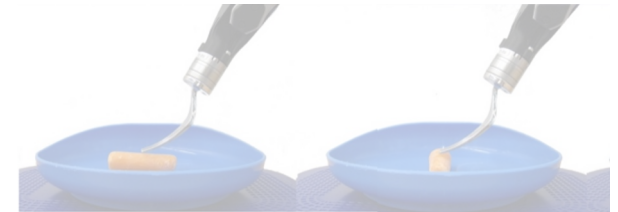
Vertical
(VS)



Tines
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(TV)



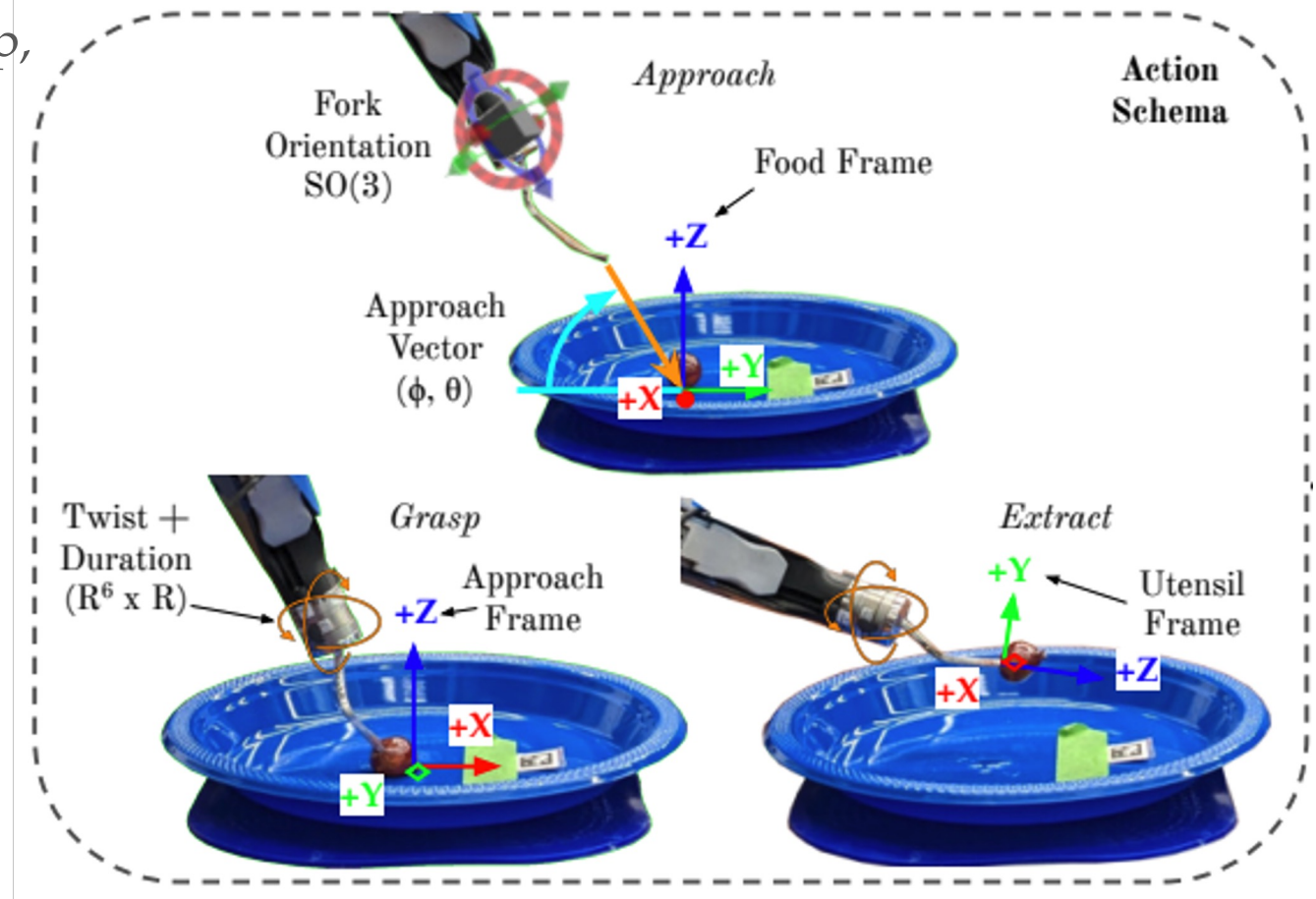
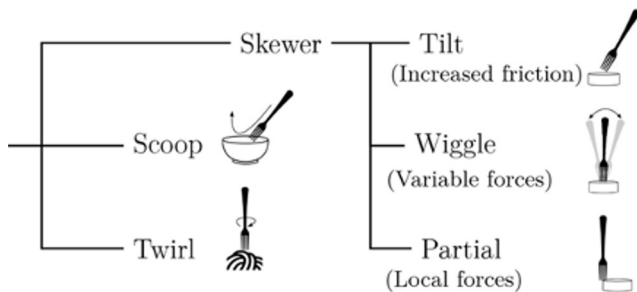
Angled
(TA)



Feng, Ryan, et al. "Robot-assisted feeding: Generalizing skewering strategies across food items on a plate." *The International Symposium of Robotics Research*. (2019)

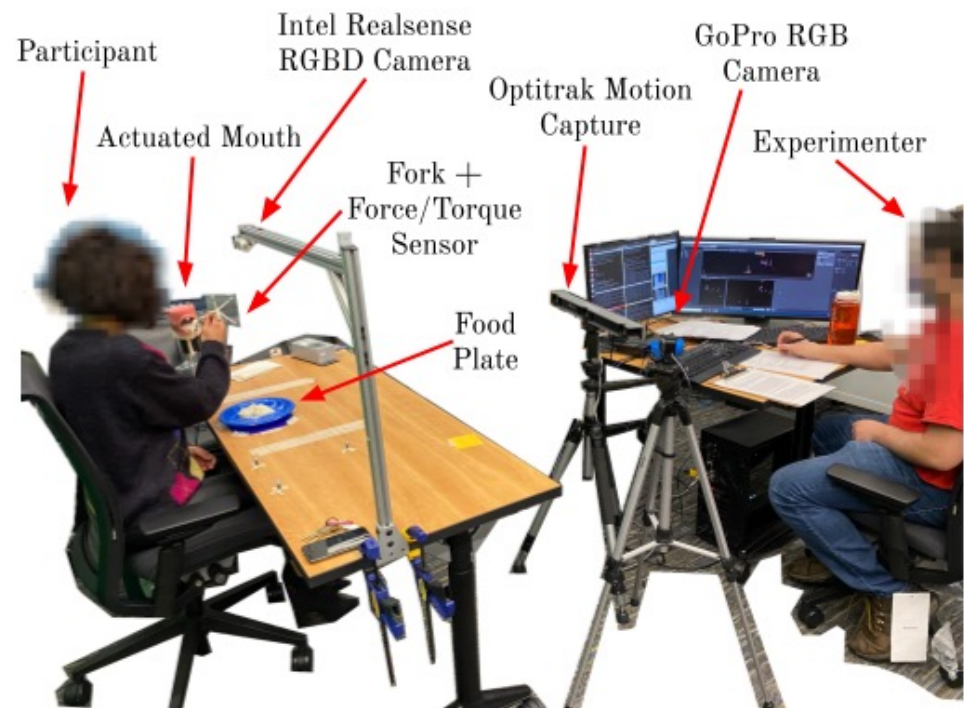
Key Insight: Bite Acquisition Actions are Structured

- 3 steps: Approach, Grasp, Extract
- **Action Schema:** 26 continuous parameters
- Encompasses entire taxonomy



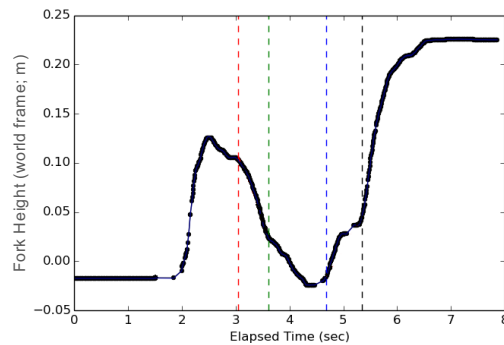
What actions within this schema do humans use?

- 9 participants
- 13 foods
 - e.g., sandwich bites, pizza, chicken tenders, noodles, rice & beans, etc.
- Data:
 - Fork motion (SE(3) over time)
 - Fork forces & torques
 - Food RGB-D data
- ~9 hours, 500+ trajectories
 - open-sourced

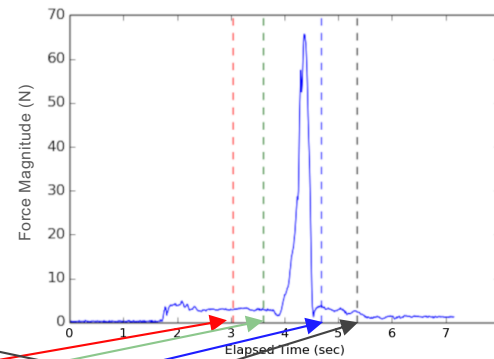
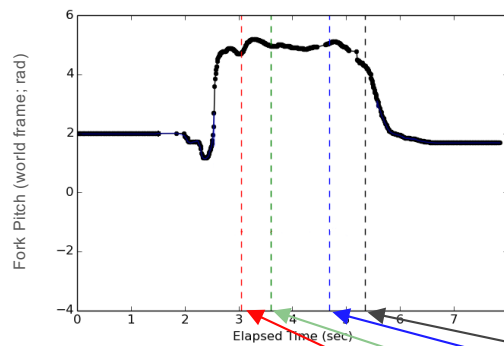


Data Processing: Human Data → Schema

Food Detection



1. Segment food masks (above).
2. Extract key timestamps, based on fork position.
3. Extract "approach" parameters by linearly extrapolating fork back from contact.
4. Extract "grasp" and "extraction" twists using start + end poses at the timestamp.

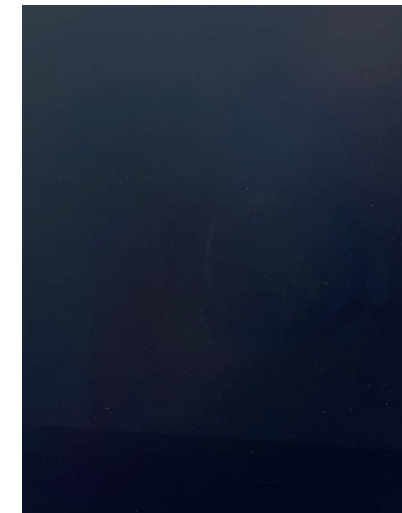


Start Time

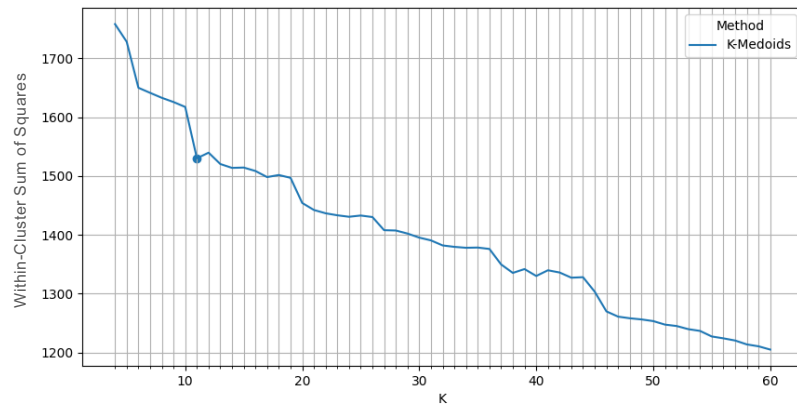
Contact Time

Extraction Start

End Time



Clustering Representative Actions



k-medoids on standardized actions

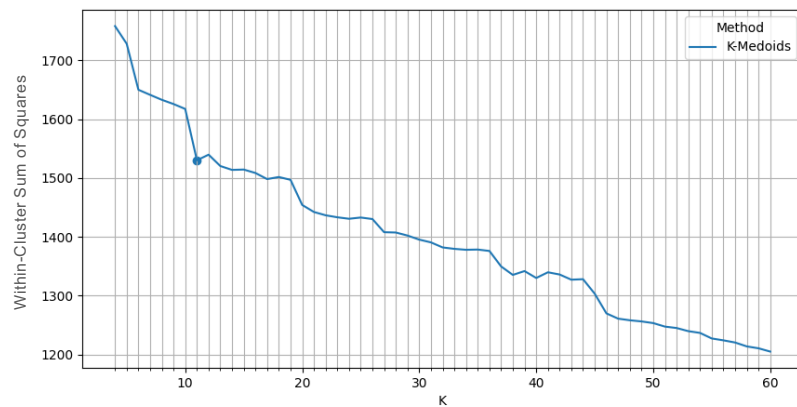
k=11 (elbow point)

Scooping

Action 6; Mashed Potato



Clustering Representative Actions

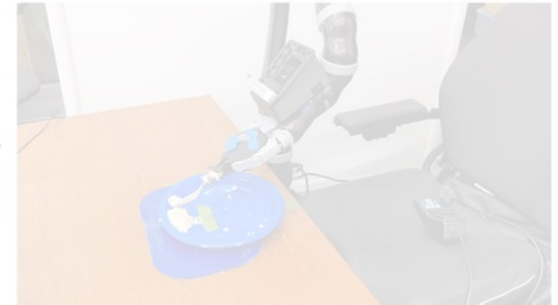


k-medoids on standardized actions

k=11 (elbow point)

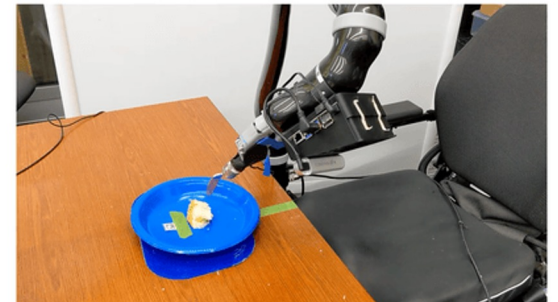
Scooping

Action 6; Mashed Potato

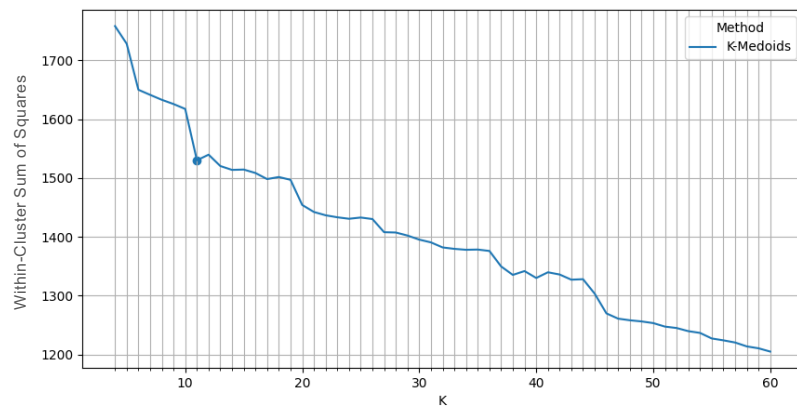


Action 10; Sandwich

Tilted
Tines for
Higher
Pressure



Clustering Representative Actions

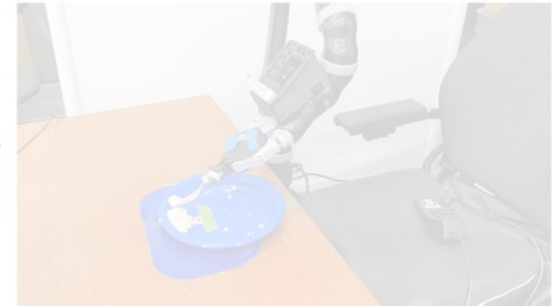


k-medoids on standardized actions

k=11 (elbow point)

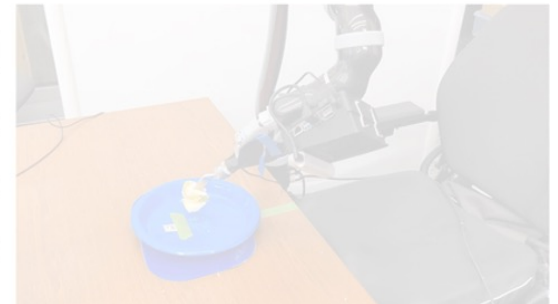
Scooping

Action 6; Mashed Potato



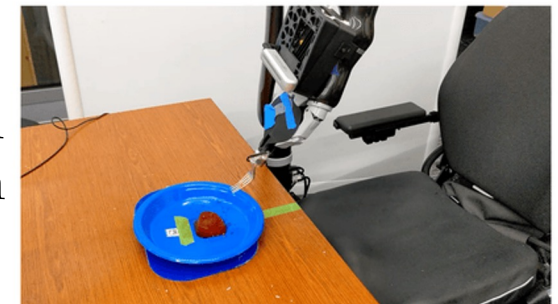
Tilted
Tines for
Higher
Pressure

Action 10; Sandwich



Action 8; Jello

Tilted
Extraction



Evaluating Actions

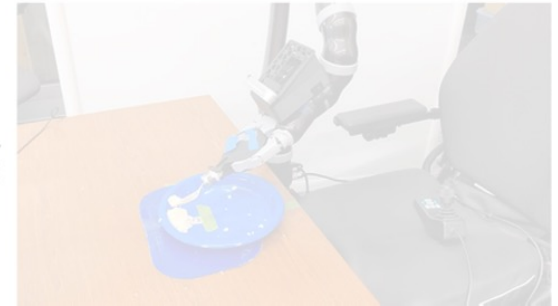
1. Coverage

2. Learnability

14 food items (9 unseen)

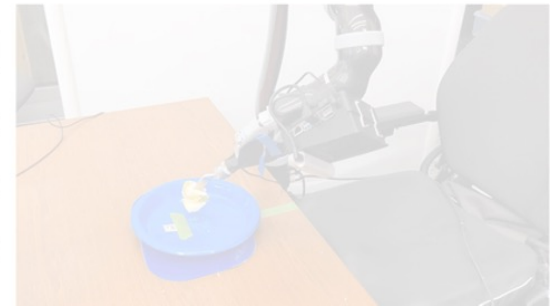
Scooping

Action 6; Mashed Potato



Tilted
Tines for
Higher
Pressure

Action 10; Sandwich

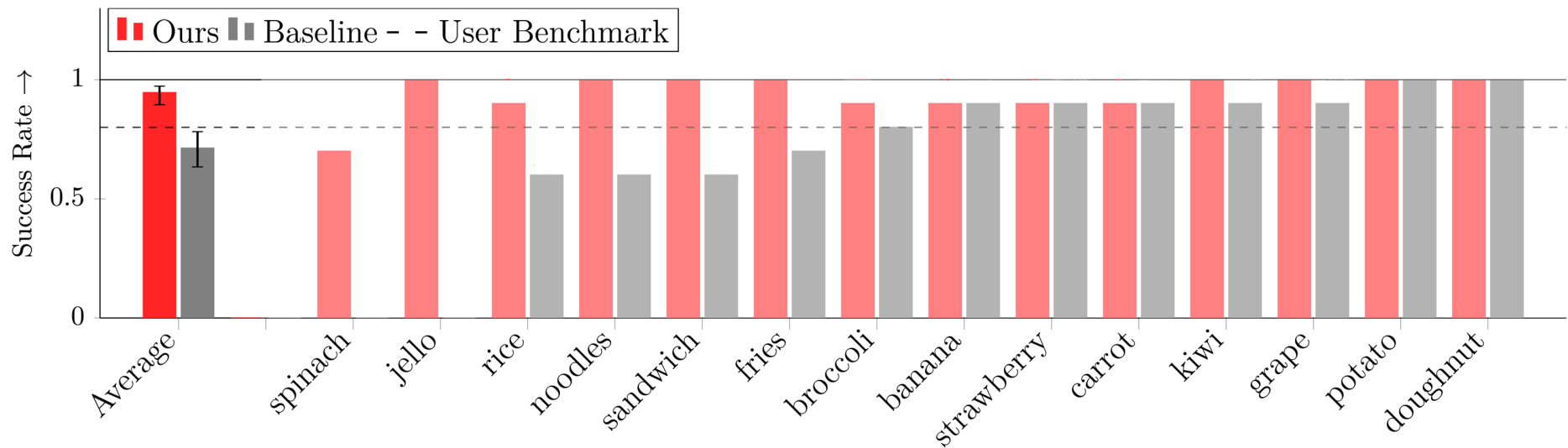


Tilted
Extraction

Action 8; Jello



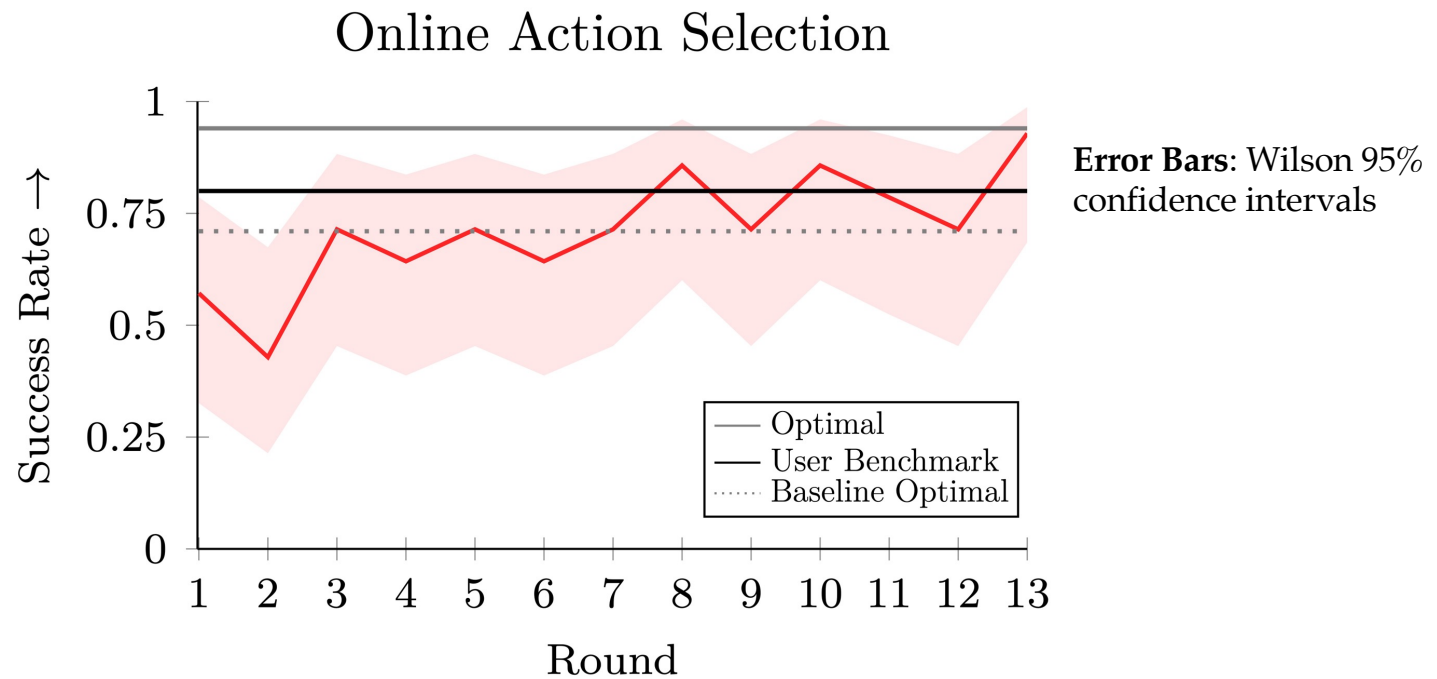
Evaluating Actions: Coverage



For every food but single-leaf spinach, there exists an action to acquire it with $\geq 80\%$ * success.

* Bhattacharjee, Tapomayukh, et al. "Is more autonomy always better? exploring preferences of users with mobility impairments in robot-assisted feeding." *HRI*. (2020)

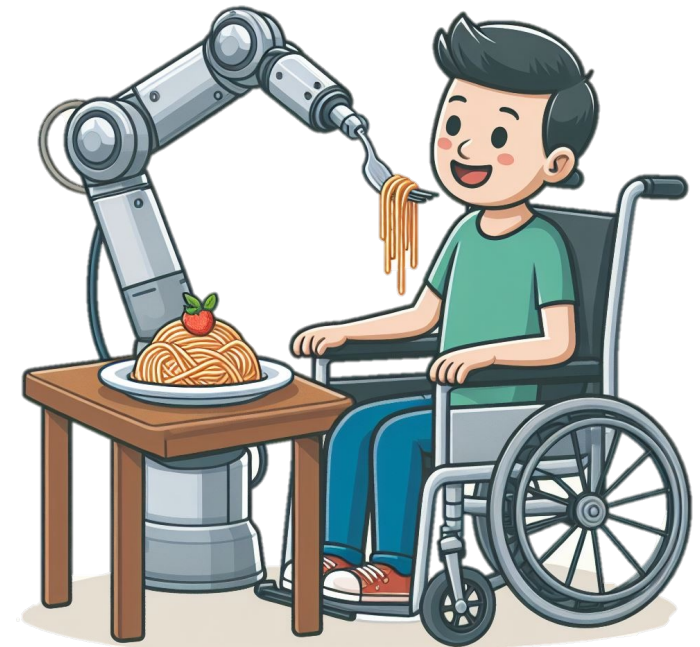
Evaluating Actions: Learnability

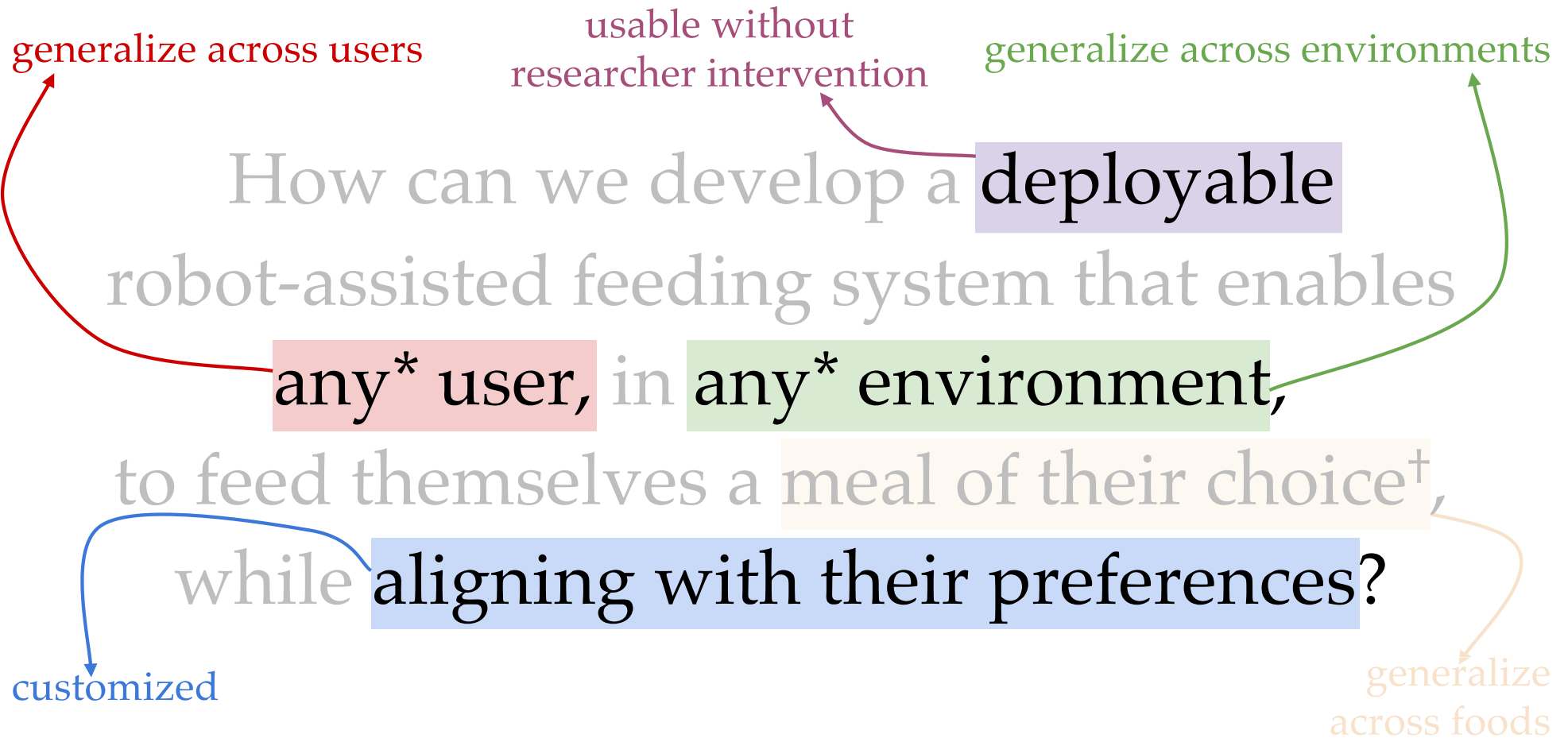


~30s / acquisition \rightarrow learn optimal action in ~4m of pre-meal training!

Roadmap

1. Motivation
2. Robot-Assisted Feeding Overview
3. RQ1: Users' Needs Assessment
4. RQ2: Generalizing Bite Acquisition
5. RQ3: Developing a Deployable System
6. Evaluations & Lessons Learned





RQ3: How can we develop a robot-assisted feeding system to feed users in diverse out-of-lab and in-home contexts?

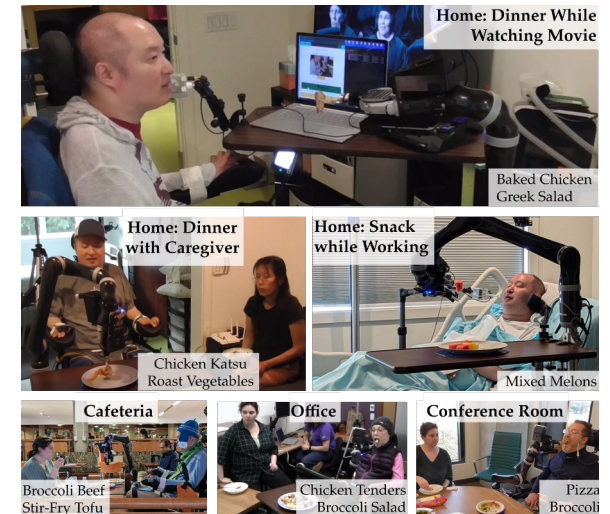
Nanavati, Amal, et al. "Lessons Learned from Designing and Evaluating a Robot-assisted Feeding System for Out-of-lab Use." *HRI*. (2025)

Gordon, Ethan K*, Jenamani, Rajat K*, Nanavati, Amal*, et al. "An Adaptable, Safe and Portable Robot-Assisted Feeding System." *HRI*. (2024)
Best Demo Award 🏆

RQ3: Key System Design Principles for Deployability

1. Portability

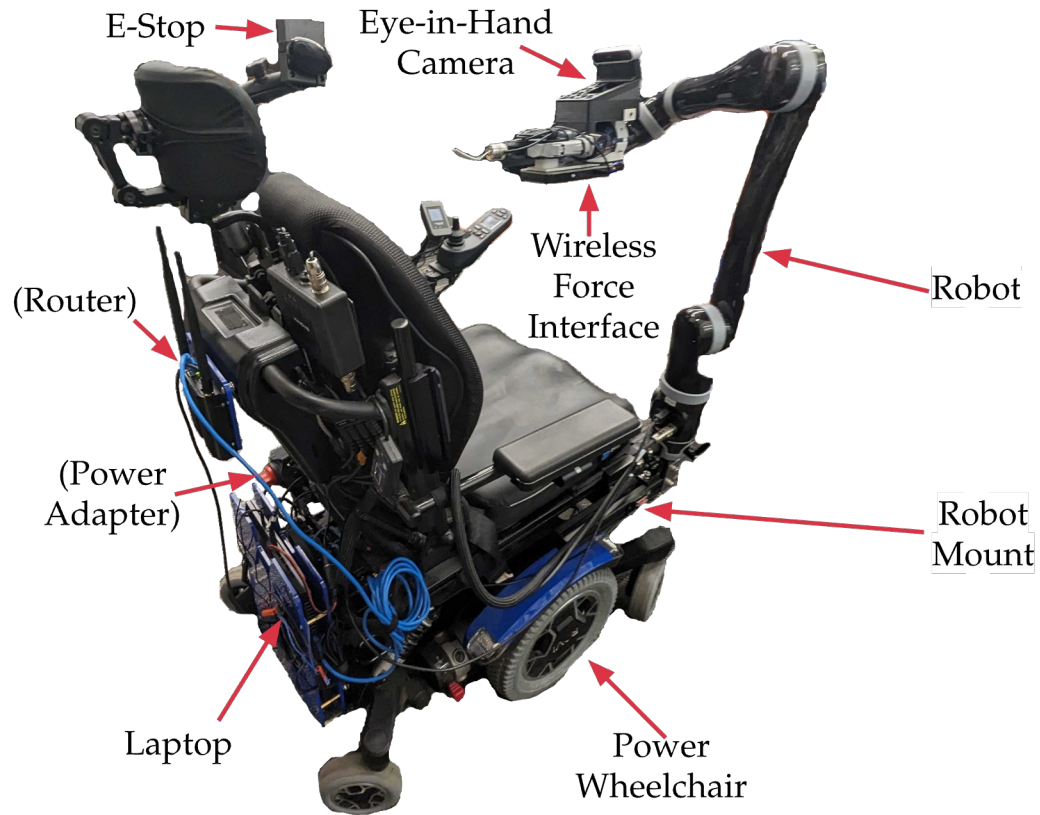
2. Safety



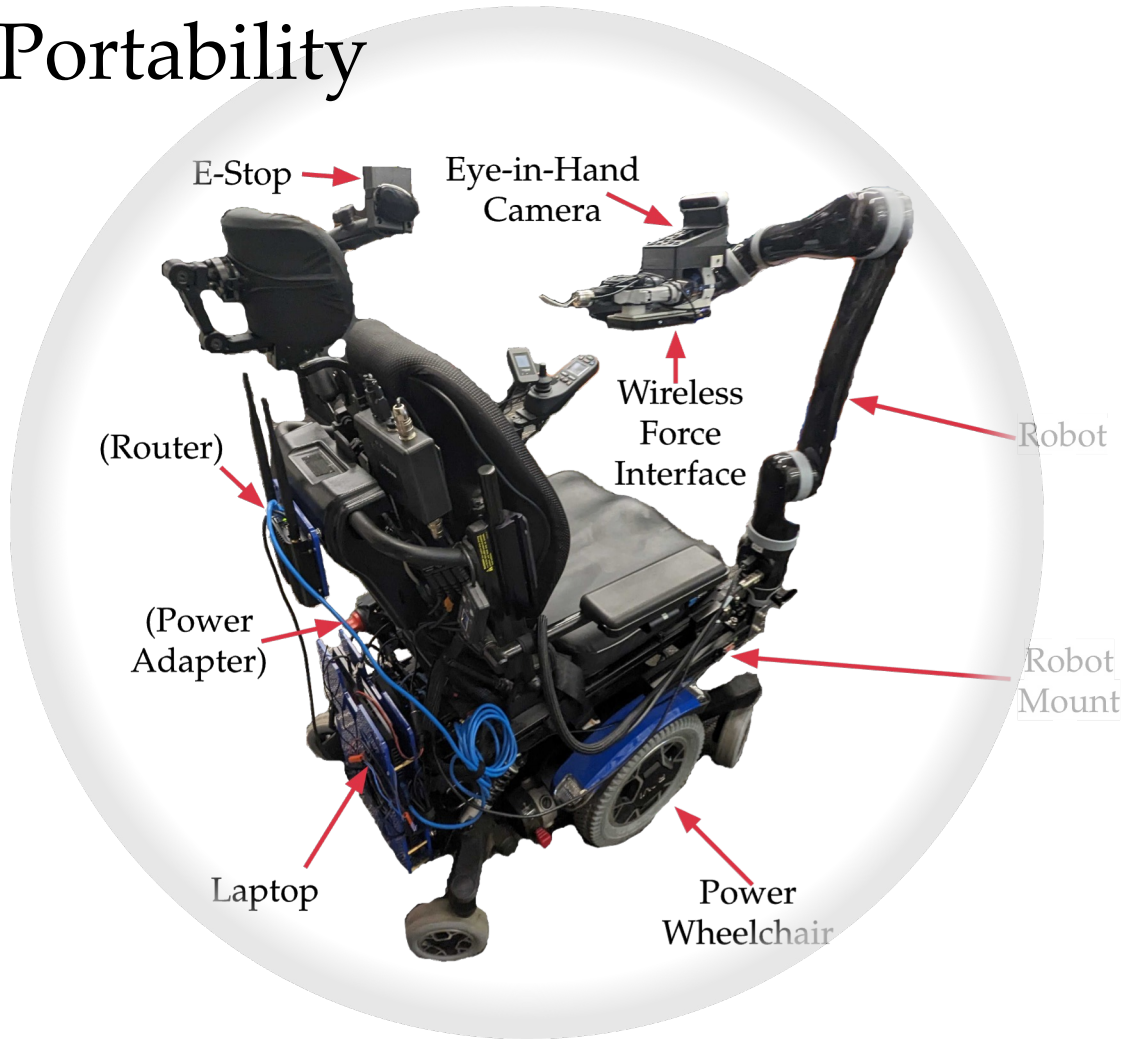
3. User Control

4. Customizability

Portability

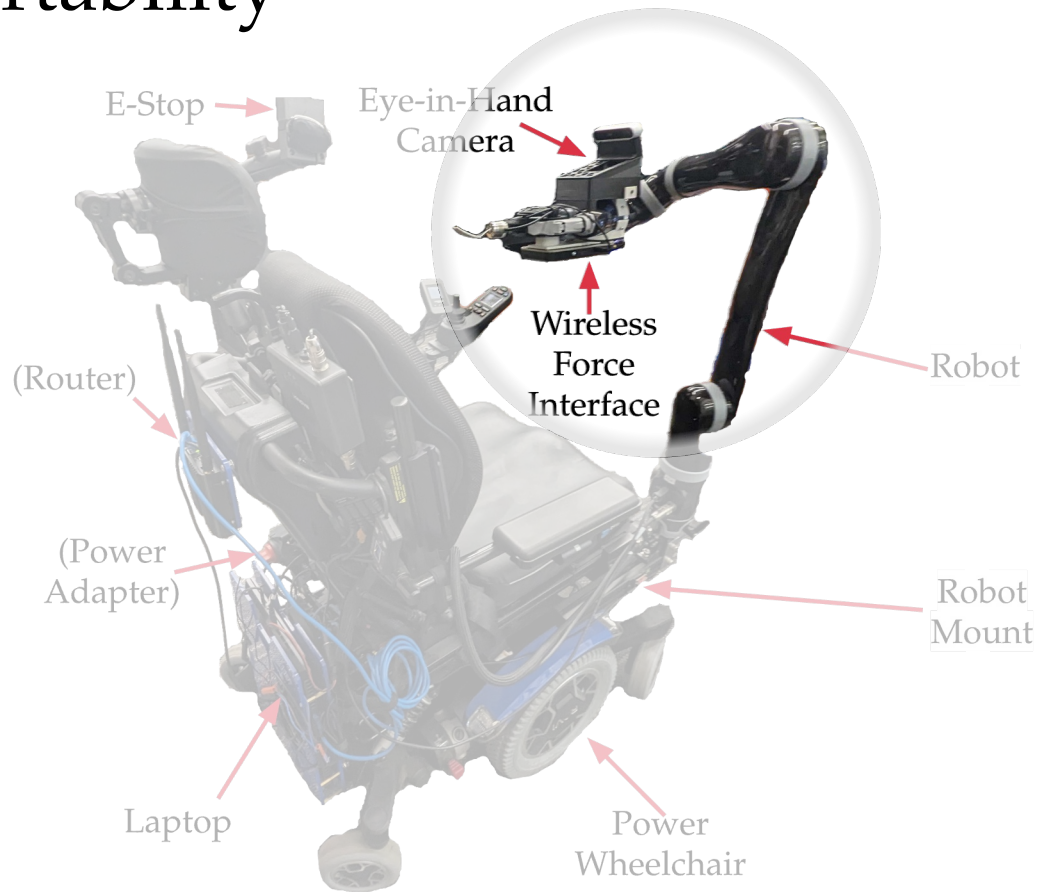


Portability



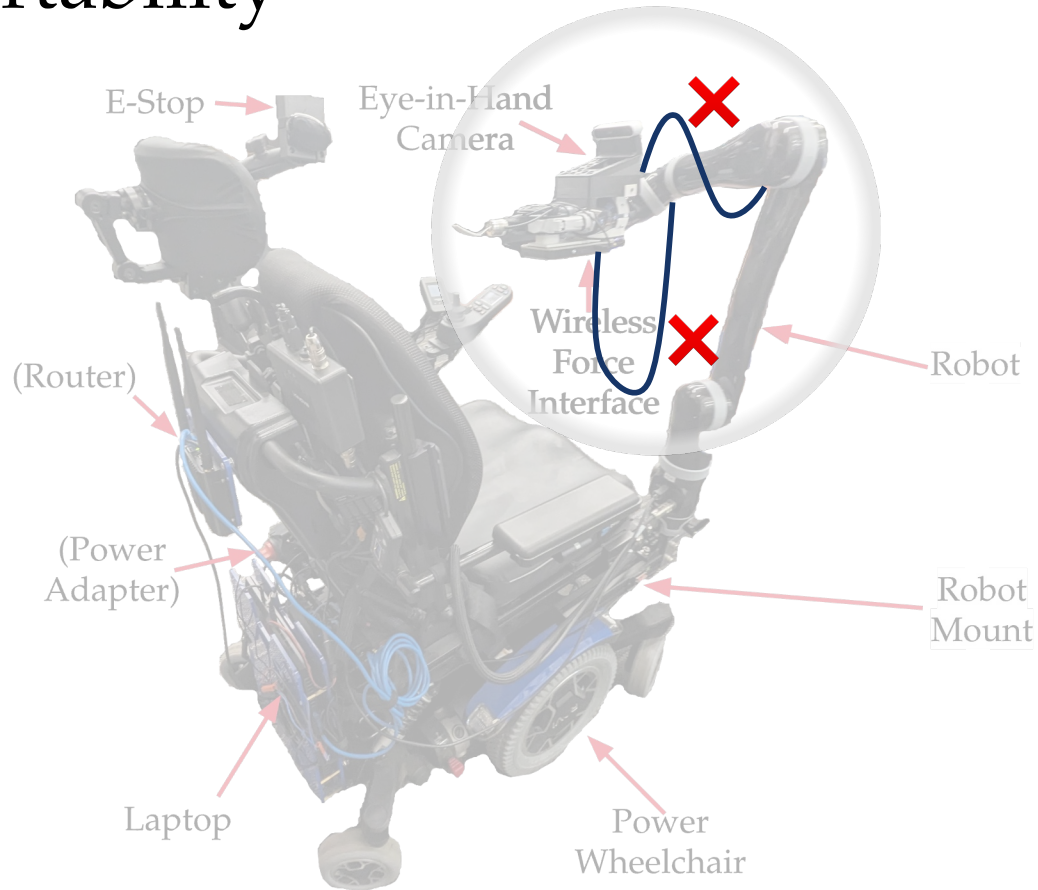
No wires
leave the
system

Portability



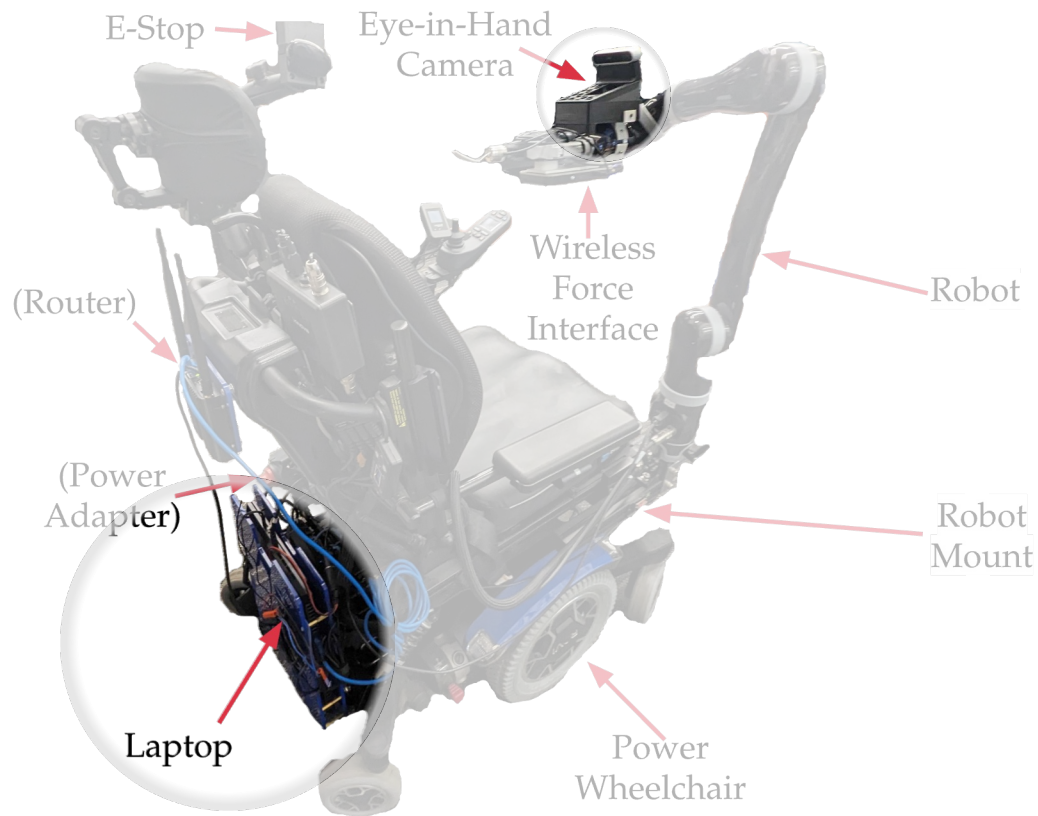
No wires
across
robot joints

Portability



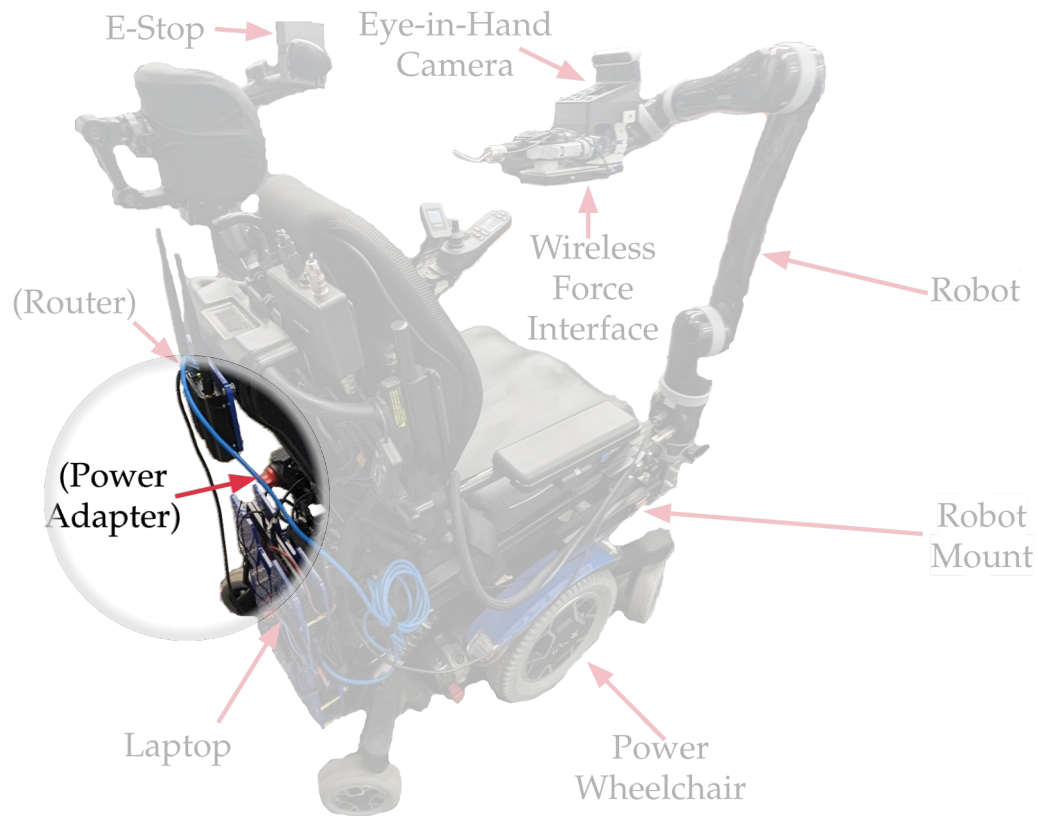
No wires
across
robot joints

Portability



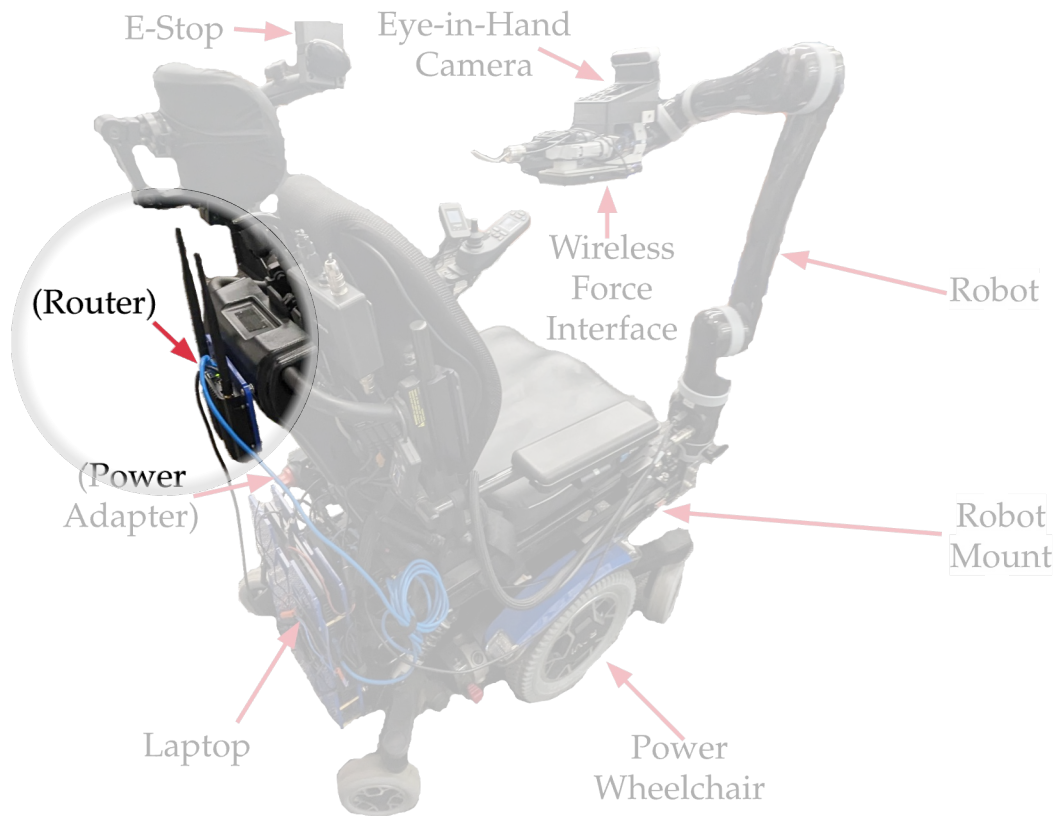
Portable
compute

Portability



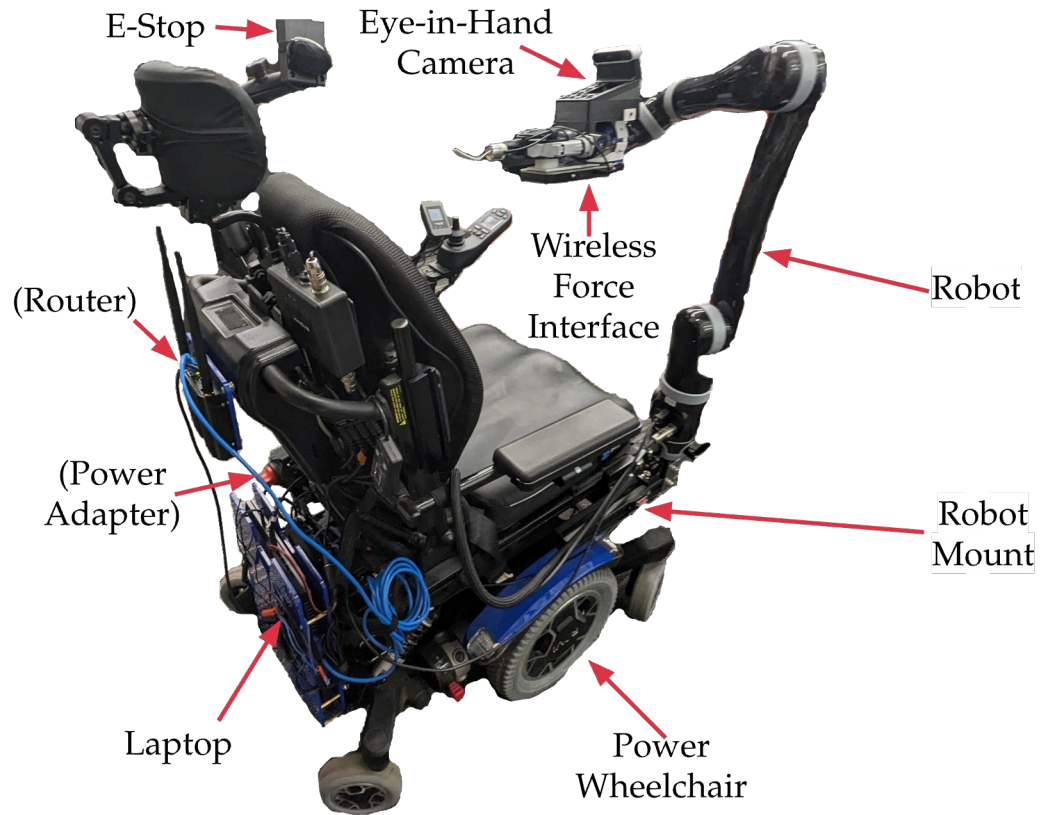
Portable
power

Portability

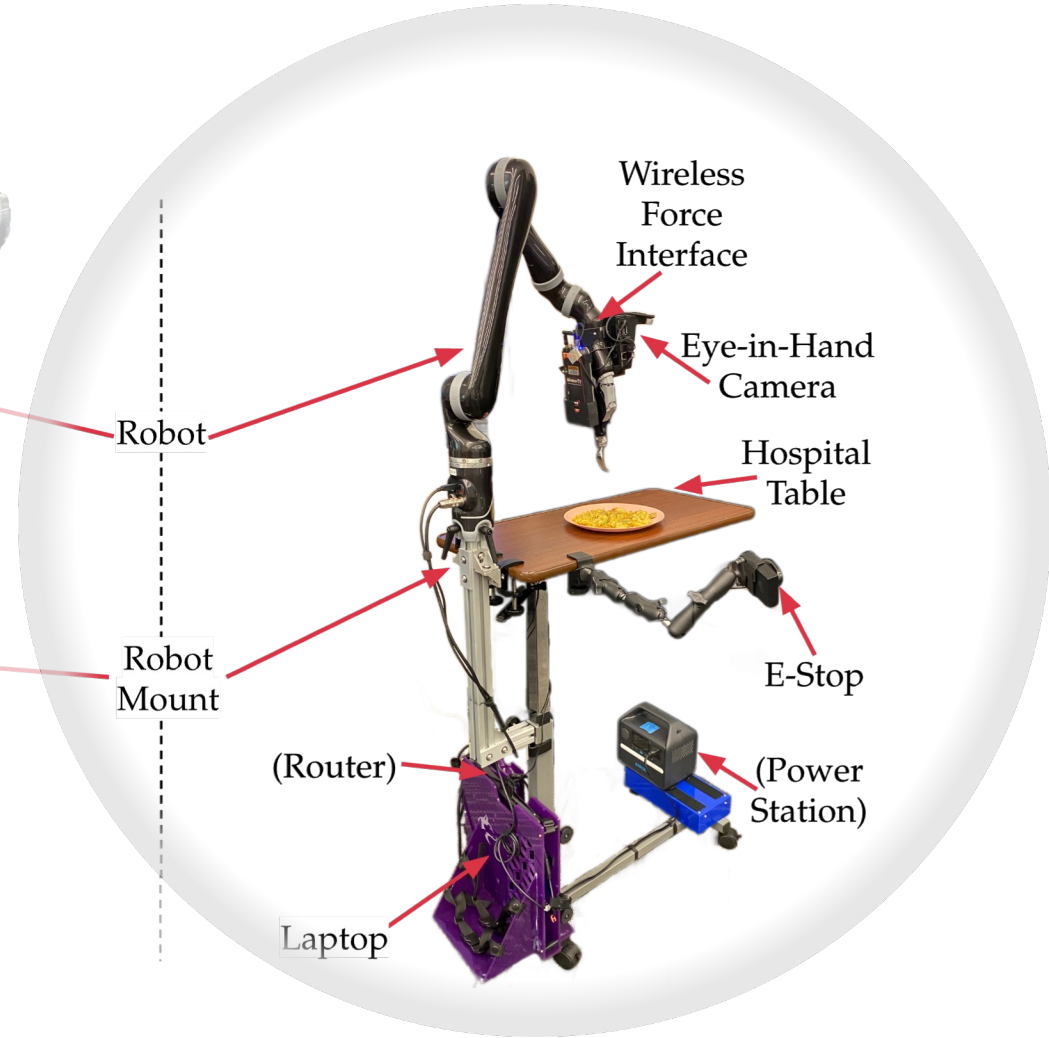
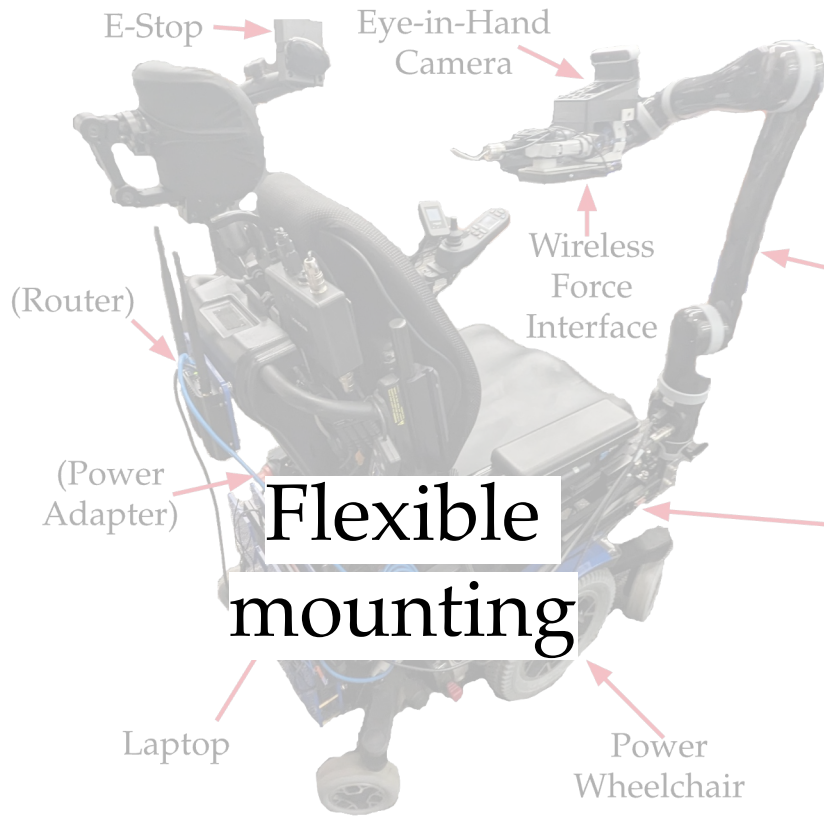


Portable
networking

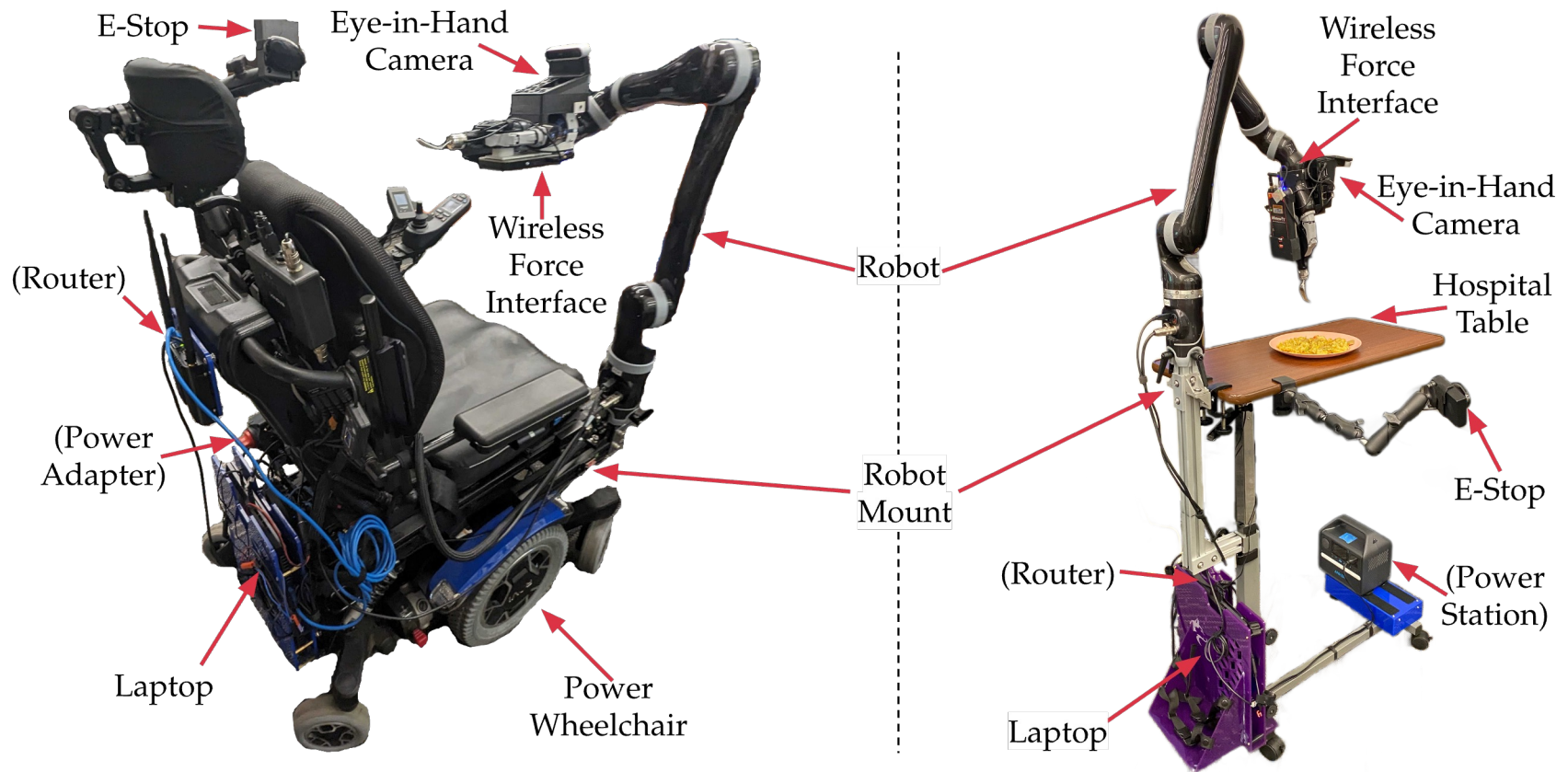
Portability



Portability



Portability



RQ3: Key System Design Principles for Deployability

1. Portability

2. Safety



3. User Control

4. Customizability

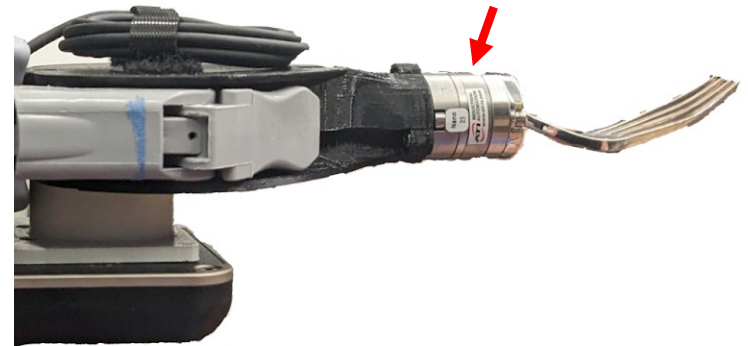
What Can Go Wrong? Understanding Off-Nominals

User	Robot	Environment
<p>User no longer wants bite</p> <p>User cannot eat (e.g., is coughing)</p> <p>User takes a partial bite</p> <p>User clicks unintended button</p> <p>...</p>	<p>Robot collides with object</p> <p>Robot fails to perceive bite</p> <p>Robot fails to acquire bite</p> <p>Robot stops far from face</p> <p>...</p>	<p>Food falls off the fork</p> <p>Plate moves (e.g., caregiver serves food)</p> <p>Local area network fails</p> <p>Device running web app fails</p> <p>...</p>

The multitude & diversity of off-nominals makes it challenging to develop a deployable robot feeding system.

Low-Level Safety Protections Against Off-Nominals

- Force-gated
 - controllers stop if force-threshold is exceeded
- E-stop
 - controllers stop if e-stop button pressed
- Watchdog ensures liveness of safety system
 - controllers stop if haven't received "all-clear" watchdog message in n ms
- This is about *preventing negative outcomes* from off-nominals.
- What about *resolving* them to resume the meal?



Key Observation:

Users' goal fully aligns with the robot, they are co-located and temporally synchronized with the robot, and desire control over the robot.

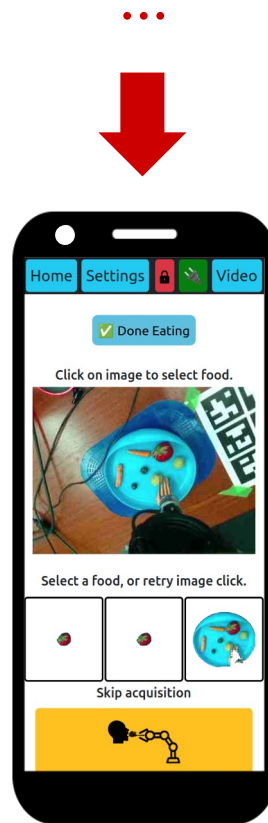
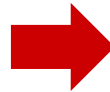
Key Insight :

Users can resolve off-nominals, given control and transparency.

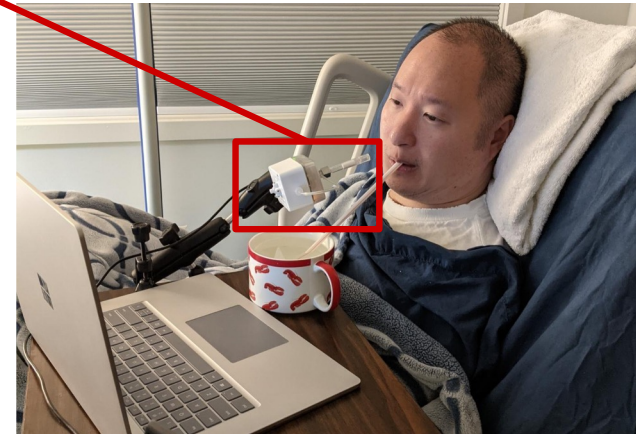
User Interface: Web App



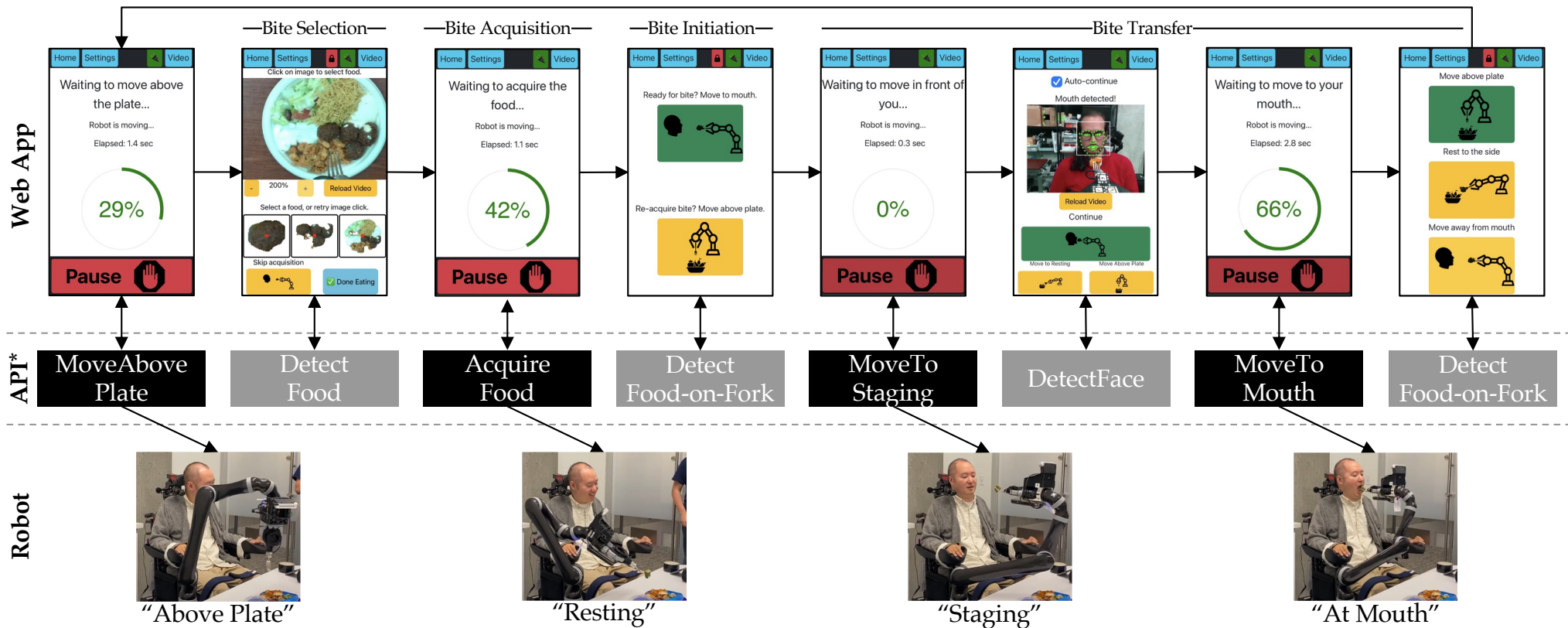
Voice Control



Mouth Joystick

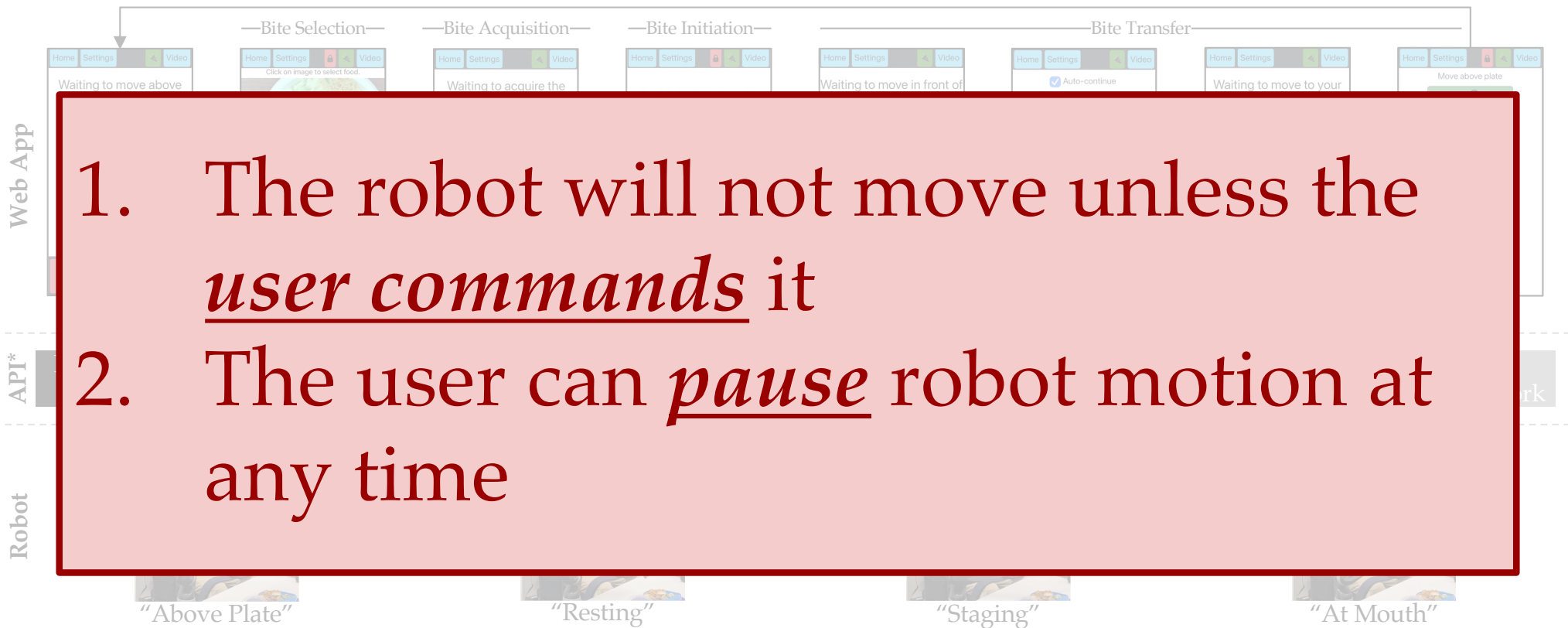


System Overview: User Controls Execution



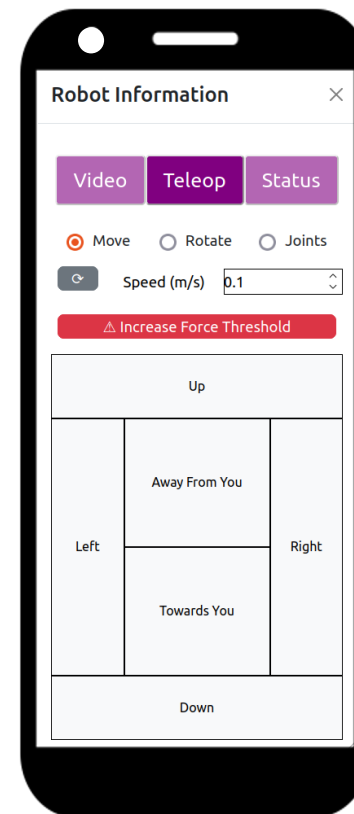
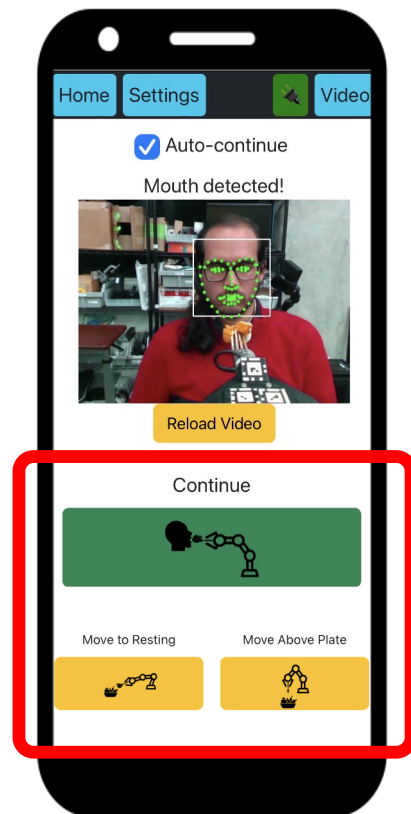
* Robot actions are implemented as behavior trees

System Overview: User Controls Execution



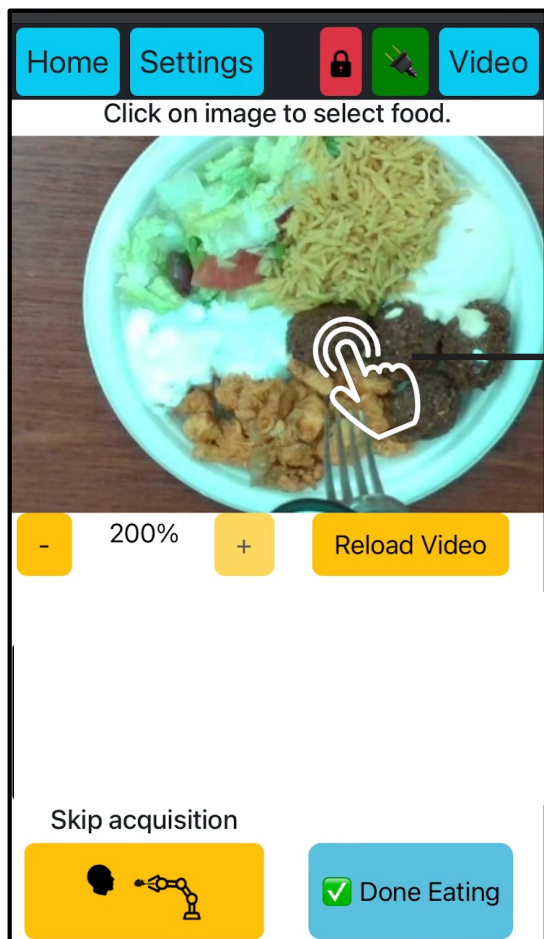
* Robot actions are implemented as behavior trees

Flexible User Control is key to resolve off-nominals



* Cartesian control provided via the Selectively Damped Jacobian Pseudo-Inverse

Transparency is necessary to enact user control



image, seed point

Segment
Anything
Model (SAM)

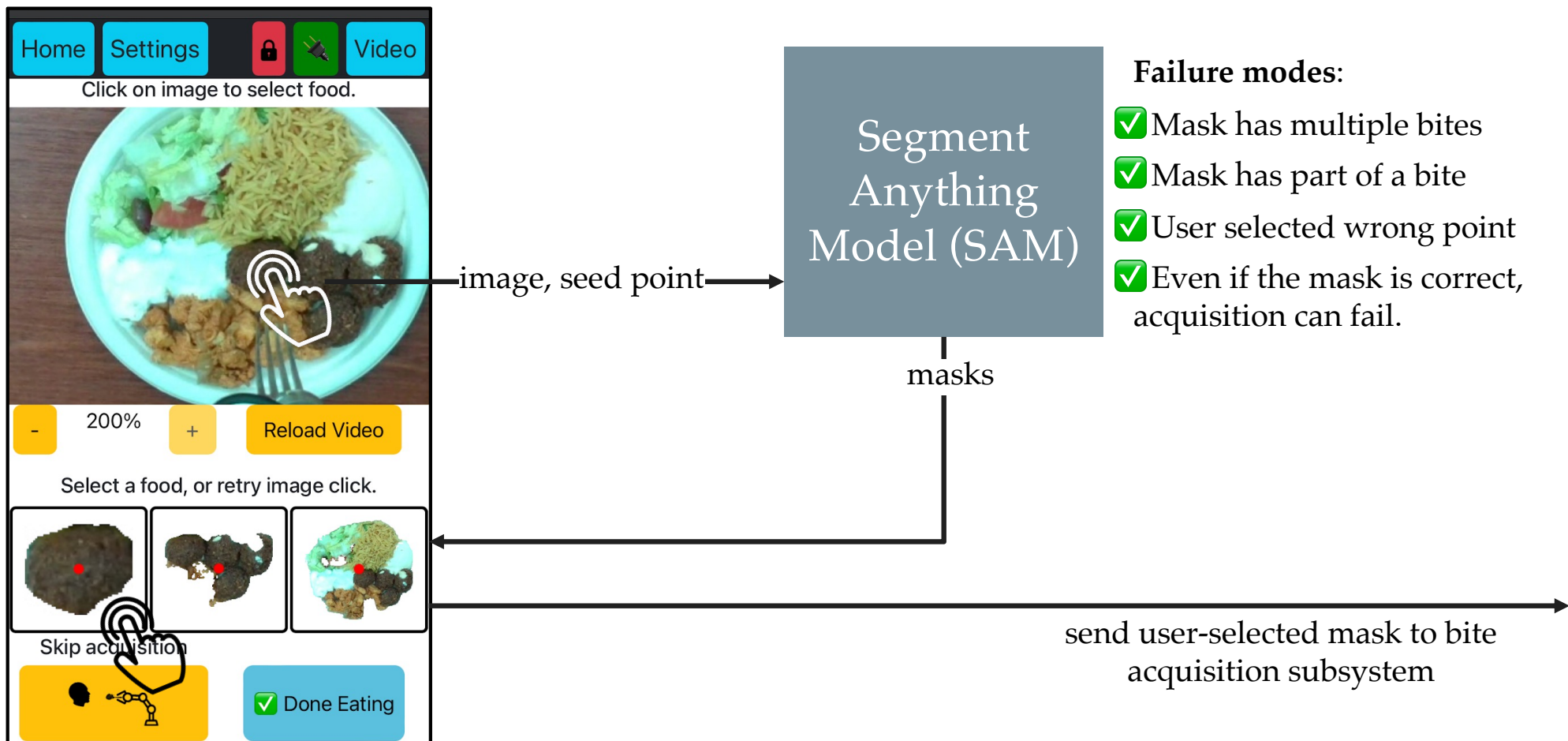
masks

send most confident mask to bite
acquisition subsystem

Failure modes:

- Mask has multiple bites
- Mask has part of a bite
- User selected wrong point
- Even if the mask is correct, acquisition can fail.

Transparency is necessary to enact user control



Transparency and control are
two sides of the same coin;
users need *transparency to*
understand a problem and
control to resolve it.



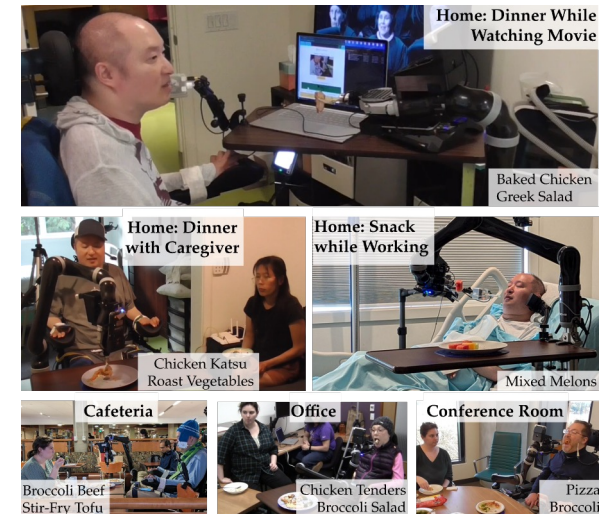
✓ Done Eating

acquisition subsystem

RQ3: Key System Design Principles for Deployability

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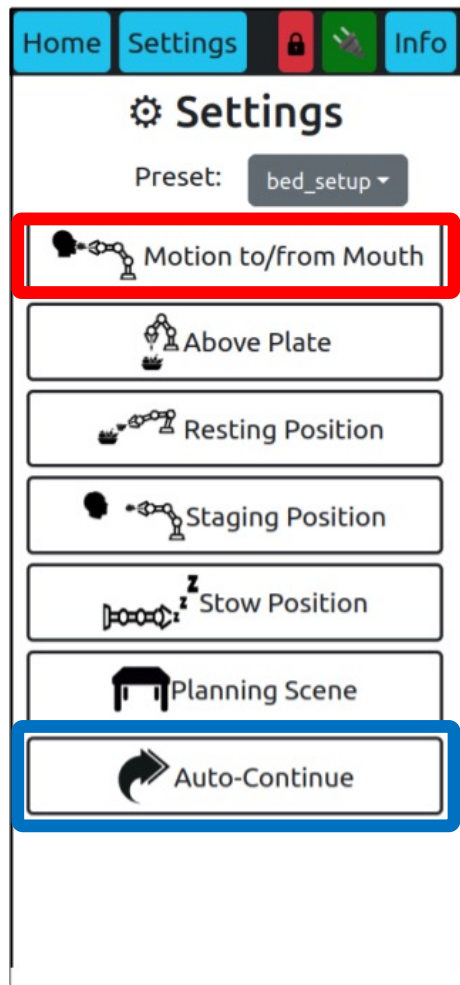
2. Safety



3. User Control

4. Customizability

Customizability

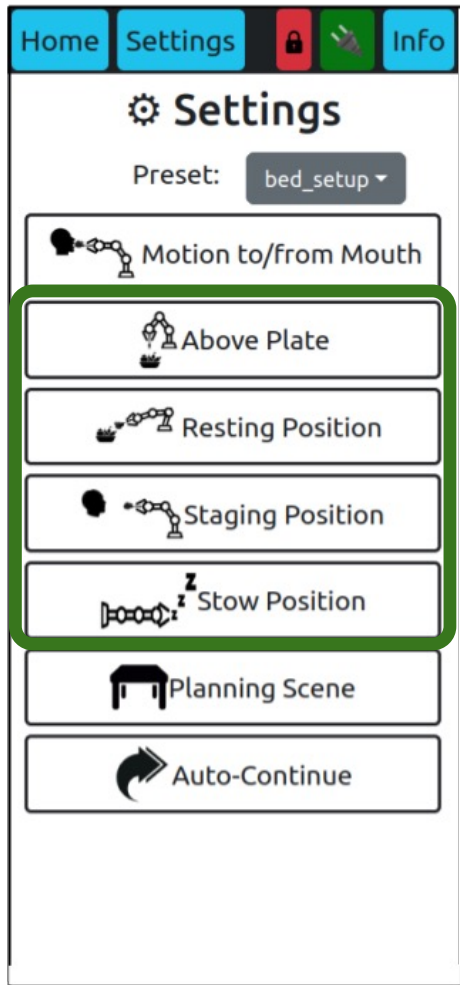


- distance to mouth
- speed to/from mouth

At each transition, does the robot wait for user input, or auto-continue?

- post-acquisition
- pre-transfer
- post-transfer

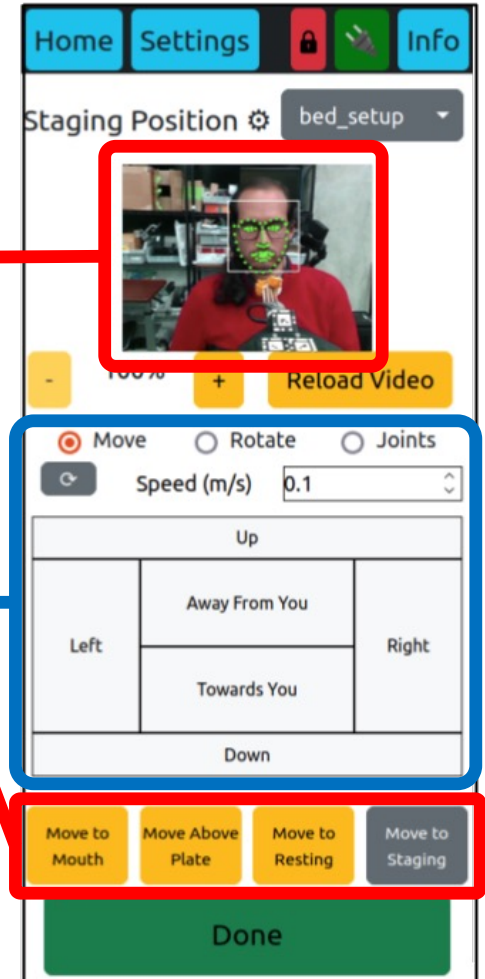
Customizability: Arm Configurations



transparency into
upstream impacts of
customization

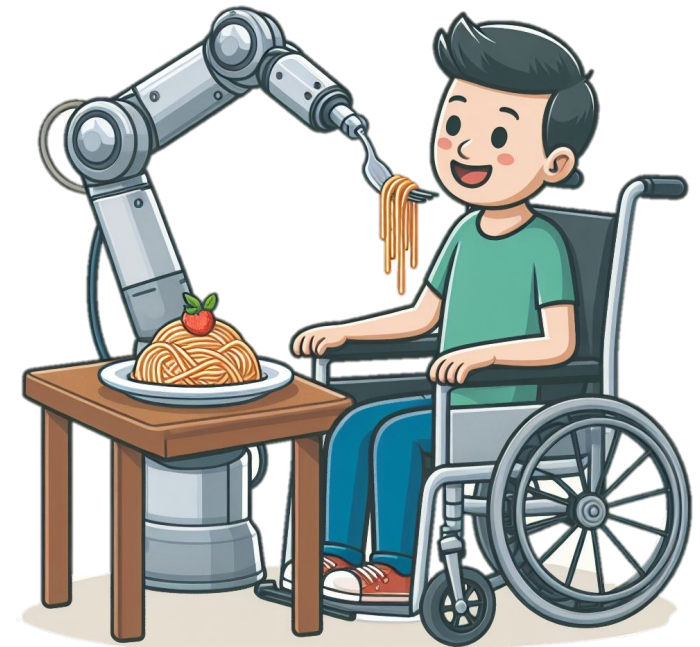
direct, intuitive access to
parameter space

Resnick, Mitchel, and Eric Rosenbaum. "Designing for tinkerbility." *Design, make, play: Growing the next generation of STEM innovators* (2013)



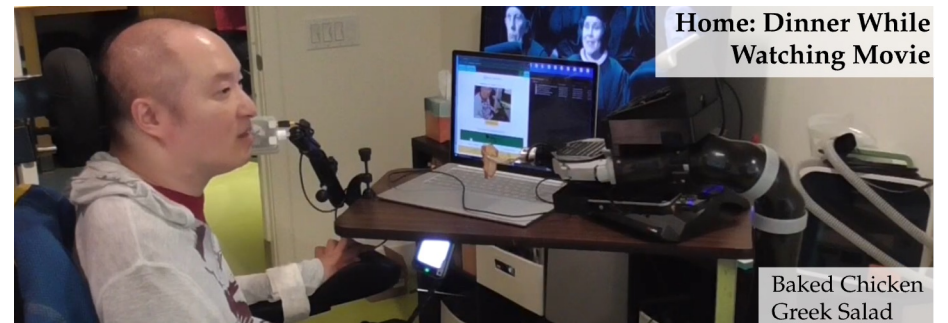
Roadmap

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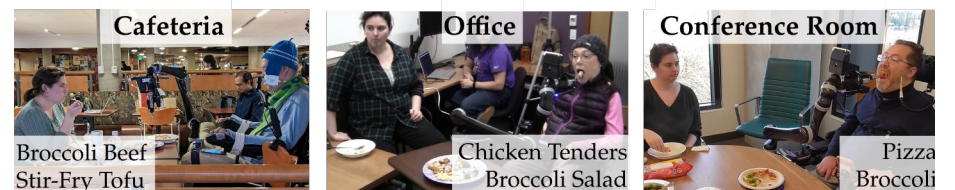
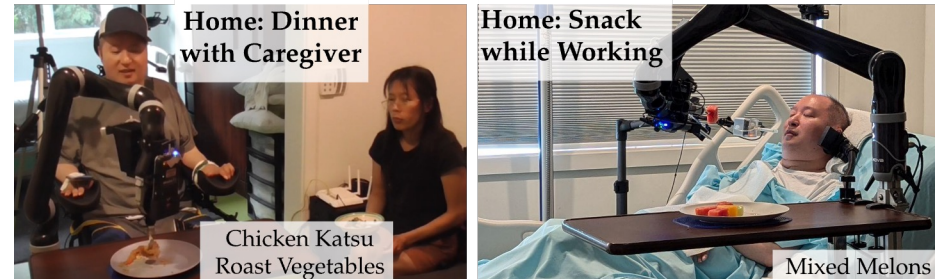


Evaluations Overview

1. Quantitative, Multi-User, Out-of-Lab



2. Qualitative, Single-User, In-Home



Evaluation 1: Quantitative, Multi-User, Out-of-Lab

How does the system perform across the needs/ preferences of *different users*?

- 5 participants & 1 community researcher
- Meal of their choice
- 3 locations: office, conference room, public cafeteria
- Used their own devices and assistive technologies



User ID	Age	Gender	Impairment	Selected meal(s) items ¹⁷	Study location(s)	Device interaction
P1	49	M	C3 SCI ¹⁸	Pizza, broccoli	Conference room	Voice control
P2	42	F	C5 SCI	Chicken, salad	Office	Stylus
P3	45	M	Arthrogryposis	Sandwich, brownies	Conference room	Stylus
P4	62	M	C3 SCI	Chicken, potatoes	Office	Touch
P5	61	F	C5-6 SCI	Salmon, brussels	Office	Touch
CR2	43	M	C2 SCI	Stir-fry beef, tofu	Cafeteria	Mouth joystick

Evaluation 1: Bite Acquisition

User ID	Acquisition Success Rate	Most Successful Food
P1	0.79 (15/19)	Pizza: 0.78 (14/18)
P2	0.65 (24/37)	Chicken: 0.85 (11/13)
P3	0.69 (31/45)	Sandwich: 0.94 (16/17)
P4	0.88 (30/34)	Chicken 1.0 (13/13)
P5	0.79 (23/29)	Brussels: 0.86 (9/7)
CR2	0.78 (14/18)	Tofu: 1.0 (3/3)



Evaluation 1: Bite Duration

User ID	Median Bite Time (IQR)
P1	2:26 (0:54)
P2	1:10 (0:12)
P3	1:00 (0:09)
P4	1:10 (0:21)
P5	1:15 (0:20)
CR2	1:41 (0:24)

Full Teleop: ≥ 5 mins / bite

With Robot: ≥ 1 min / bite

Caregiver: ≥ 20 s / bite



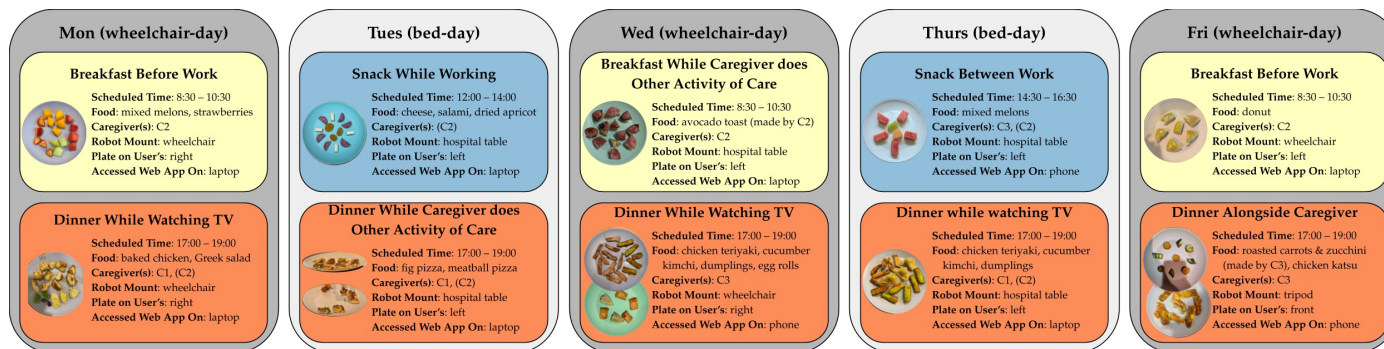
Evaluation 1: Subjective Data

User ID	Cognitive Workload (Baseline: 37 [95])	Usability Grade (Baseline: C [92])
P1	17.50	D
P2	29.17	C
P3	38.33	F
P4	20.00	A+
P5	19.17	B+
CR2	19.17	A



Evaluation 2: Qualitative, Single-User, In-Home

How does the system perform across the *different contexts* that arise in-home?



Jonathan Ko

Evaluation 2: Spatial Context



Bed-Days



Wheelchair-Days

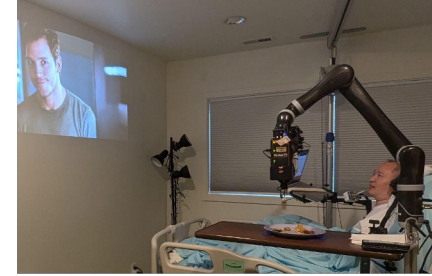
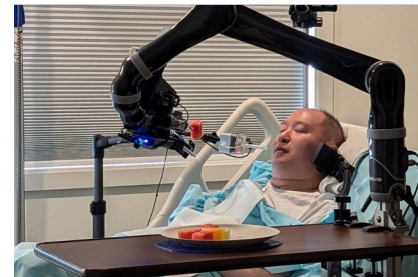
Evaluation 2: Social Context

ID	Age Group	Gender	Years Worked with CR2	Live-in?
C1	25–34	F	0.5	✗
C2	55–64	M	25	✓
C3	35–44	F	7	✗



Evaluation 2: Activity Context

- Jonathan's deployment goals:
 - Feed himself dinner while watching TV
 - Spend time with a caregiver while both eat
 - Feed himself while a caregiver does other work
 - Feed himself breakfast while working
 - Feed himself a mid-day snack while working



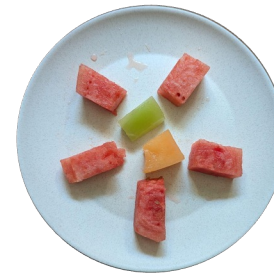
Results & Lessons Learned

Results Overview

charcuterie



avo toast



grilled
chicken



specialty
pizza



chicken
teriyaki



How did Jonathan's level of independence change?

Medicare Section GG

6. Independent

5. Setup assistance

with
robot

4. Supervision

3. Partial assistance

2. Maximal assistance

baseline

1. Dependent



Real-Time (1x)

Spatial Contexts

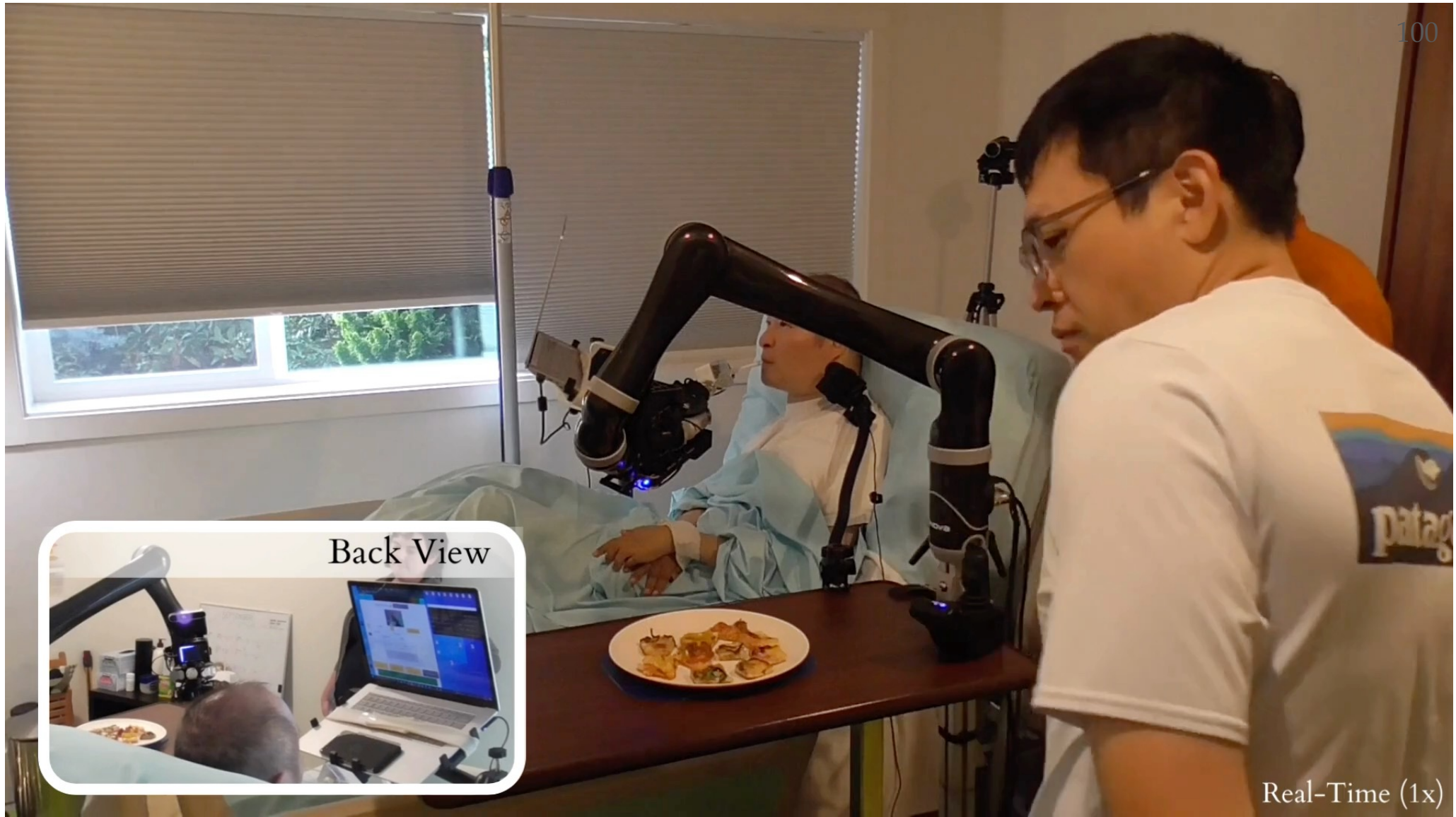
Environmental objects

- Laptops / smartphones
- Hospital tables
- Mouth joystick
- E-stop

Variability

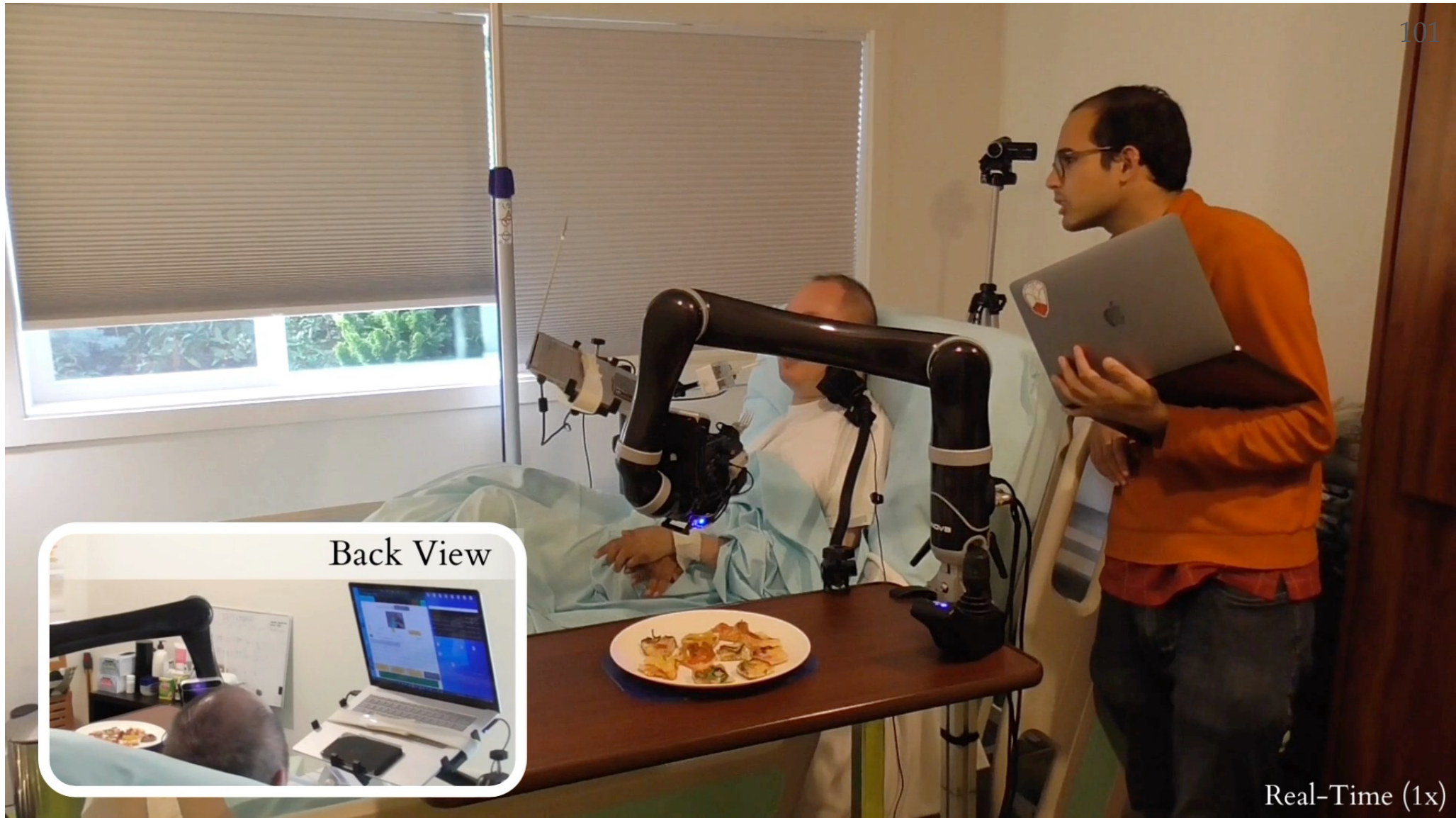
- Bed tilt
- User's lateral position in bed
- Wheelchair tilt
- Hospital table height & orientation





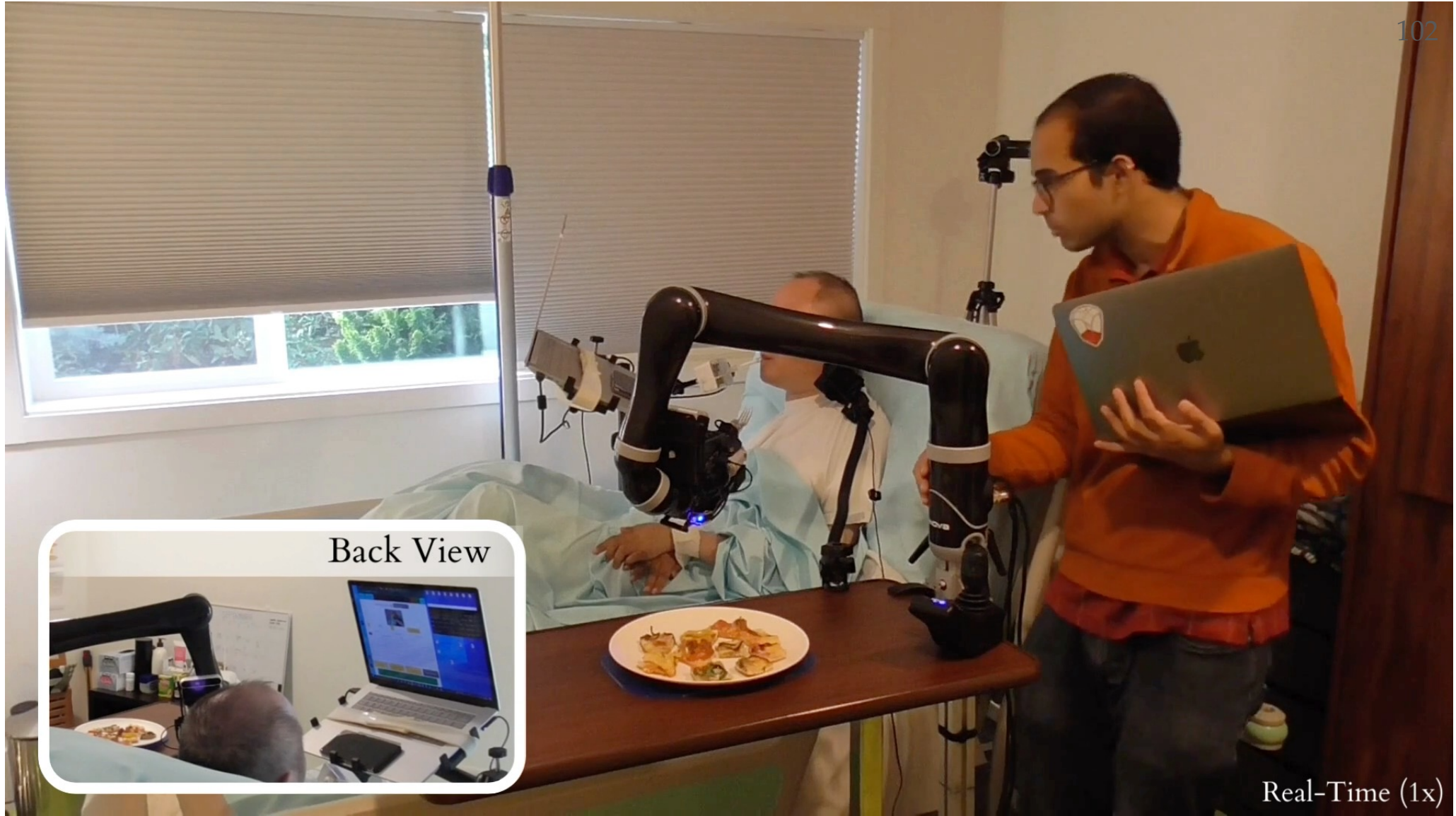
Back View

Real-Time (1x)



Back View

Real-Time (1x)



Back View

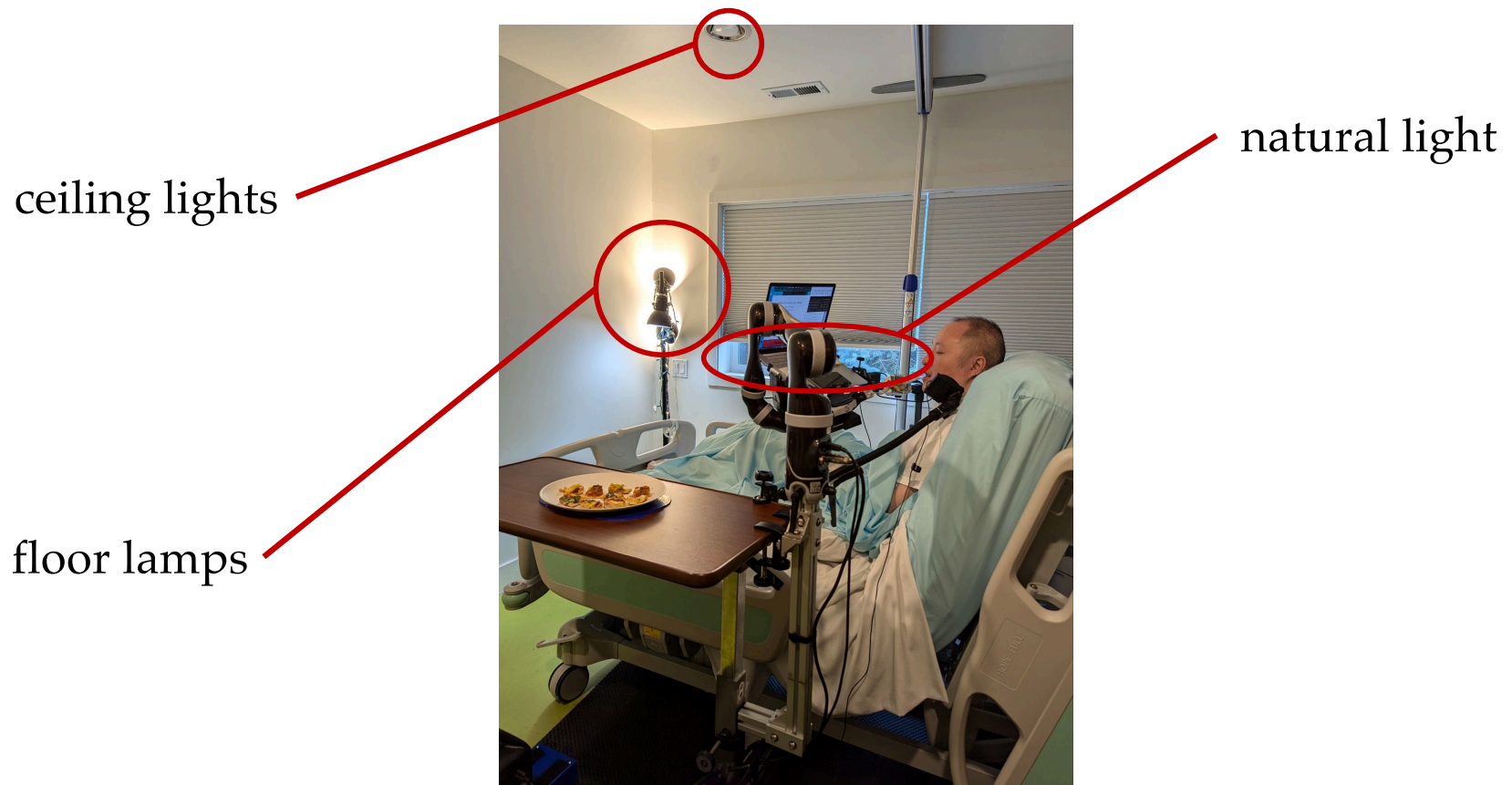
Real-Time (1x)

Lesson # 1:

- Spatial contexts are numerous
- Tinkering is inherent to assistive robot setup*
- Customizable systems enable easy tinkering

*Mossfeldt Nickelsen, Niels Christian. "Imagining and tinkering with assistive robotics in care for the disabled." *Paladyn, Journal of Behavioral Robotics* (2019).

Off-nominals: Face Detection





Back View

Real-Time (1x)



Back View

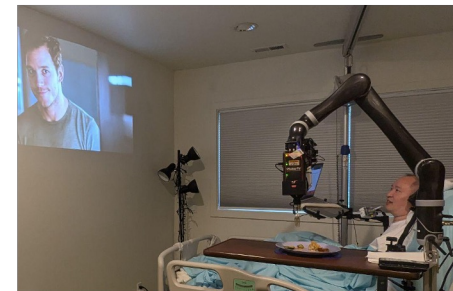
Real-Time (1x)

Lesson #2:

- Off-nominals will arise
- Variable autonomy lets users overcome them

Jonathan's Goal Attainment

- ✓ Feed himself dinner while watching TV
- ✓ Spend time with a caregiver while both eat
- ✓ Feed himself while a caregiver does other work
- ✗ Feed himself breakfast while working
- ✗ Feed himself a mid-day snack while working



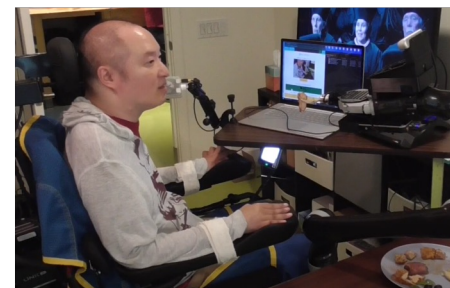
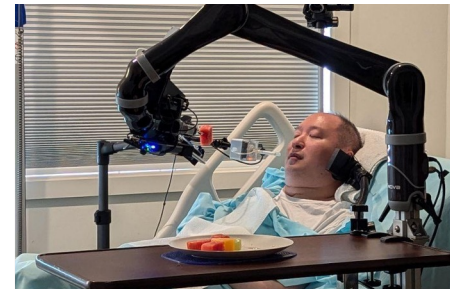
Context-dependent Robot Use

Food-dependent use:

“I wouldn’t eat all my meals with it. Some foods I like [e.g., ramen] can be difficult for it. [But] I like pizza a lot; it did fine with pizza.” (CR2)

Time-dependent use:

“[When I’m] eating for enjoyment, during dinner, [using the robot] is great. For breakfast and snack, where I feel I should be working, things are rushed.” (CR2)



Lesson #3:

- Assistive robots integrate into a user's life
- They provide contextual benefits
- They can still add value to users' ADL toolkit



community
researchers



occupational
therapists

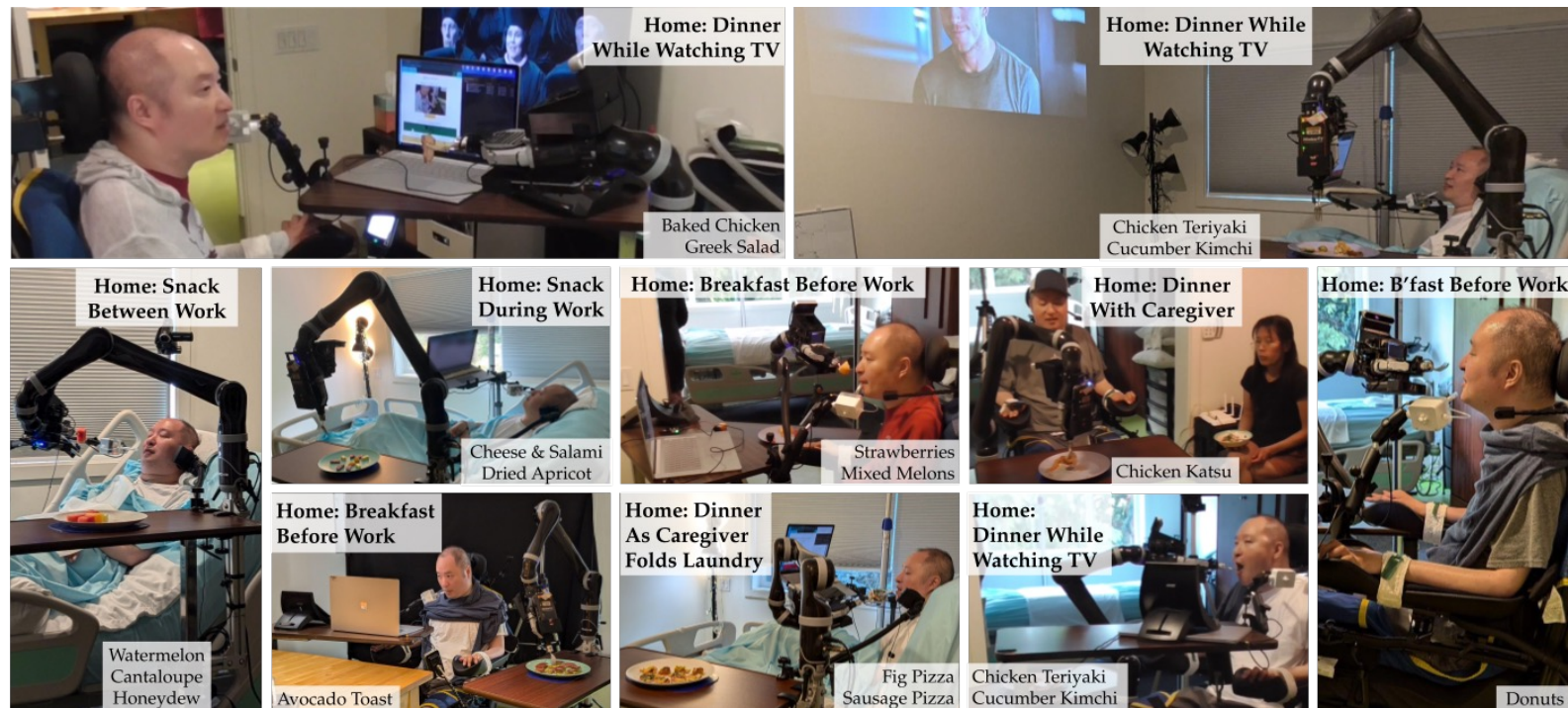


Lesson #4: Work with end-users & stakeholders



caregivers

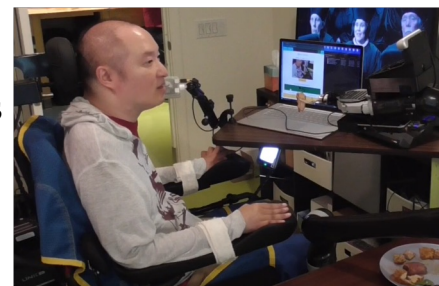
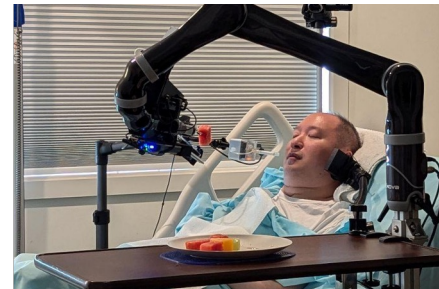




“Sometimes people feed me, and I don’t like how they’re doing it. It’s weirdly empowering, as someone who’s been paralyzed as long as I have, to say, ‘I’m going to eat this. It’ll take me 3 times as long, but I’m not going to be frustrated while I eat.’” (CR2)

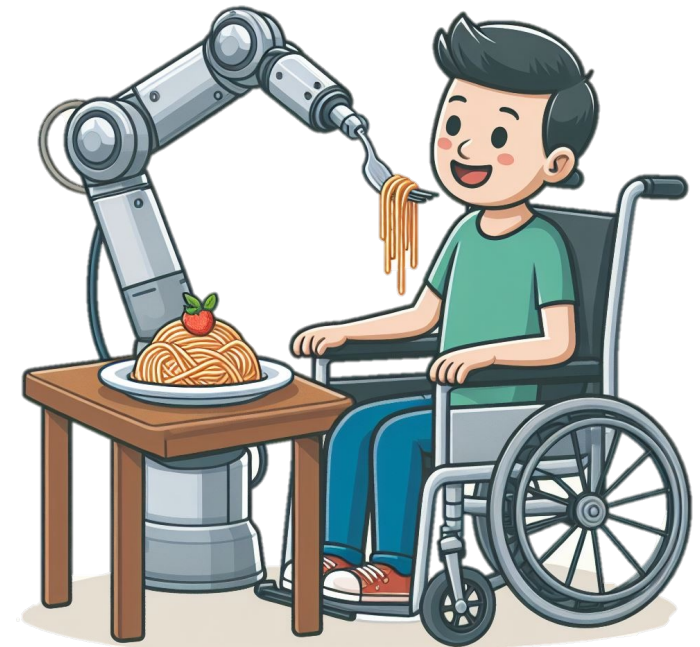
Future Work

- **Bite Acquisition:**
 - Online failure prediction & recovery
 - More food types, e.g., ramen
- **Bite Transfer:**
 - Approaching below the eyeline
- **Commercial Viability:**
 - Reduce system cost (from \$50K)
 - Make the case for insurance approval
- **Integration into Care Routines:**
 - Co-design setup & maintenance with caregivers



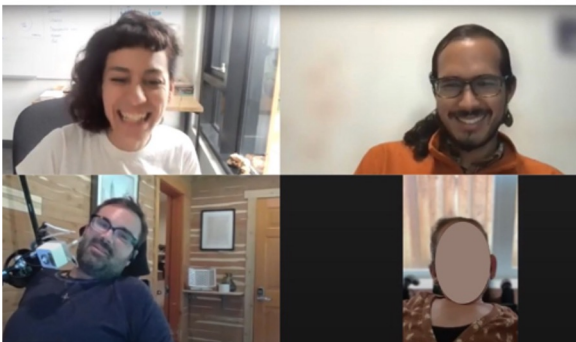
Roadmap

1. Motivation
2. Robot-Assisted Feeding Overview
3. RQ1: Users' Needs Assessment
4. RQ2: Generalizing Bite Acquisition
5. RQ3: Developing a Deployable System
6. Evaluations & Lessons Learned



Media

Setting the table for a brighter future: With help from robots, Allen School researchers are making social dining more accessible



GeekWire

UW computer science research event offers a glimpse of the future at the dawn of AI

BY TAYLOR SOPER & TODD BISHOP on November 15, 2023 at 10:31 am



University of Washington student Atharva Kashyap demonstrates a robot-assisted feeding system at the UW's computer science Open House event on Tuesday in Seattle. (GeekWire Photo / Taylor Soper)

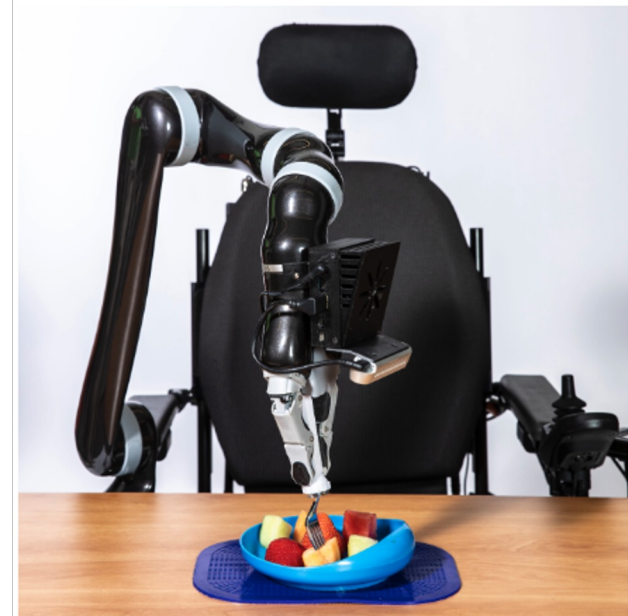
November 16, 2023

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Q&A: How an assistive-feeding robot went from picking up fruit salads to whole meals

[Stefan Milne](#)

UW News



A team led by researchers at the University of Washington created a set of 11 actions a robotic arm can make to pick up nearly any food attainable by fork. This allows the system to learn to pick up new foods during one meal. Here, the robot picks up fruit. *University of Washington*

November 22, 2022

Welcome to the first annual Robot Assisted Feeding Retreat!

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Paying it Forward

ANNUAL REVIEWS

Annual Review of Control, Robotics, and Autonomous Systems

Physically Assistive Robots: A Systematic Review of Mobile and Manipulator Robots That Physically Assist People with Disabilities

Amal Nanavati*, Vinitha Ranganeni*, and Maya Cakmak

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Keywords: physically assistive robots, accessibility, user-centered design, human-robot interaction, assistive technology

Abstract: More than 1 billion people in the world are estimated to experience significant disability. These disabilities can impact people's ability to independently conduct activities of daily living, including ambulating, eating, dressing, taking care of personal hygiene, and more. Mobile and manipulator robots which can move about human environments and physically interact with objects and people, have the potential to assist people with disabilities in activities of daily living. Although the vision of robotics for decades, such research has motivated research across subfields of robotics for safety, and price. More and more research involves end-to-end robotic systems that interact with people with disabilities in real-world settings. In this article, we survey papers about physically assistive robots intended for people with disabilities from top conferences and journals in robotics, human-computer interactions, and accessible technology, to identify the general trends—research methodologies. We then dive into three specific research themes—interaction interfaces, levels of autonomy, and adaptation—and present frameworks for how these themes manifest across physically assistive robot

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<https://doi.org/10.1146/annurev-control-062823-024952>

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*These authors contributed equally to this article

OPEN ACCESS

Nanavati, Amal*, Vinitha Ranganeni*, and Maya Cakmak. "Physically assistive robots..." *Annual Review of Control, Robotics, and Autonomous Systems* (2023).

Multiple Ways of Working with Users to Develop Physically Assistive Robots

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1 INTRODUCTION

When designing, developing, and evaluating physically assistive robots (PARs) for people with motor impairments, it is crucial to work with them to ensure the technology addresses their needs and integrates with their lived circumstances [16, 29]. However, only about half of PAR user studies, and less than half of summative studies¹, incorporate members of the target community [29]. Reasons for this include: (1) outreach and recruitment of people with disabilities is challenging because they tend to have lower technology access and usage [26], (2) systemic barriers hinder people with disabilities' access to college education [1], making them underrepresented amongst a population that is commonly used for studies; and (3) coordinating travel to the research venue is challenging, as transportation access and usage tends to be lower amongst people with disabilities [2]. These factors extend the time it takes to do rigorous studies with participants with motor impairments, which can be incompatible with rapid research timelines.

2 CONTRIBUTION

We critically reflect on our experiences and methodological insights working with users with motor impairments across three PAR projects: (1) assistive feeding with a robot arm; (2) assistive teleoperation with a mobile manipulator; and (3) shared-control with a robot arm. These projects were conducted independently by 3 different research labs, and the insights emerged from joint discussions. Across the projects, we employed diverse ways of engaging end-users: community research, remote studies, home deployments, and an in-the-wild study at a trade fair. We discuss these approaches along three key dimensions:

(1) **Individual- vs. Community-Level Insights:** How should we balance between conducting deep research with few participants versus broad research with many participants?

(2) **Logistical Burdens on End-Users vs. Researchers:** How can we navigate the differential logistical burdens that end-users and researchers face during a user study?

*Each author contributed equally to this paper
¹Summative studies evaluate an "existing" technology, whereas formative studies explore early iterations that inform the design of a technology

Robotics: Human-centered accessibility technologies.

robot interaction, user studies

Nanavati, Amal*, Max Pascher* et al. "Multiple Ways of Working with Users..." *A3DE@HRI* (2024).

Insurance and Policy Considerations for Physically Assistive Robotics Researchers

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Kashif, Alifah, Amal Nanavati, and Maya Cakmak. "Insurance and Policy Considerations..." *To be submitted.*

Historical Archive

The below works were foundational to robot-assisted feeding research. Although not write maintainers of this website, they are hosted here for archival purposes.

- [Assistive Dining Technology 1970 through 2005](#)
Mealtime Partners, Inc., 2005.
Shared with us by Catherine Wyatt of Mealtime Partners, Inc.
- [Feasibility Study for Assistive Feeder](#)
G. N. Phillips.
Southwest Research Institute, 1987.
Shared with us by Catherine Wyatt of Mealtime Partners, Inc.
- [Sensing Shear Forces During Food Manipulation: Resolving the Trade-Off Between Accuracy and Force](#)
Best Paper Award Winner for Technical Advances in HRI
IEEE International Conference on Human-Robot Interaction, 2019.
- [A Community-Centered Design Framework for Robot-Assisted Feeding Systems](#)
T. Bhattacharjee, M. E. Cabrera, A. Caspi, M. Cakmak, and S.S. Srinivasa.
IEEE International Conference on Robotics and Automation, 2019.
- [Robot-Assisted Feeding: Generalizing Skewing Strategies across Food Items on International ACM SIGACCESS Conference on Computers and Accessibility, 2019.](#)
- [Autonomous robot feeding for upper-extremity mobility impaired people: Integrating learning, motion planning, and robot control.](#)
T. Bhattacharjee, D. Gallenberger, D. Dubois, L. L'Ecuyer-Lapierre, Y. Kim, A. Mandalika, Song, E.K. Gordon, and S. Srinivasa.
Conference on Neural Information Processing Systems, 2018.
Best Demo Award Winner

Robot Assisted Feeding
robotfeeding.io/publications

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Haya Bolotski
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Leila Takayama
...and all labmates!

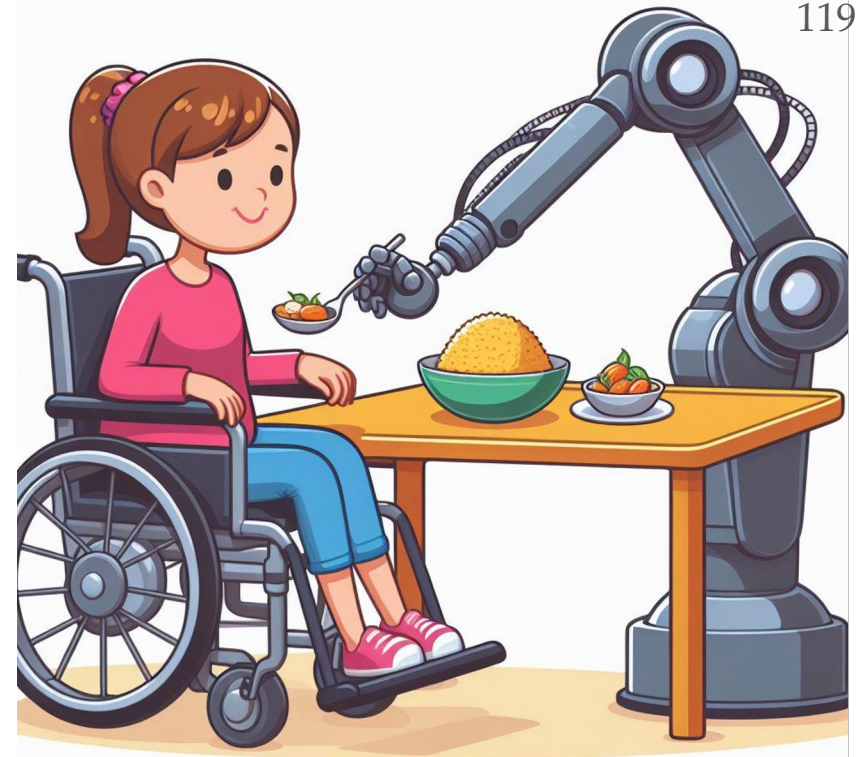
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Thank You Any Questions?

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