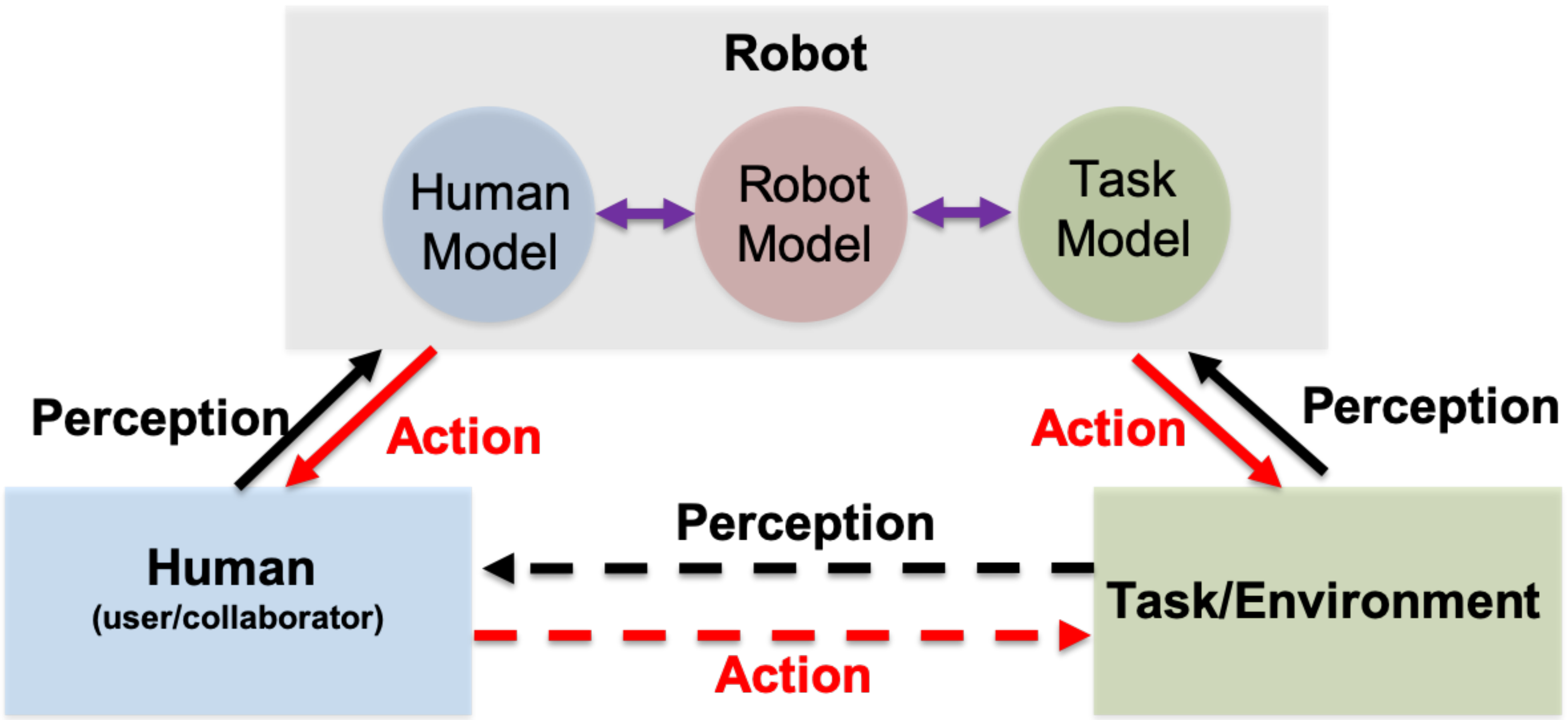
# Assistive Robotics

Prof. Monroe Kennedy III   Assistive Robotics and Manipulation Laboratory, Stanford University

Assistive Robotics and Manipulation Laboratory

Stanford University

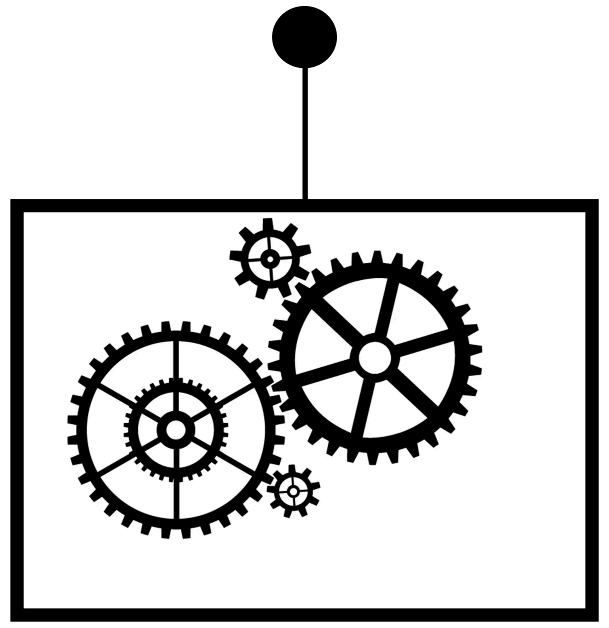
# Assistive Robotics and Manipulation Laboratory

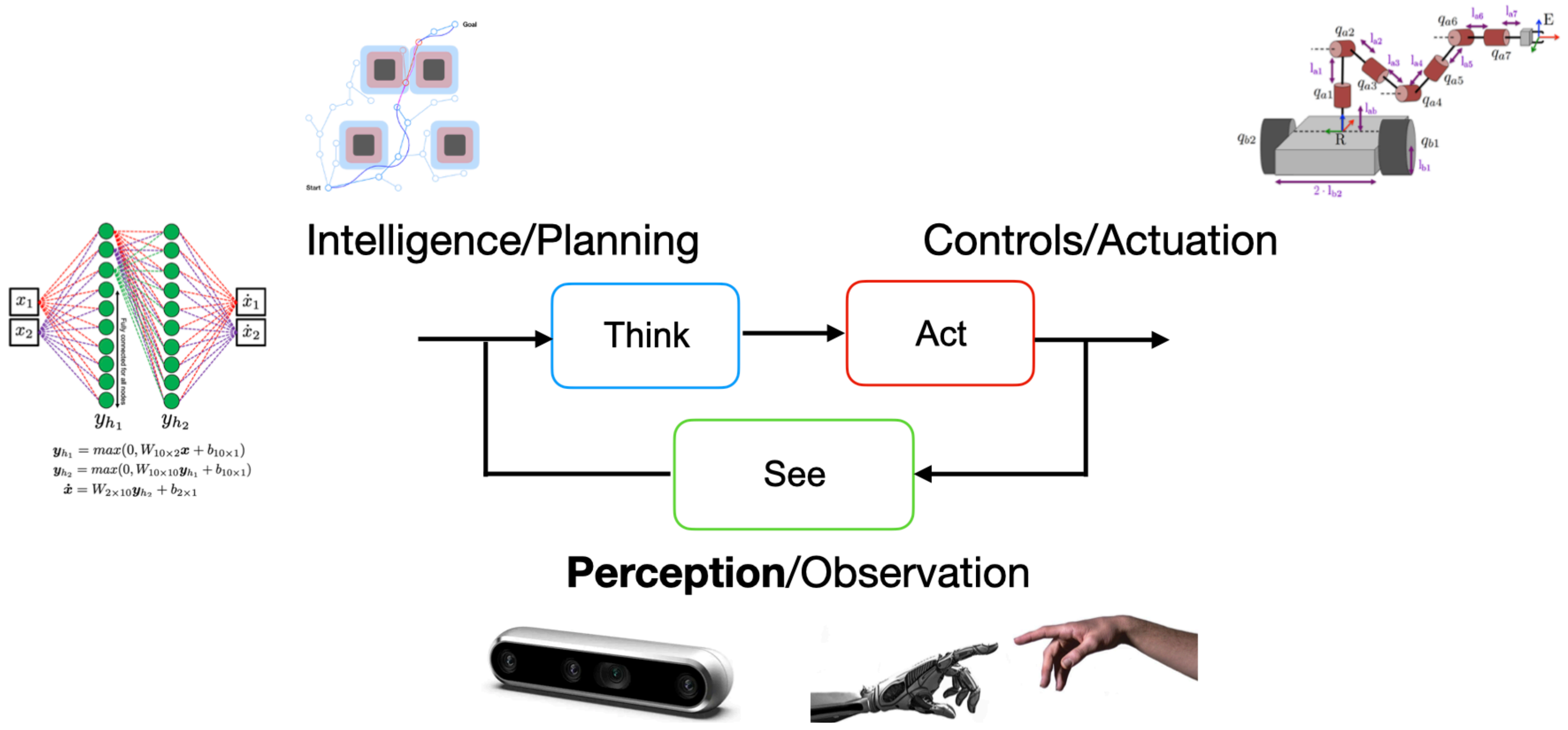


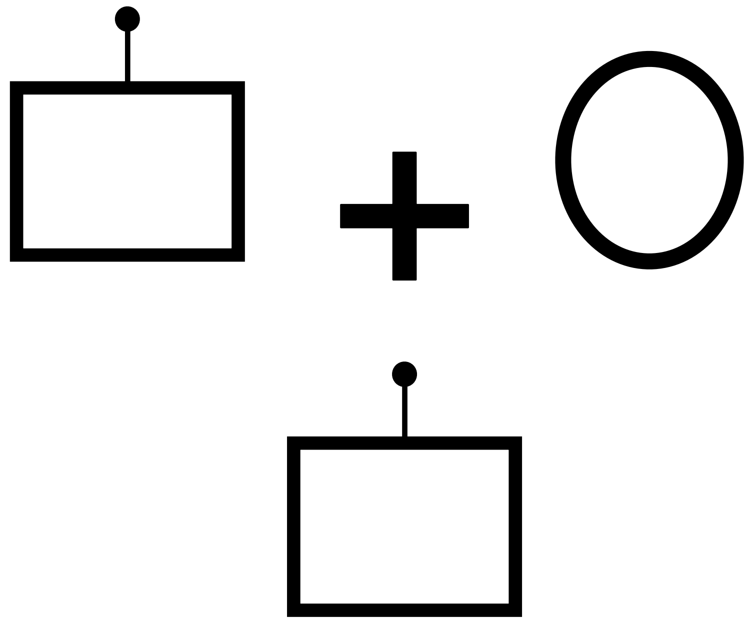
# Robotic Hardware Design

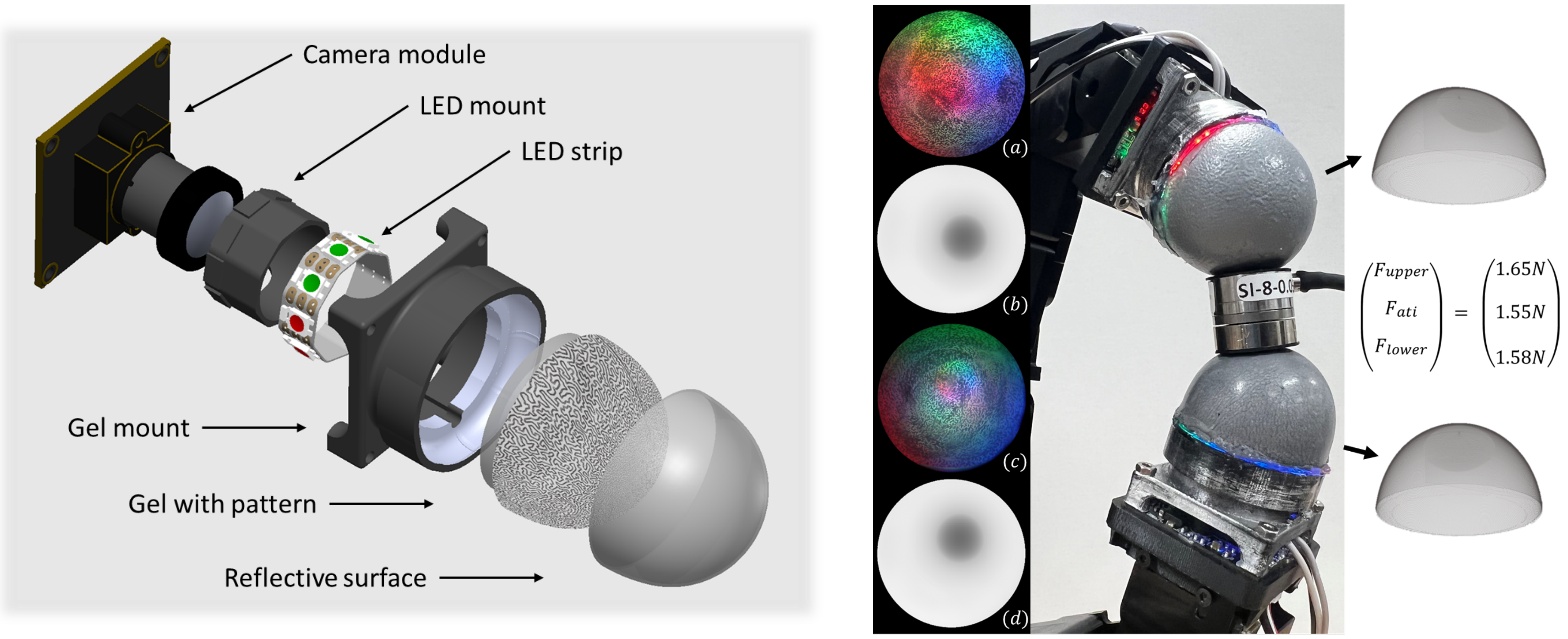
# Robotic Autonomy

# Collaborative Robotics





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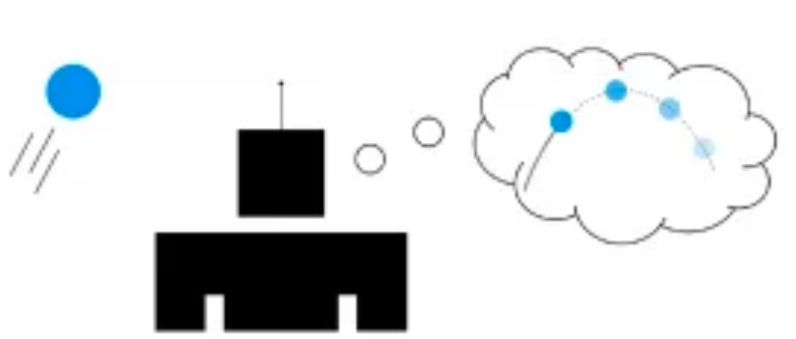

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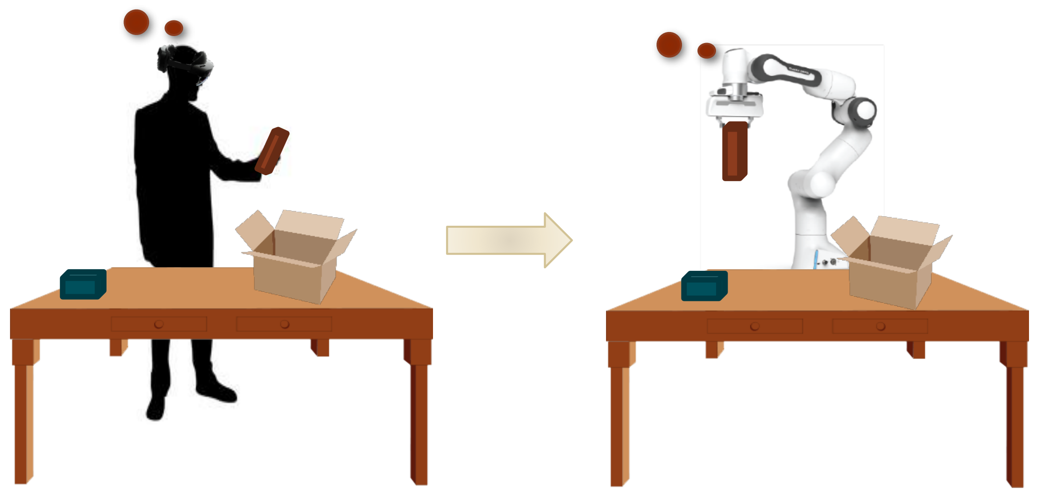
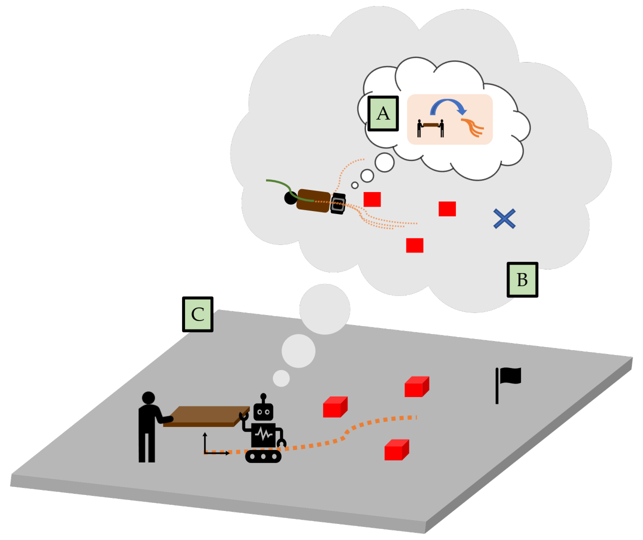
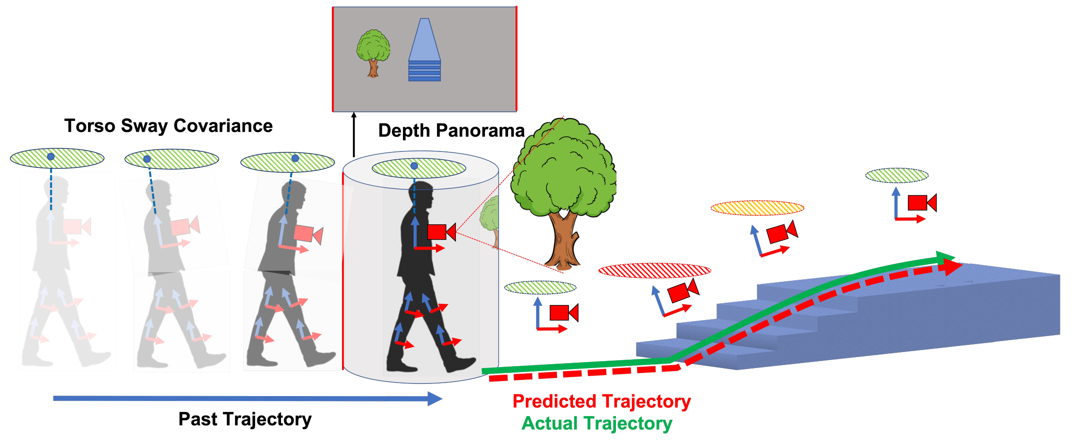


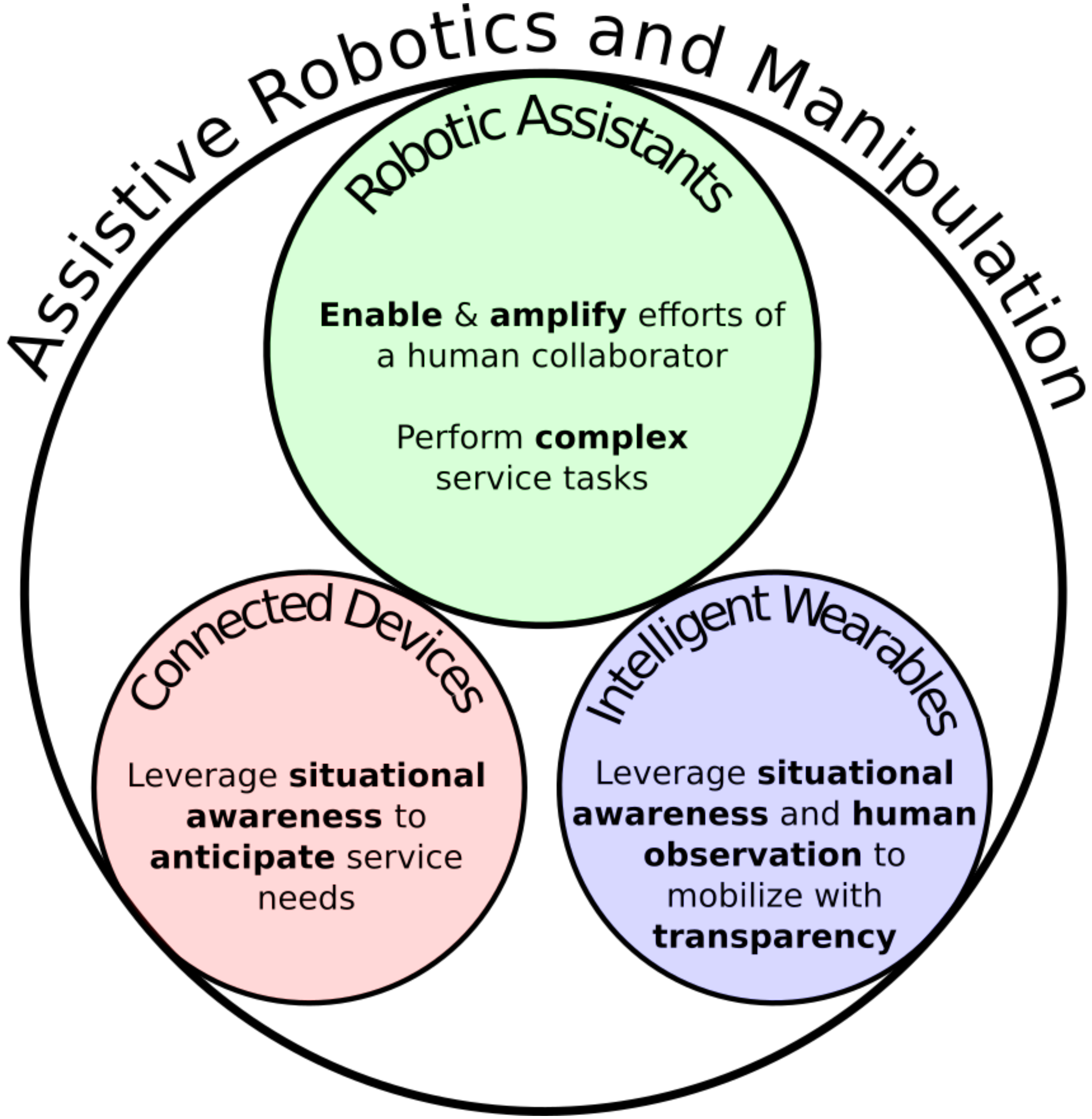



Ng, E., Liu, Z., & Kennedy, M. **It Takes Two: Learning to Plan for Human-Robot Cooperative Carrying**. ICRA 2023 Accepted

Guptasarma, S., & Kennedy, M. (2021). **Considerations for the Control Design of Augmentative Robots**. *IEEE IROS Workshop on Building and Evaluating Ethical Robotic Systems*.



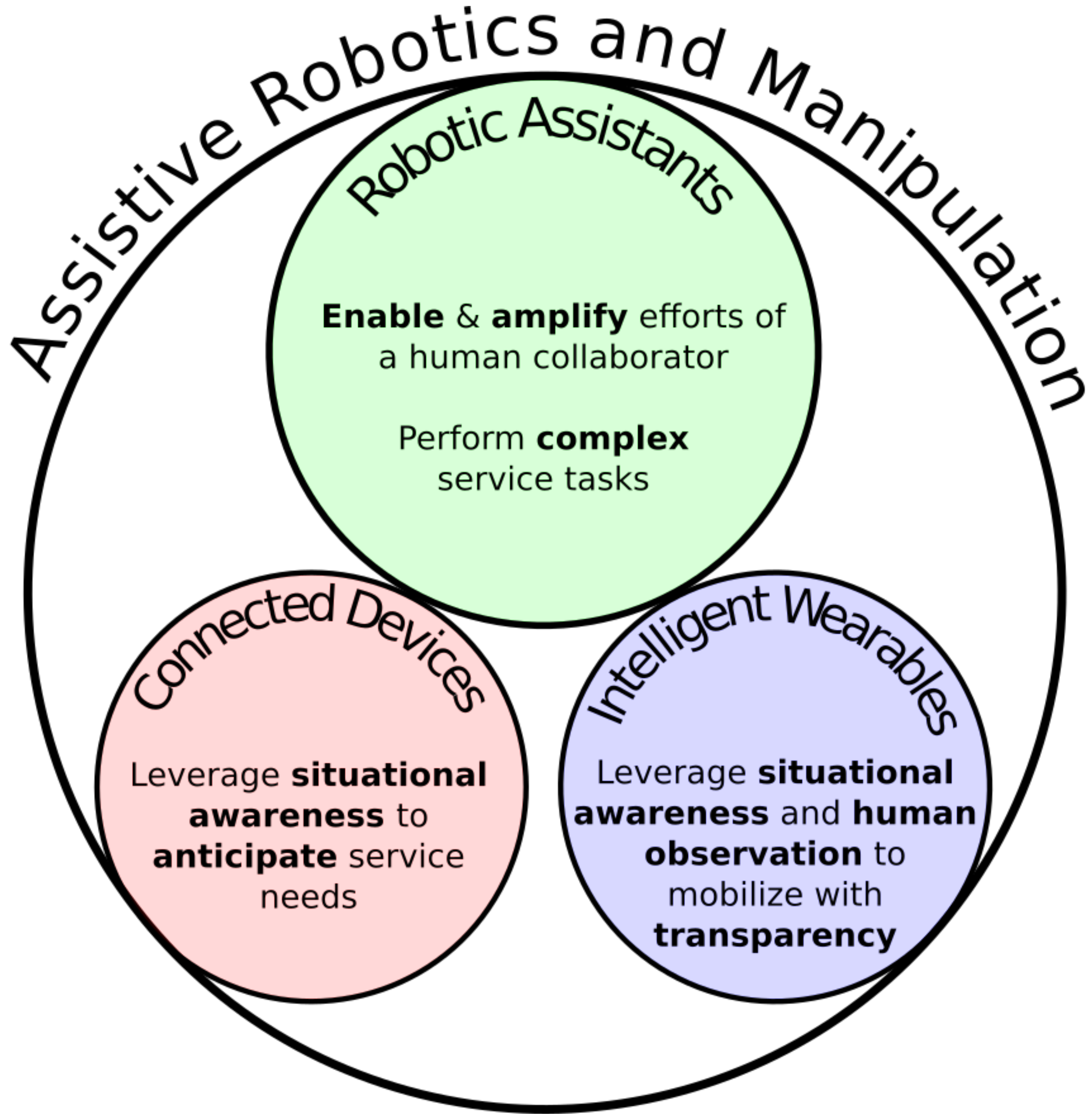

Wang, W., Raitor, M. ., Collins, S., Liu, K. ., & Kennedy, M. **Trajectory and Sway Prediction Towards Fall Prevention** ICRA 2023 accepted.

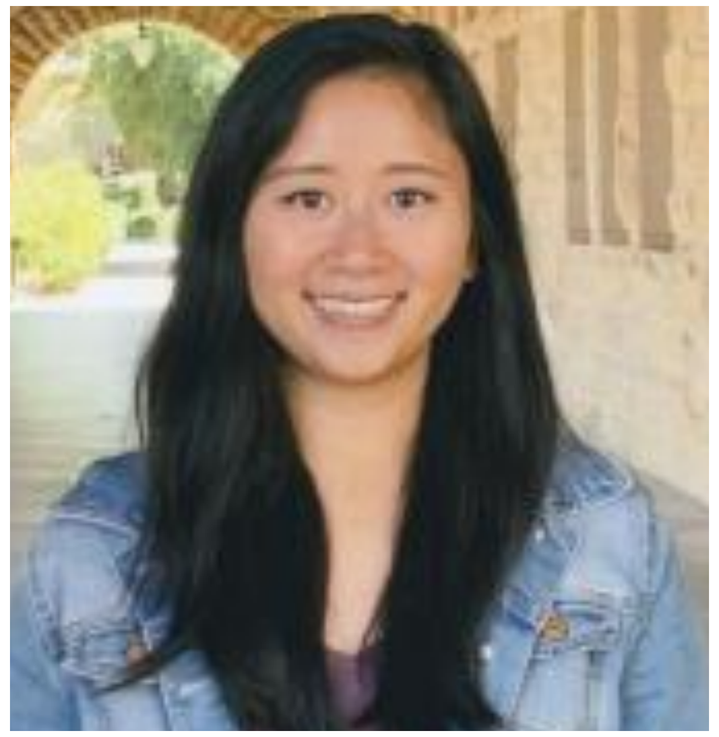
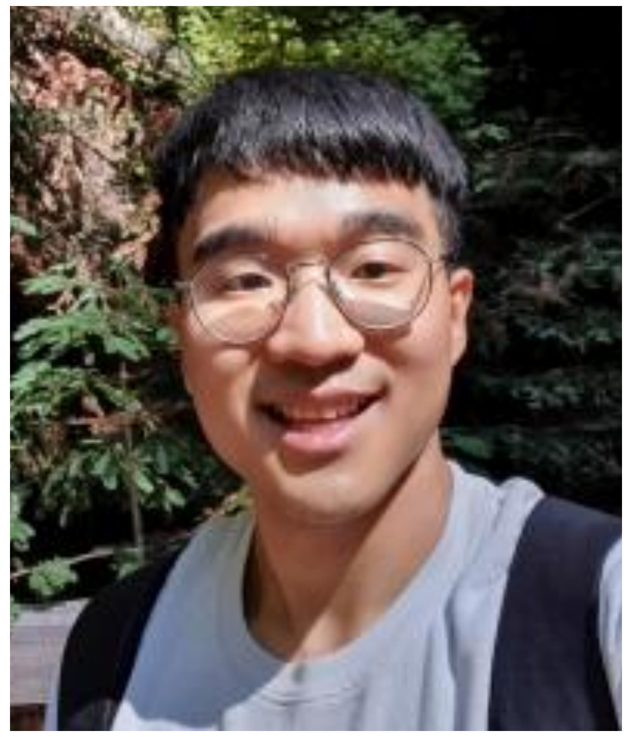



**<u>Mission</u>**

The mission of the **A**ssistive **R**obotics and **M**anipulation Lab is to develop **intelligent**, **assistive** technology that **improves** human life

# Assistive Robotics and Manipulation Laboratory (ARMLab)

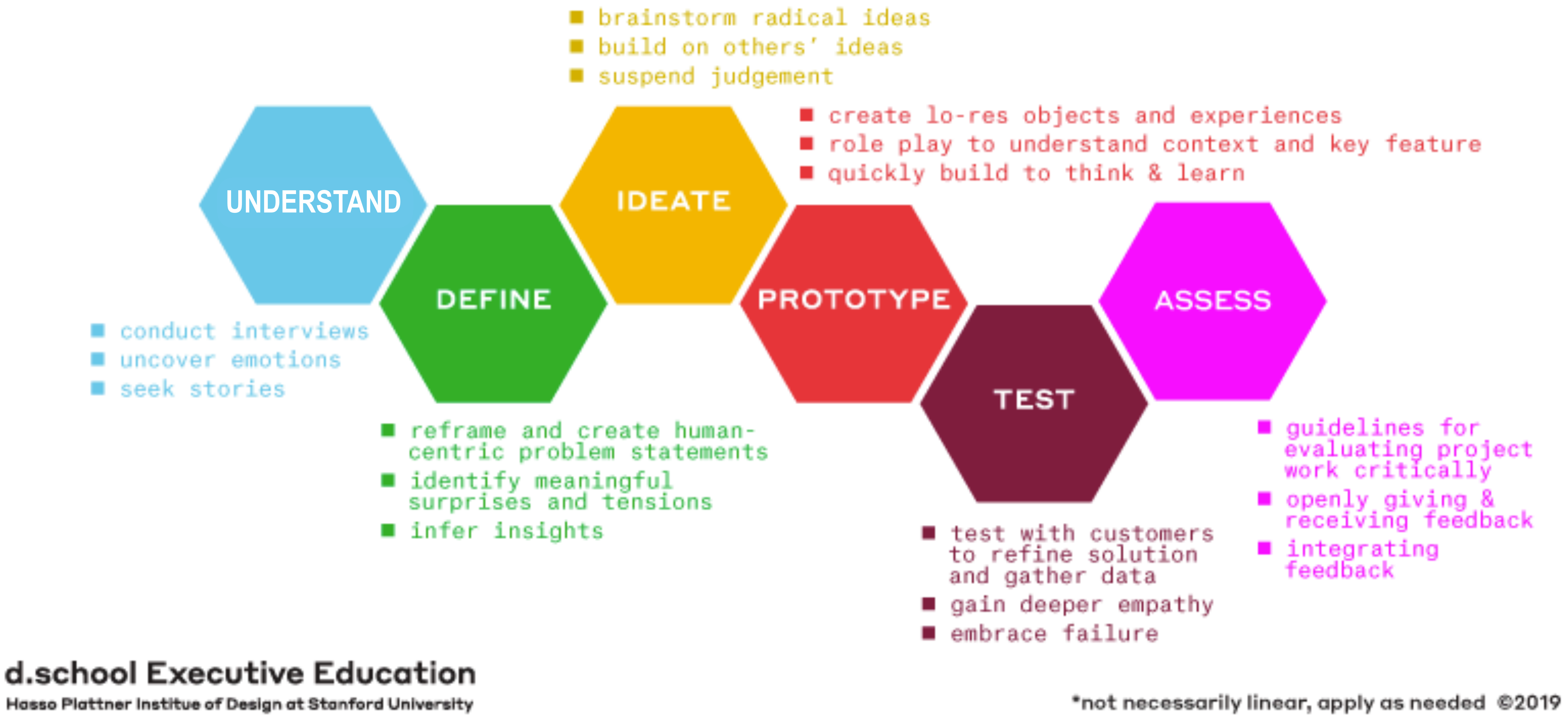



ARMLab PhD Students

# Passive versus Active Assistive Devices

# Assistive Technology Design Process



# Assistive Technology

## Passive Devices - Body Powered

Arm Dynamics: https://www.armdynamics.com/upper-limb-library/introduction-to-body-powered-prostheses

# Assistive Technology

## Passive Devices - Body Powered


https://youtu.be/EodwiLAR3qI (0-40s)

# Assistive Technology

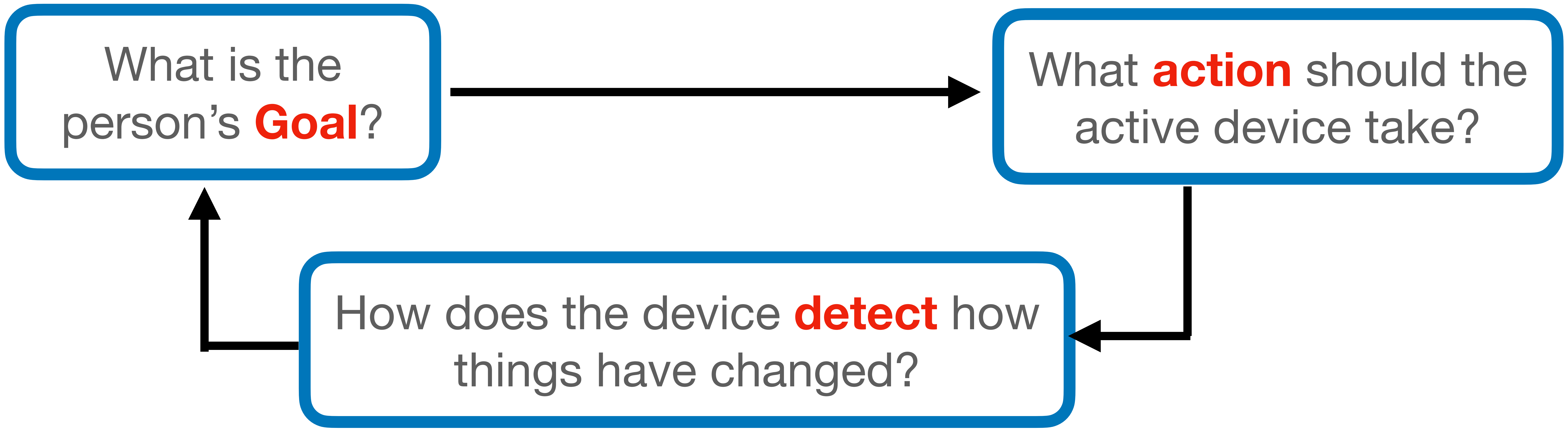
## Passive Devices - Body Powered


Carbon Fiber Reinforced polymer for running prosthesis
https://youtu.be/42mI6kDvPeE (0-30s)

# Assistive Technology

## Active Devices

What do you do when input does not *passively* map to the desired output/action/result?
Active Control Devices must be employed to reach the target result



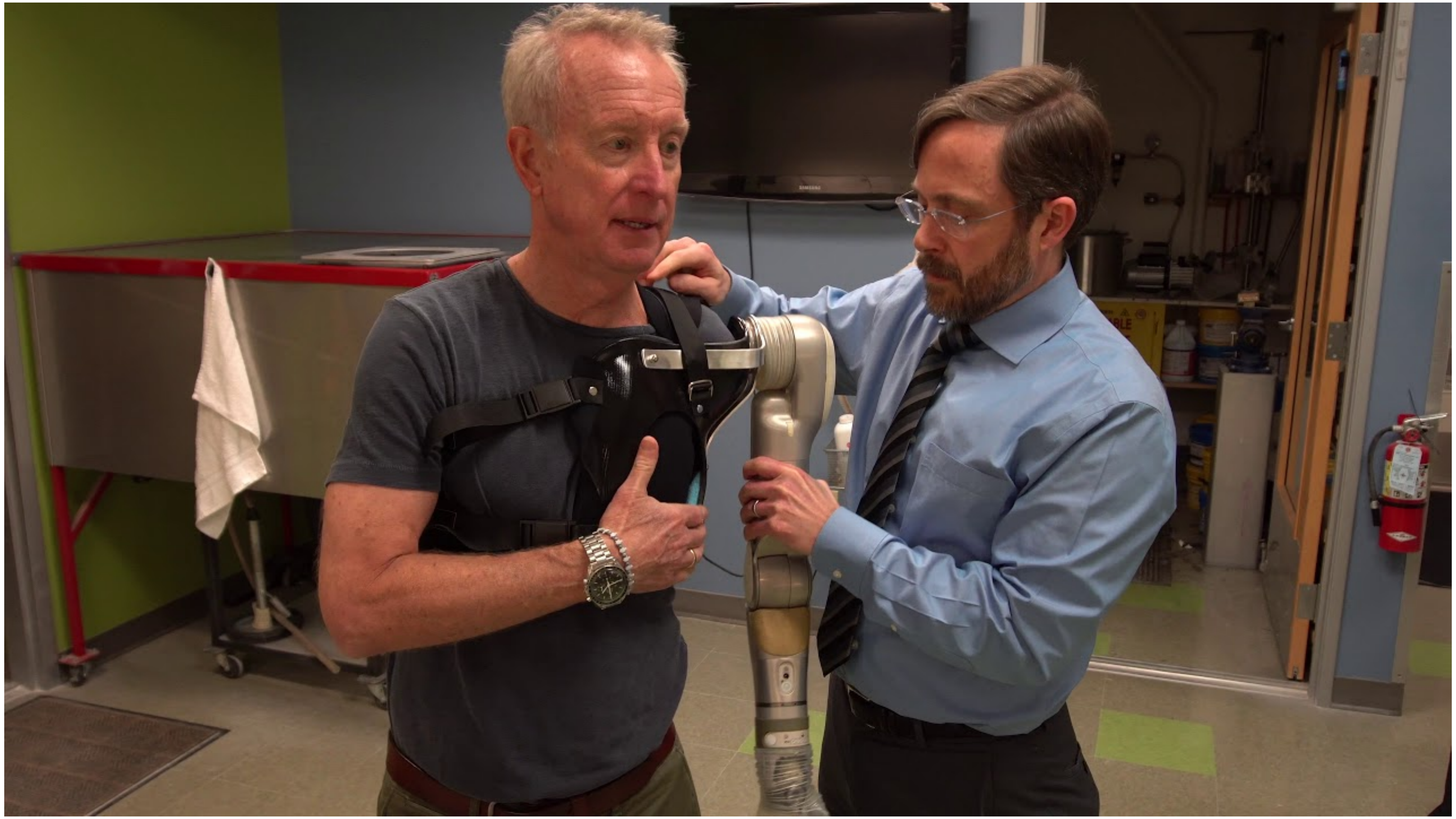
# Assistive Technology

## Active Devices


LiftWare: https://www.liftware.com/; YouTube link: https://youtu.be/YNwfXeLlqsU

# Assistive Technology

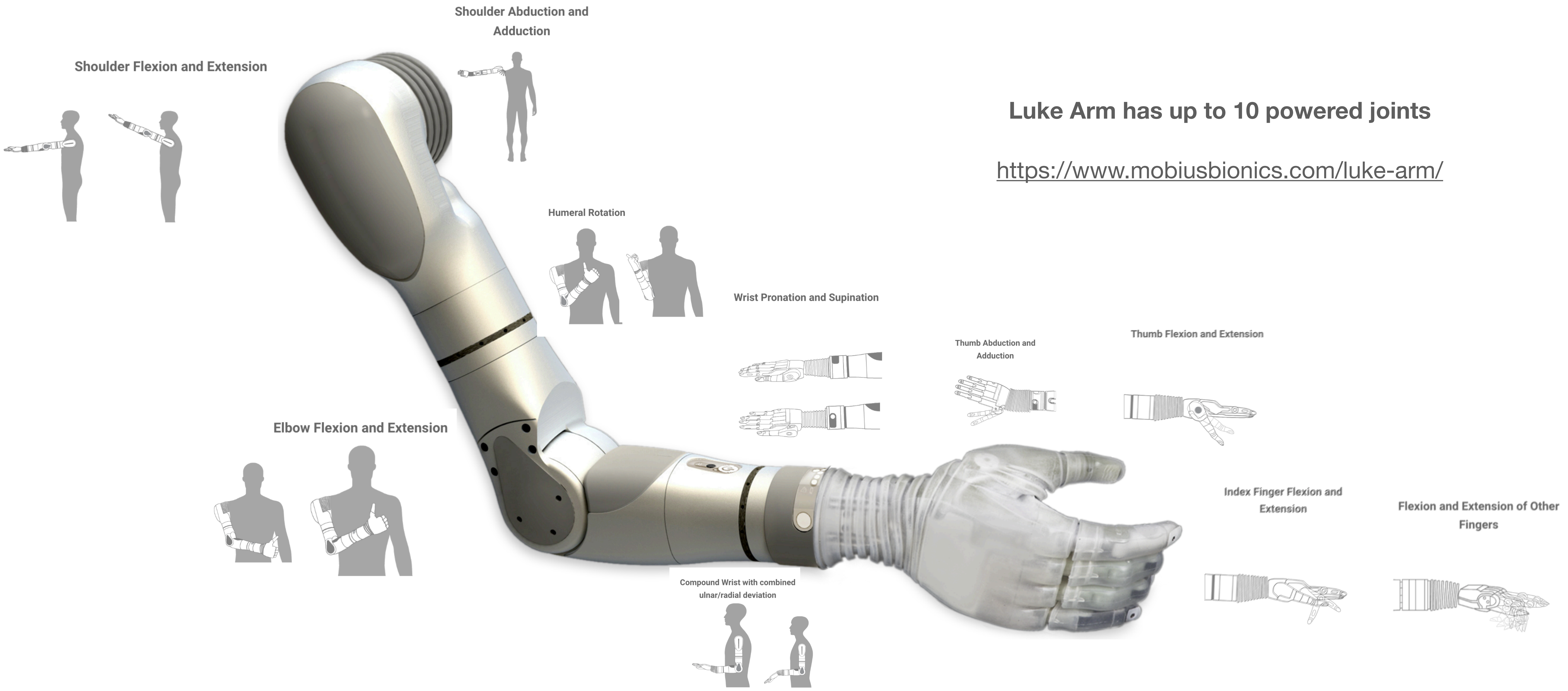
## Active Devices - Luke Arm (Mobius Bionics)



https://www.mobiusbionics.com/luke-arm/. Youtube: https://youtu.be/QGPEmtwGqZA

# Assistive Technology

## Active Devices - Luke Arm (Mobius Bionics)




**Luke Arm has up to 10 powered joints**

https://www.mobiusbionics.com/luke-arm/

# Assistive Technology

## Active Devices - Modular Prosthetic Limb (MPL) Johns Hopkins APL

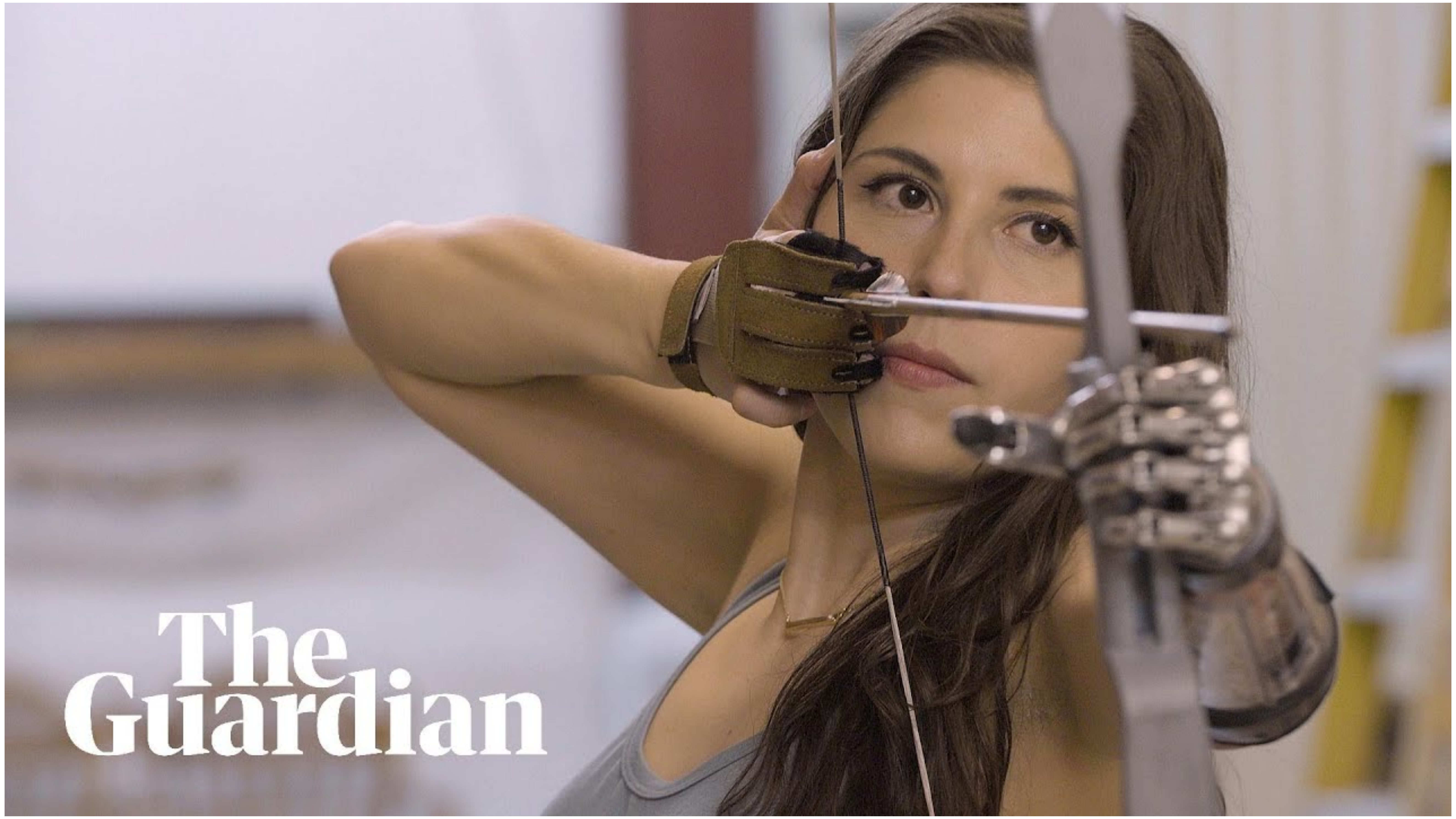

https://www.jhuapl.edu/Prosthetics/ResearchMPL YouTube: https://youtu.be/F_brnKz_2tI (0-1:30)

**An Overview of the Developmental Process for the Modular Prosthetic Limb** Johannes et al. Johns Hopkins tech digest 2011

# Limitations of Existing Assistive Technology

Traditionally, increased functionality has required a degree of invasive procedures to extract human input (e.g. Targeted Muscle Reinnervation (TMR: for motor control); or  Target Sensory Reinnervation (TSR: for sensory feedback)

Is there a way to maintain functionality but reduce invasiveness?



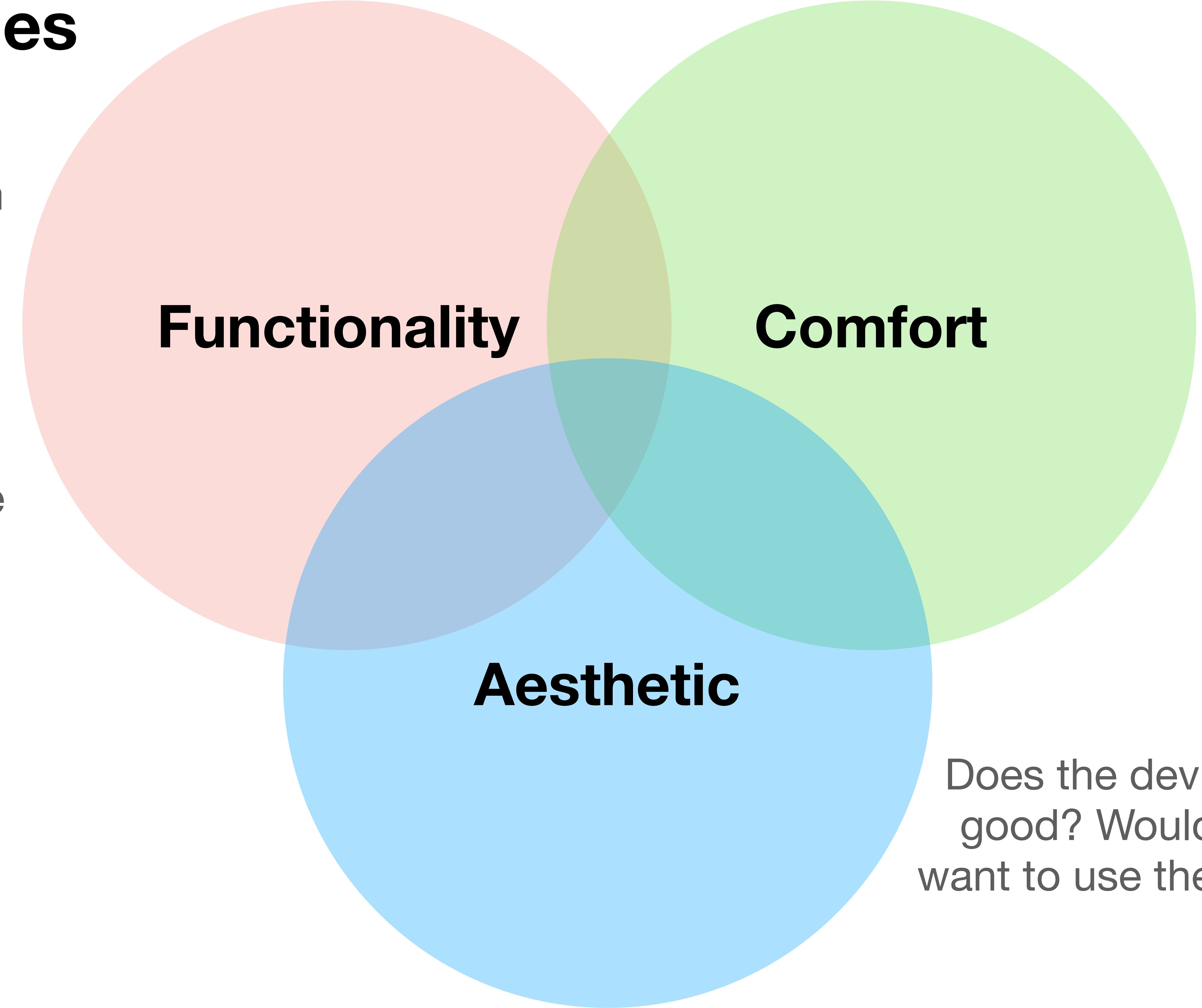

https://youtu.be/GgTwa3CPrIE?t=791.   (13:15 - 13:41)

# Limitations of Existing Assistive Technology

## Design priorities

Does the system perform as desired and make it worth use?

Do solutions need to be severely tailored to every case or can an adaptable solution be devised?




Is it comfortable for users?

Does the device look good? Would users want to use the device?

# Limitations of Existing Assistive Technology

## Design priorities

User Dissatisfaction with upper-limb prosthesis

Table II. Prosthesis rates of use and rejection.

| Prosthesis | Currently used | Previously used | Rejection Rate | Primary Prosthesis | Interested in future use |
|---|---|---|---|---|---|
| *Adults* | | | | | |
| Passive hook | 5 | 19 | 74% | 2% | 1% |
| Passive hand | 33 | 62 | 47% | 18% | 10% |
| Body-powered hook | 43 | 87 | 51% | 32% | 2% |
| Body-powered hand | 15 | 43 | 65% | 3% | 3% |
| Electric hook | 13 | 21 | 38% | 3% | 13% |
| Electric gripper | 10 | 24 | 58% | 1% | 10% |
| Electric hand | 58 | 98 | 41% | 41% | 26% |
| Other | 11 | 19 | 42% | – | 11% |
| None | – | – | – | – | 25% |
| *Pediatric* | | | | | |
| Passive hook | 2 | 3 | 33% | 6% | 0% |
| Passive hand | 18 | 46 | 61% | 23% | 10% |
| Body-powered hook | 12 | 23 | 48% | 14% | 2% |
| Body-powered hand | 9 | 17 | 47% | 15% | 7% |
| Electric hook | 0 | 0 | – | 0% | 8% |
| Electric gripper | 0 | 2 | 100% | 0% | 7% |
| Electric hand | 27 | 42 | 36% | 42% | 33% |
| Other | 5 | 14 | 64% | – | 7% |
| None | – | – | – | – | 26% |

Elaine Biddiss, Dorcas Beaton & Tom Chau (2007) Consumer design priorities for upper limb prosthetics, Disability and Rehabilitation: Assistive Technology, 2:6, 346-357, DOI: 10.1080/17483100701714733

# Limitations of Existing Assistive Technology

## Design priorities

Myoelectric versus Body-Powered devices for

- Sensory feedback
- Functionality
- Usage
- Comfort

Table III. Claimed merits of body-powered and myoelectric prostheses.

| | Myoelectric (ME) | Body-powered (BP) |
|---|---|---|
| Sensory feedback | Greater feedback due to auditory cues from motor and vibrations through the close-fitting socket (Northmore-Ball et al. 1980, Silcox et al. 1993) | Better finger position feedback and object visibility (Kruger and Fishman 1993) |
| Function | Preferred by the majority of children (64%) for function (Glynn et al. 1986)<br>Decreased task difficulty and more frequent bilateral use (Weaver et al. 1988)<br>Better grasp of heavy objects (Kruger and Fishman 1993) | Better manipulative function (van Lunteren et al. 1983)<br>Better overall function (voluntary closing mechanism) (Crandall and Tomhave 2002)<br>Less inadvertent activation, and less effort required to open slightly (Kruger and Fishman 1993) |
| Usage | More frequently and actively used (van Lunteren et al. 1983)<br>Decrease from full-time to part-time wear upon exchanging conventional for myoelectric prostheses in a pediatric sample, possibly due to weight and durability issues (Balance et al. 1989).<br>ME wear widely reported in excess of 8 hours per work day in adult populations (Millstein et al. 1986; Datta et al. 1989; Weaver et al. 1988; Kejlaa 1993; Wright et al. 1995). | BP hooks most frequently used (Kruger and Fishman 1993)<br>Active users preferred BP while passive users of active prostheses preferred ME (Kruger and Fishman 1993)<br>Only 30% of children used ME for active prehension and none under the age of 5. (Kruger and Fishman 1993)<br>Full-time use of ME rare before adolescence (Menkveld et al. 1987)<br>BP hook wear widely reported in excess of 8 hours per work day (Millstein et al. 1986; Kejlaa 1993; Scotland and Galway 1983; Weaver et al. 1988; Wright et al. 1995).<br>BP hands less frequently worn (Millstein et al. 1986; Silcox et al. 1993; Kejlaa et al. 1993; Gaine et al. 1997) |
| Comfort | Increased comfort due to freedom from harness – suggests that the greater the aversion to the harness, the greater probability that the ME device will be accepted (Northmore-Ball et al. 1980; Heger et al. 1985) | Reduced weight in comparison with ME (Northmore-Ball et al. 1980; Heger et al. 1985; Kruger and Fishman 1993)<br>Reduced noise levels (Kruger and Fishman 1993)<br>Preferred for overall comfort (Kruger and Fishman 1993) |

Biddiss, E. A., & Chau, T. T. (2007). Upper limb prosthesis use and abandonment: A survey of the last 25 years. Prosthetics and Orthotics International, 31(3), 236–257. https://doi.org/10.1080/03093640600994581

# Limitations of Existing Assistive Technology

## Design priorities

Study was performed with veterans to describe and compare satisfaction by prosthesis and terminal device type and to identify factors associated with satisfaction

**Table 2.** Prosthesis use characteristics.

| | **Body-powered** ***N*=334** | **Myoelectric/hybrid** ***N*=93** | **Cosmetic** ***N*=22** |
|---|---|---|---|
| Frequency of prosthesis use | | | |
| Daily | 257 (78.1) | 72 (78.3) | 14 (63.6) |
| Weekly | 43 (13.1) | 8 (8.7) | 5 (22.7) |
| Monthly | 14 (4.3) | 5 (5.4) | 0 (0.0) |
| Every few months | 11 (3.3) | 2 (2.2) | 1 (4.6) |
| 1 to 2 times per year | 4 (1.2) | 5 (5.4) | 2 (9.1) |
| Intensity of prosthesis use (h) | | | |
| <2 | 68 (20.6) | 12 (13.0) | 4 (18.2) |
| 2 to <4 | 29 (8.8) | 11 (12.0) | 2 (9.1) |
| 4 to <8 | 58 (17.6) | 20 (21.7) | 5 (22.7) |
| 8 to <12 | 64 (19.4) | 18 (19.6) | 3 (13.6) |
| ⩾12 | 111 (33.6) | 31 (33.7) | 8 (36.4) |
| Most recent prosthesis received | | | |
| <2 years ago | 135 (40.4) | 53 (57.0) | 6 (27.3) |
| 2+ years ago | 198 (59.3) | 39 (41.9) | 16 (72.7) |
| Unknown | 1 (0.3) | 1 (1.1) | 0 (0.0) |
| Number of prostheses used | | | |
| One | 229 (68.6) | 41 (41.1) | 14 (63.6) |
| Two or more | 105 (31.4) | 52 (55.9) | 8 (36.4) |
| Number of terminal devices used | | | |
| One | 209 (62.6) | 30 (32.3) | 17 (77.3) |
| Two or more | 123 (36.8) | 60 (64.5) | 4 (18.2) |
| Unknown | 2 (0.6) | 3 (2.9) | 1 (4.7) |
| Primary type of terminal device used | | | |
| Body-powered hook | 334 (100.0) | 0 (0.0) | 0 (0.0) |
| Greifer | 0 (0.0) | 6 (6.5) | 0 (0.0) |
| Power hook (ETD) | 0 (0.0) | 15 (16.1) | 0 (0.0) |
| Sensor speed hand | 0 (0.0) | 9 (9.7 | 0 (0.0) |
| I-Limb/Michaelangelo hand/Bebionic hand | 0 (0.0) | 40 (43.0) | 0 (0.0) |
| Cosmetic | 0 (0.0) | 0 (0.0) | 22 (100.0) |
| Unknown | 0 (0.0) | 23 (24.7) | 0 (0.0) |
| DOF of primary terminal device | | | |
| No DOF (cosmetic) | 0 (0.0) | 0 (0.0) | 22 (100.0) |
| Single DOF | 334 (100.0) | 30 (32.3) | 0 (0.0) |

*(Continued)*

Resnik, L., Borgia, M., Heinemann, A. W., & Clark, M. A. (2020). Prosthesis satisfaction in a national sample of Veterans with upper limb amputation. Prosthetics and Orthotics International, 44(2), 81–91. https://doi.org/10.1177/0309364619895201

# Limitations of Existing Assistive Technology

## Design priorities

Study was performed with veterans to describe and compare satisfaction by prosthesis and terminal device type and to identify factors associated with satisfaction

**Table 2.** (Continued)

| | Body-powered *N*=334 | Myoelectric/hybrid *N*=93 | Cosmetic *N*=22 |
|---|---|---|---|
| Multi-DOF | 0 (0.0) | 40 (43.0) | 0 (0.0) |
| Unknown | 0 (0.0) | 23 (24.7) | 0 (0.0) |
| Received training to use initial prosthesis | | | |
| Yes | 254 (76.1) | 75 (80.7) | 11 (50.0) |
| No | 77 (23.1) | 18 (19.4) | 10 (45.5) |
| Unknown | 3 (0.9) | 0 (0.0) | 1 (4.9) |
| Received training to use current prosthesis | | | |
| Yes | 216 (64.7) | 75 (76.3) | 7 (31.8) |
| No | 113 (33.8) | 21 (22.6) | 15 (68.2) |
| Unknown | 5 (1.5) | 1 (1.1) | 0 (0.0) |
| How many times was your prosthesis repaired in the past 12 months? | | | |
| 0 | 138 (42.6) | 37 (40.2) | 12 (57.1) |
| 1 | 85 (26.2) | 14 (15.2) | 6 (28.6) |
| 2–3 | 68 (21.0) | 22 (23.9) | 3 (14.3) |
| ⩾4 | 33 (10.2) | 19 (20.7) | 0 (0.0) |
| How many times did you visit a prosthetist for adjustment to your socket in the past 12 months? | | | |
| 0 | 217 (66.4) | 49 (53.3) | 12 (60.0) |
| 1 | 42 (12.8) | 16 (17.4) | 4 (20.0) |
| 2–3 | 46 (14.1) | 19 (20.7) | 1 (5.0) |
| ⩾4 | 22 (6.7) | 8 (8.7) | 3 (15.0) |

| **Prosthetic users with two or more prostheses** | **Body-powered *N*=98** | **Myoelectric/hybrid *N*=59** | **Cosmetic *N*=8** |
|---|---|---|---|
| Secondary type of prosthesis used | | | |
| Body-powered | 43 (41.0) | 28 (53.9) | 1 (12.5) |
| Myoelectric/hybrid | 50 (47.6) | 12 (23.1) | 3 (37.5) |
| Cosmetic | 1 (1.0) | 1 (1.9) | 3 (37.5) |
| Sports/recreation | 8 (7.6) | 9 (17.3) | 1 (12.5) |
| Unknown | 3 (2.9) | 2 (3.9) | 0 (0.0) |
| Frequency of secondary prosthesis use | | | |
| Daily | 23 (21.9) | 16 (30.8) | 4 (50.0) |
| Weekly | 45 (42.9) | 22 (42.3) | 1 (12.5) |
| Monthly | 11 (10.5) | 5 (9.6) | 1 (12.5) |
| Every few months | 12 (11.4) | 3 (5.8) | 0 (0.0) |
| 1 to 2 times per year | 14 (13.3) | 4 (7.7) | 2 (25.0) |
| Unknown | 0 (0.0) | 2 (3.9) | 0 (0.0) |

ETD: electronic terminal devices; DOF: degrees of freedom.

Resnik, L., Borgia, M., Heinemann, A. W., & Clark, M. A. (2020). Prosthesis satisfaction in a national sample of Veterans with upper limb amputation. Prosthetics and Orthotics International, 44(2), 81–91. https://doi.org/10.1177/0309364619895201

# Limitations of Existing Assistive Technology

## Human input

**How many advanced human-machine interfaces rely on bio signals to interpret user's intentions to control the corresponding prosthesis**

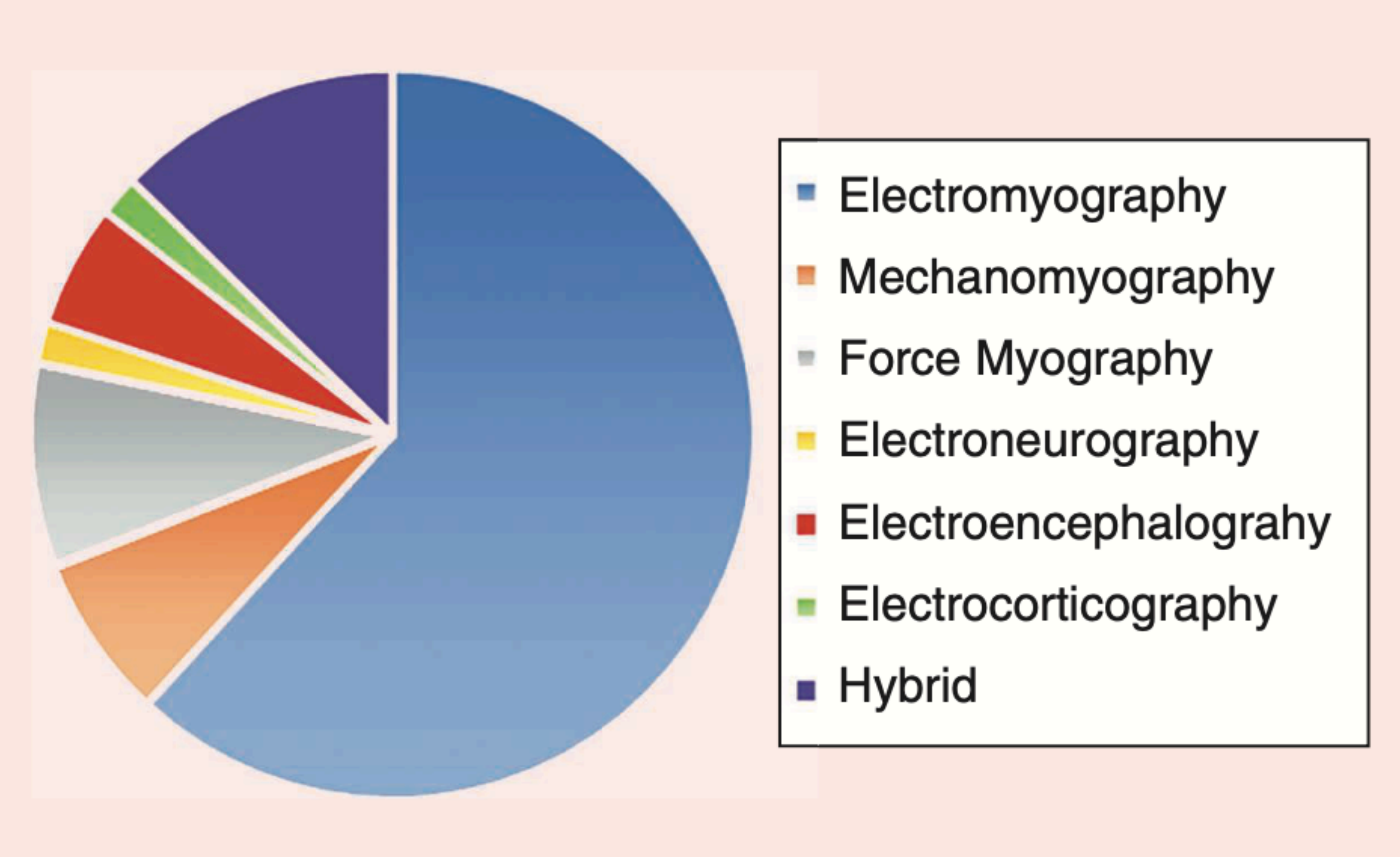



**FIGURE 1.** The prevalence of different types of biosignals used as the basis of HMIs in selected papers.

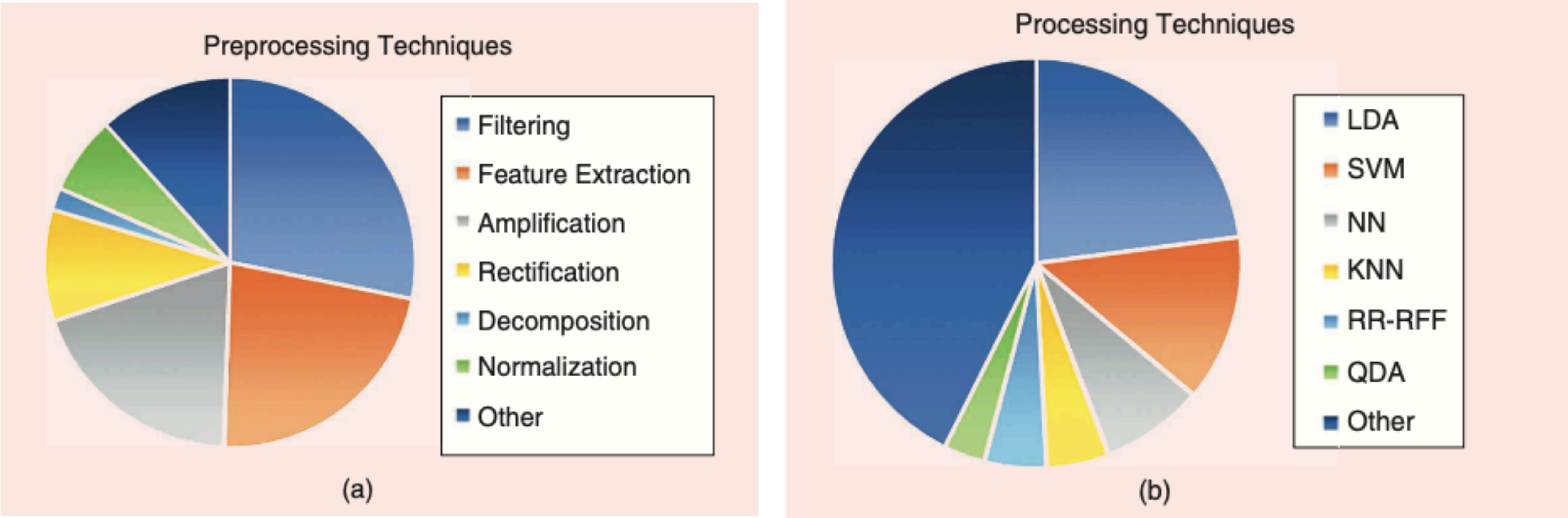



**FIGURE 2.** The prevalence of (a) preprocessing and (b) processing techniques used in EMG-based studies. LDA: linear discriminant analysis; SVM: support vector machine; NN: neural network; KNN: k-nearest neighbors; RR-RFF: ridge regression with random Fourier features; QDA: quadratic discriminant analysis.


C. Ahmadizadeh, M. Khoshnam and C. Menon, "Human Machine Interfaces in Upper-Limb Prosthesis Control: A Survey of Techniques for Preprocessing and Processing of Biosignals," in IEEE Signal Processing Magazine, vol. 38, no. 4, pp. 12-22, July 2021, doi: 10.1109/MSP.2021.3057042.

# Limitations of Existing Assistive Technology

Obtaining input from a human can be expensive (computationally) and taxing (to the human - cognitive load). How can we provide a mechanism that provides high functionality while preserving non-invasive, low cognitive demand interfacing?

↓

**Robotic Autonomy**

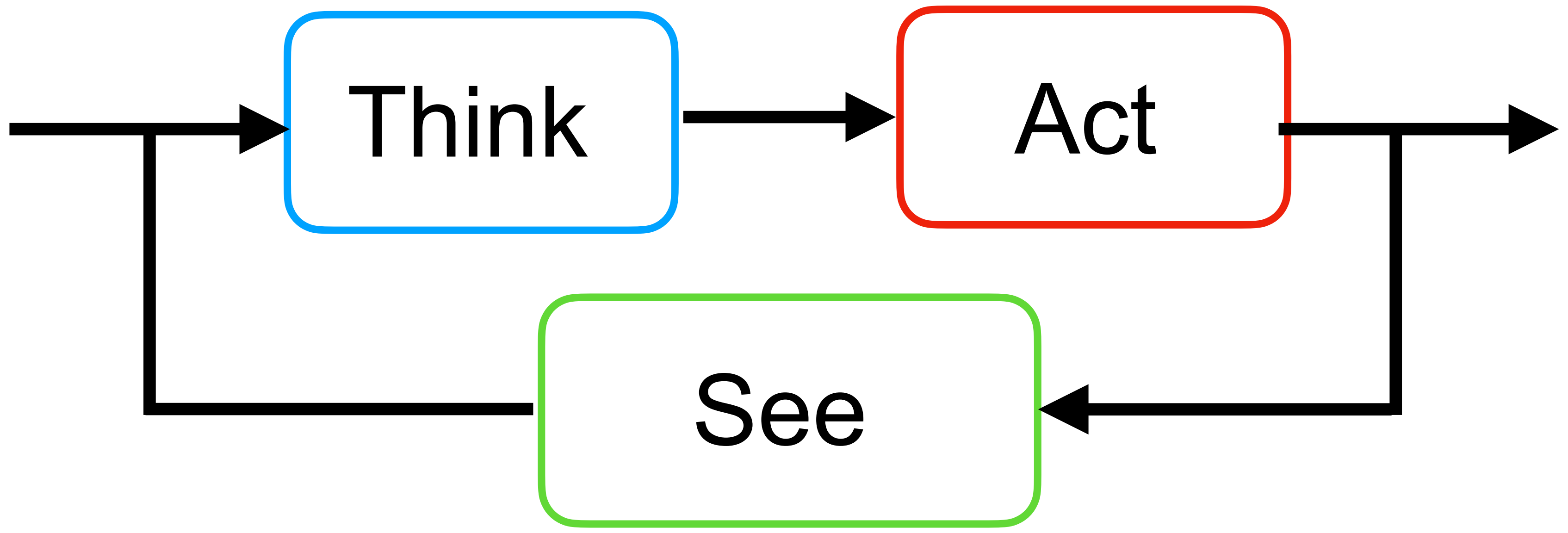
# Robotics - Thinking Machines

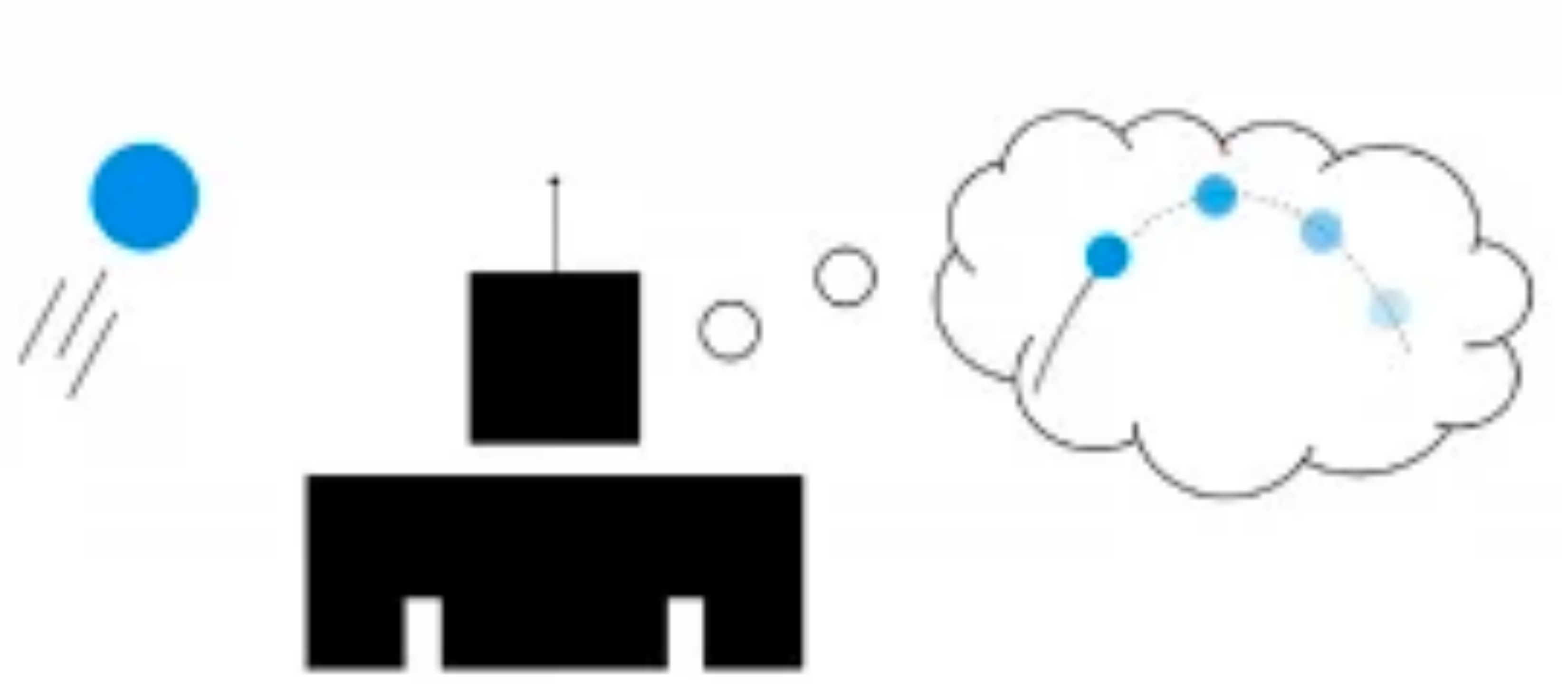
# Overview of Robotics Considerations

## See - Think - Act

The Key Elements of Robotics

- **See** (Perception - sense your environment)
- **Think** (Planning - given experience what should be done?)
- **Act** (Execution - perform the action according to the plan)

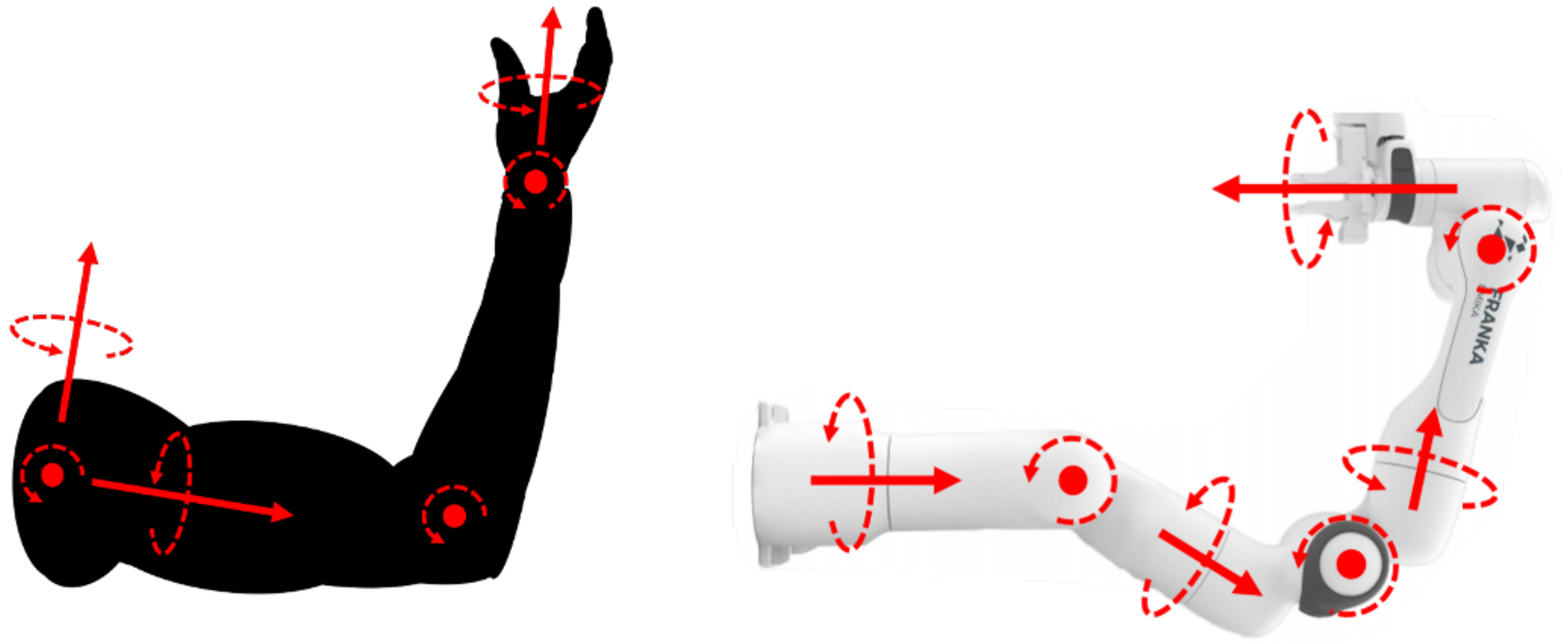


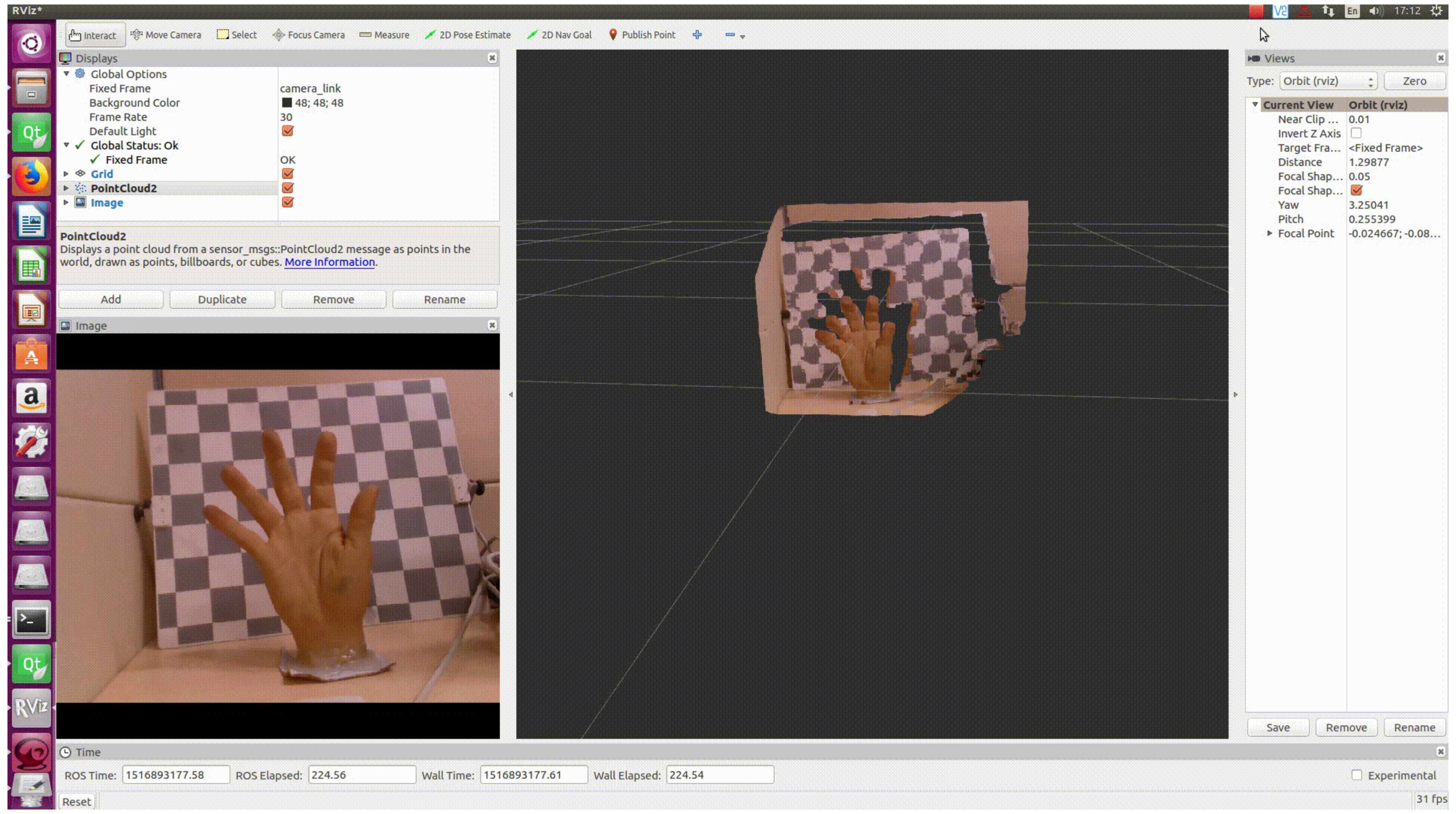
Li, A., Wu, P., & Kennedy III, M. (2021). **Replay Overshooting: Learning Stochastic Latent Dynamics with the Extended Kalman Filter**. *IEEE International Conference on Robotics and Automation (ICRA)*

# Robotic Perception

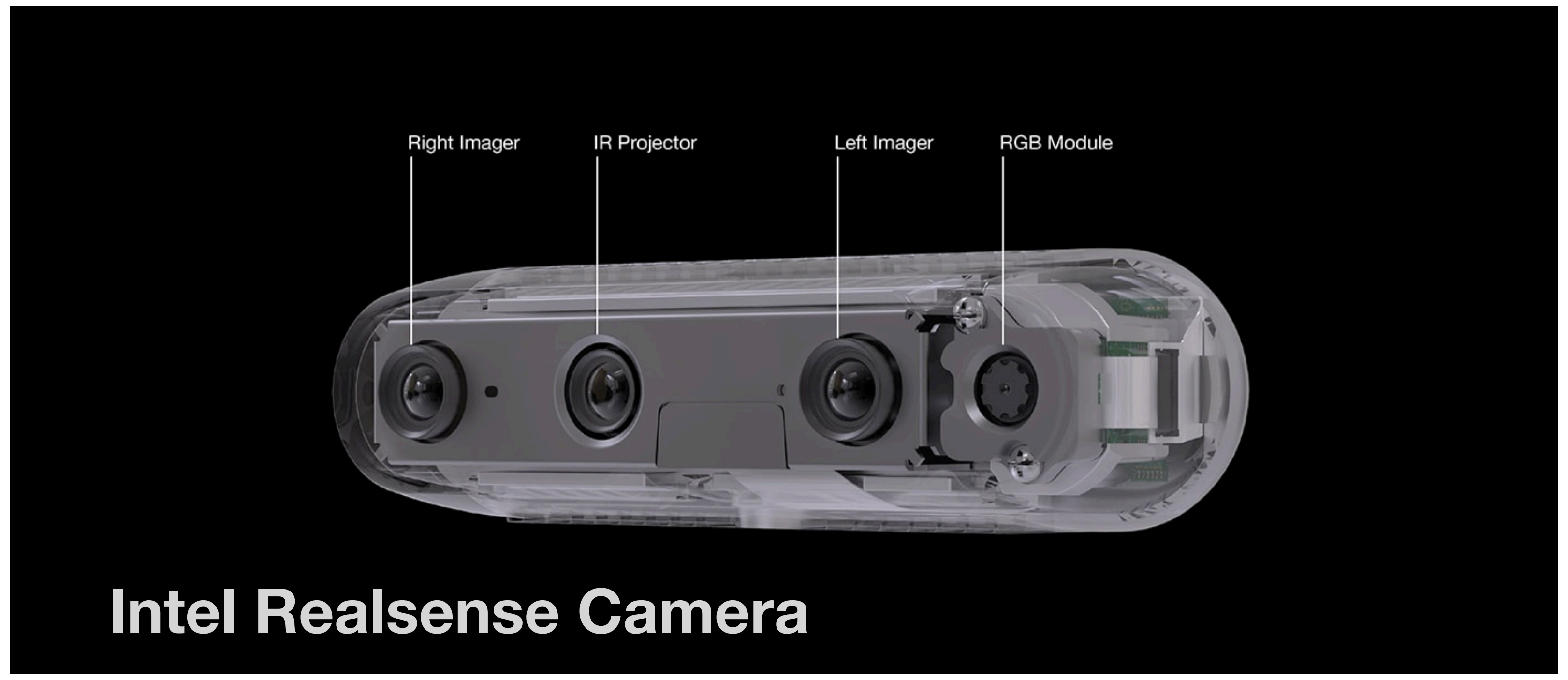
## Ego or Environment Observation



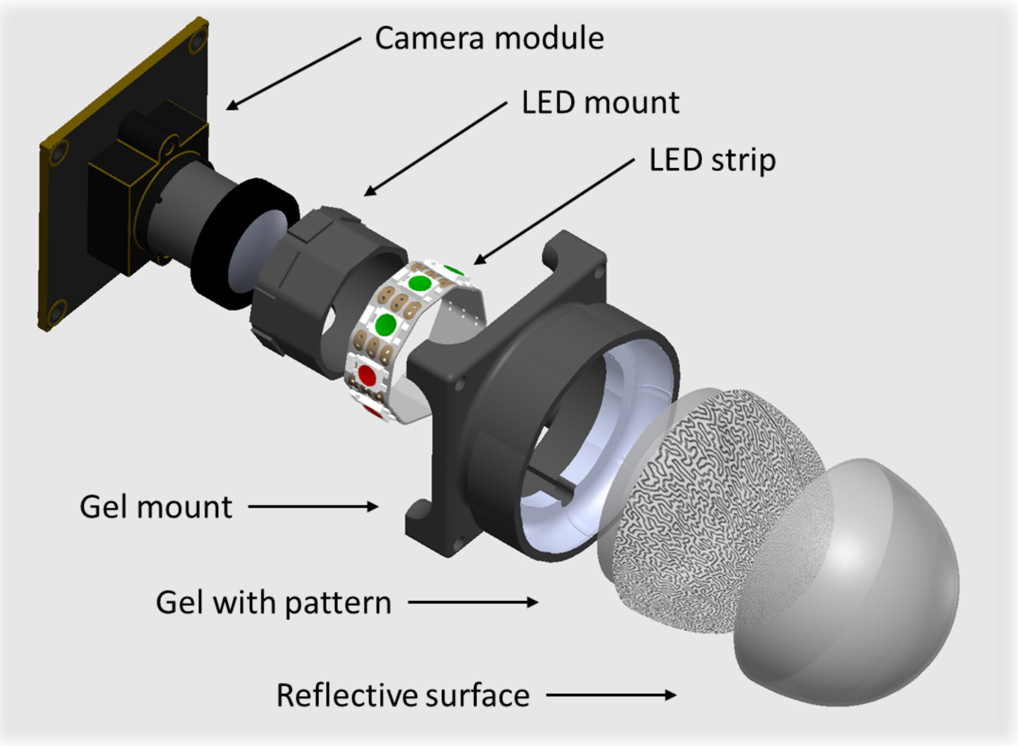
**Proprioception**: sense of embodiment - perception/awareness of the position and movement of the body

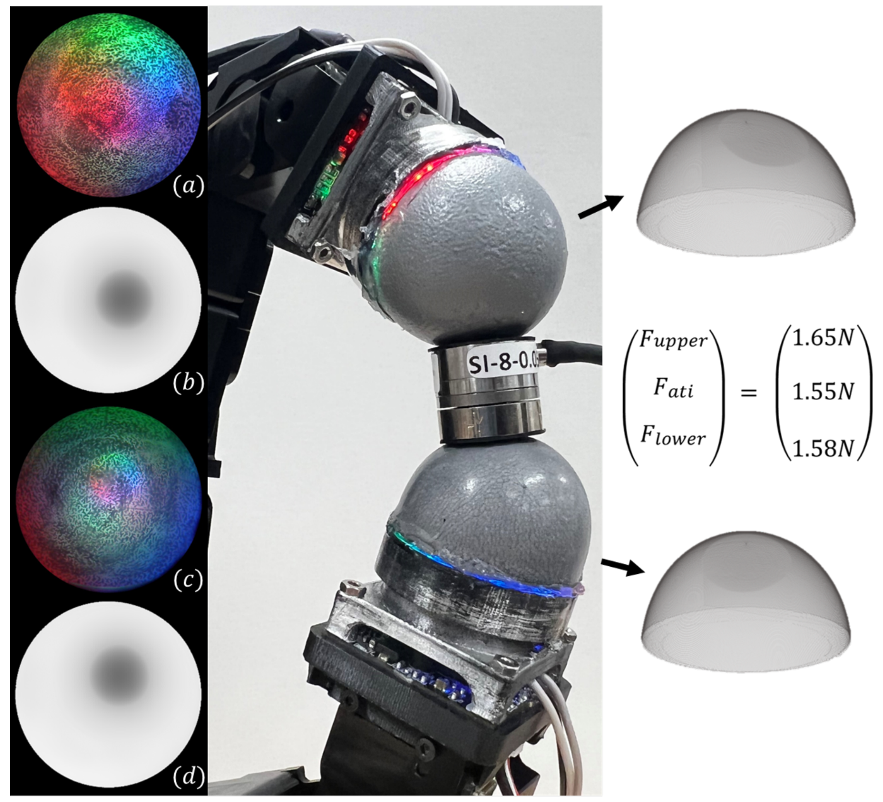


**Vision**: optical observation of the environment




**Touch**: tactile feedback of environment (Shown: ARMLab DenseTact sensor)



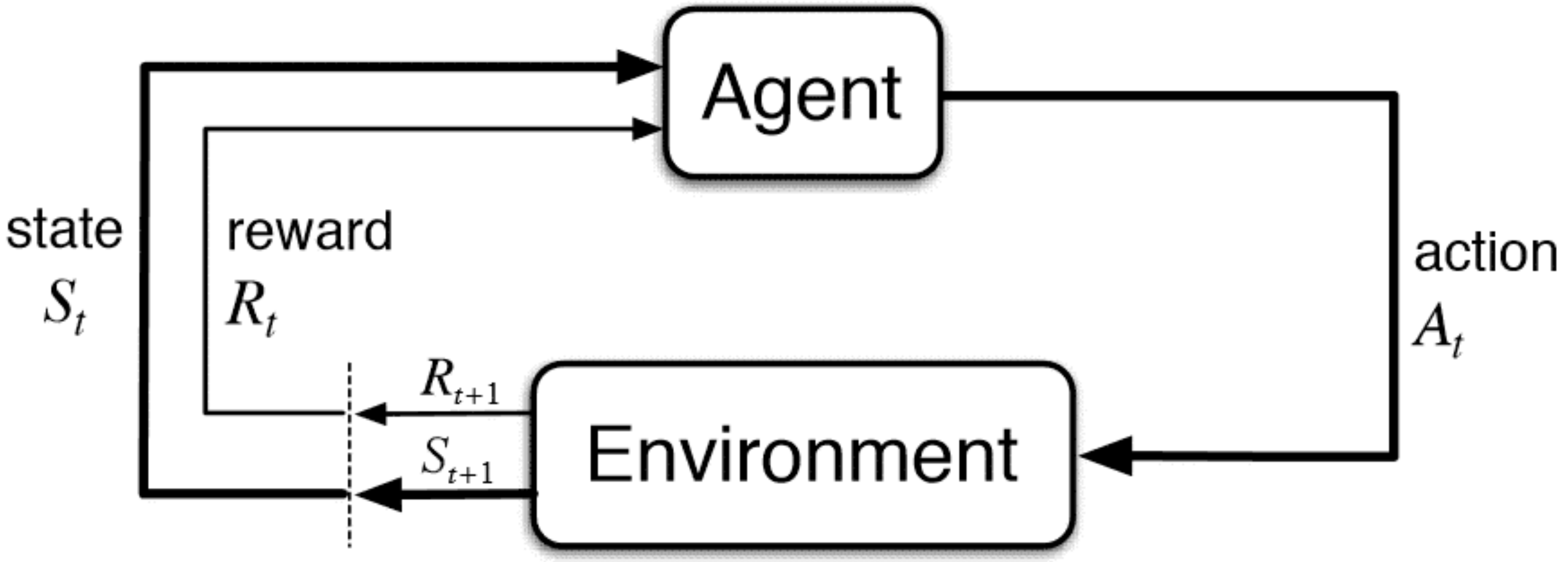




Do, W. K., Jurewicz, B., & Kennedy, M. (2022, September). **DenseTact 2.0: Optical Tactile Sensor for Shape and Force Reconstruction**. ICRA 2023 accepted

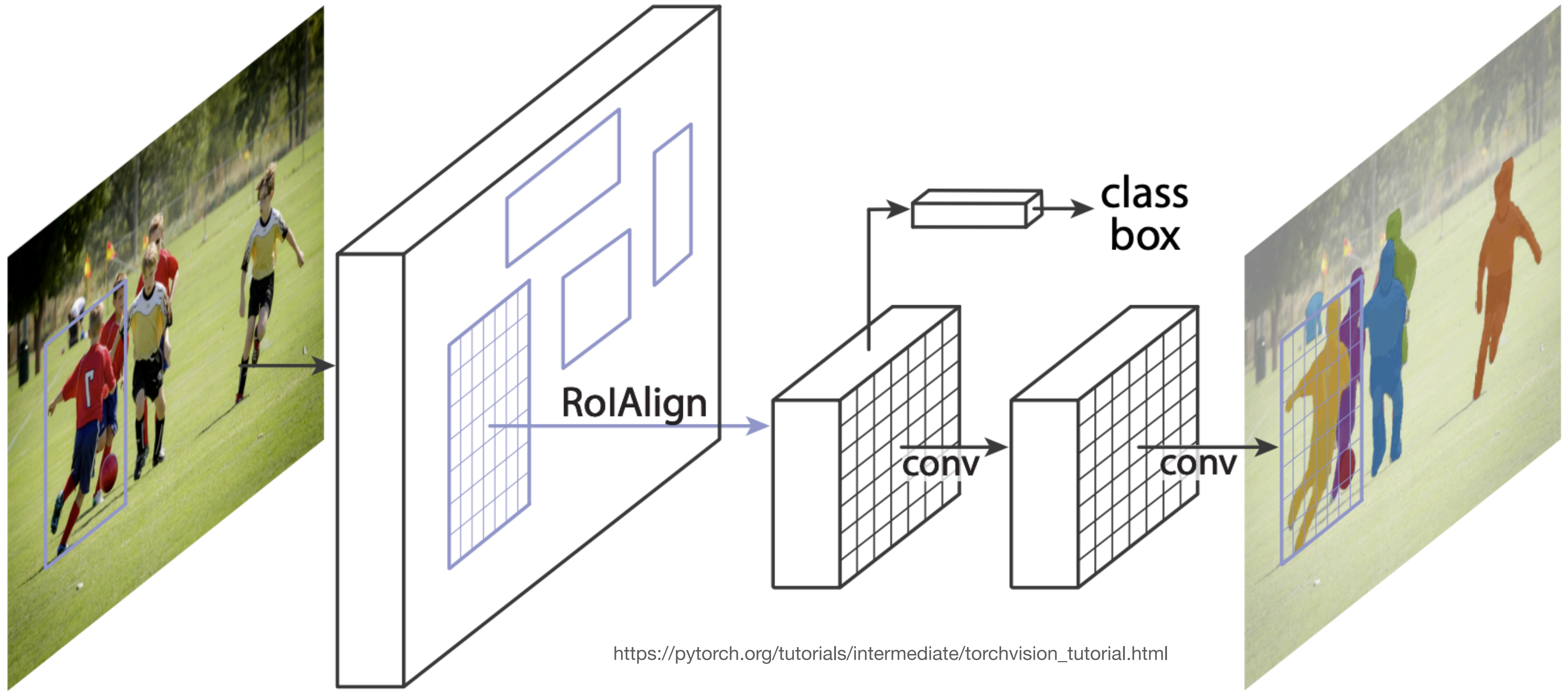
Do, W. K., & Kennedy III, M. (2022). **DenseTact: Optical Tactile Sensor for Dense Shape Reconstruction**. *IEEE*, 6188-6194.

# Robotic Intelligence

## Ego, Teammate and Task/Environment Modeling

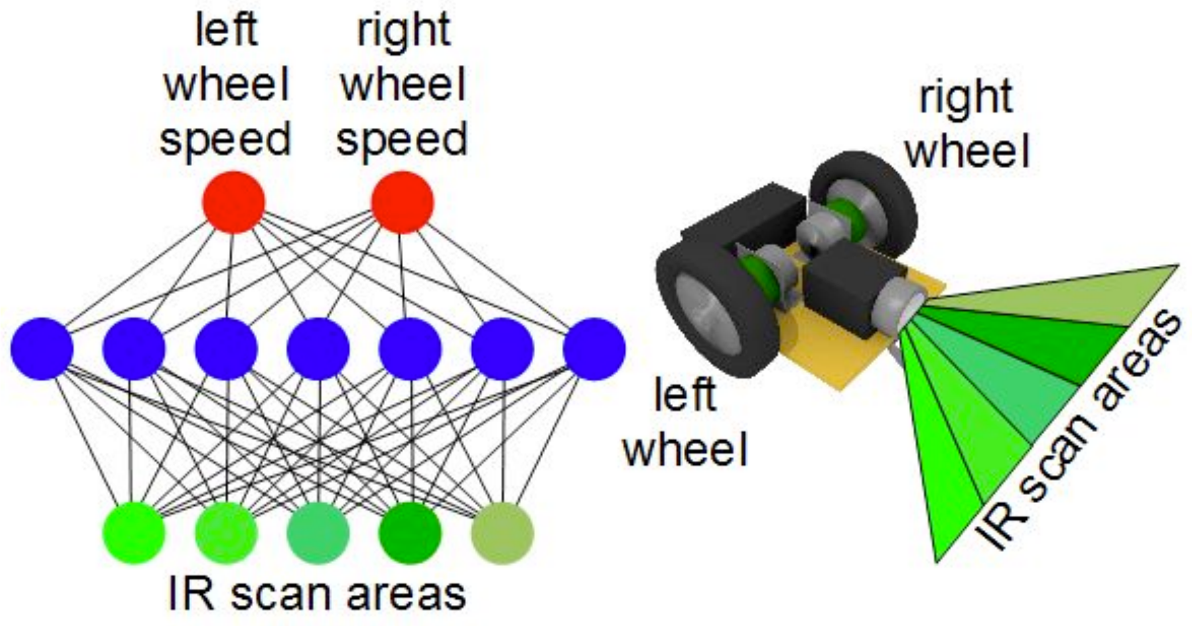



Reinforcement Learning Paradigm:
What action leads to the best reward?




https://pytorch.org/tutorials/intermediate/torchvision_tutorial.html

**Vision interpretation:** Shown is a Convolutional Neural Network (CNN) determining the location of people in an image




Neural Network (multi-layer perceptron) for decision making

https://rimstar.org/science_electronics_projects/neural_networks.htm

# Robotic Action

## Analytical versus Data Driven Approaches

Given an observation (z) of an environment state (a person or task) (s) how does the robot determine what action (a) to take?

<u>Analytical Approach</u>

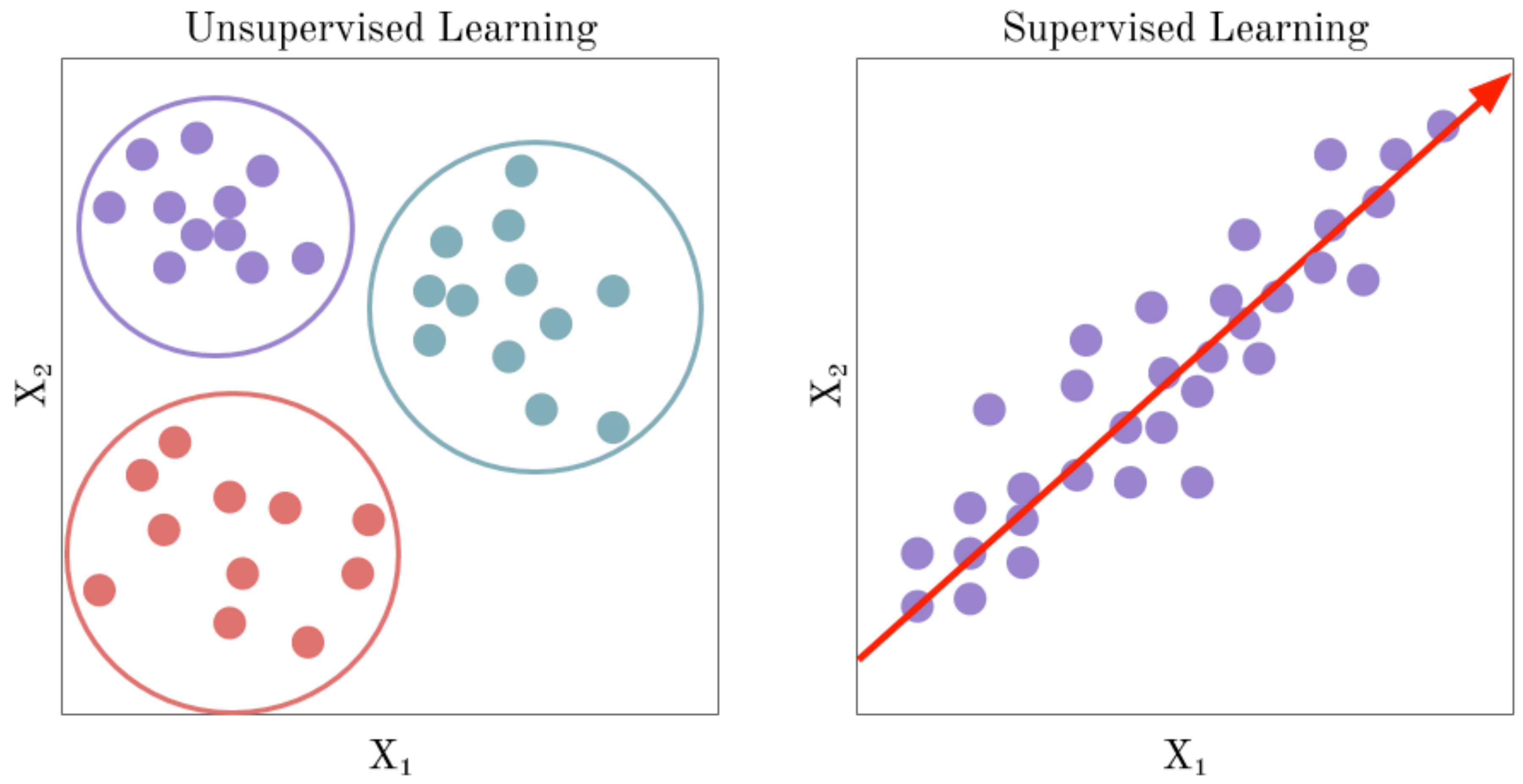
Have an explicit analytical function that maps the observation to the action

$$a_t = g(z_t)$$

This form of $g(\cdot)$ must be known, and may be hard to adapt to new information

<u>Data Driven Approach</u>

Leverage history of observations (and new observations) to drive behavior in either a supervised or unsupervised paradigm

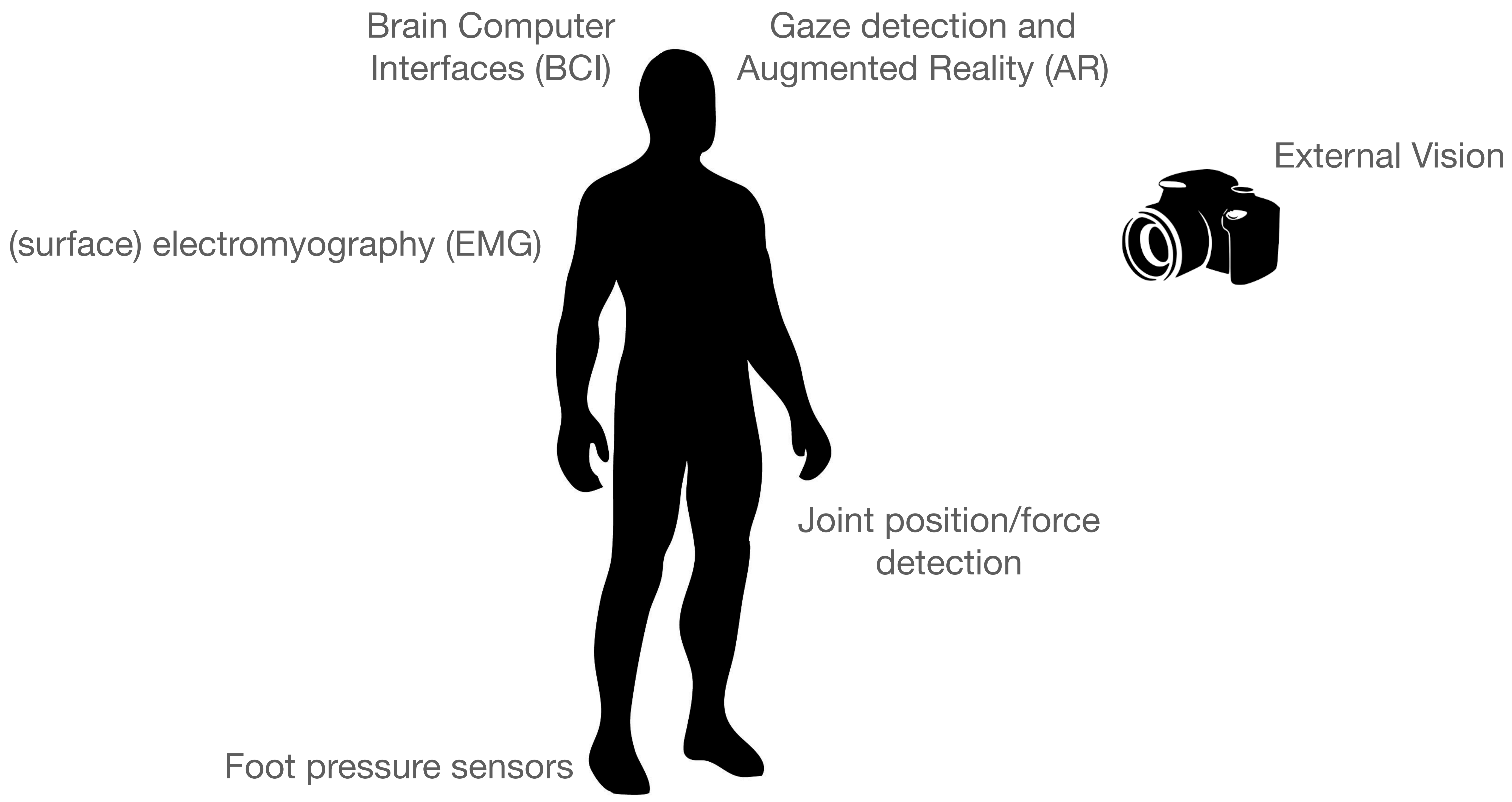



https://towardsdatascience.com/a-brief-introduction-to-unsupervised-learning-20db46445283

# Robotic Perception

## Human Perception

For assistive robotics, the human must be observed either passively (from external sensors e.g. cameras) or actively (from wearable or implanted sensors)

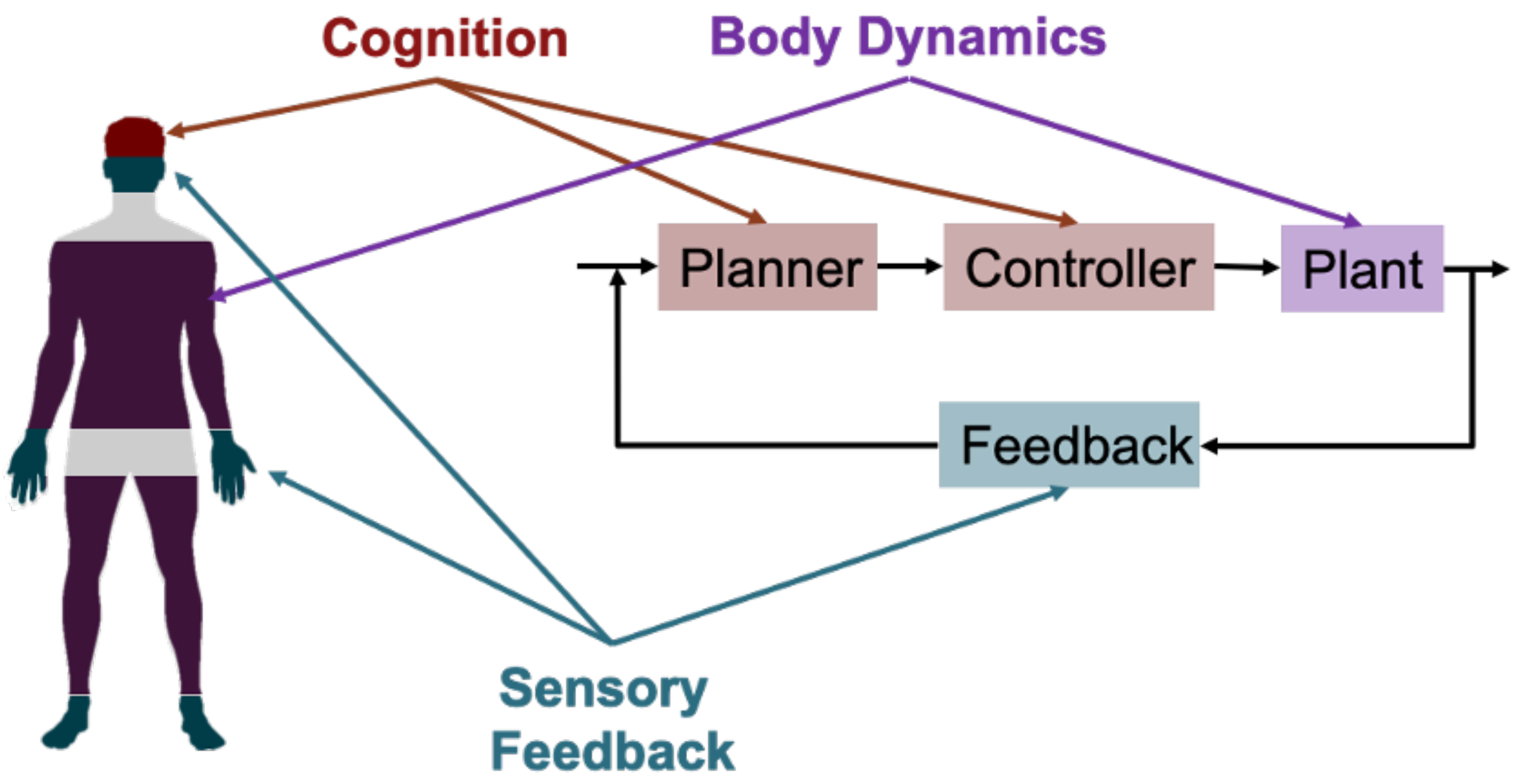


# Robotics Role in Assistive Technology

# When is Robotics the Best Option?

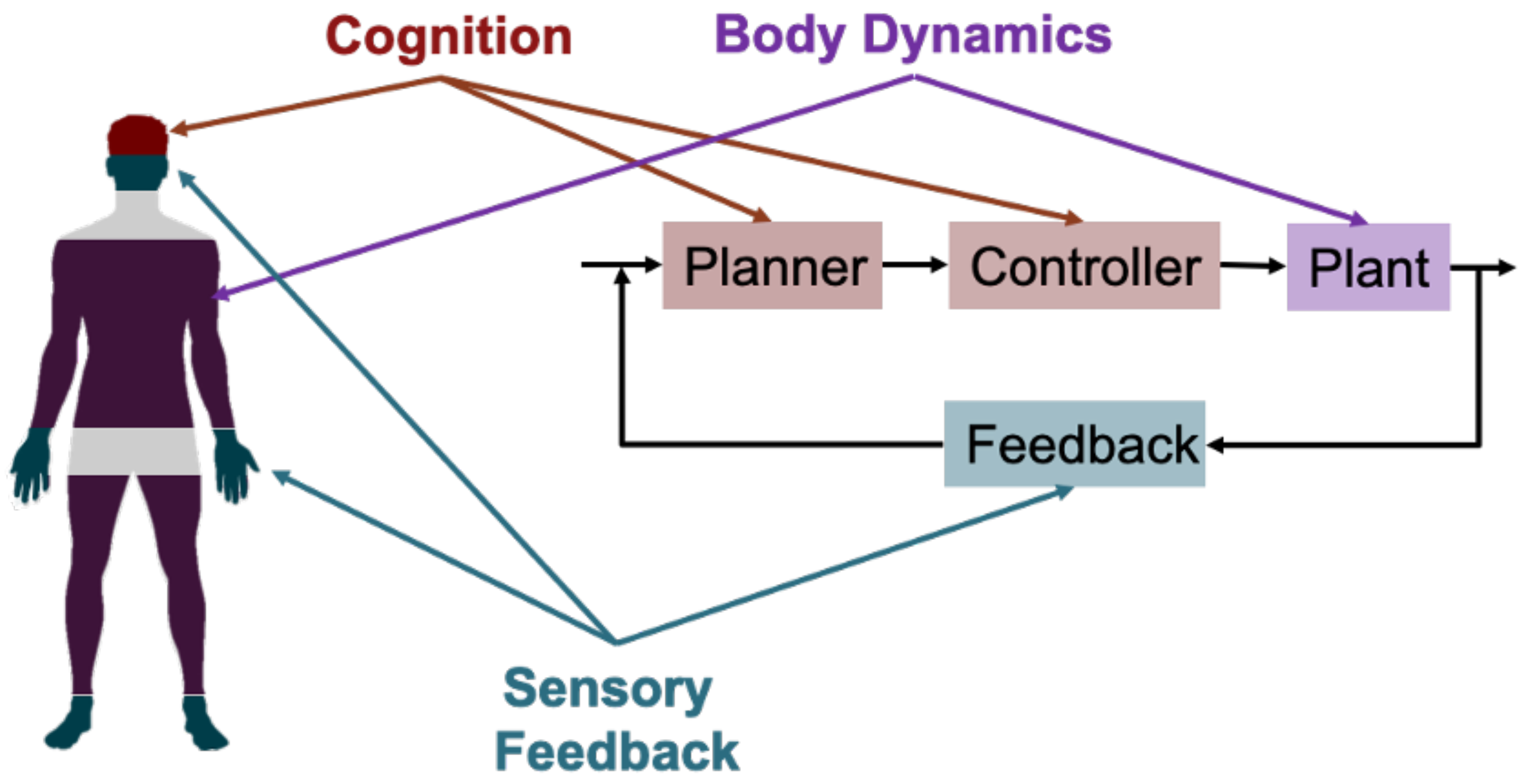
Robotics serve as a useful tool when the task requires

- High operational complexity (decisions/actions are not obvious)
- Human control/input that is limited for the complexity of the desired task



# Robotics Fills the Gap

## Wearable Robotics

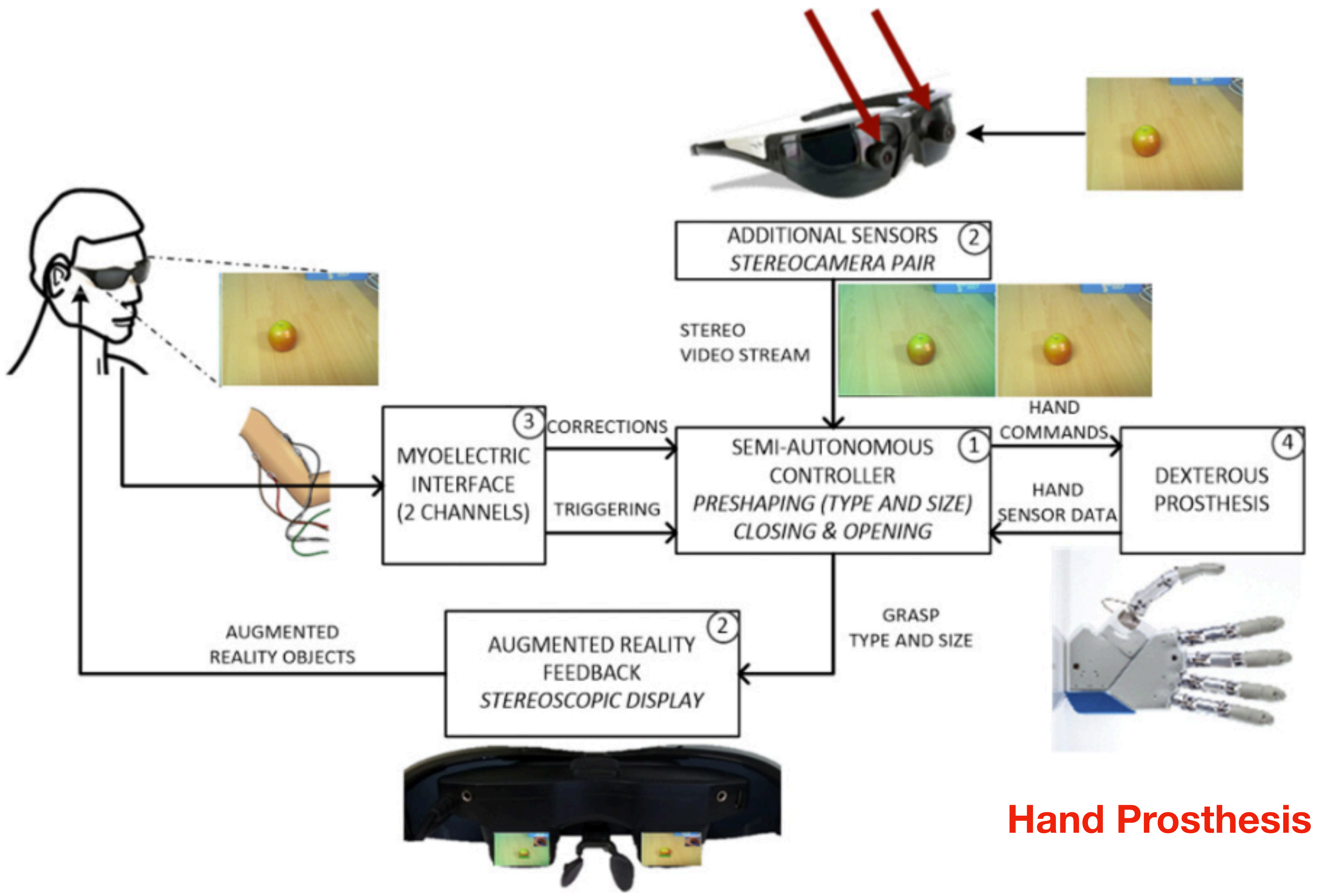



**Particularly for wearables, what part of the human is being augmented or substituted?**

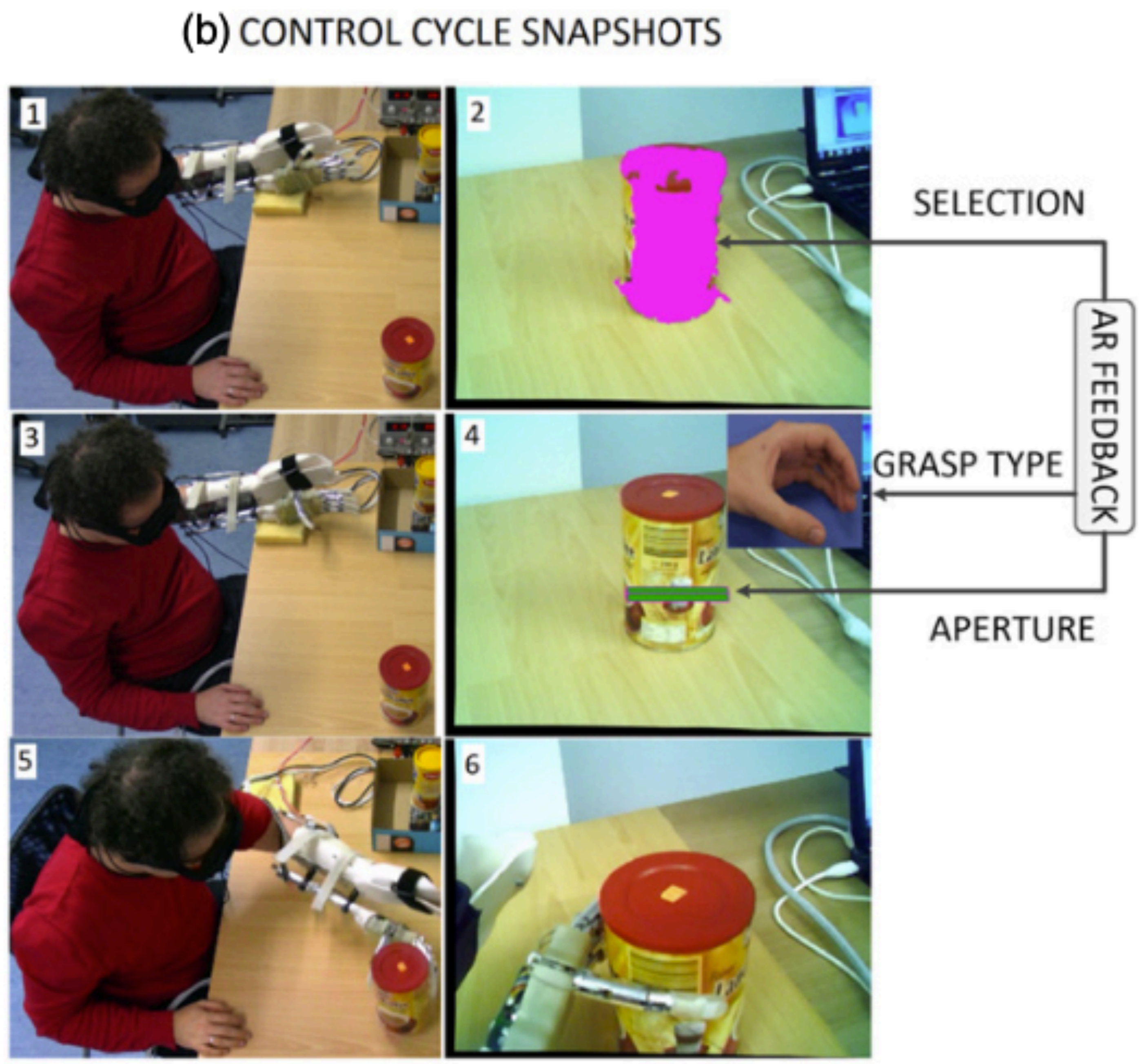
1. **Is the robotic augmentation functionally adequate?**
2. **Does the presence of the robot feel 'natural' (easy to use)?**

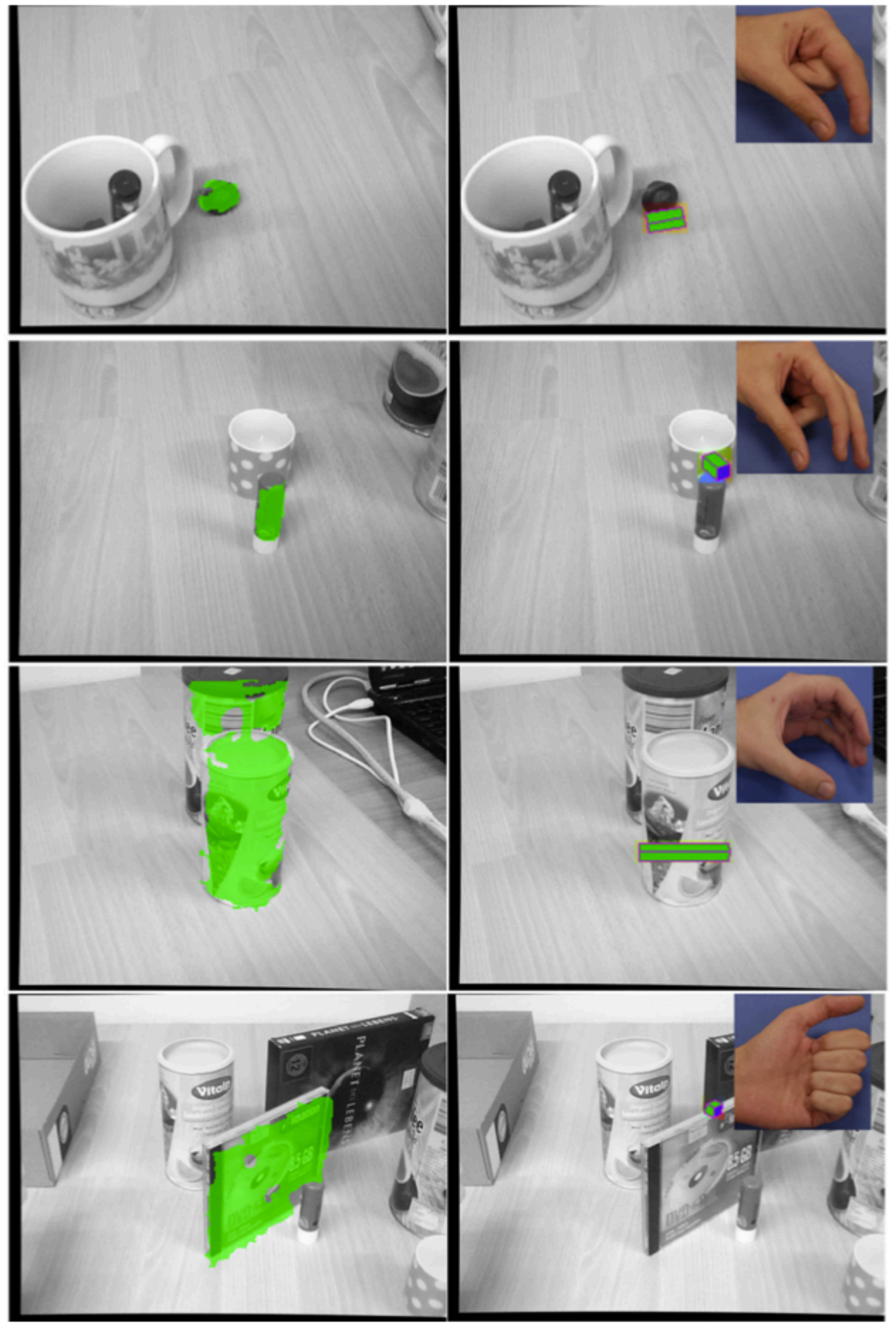
# Robotics Fills the Gap

## Robotics for Prosthesis: AR + Perception + Planning + Controls




Hand Prosthesis



Markovic, Marko, et al. "Stereovision and augmented reality for closed-loop control of grasping in hand prostheses." *Journal of neural engineering* 11.4 (2014): 046001.

# Assistive Robotics and Manipulation Laboratory

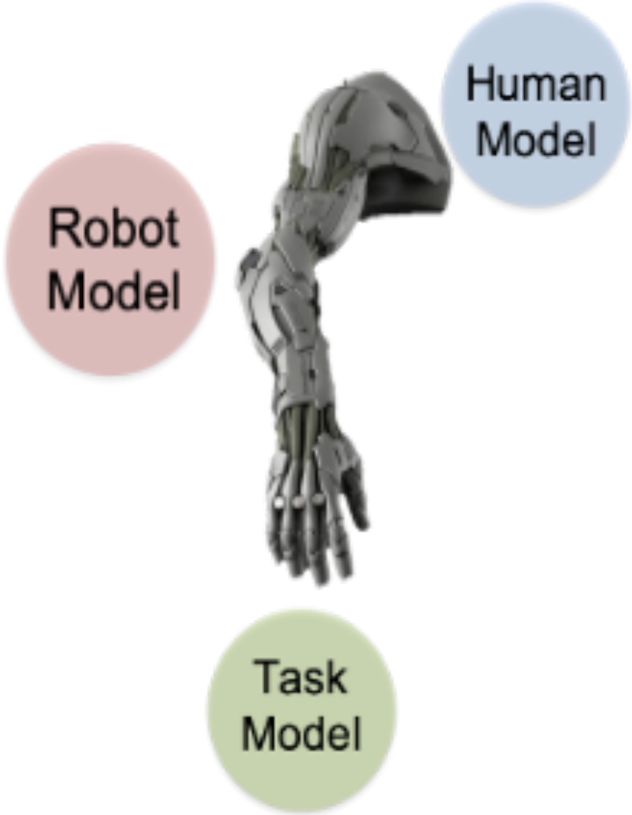
## Intelligent Wearables - Intelligent Prosthetic Arm


ARMLab Project:
Intelligent Prosthetic Arm

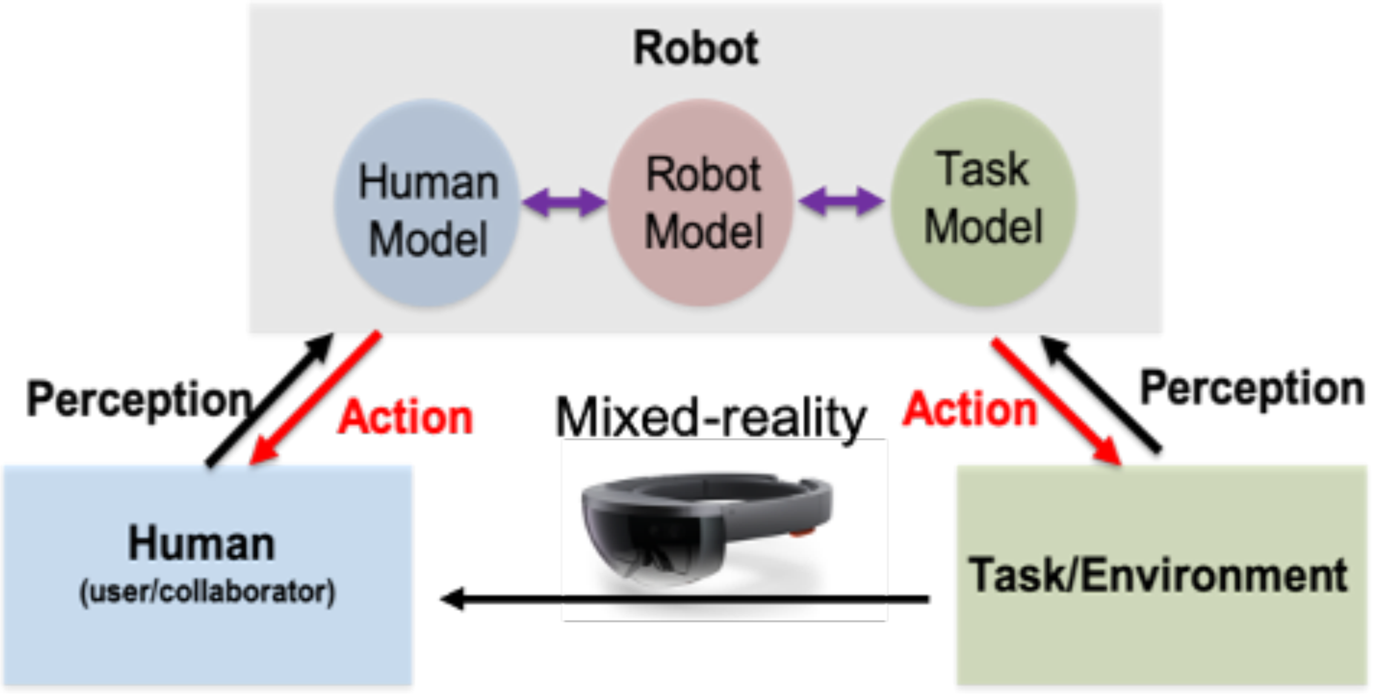
# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Intelligent Prosthetic Arm

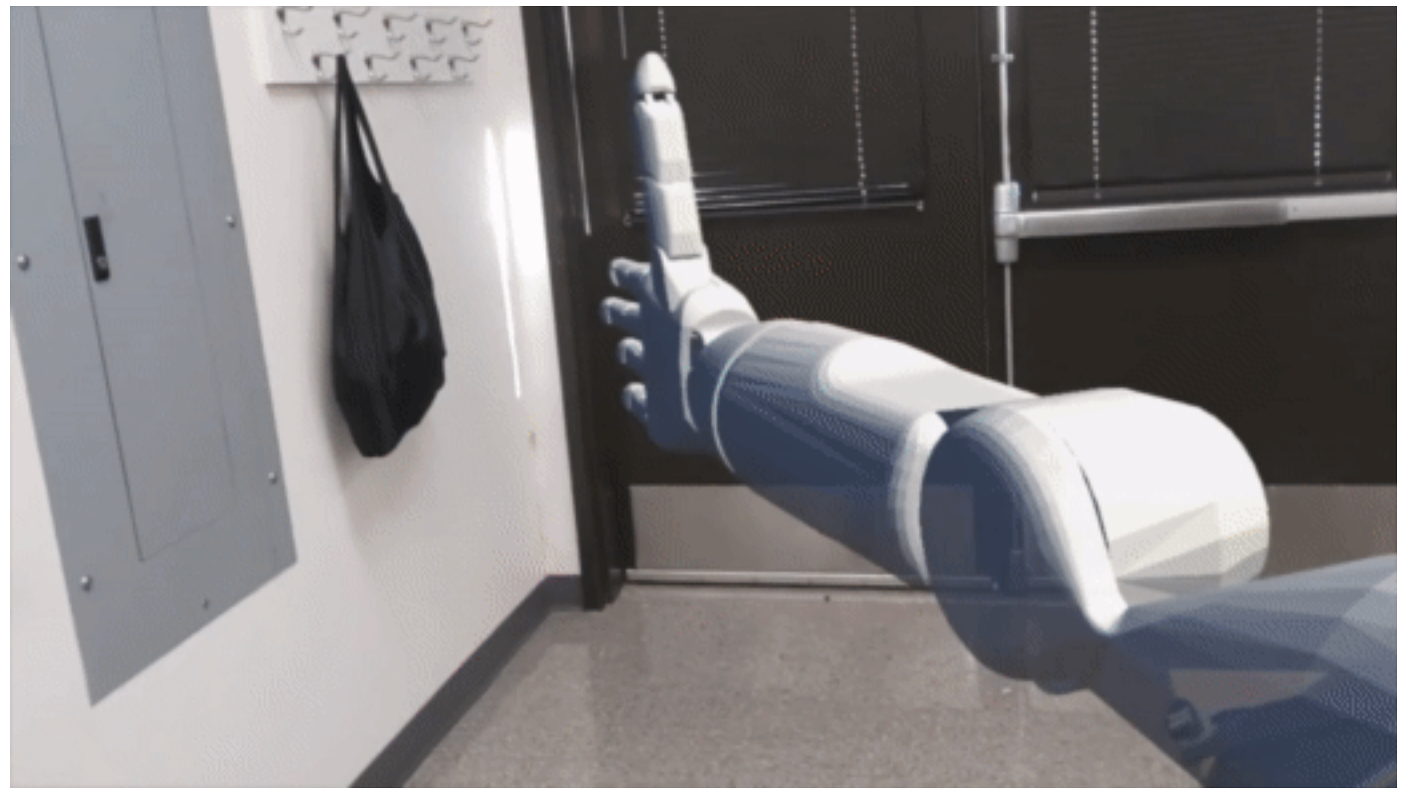
ARMLab Project:
**I**ntelligent **P**rosthetic **Arm**




**EMG Measurements**



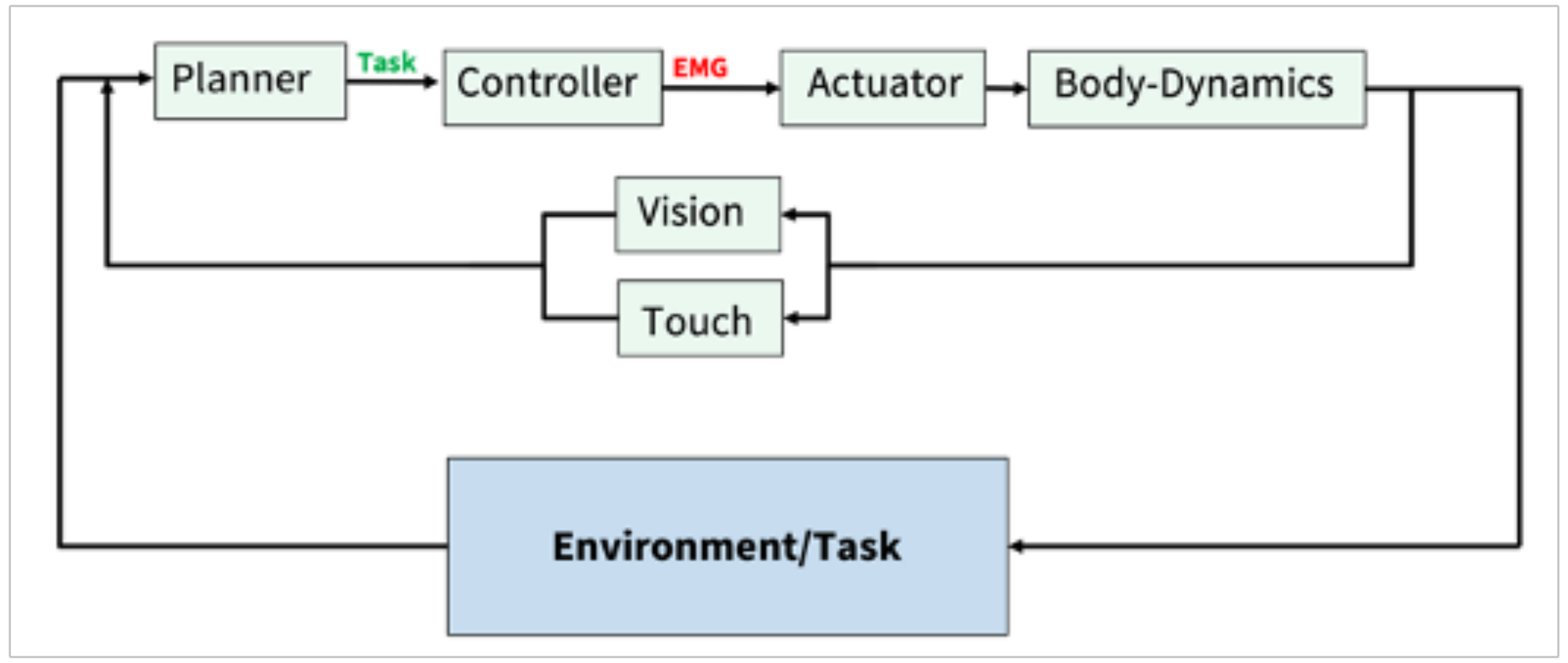

**Visuo-Tactile Measurements**



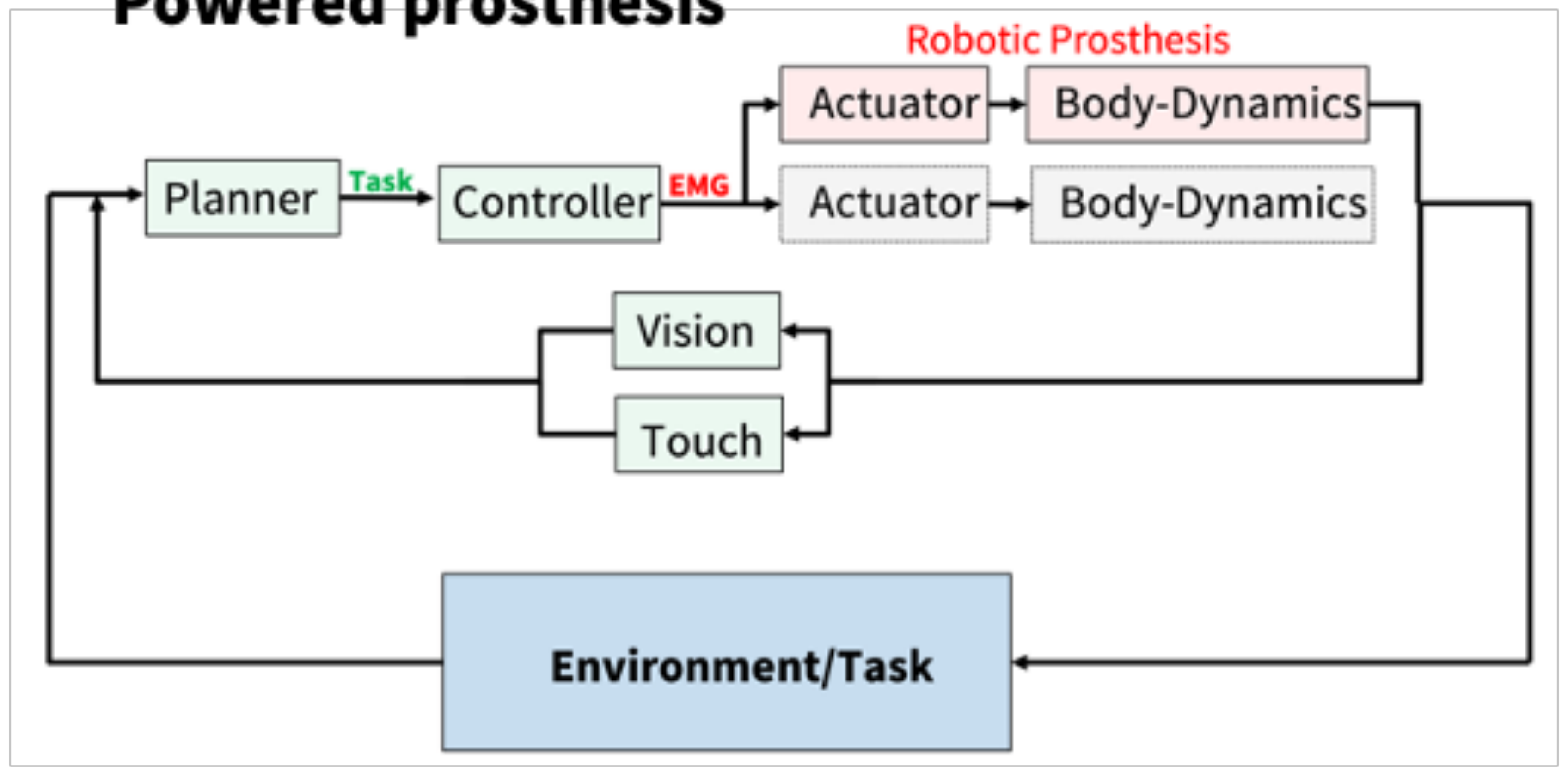
# Assistive Robotics and Manipulation Laboratory

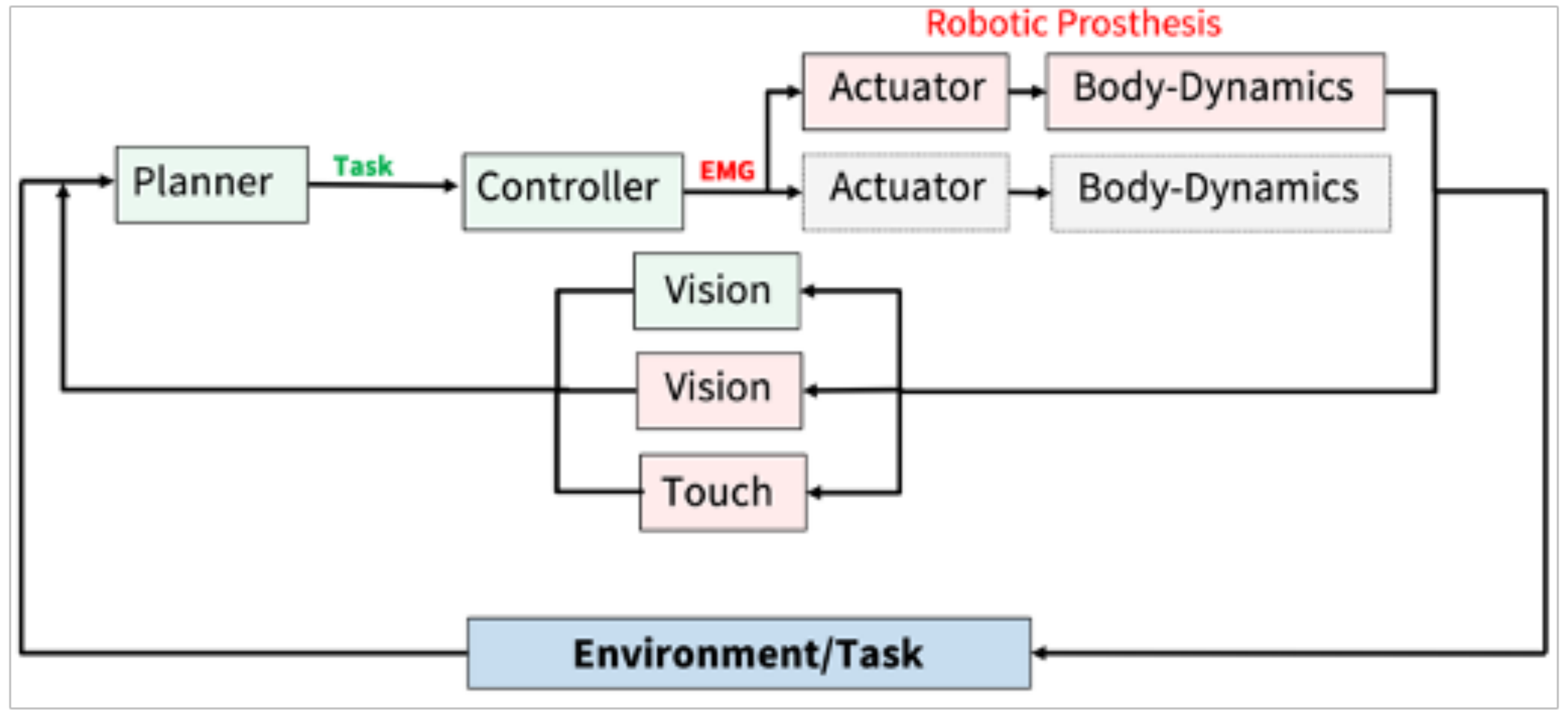
## Intelligent Wearables - Intelligent Prosthetic Arm

**Able-bodied person**

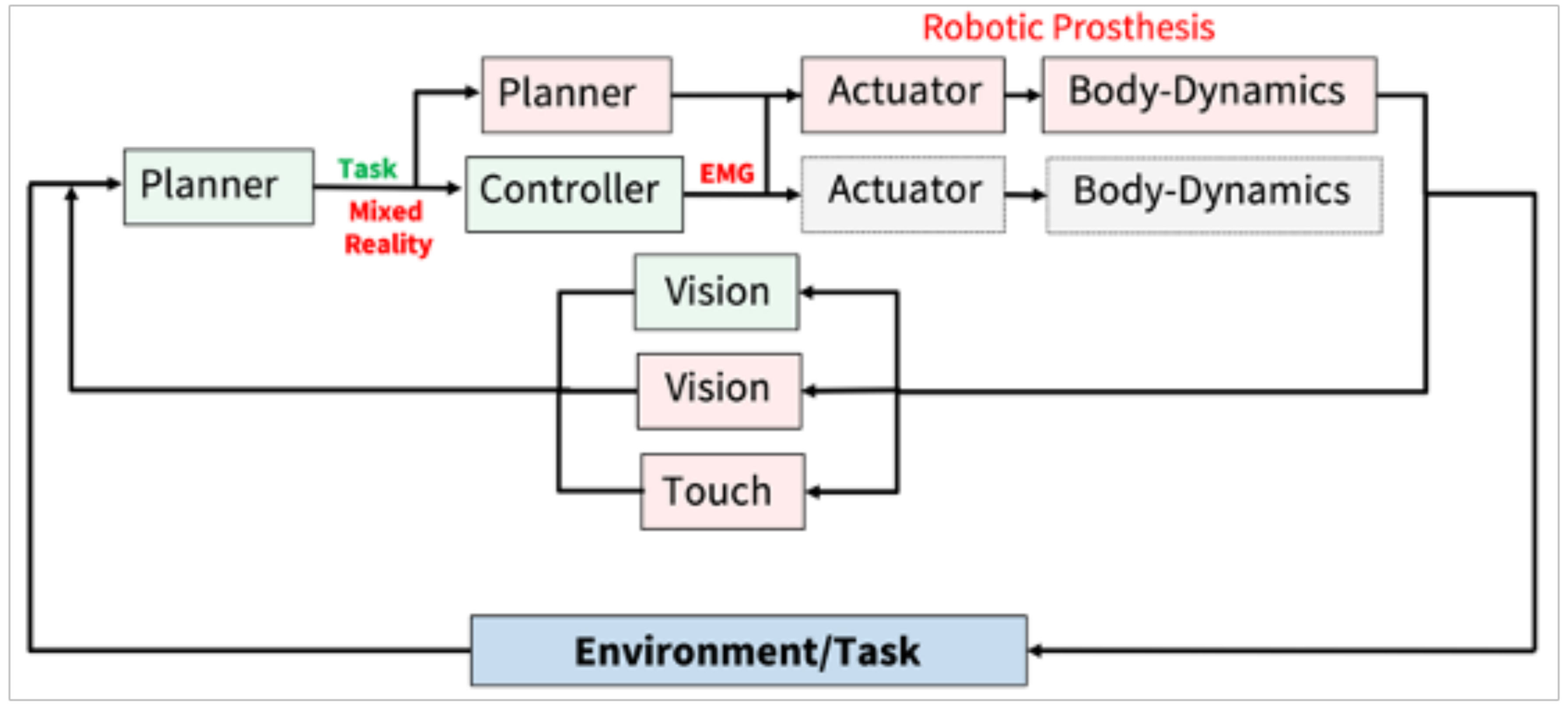



**Powered prosthesis**




**Powered prosthesis with 'basic reflex'**

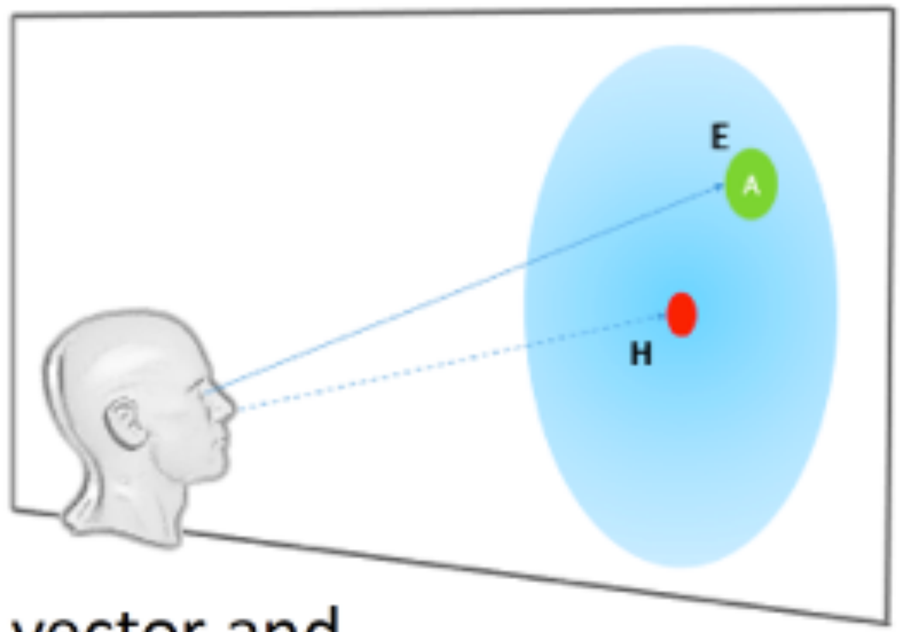


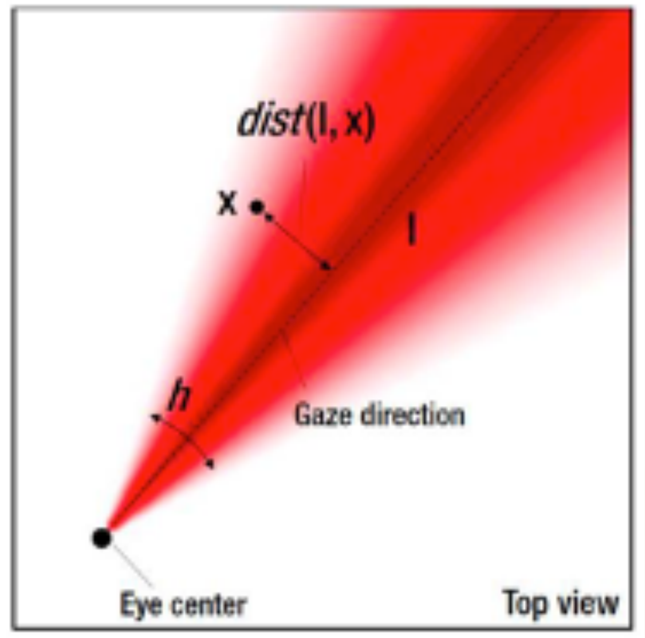

**Intelligent powered prosthesis**

# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Intelligent Prosthetic Arm

Augmented reality (AR) is a powerful tool allowing the robot to both **extract** and **present information** *to the wearer*




Object affordances

Eye gaze vector and head gaze cone

Pose, motion of other limb(s)


Scene understanding

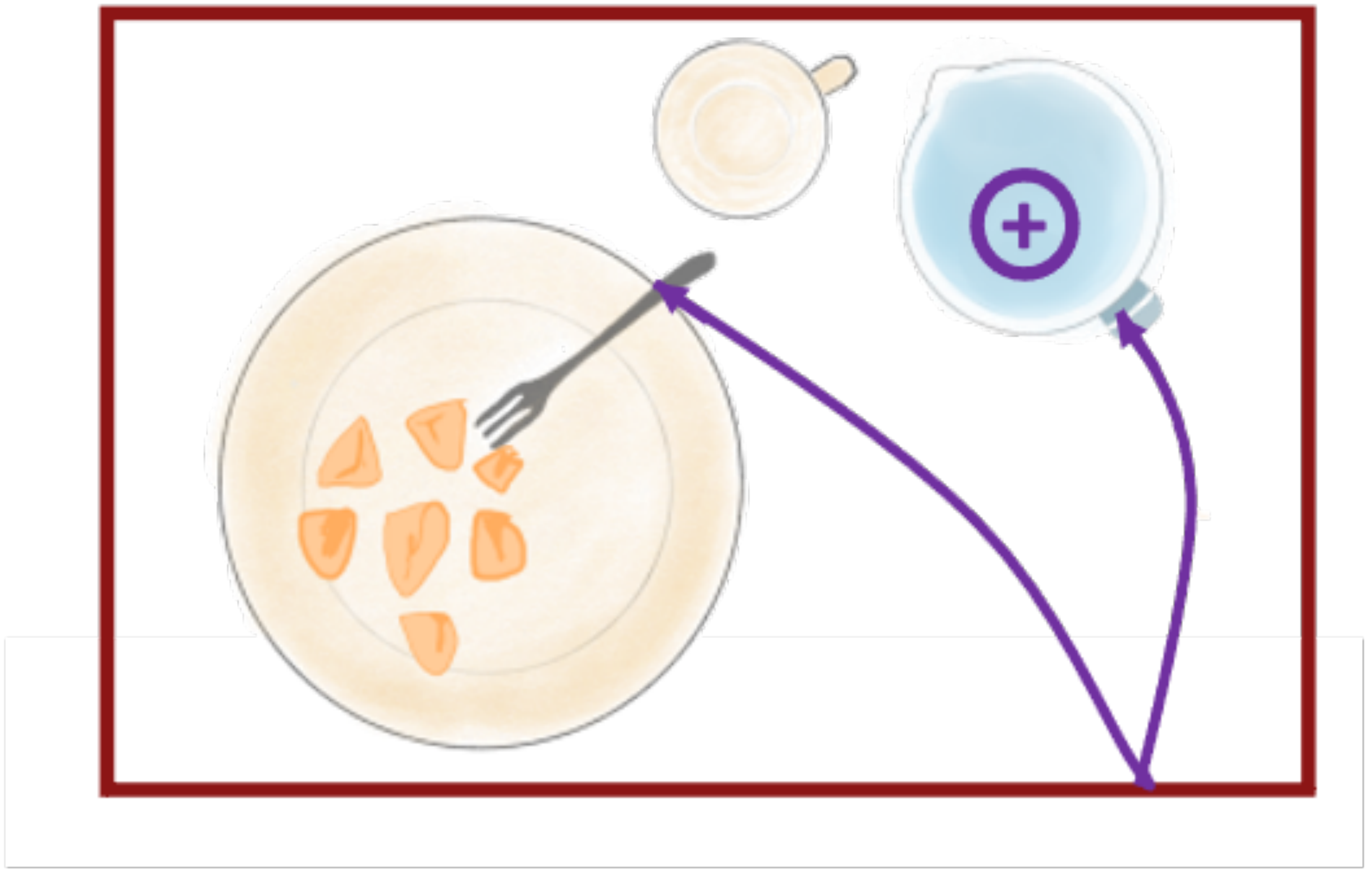
Pose, motion of other agents

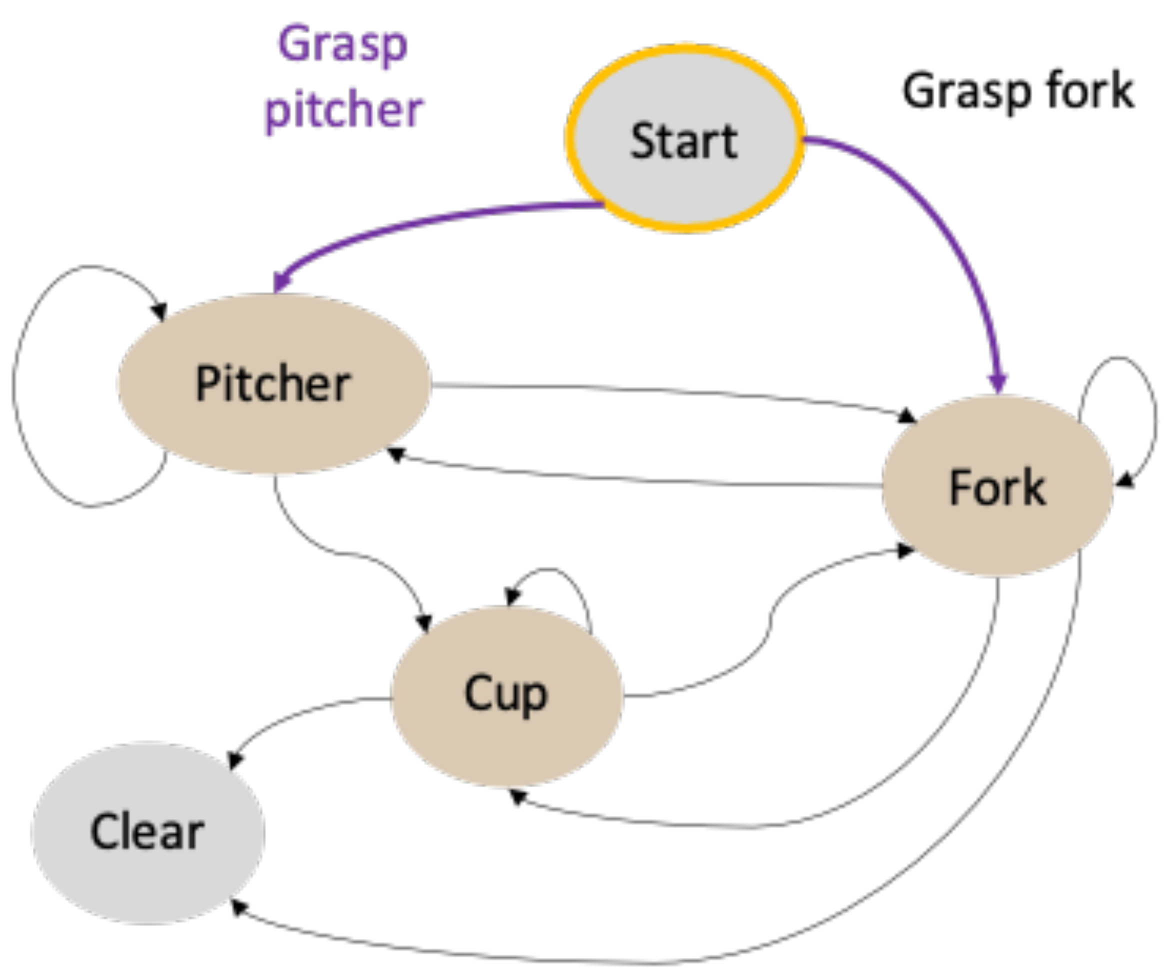
# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Intelligent Prosthetic Arm

ARMLab Project:
**I**ntelligent **P**rosthetic **Arm**

**Example**: IPArm state-machine for ADL





# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Intelligent Prosthetic Arm

ARMLab Project:
**I**ntelligent **P**rosthetic **Arm**

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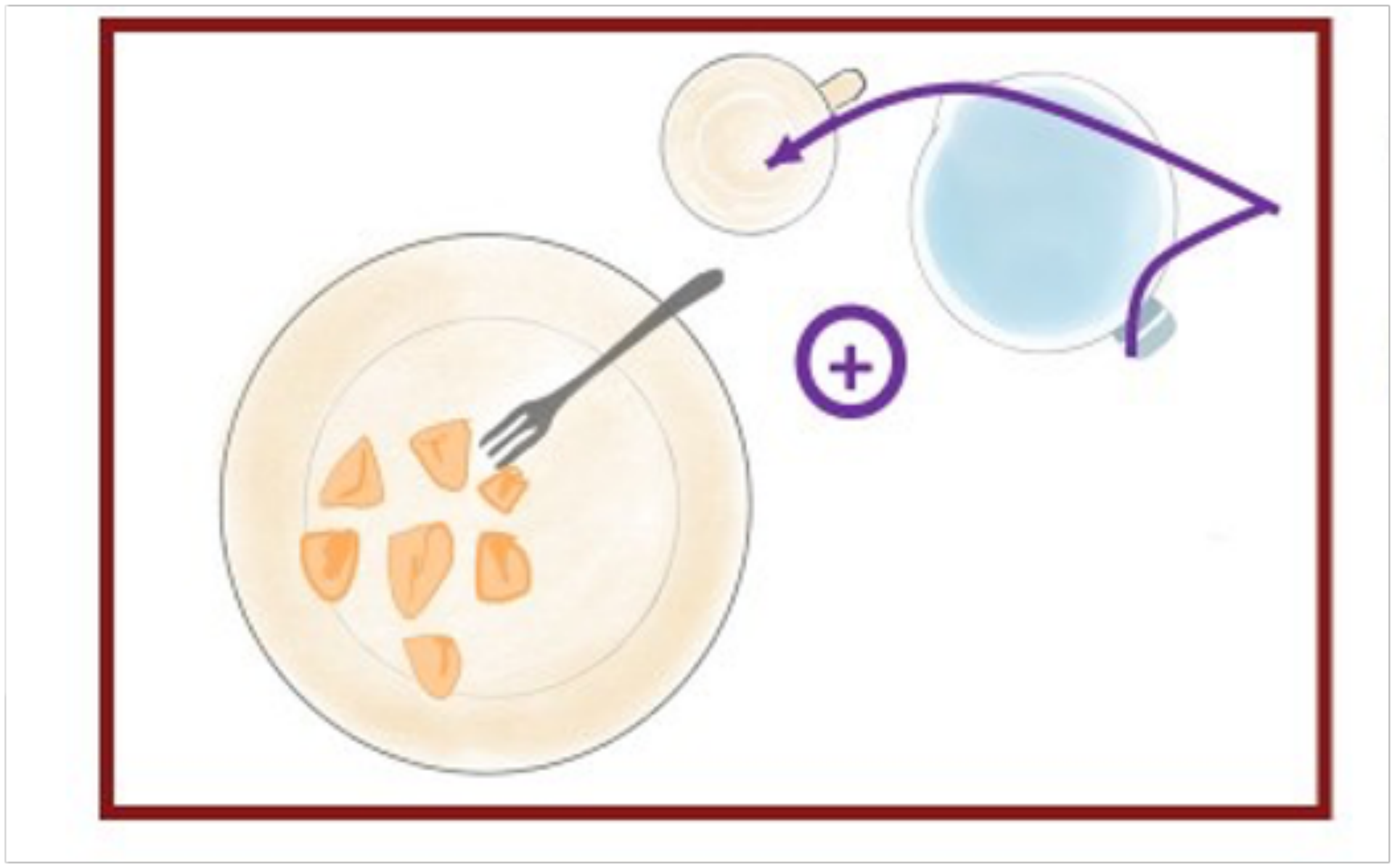
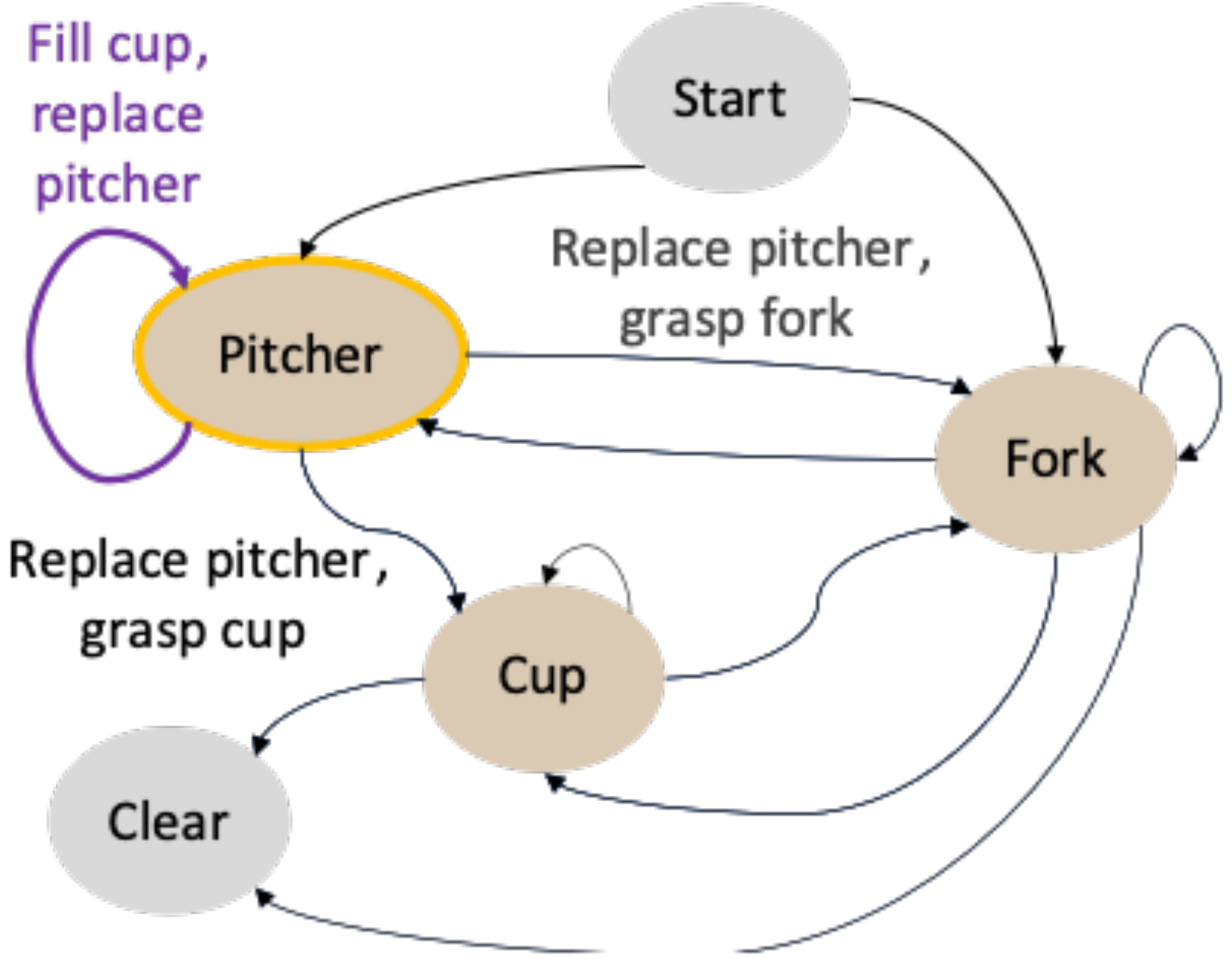


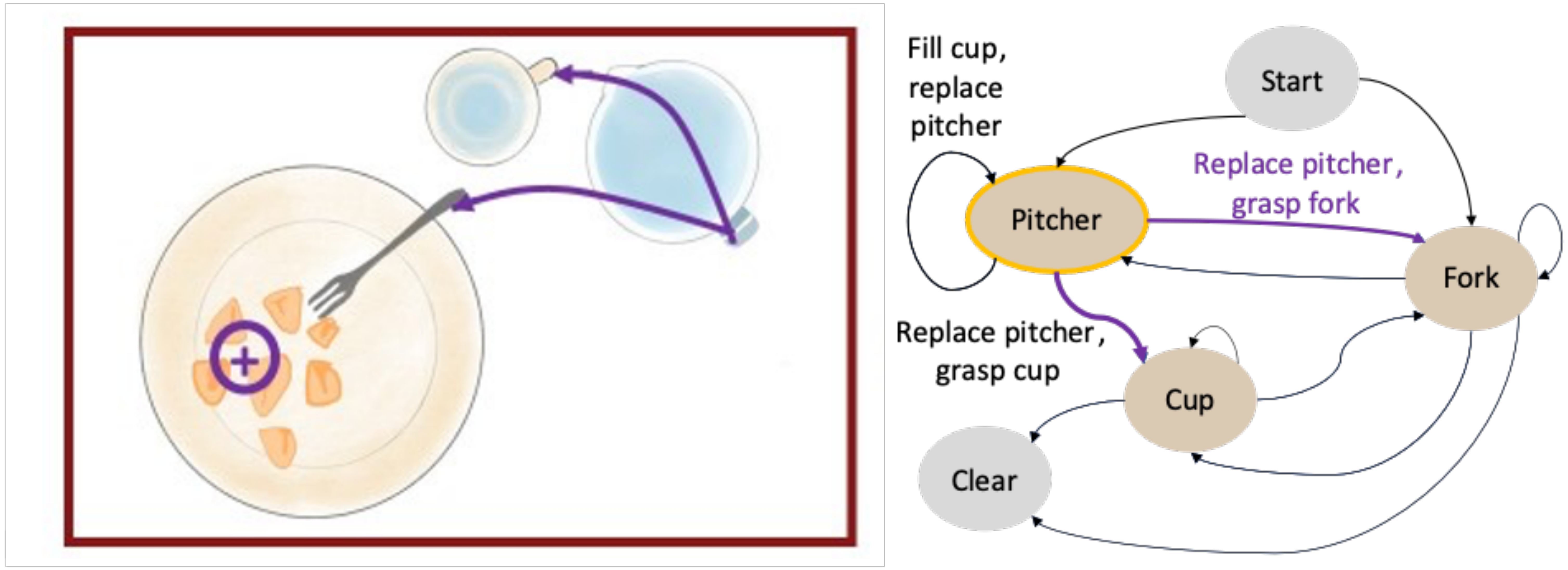


# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Intelligent Prosthetic Arm

ARMLab Project:
Intelligent Prosthetic Arm

**Example:** IPArm state-machine for ADL



# Assistive Robotics and Manipulation Laboratory

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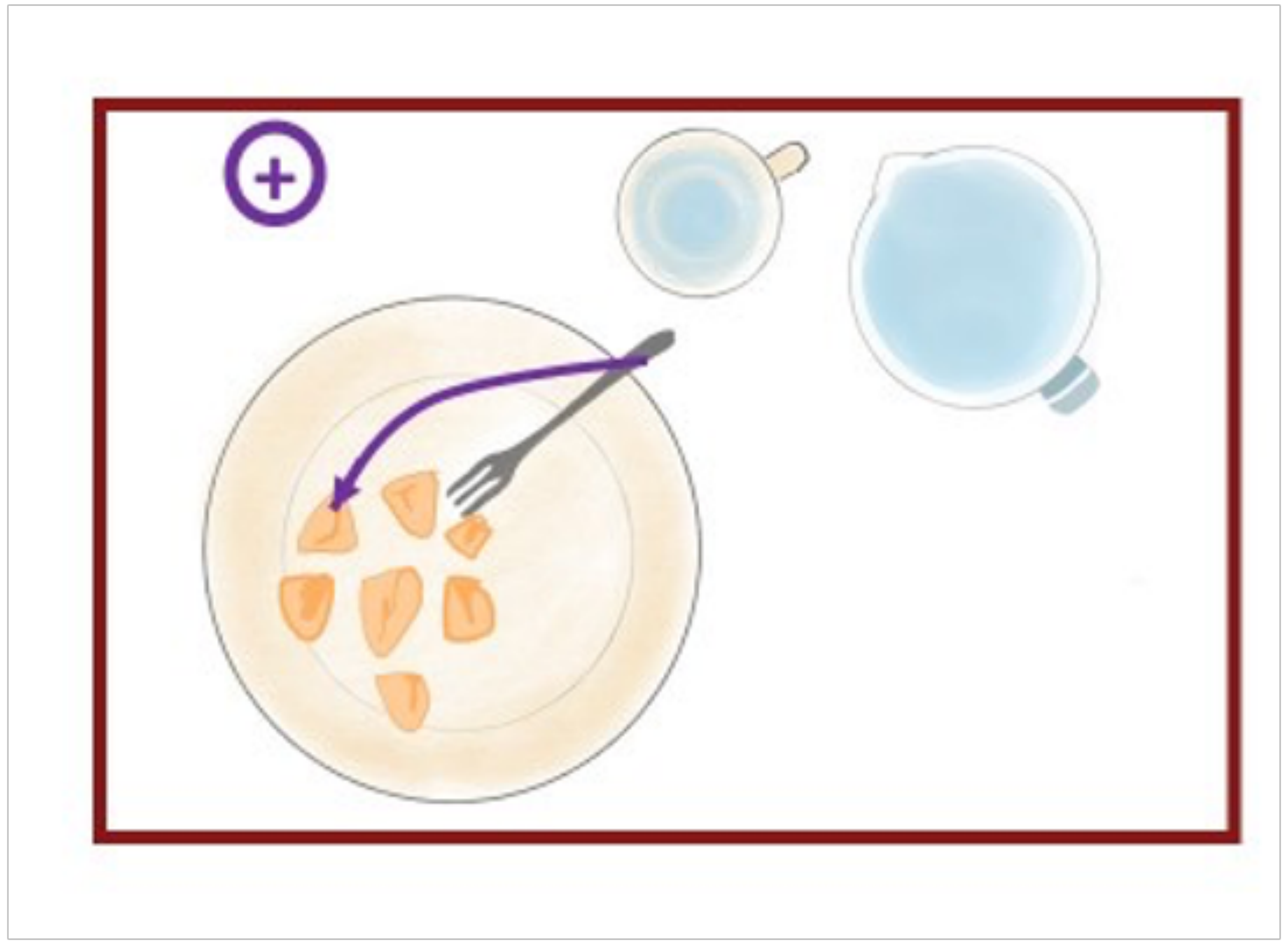
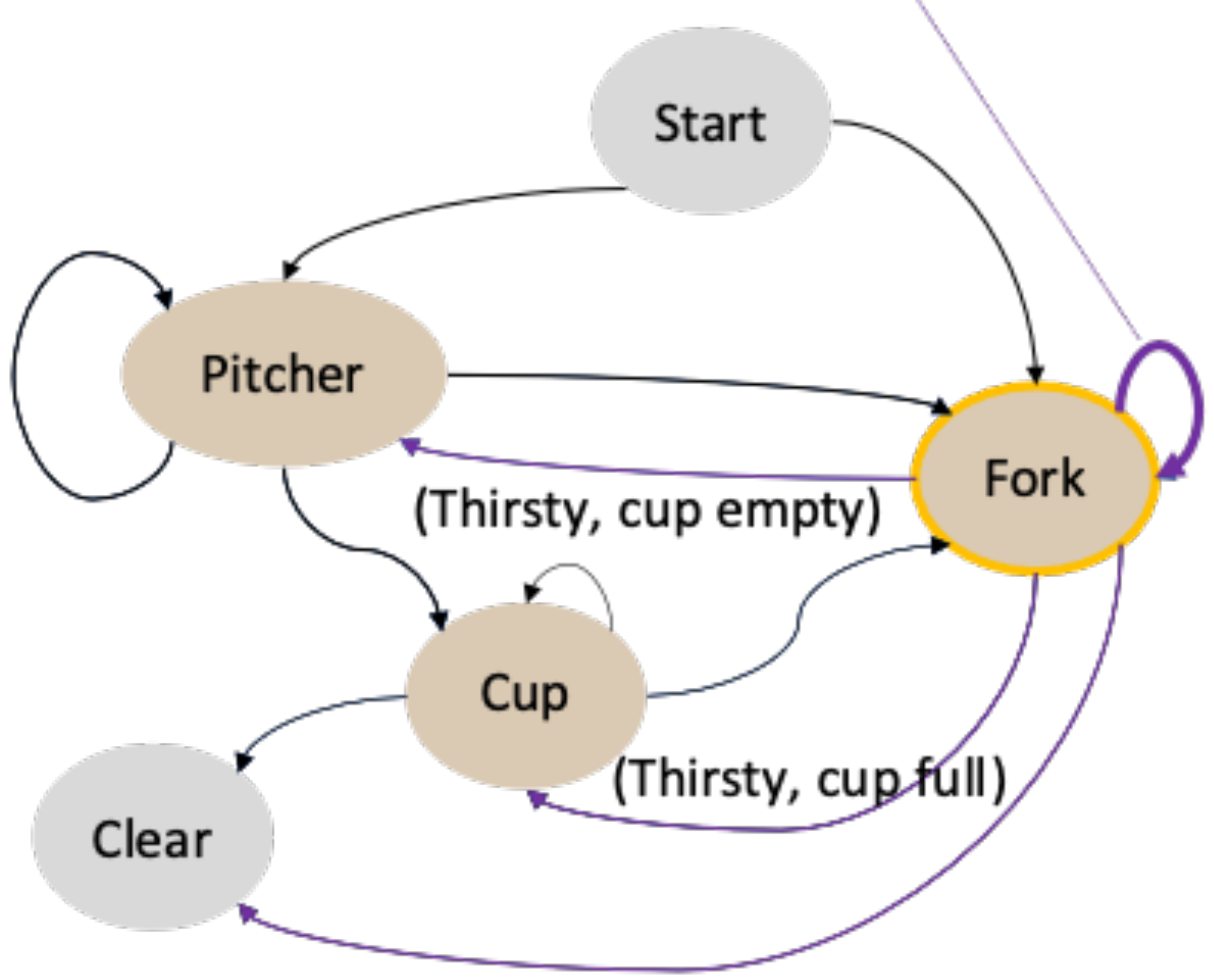


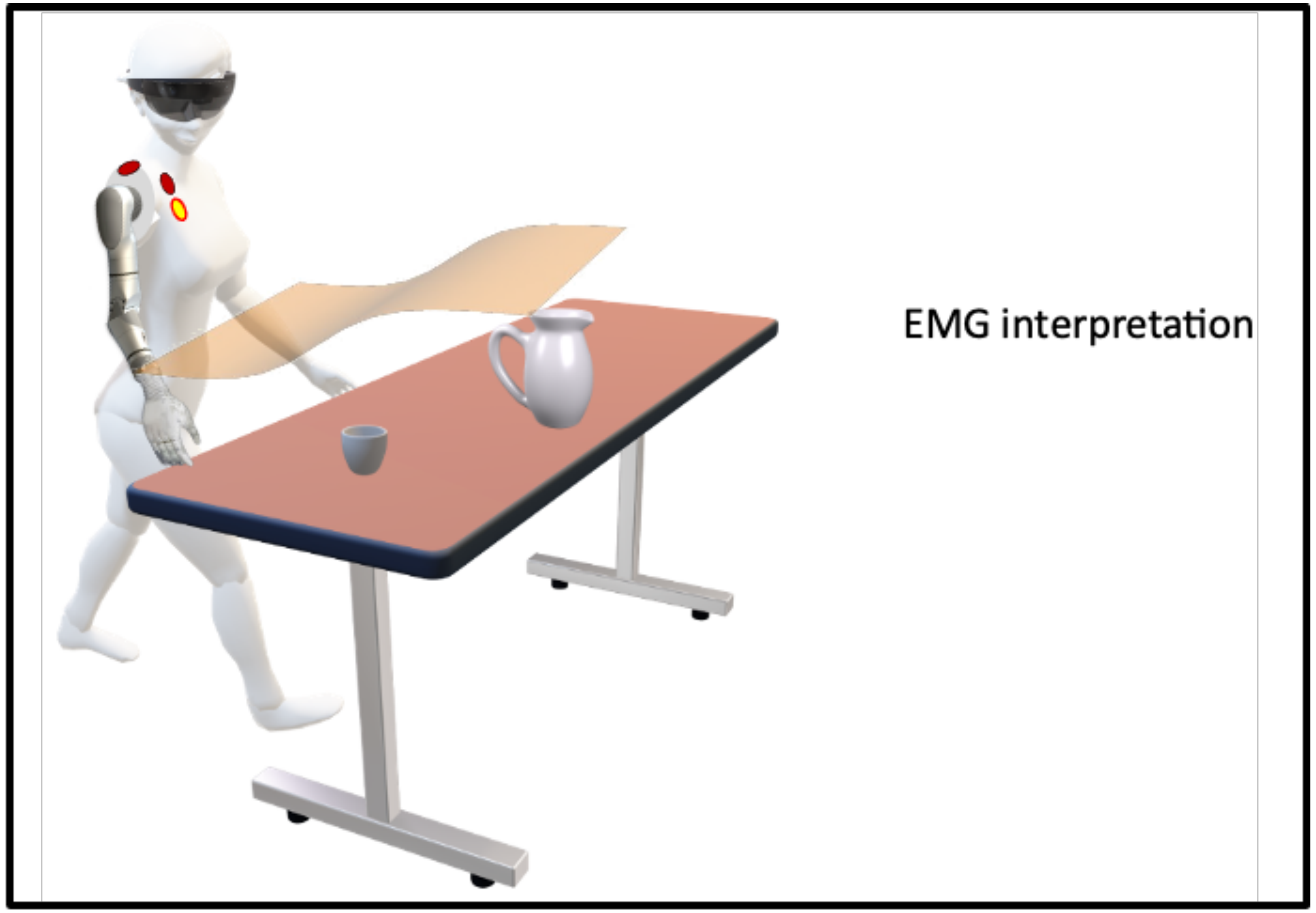


# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Intelligent Prosthetic Arm

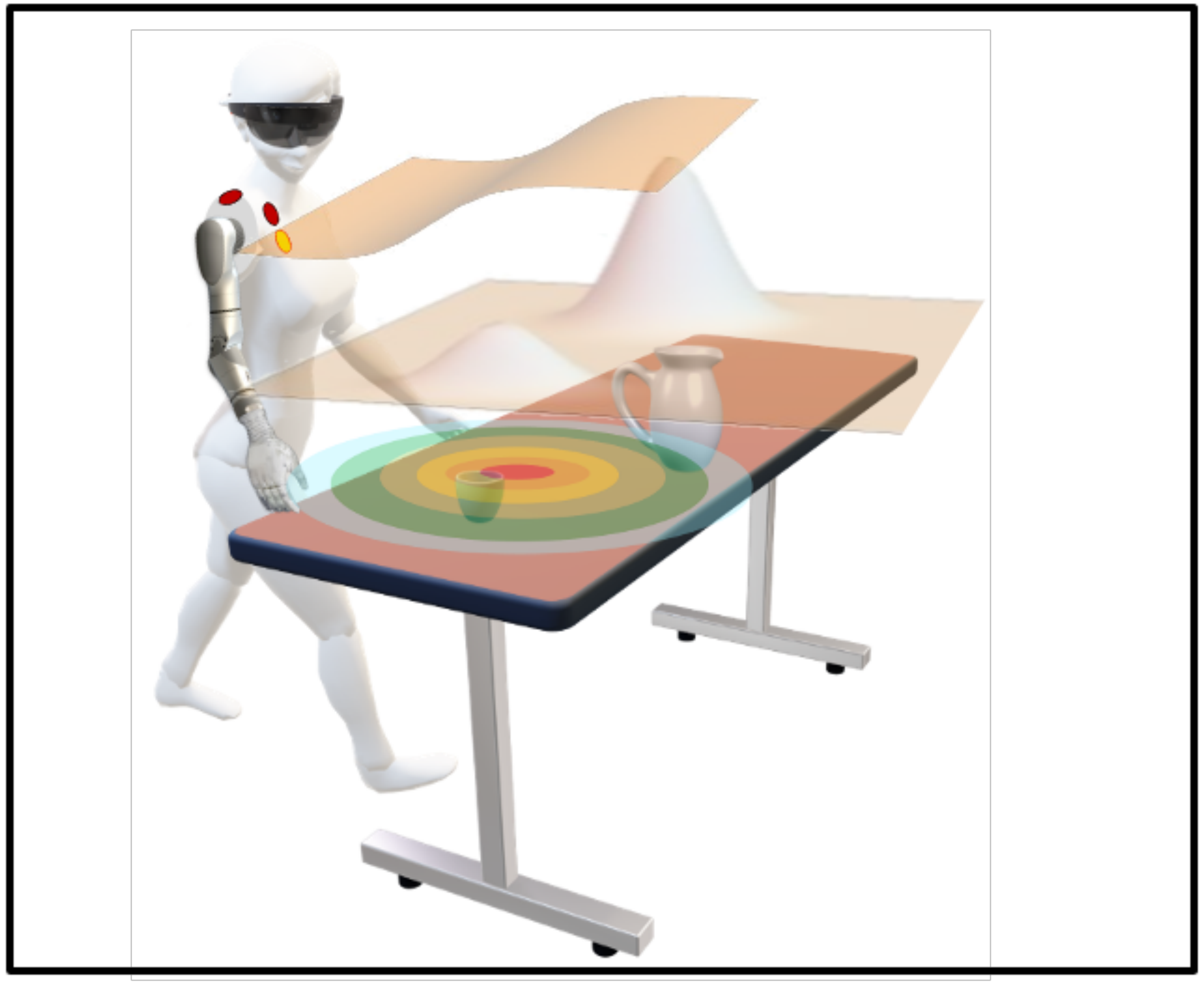

# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Intelligent Prosthetic Arm

# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Intelligent Prosthetic Arm



# Assistive Robotics and Manipulation Laboratory

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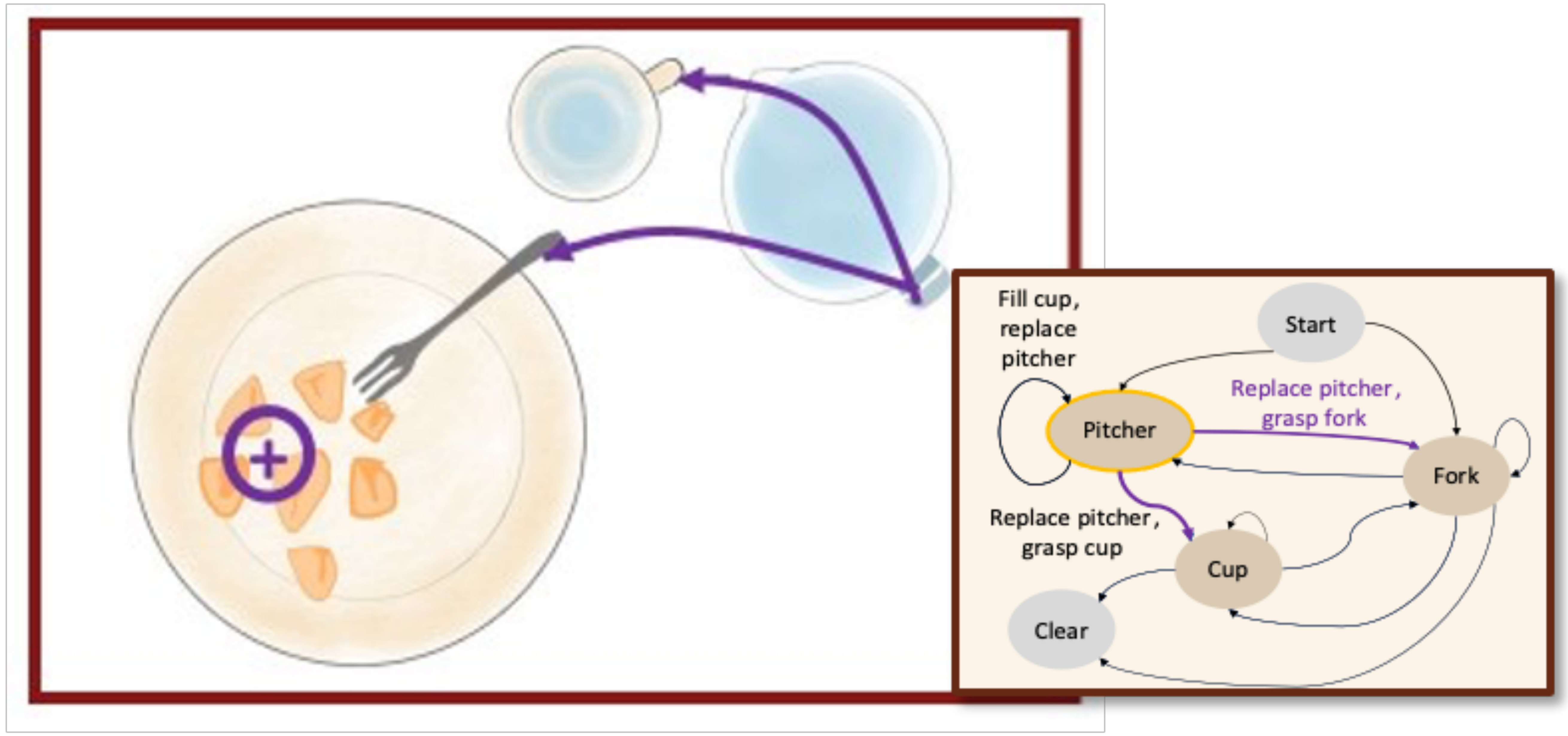


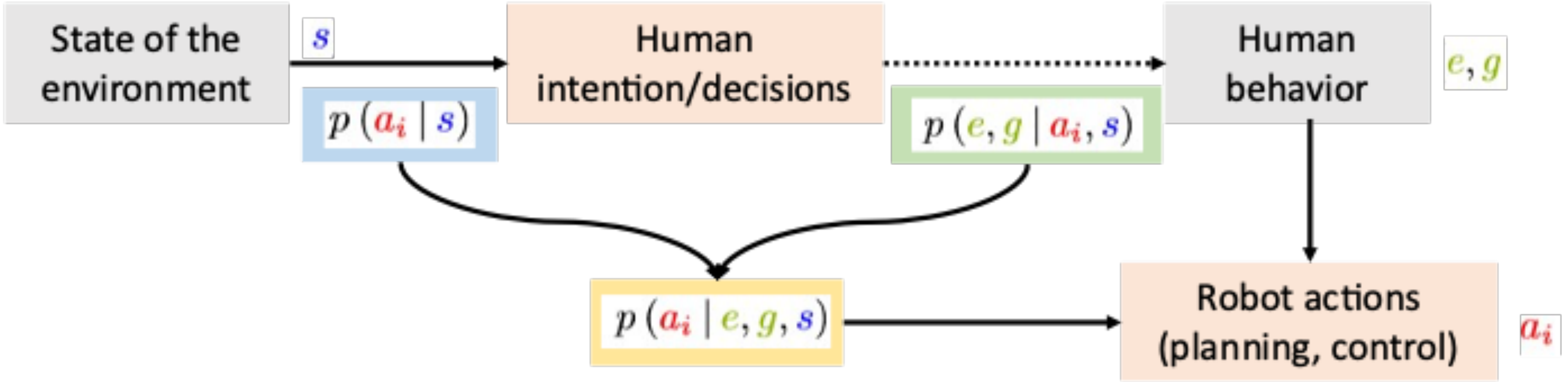

# Assistive Robotics and Manipulation Laboratory

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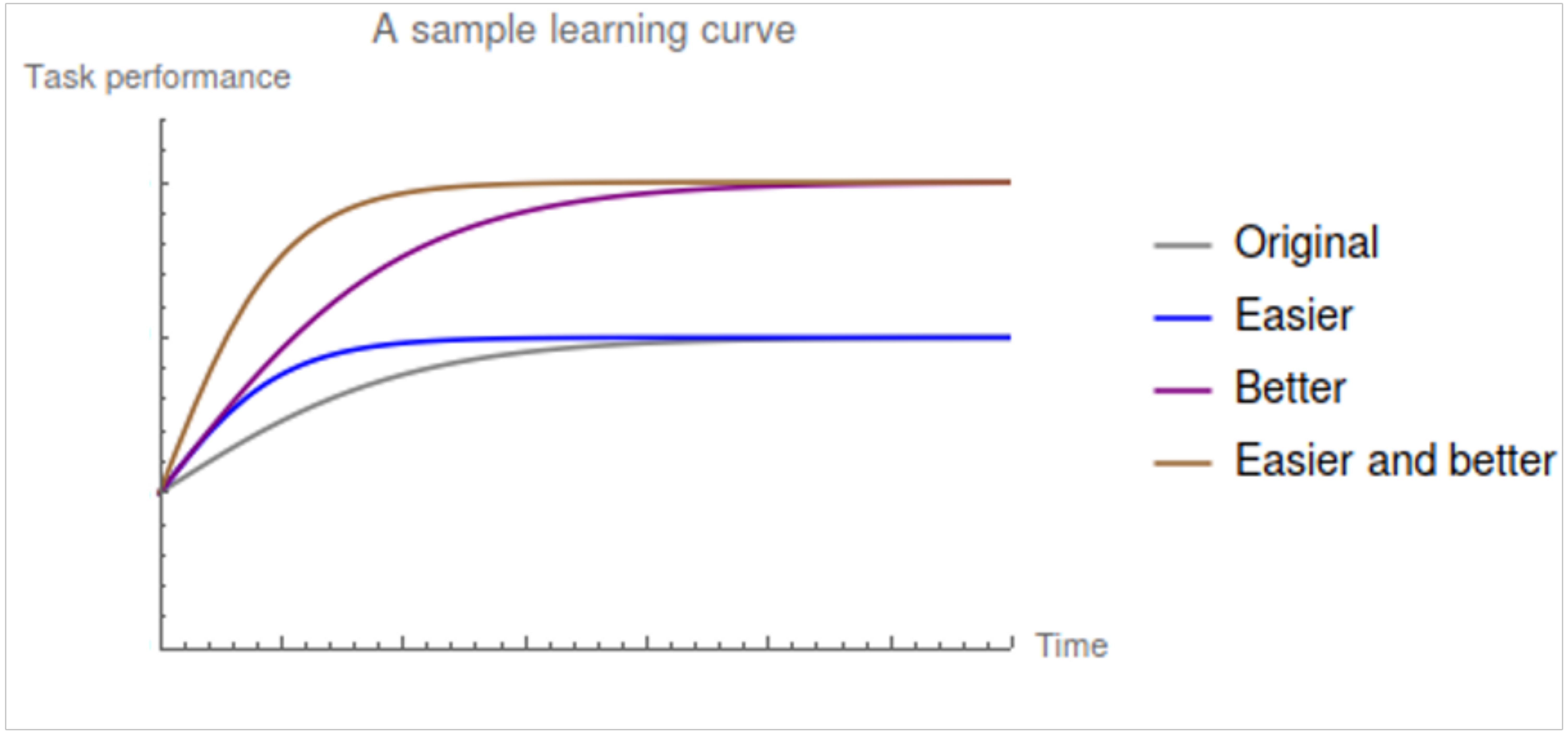
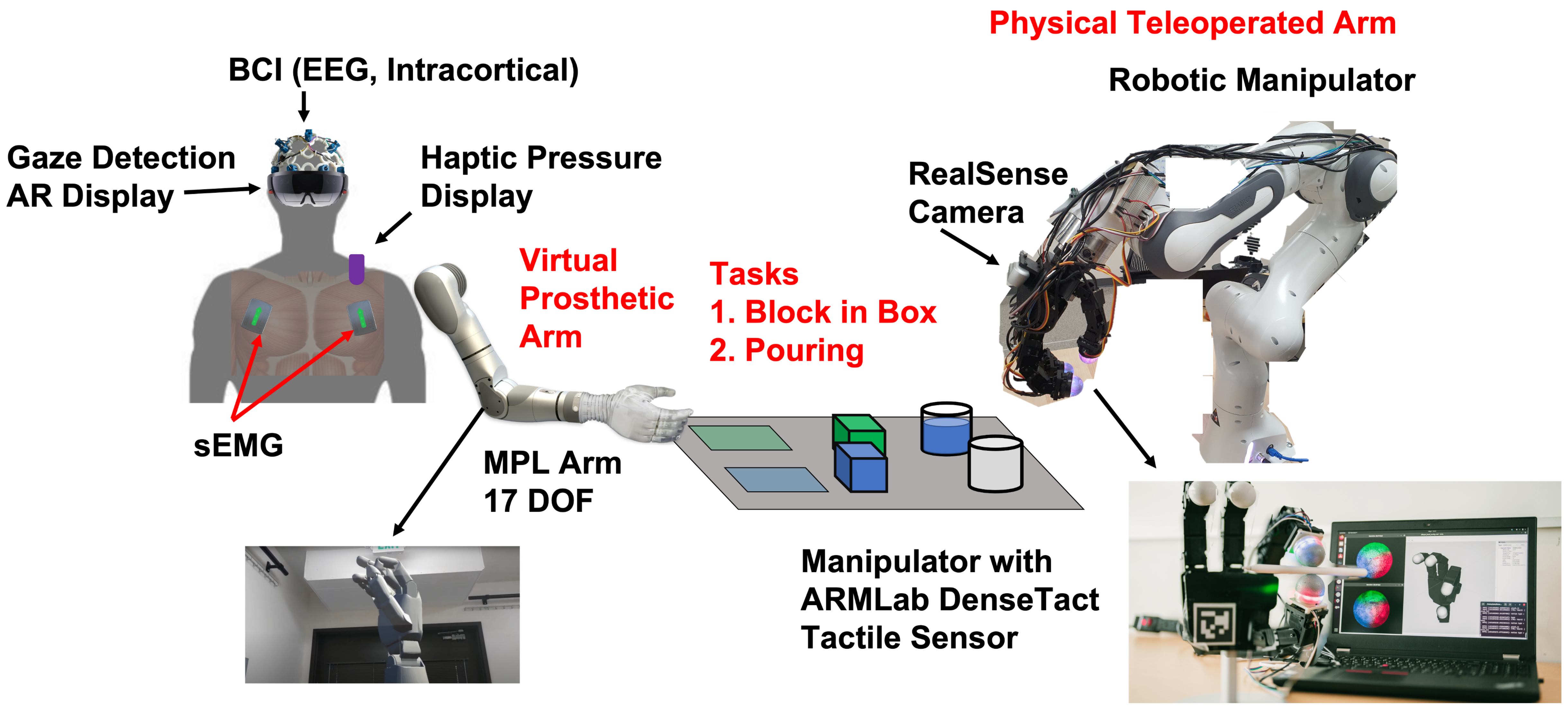
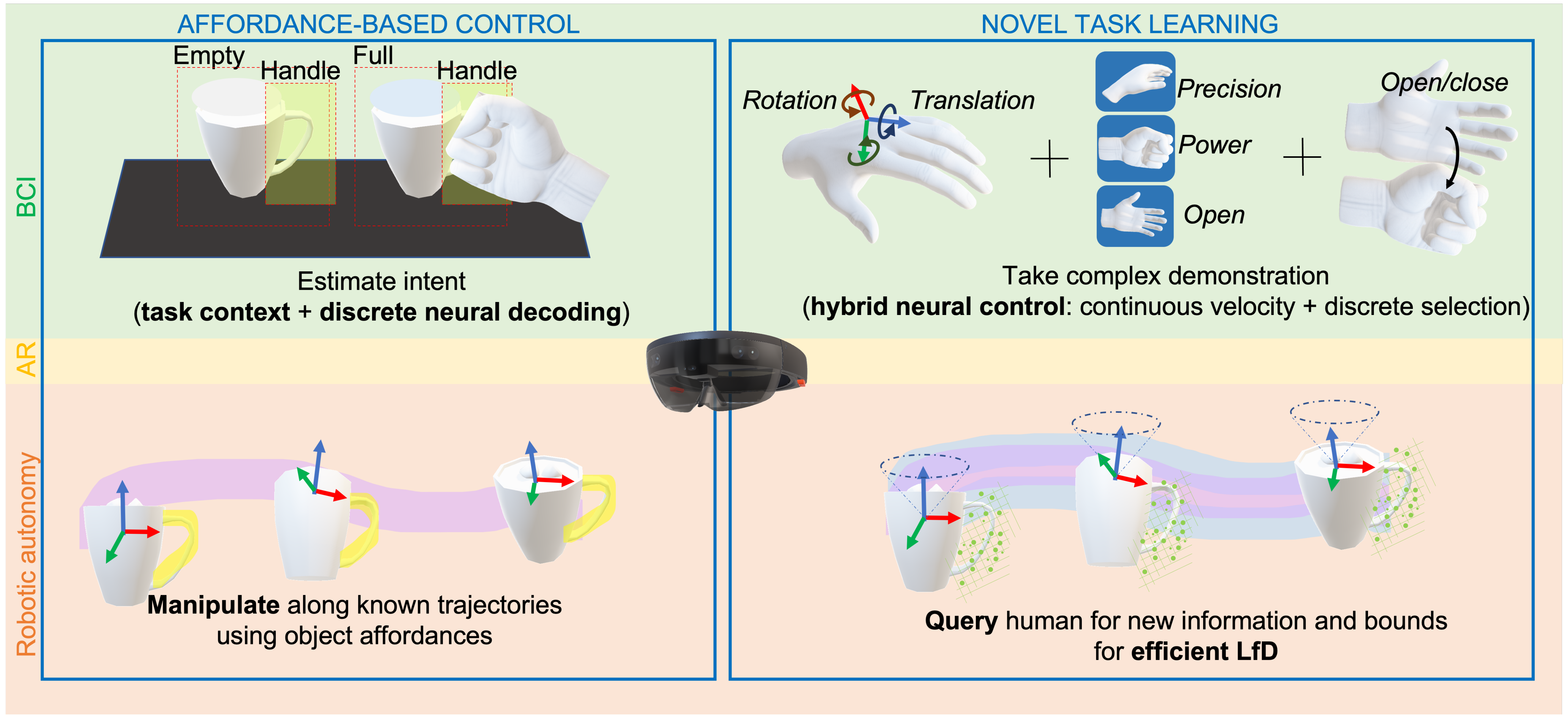
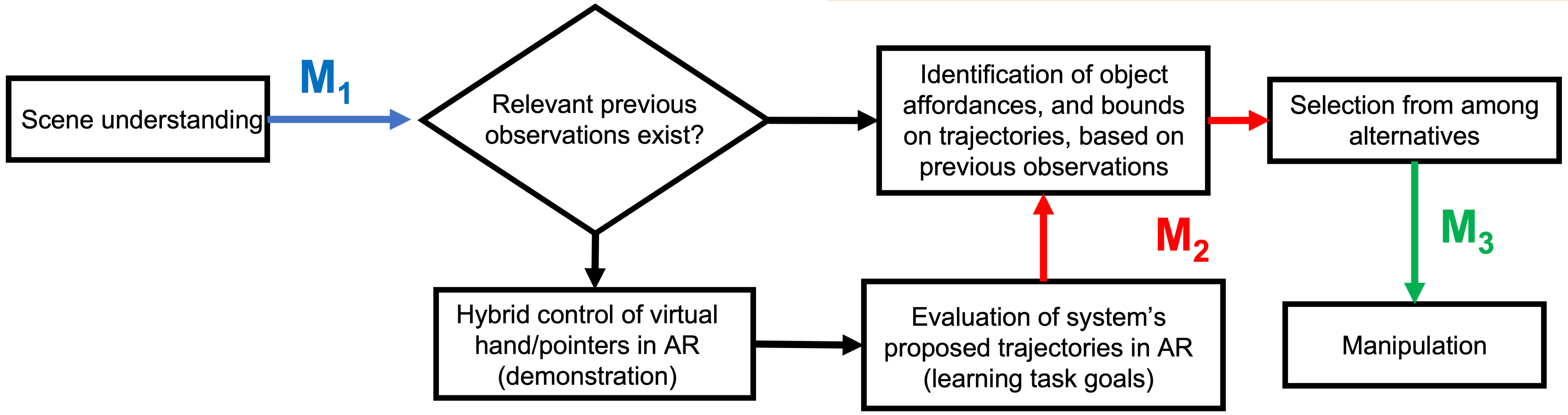


# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Intelligent Prosthetic Arm

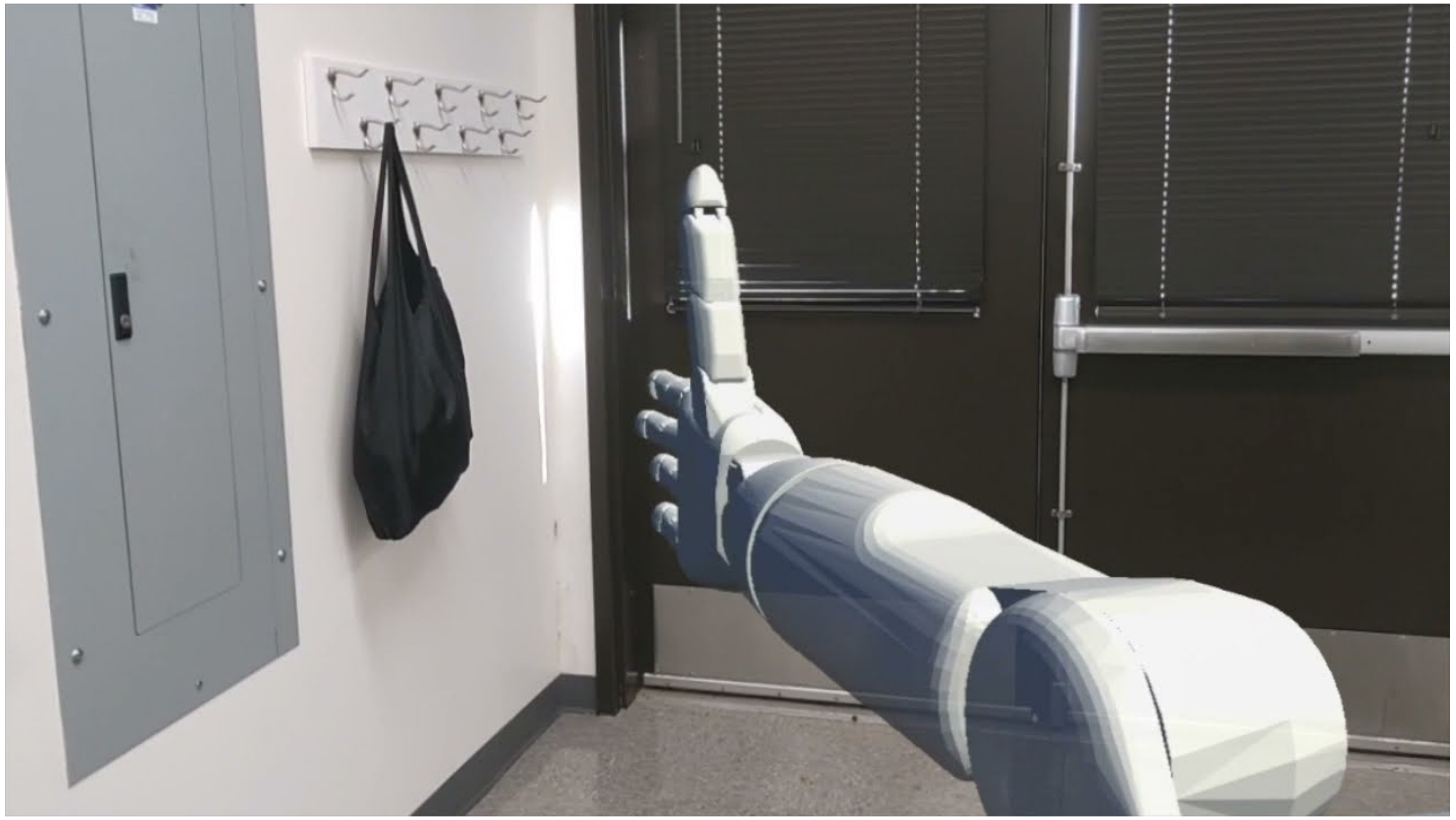


# Assistive Robotics and Manipulation Laboratory

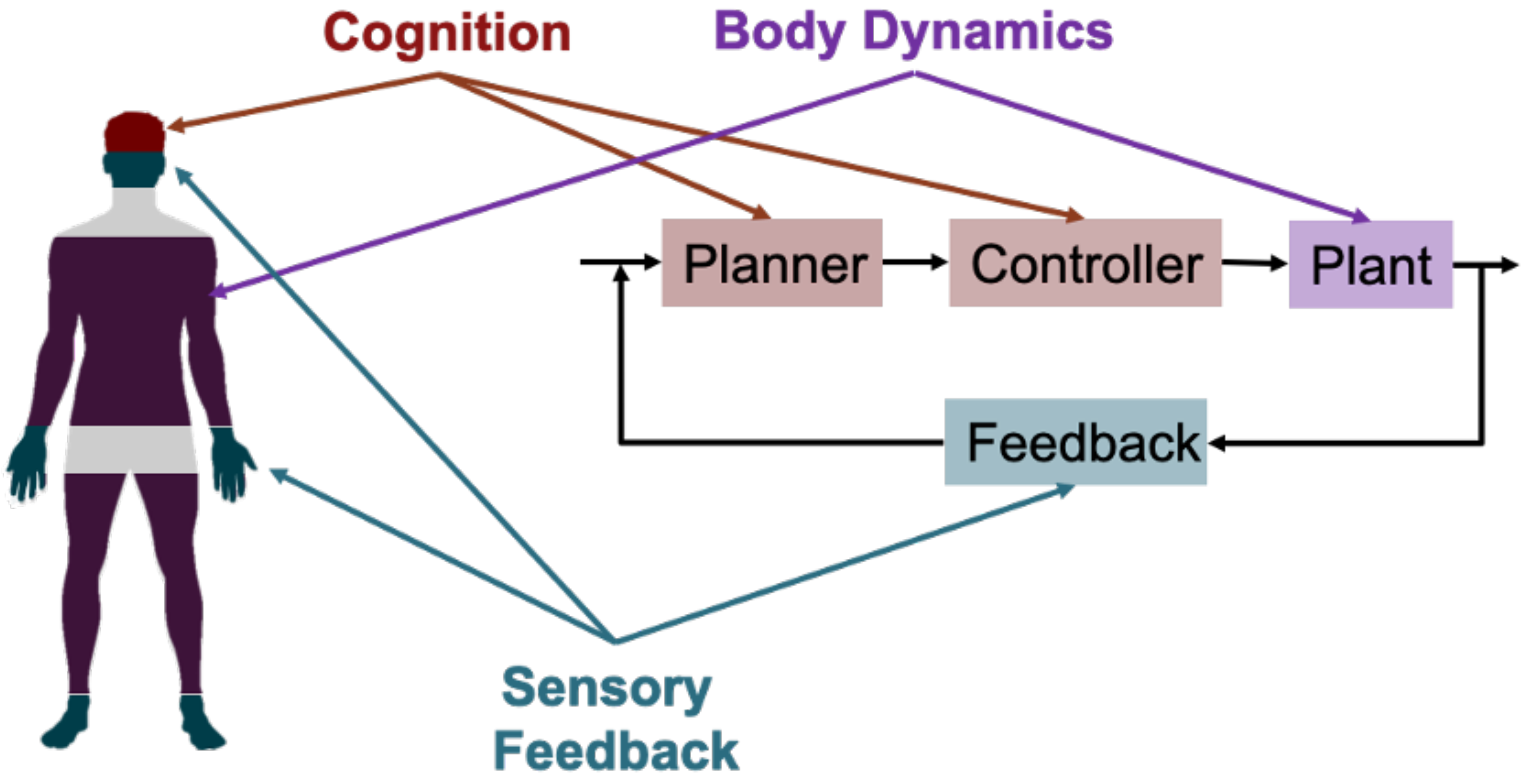
## Intelligent Wearables - Intelligent Prosthetic Arm




Guptasarma, S., & Kennedy, M. (2021). **Considerations for the Control Design of Augmentative Robots**. *IEEE IROS Workshop on Building and Evaluating Ethical Robotic Systems*.

# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Fall Prevention Sensor




Ability enhancing device usually **improves sensory feedback** concerning the world

# Assistive Robotics and Manipulation Laboratory

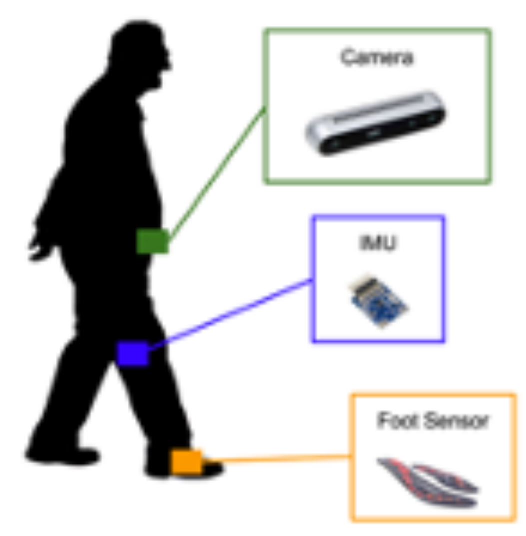
## Intelligent Wearables - Fall Prevention Sensor

**Motivation**:
Falls are the leading cause of fatal and non-fatal injuries in older adults (ages 65+). Can falls be predicted and mitigated using a wearable sensor that observes the person and the environment?

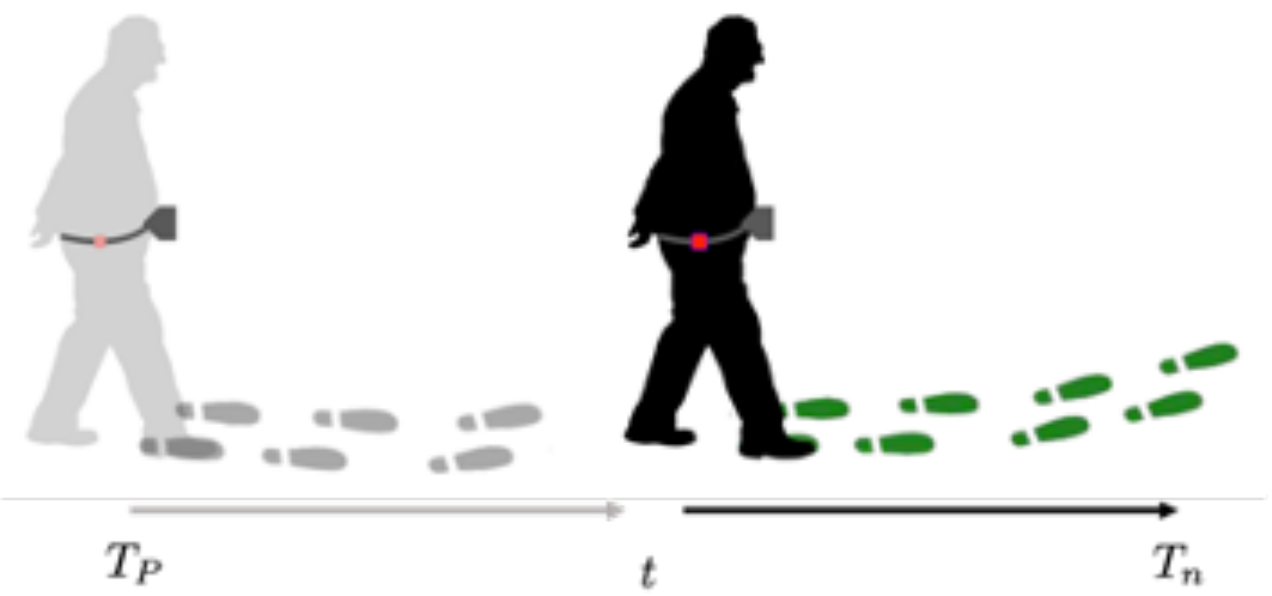
**Related work**:
**"The elderly fall risk assessment and prediction based on gait analysis"** by Jiang, Zhang, Wei.
Used wearable accelerometer to sense gait cycle and correlate to wearer fall risk (conditioned only on gait)

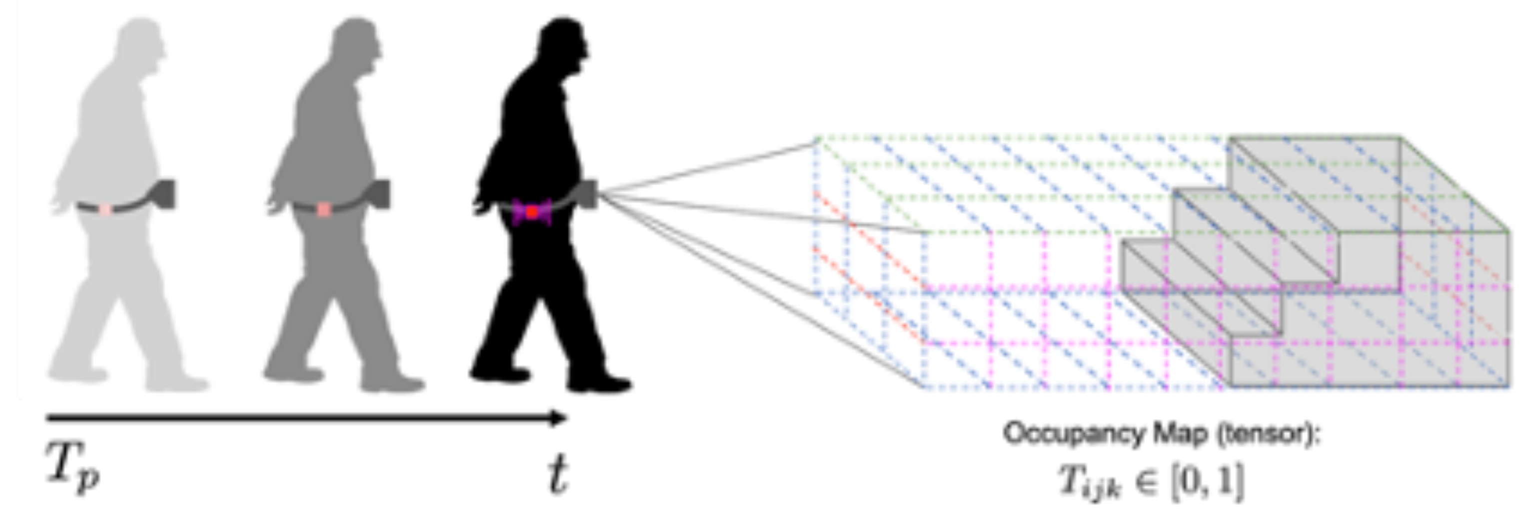
**Approach**:
We observe the persons gait and the surroundings to **predict** the path the wearer will take, their gait over that path and the associated risk of falling given that path and gait.

**Expected outcomes**:
Wearable sensor (with iterative user informed design) capable of predicting wearers path, gait and stability and warning user when risk of falling is significant.



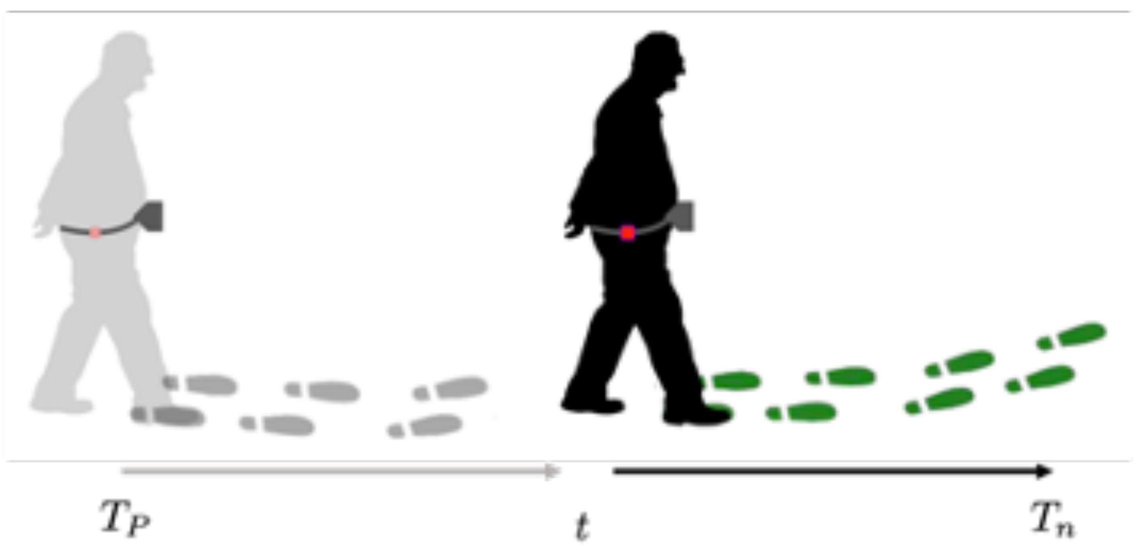

| Sensory Measurement | Model Training | Model Deployment |
|---|---|---|
| Torso Odometry (pose/twist) | ✓ | ✓ |
| Occupancy Map (obstacles) | ✓ | ✓ |
| Gait Cycle (scalar) | ✓ | ✓ |
| Leg Joint Angles (hip, knee, ankle) | ✓ | |
| Foot Pressure Map | ✓ | |



# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Fall Prevention Sensor




Past Observation (path, gait, stability)

Future Prediction (path, gait, stability)

**Inputs**

Camera, depth image

Inertial Measurement Unit
(Acceleration, angular velocity)

**Machine Learning Modeling and Prediction**

Use time series data (state history) and obstacles to predict the future states. (AutoEncoder and Recurrent Neural Networks)

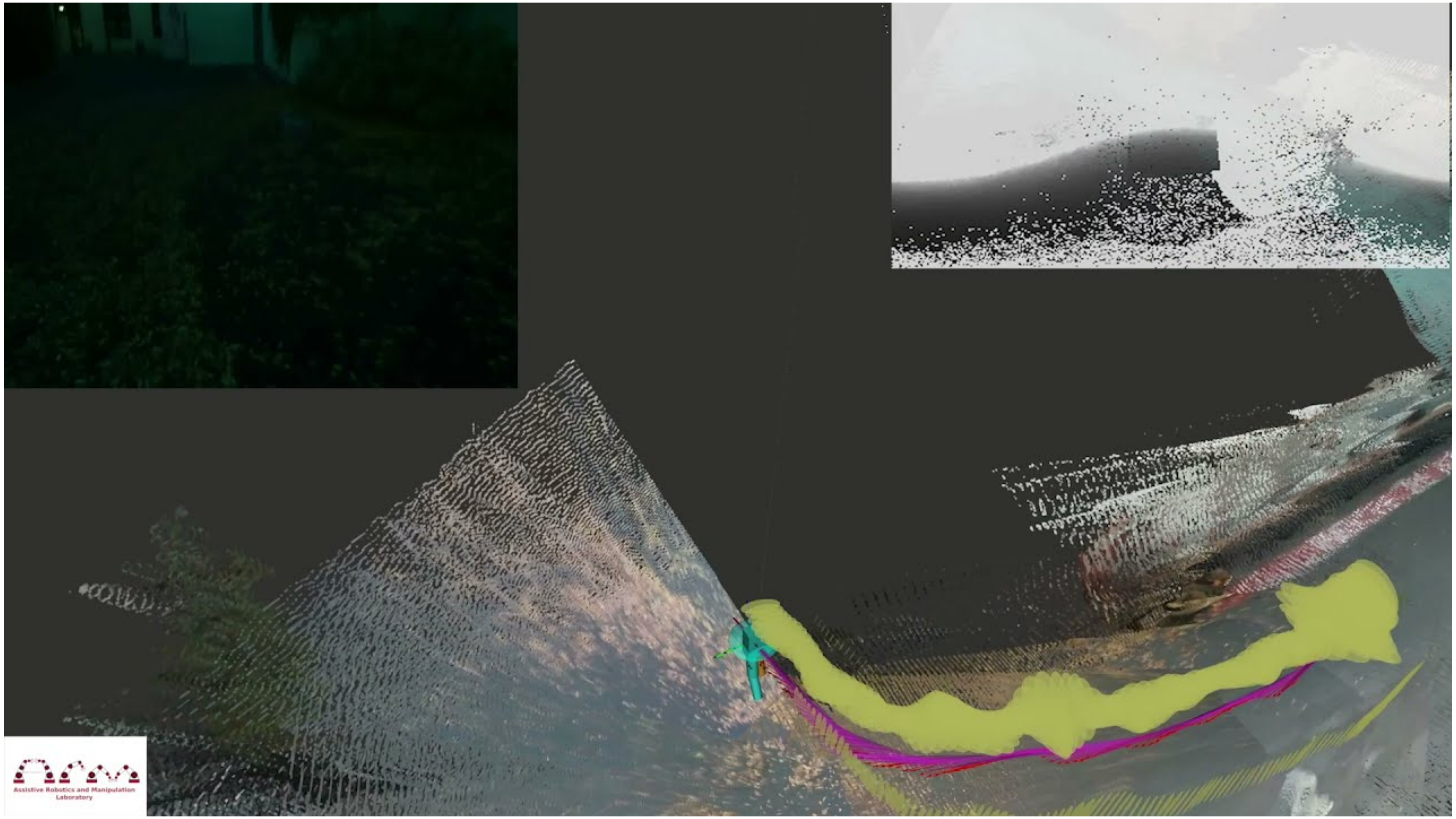
**Outputs**

Expected path, gait, stability

Alert user if instability is predicted

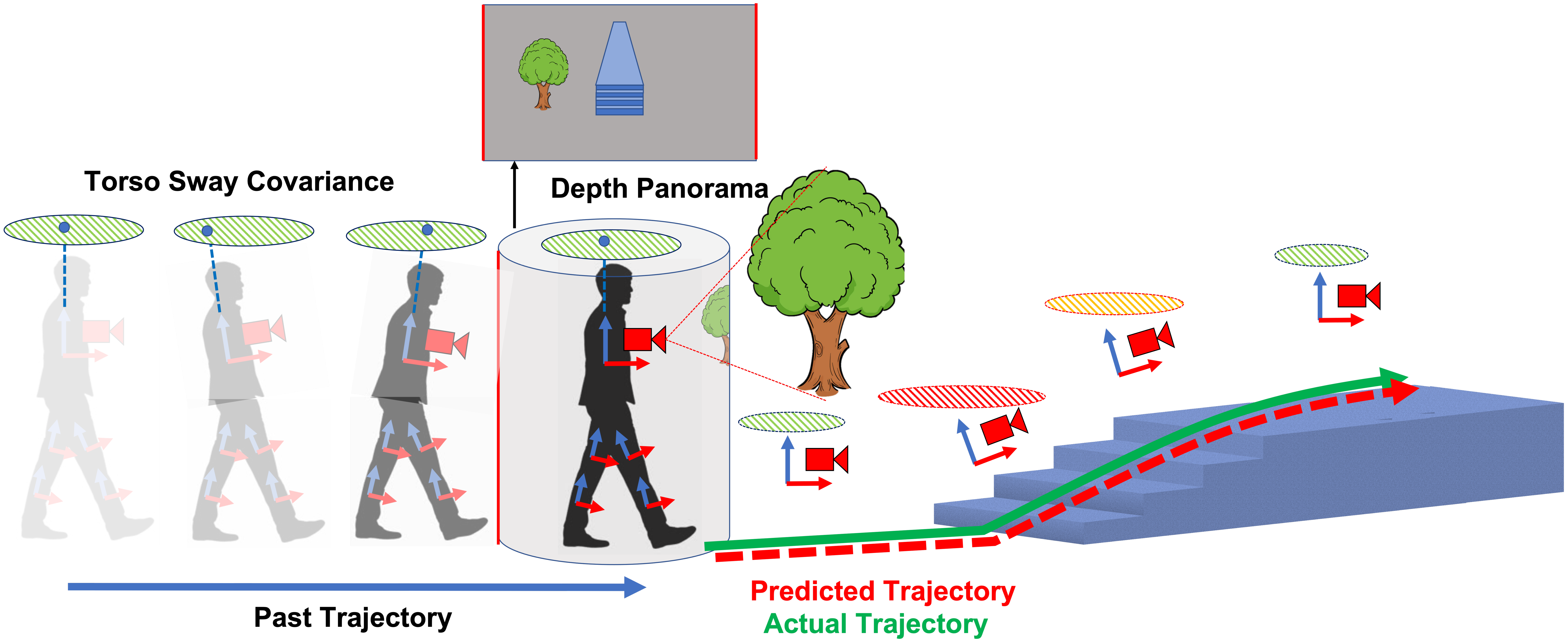
# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Fall Prevention Sensor



# Assistive Robotics and Manipulation Laboratory

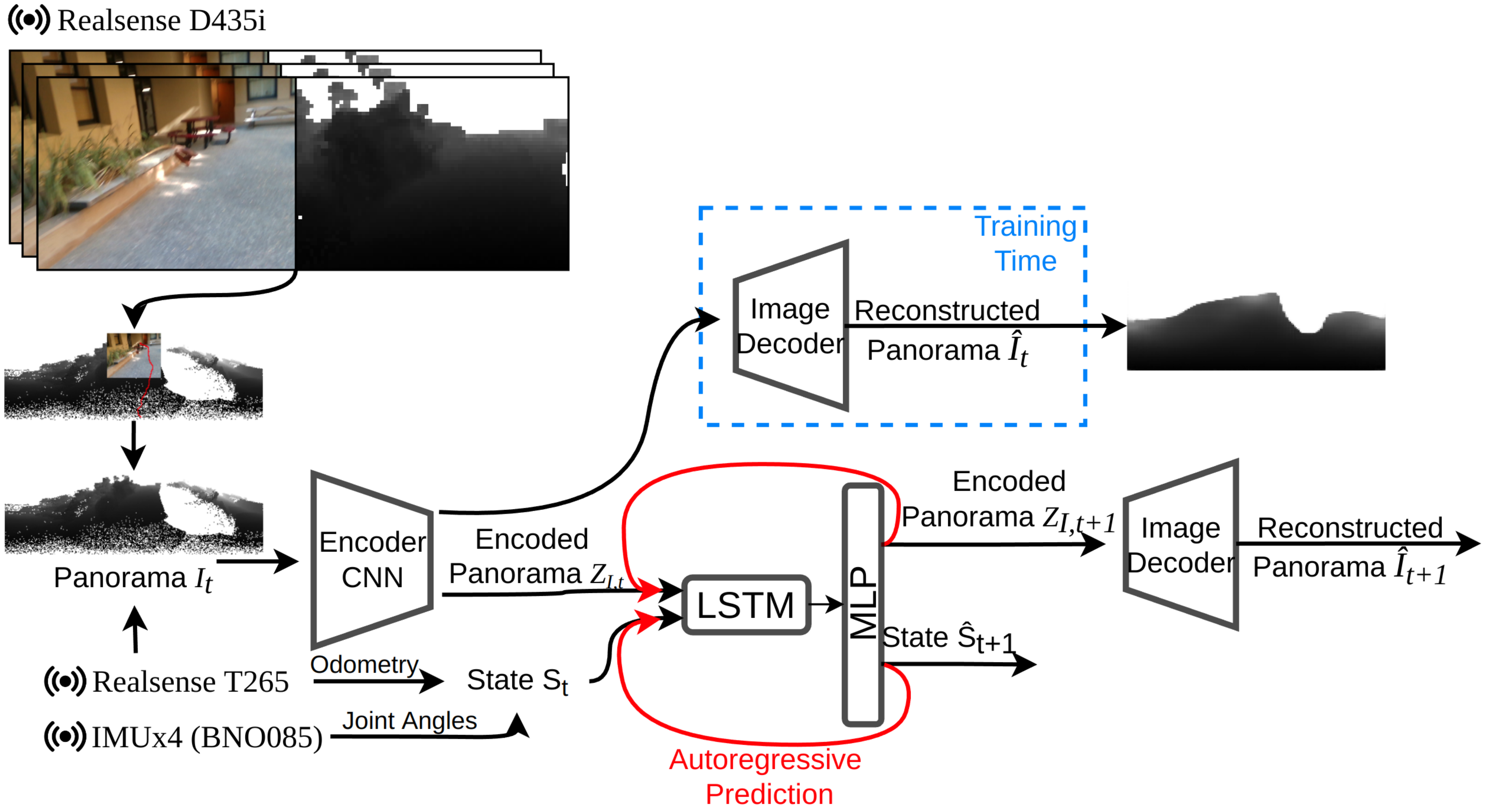
## Intelligent Wearables - Fall Prevention Sensor

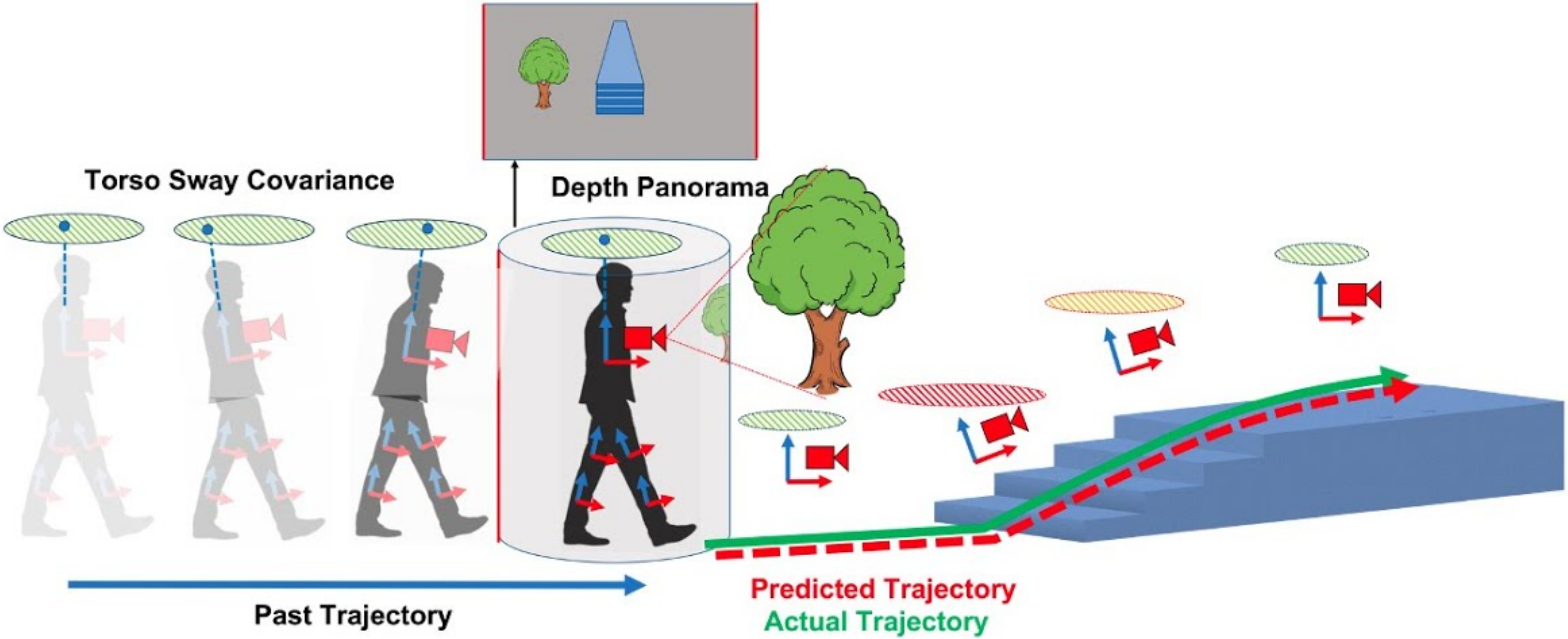



Wang, W., Raitor, M. ., Collins, S., Liu, K. ., & Kennedy, M. **Trajectory and Sway Prediction Towards Fall Prevention** ICRA 2023 accepted.

# Assistive Robotics and Manipulation Laboratory

## Intelligent Wearables - Fall Prevention Sensor





Torso Sway Covariance
Depth Panorama
Past Trajectory
Predicted Trajectory
Actual Trajectory

# Summary and Takeaways

- Prosthesis and assistive technology has made many advances over the years, but many problems exist that are still extremely burdensome for those who use this technology
- Often there is a tradeoff between performance of traditional assistive technology and the invasive requirements needed in order to afford the person a high degree of control
- **Robotics** (thinking machines) provides a unique opportunity to *bridge the gap* between the limitations of non-invasive assistive technology and the complex tasks through their ability to ***see, think and act***

# Thank you!