NRI:FND: Communicating Physical Interactions

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Goal

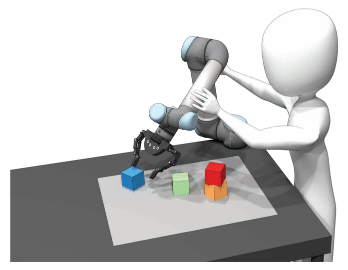
This project will develop a better understanding of and methods for communicating with robots about physical interactions.

Robot actions (grasping, pushing, stabilizing, squeezing, snapping, etc) are:
Physical Interactions: Robots must apply forces in the right places in response to the world **as well as...**
Informational Interactions: People must **specify** what they want, **interpret** what the robot is going to do and **monitor** that the robot is doing it correctly.

Communicating about physical interactions is hard enough for people:

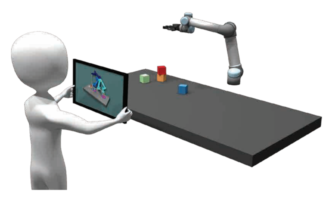
- Unfamiliar quantities (forces, torques, compliance, ...)
- Ranges of possibilities (compliances, degrees of freedom)
- Contingent behaviors (when to stop pushing or change direction)
- Need to know what not to do (as well as what to do)

But we must communicate with robots about physical interactions!

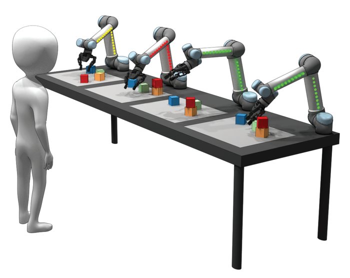


People must **specify** robot actions (e.g., teach or program robots)
How to specify the physical properties of an action conveniently?
Physical interactions are complicated to specify!
Can we make it feasible for non-experts to teach robots how to perform physical interactions?

People must **control** robots in real-time to perform physical tasks.
How to provide sufficient sensing and control of physical actions?
Users must perceive and specify physical properties.
Can we create effective real-time control without detailed haptic feedback?



People must **interpret** robot plans and policies to predict behaviors.
How present a robot's plan/ability to perform an action?
Programs for physical interactions are complicated because they involve complex actions with invisible properties and contingencies.
Can we convey robot plans and policies to non-experts?



People must **monitor** robots while they perform physical actions.
How do we monitor the robot as it performs an action?
Actions may be complex, long-running, and have invisible properties.
Can we show users the current (and historical) state of a robot action so they can be sufficiently aware?

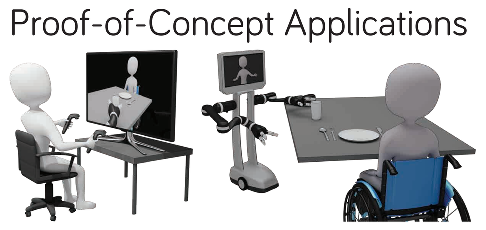
Plan

Develop strategies for more effective communication between people and robots focusing on physical interactions.

Formative Studies

Method Development

Proof-of-Concept Applications



Key Ideas

Develop strategies for effective communication between people and robots about physical interactions.

Augmented Demonstrations: It is often easier to show physical action than to describe it. However, demonstrations may not reveal the *invisible* properties in the visible actions:
- the physical properties
- the contingencies and reactivity
- the reasons why things happened
- what should *not* happen

Interpretable Representations: We need to represent actions in ways that will allow people to interpret, assess, and edit them.
- break actions into semantic segments
- use constraints to represent physical aspects of actions
- build on HCI and Data Visualization

Multimodal feedback: We need to provide information to people using careful design applying HCI and Data Visualization concepts.
- use carefully designed, task directed displays
- create real time presentation using visual, auditory, tactile, and (psuedo?) haptic feedback
- use motion properties to convey intents and other invisible aspects
- use physical displays, video overlays and augmented reality

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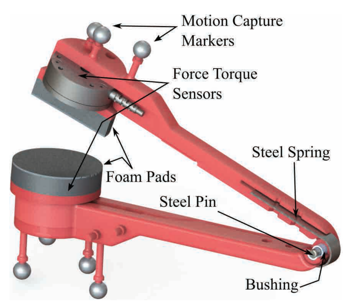
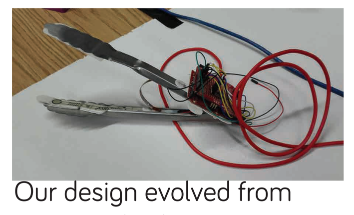
Instrumented Tongs

Obtain better demonstrations using a better input device.

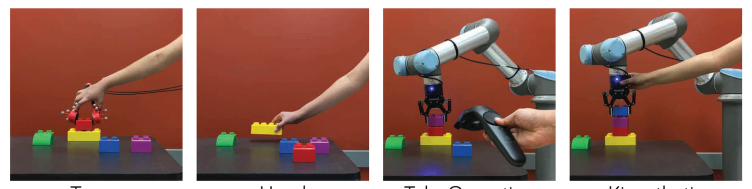


We obtain demonstrations with a device that is natural and familiar, yet more constrained than the free hand:
a pair of instrumented tongs.
Tongs are easy to instrument with position and force/torque sensors.

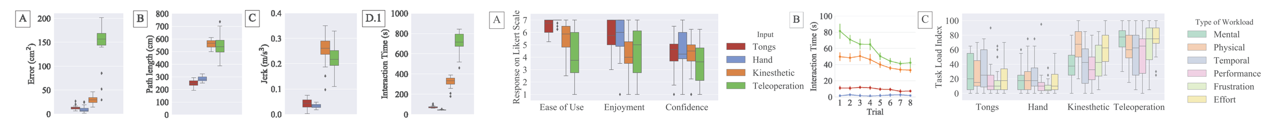


Our design evolved from common kitchen tongs

Experiment: compare tongs to common ways to obtain demonstrations [HRI19]
Results: tongs are easy and provide good demonstrations (like hands) but provide feasible demonstrations (like tele-op or kinesthetic)



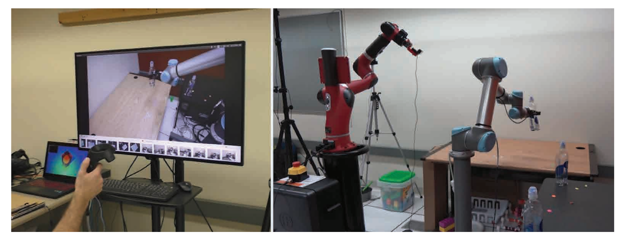
Tongs | Hand | Tele-Operation | Kinesthetic (back-drive robot)

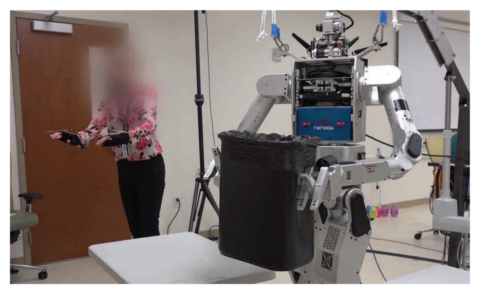


Mimicry-based Tele-operation

We create effective direct control interfaces by mapping from the user's movements to robot actions. [HRI17]
The mapping must preserve the feasibility of the robot motion while approximating the input movement.
We provide such mappings in a solver called *RelaxedIK* [RSS18].

We provide the user with awareness of the robot's movement and environment by having a second robot autonomously control a camera watching the manipulation robot. [HRI18] [RSS19]

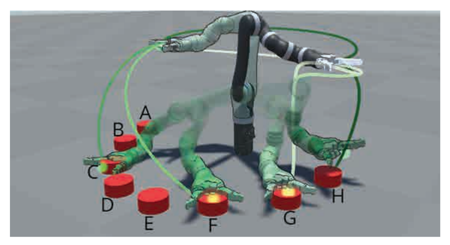




We have extended this work for bi-manual teleoperation [SciR19] allowing a user to control a pair of robot arms. To provide an effective interface, the system infers appropriate assistance modes based on the movements.
Recent work also considers the effects of latency and tobot speed on task performance [HRI20b]

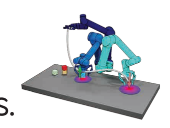
Visualization

Create visualizations to show robot motions and (in the future) plans and policies.



We have developed motion synopsis methods that visualize robot motions for rapid assessment. [ROMAN16]

Future extensions will illustrate invisible aspects such as forces.

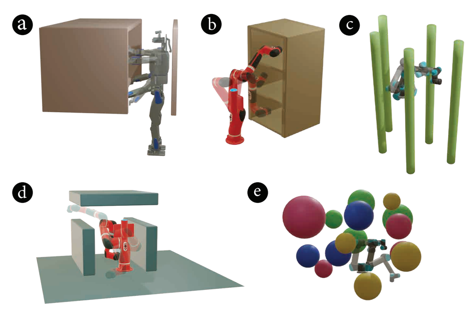


We are exploring the use of alternative displays, including Virtual Reality, Augmented Reality, and displays attached to the robot. Initial results suggest that VR offers different affordances for robot communciation [ROMAN17]

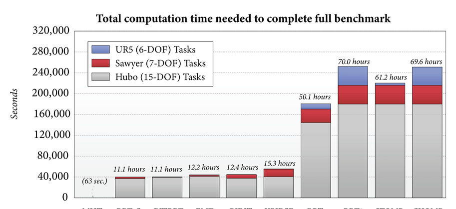
Efficient Planning

New methods provide fast, approximate methods for finding arm trajectories

We have developed motion synthesis algorithms that achieve arm trajectories that satisfy complex constraints [ICRA19a][ICRA19b].



We are developing new planning algorithms that can create motions for complex scenarios. By employing different heuristics. Our Sprint planner can create motions for single and dual arm systems much faster and more reliably than current approaches. [RAL21b]



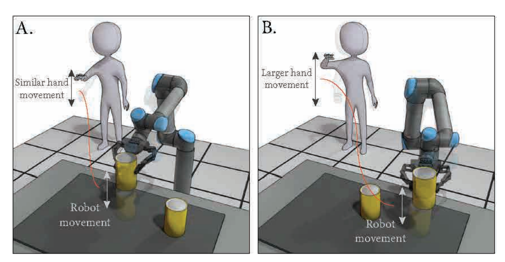
New methods can find optimal solutions for under-specified problems faster and more reliably than state-of-the-art trajectory optimizers or optimal planners [RSS21].

Haptic Illustions

Convey physical properties through movement and interaction cues, avoiding haptic displays

We have shown that we can convey a sense of weight in a tele-operation system through movement cues. [HRI20a]

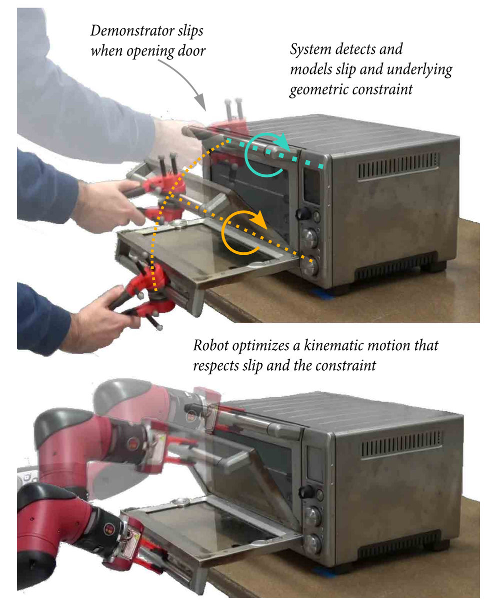
We are exploring how similar methods can be used as a general approach for conveying physical properties.



Robust Replay

Use inferred constraints to create robust robot motions from a demonstration.

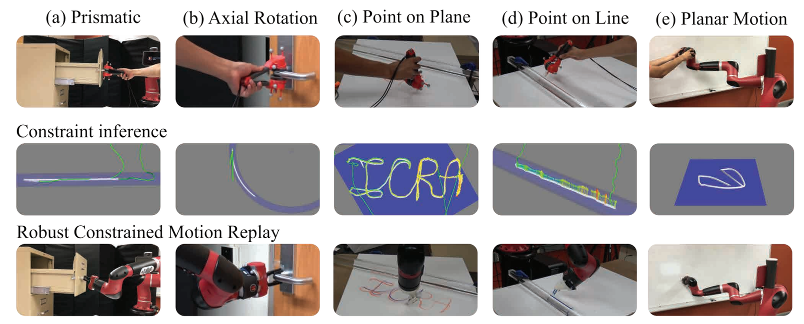
We use a demonstration, with its inferred constraints, to create robot motions that recreate movements and forces. [Arxiv20][ICRA21a]



We use *hybrid control* to "push" against the constraints as in the demonstration, matching the observed forces while mimicing other aspects of the demonstration, matching positions as possible. The robot actions are robust to changes in the constraints.

We have extended the inference process to detect intentional slip in the demonstrations, allow us to select slipping strategies where appropriate for replay.

We have used the system on a variety of tasks, including opening drawers, drawing, and turning handles.
We have used both tongs and kinesthetic demonstration to obtain actions for the robot to execute.

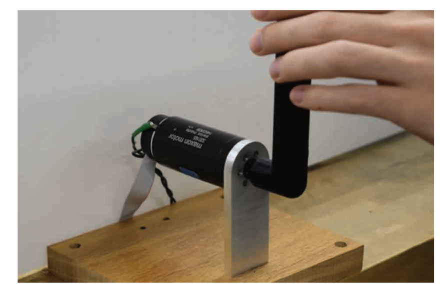


Haptic Displays

Build highly controllable haptic displays to explore how people interact with physical objects.

We have build a 1-degree of freedom haptic display that allows us to render a variety of physical sensations in a very controllable manner. A user can experience a knob or handle that provides a range of physical sensations, such as different degrees of springiness, friction, or detents.

We are using the haptic display to explore how people experience different physical sensations, how people describe what they feel, and how sensitive people are to different physical parameters.



Our goal is to establish a "haptic vocabulary" that allows us to describe a range of physical effects.

References - Recently Published/Accepted

[CoRL18] Subramani, G., Zinn, M., & Gleicher, M. (2018). Inferring geometric constraints in human demonstrations. In Conference on Robot Learning. http://arxiv.org/abs/1810.00140

[HRI19] Praveena, Subramani, Mutlu and Gleicher. Characterizing Input Methods for Human-to-Robot Demonstrations. 2019 Conference on Human Robot Interaction. doi:10.1109/HRI.2019.8673310

[SciR19] Rakita, Mutlu, Gleicher, Hiatt. Shared control-based bimanual robot manipulation. Science Robotics. 4(30). doi: 10.1126/scirobotics.aaw0955

[ICRA19a] Rakita, Mutlu, Gleicher STAMPEDE: A Discrete-Optimization Method for Solving Pathwise-Inverse Kinematics. ICRA '19. doi: 10.1109/ICRA.2019.8793617.

[ICRA19b] Praveena, Rakita, Mutlu, Gleicher. User-Guided Offline Synthesis of Robot Arm Motion from 6-DoF Paths. ICRA '19. doi: 10.1109/ICRA.2019.8793483

[RSS19] Rakita, Mutlu, Gleicher. Remote Telemanipulation with Adapting Viewpoints in Visually Complex Environments. Robotics: Science and Systems XV. doi:10.15607/RSS.2019.XV.068

[HRI20a] Praveena, Rakita, Mutlu, Gleicher. Supporting Perception of Weight through Motion-induced Sensory Conflicts in Robot Teleoperation. 2020 Conference on Human Robot Interaction.

[HRI20b] Rakita, Mutlu, Gleicher. Effects of Onset Latency and Robot Speed Delays on Mimicry-Control Teleoperation. 2020 Conference on Human Robot Interaction.

[Arxiv20] Subramani, Hagenow, Gleicher, Zinn. A Method for Constraint Inference Using Pose and Wrench Measurements. arXiv:2010.15916

[RAL21a] Hagenow, Senft, Radwin, Gleicher, Mutlu, and Zinn, Corrective shared autonomy for addressing task variabilit. Accepted for Publication,

[RAL21b] Rakita, Mutlu, Gleicher. Single-query Path Planning Using Sample-efficient Probability Informed Trees. Accepted to appear.

[ICRA21a] Hagenow, Subramani, Zhang, Mutlu, Zinn, Gleicher. Recognizing Orientation Slip in Human Demonstrations. Accepted to appear.

[ICRA21b] Rakita, Mutlu, Gleicher. Strobe: An Acceleration Meta-algorithm for Optimizing Robot Paths using Concurrent Interleaved Sub-Epoch Pods. Accepted to appear.

[ICRA21c] Rakita, Shi, Mutlu, Gleicher. CollisionIK: A Per-Instant Pose Optimization Method for Generating Robot Motions with Environment Collision Avoidance. Accepted to Appear.

References - Submitted for Publication

[RSS21] Rakita, Mutlu, Gleicher. Hydra: A Method for Efficiently Solving Boundary-objective Optimal Motion Planning. Submitted March, 2021.

References - Recently Published (supported by prior awards)

ICRA/RAL18] Subramani, G., Gleicher, M., & Zinn, M. (2018). Recognizing Geometric Constraints in Human Demonstrations Using Force and Position Signals. IEEE Robotics and Automation Letters, 3(2), 1252–1259. http://doi.org/10.1109/LRA.2018.2795648

[HRI17] Rakita, D., Mutlu, B., & Gleicher, M. (2017). A Motion Retargeting Method for Effective Mimicry-based Teleoperation of Robot Arms. In Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction - HRI '17 (pp. 361–370). http://doi.org/10.1145/2909824.3020254

[HRI18] Rakita, D., Mutlu, B., & Gleicher, M. An Autonomous Dynamic Camera Method for Effective Remote Teleoperation. In Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction - HRI '18 (pp. 325–333). http://doi.org/10.1145/3171221.3171279. Best Paper Award.

[IJRR18] Bodden, C., Rakita, D., Mutlu, B., & Gleicher, M. (2018). A flexible optimization-based method for synthesizing intent-expressive robot arm motion. The International Journal of Robotics Research, online first. http://doi.org/10.1177/0278364918792295

[IROS17] Subramani, G., Rakita, D., Wang, H., Black, J., Zinn, M., & Gleicher, M. (2017). Recognizing actions during tactile manipulations through force sensing. In 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (pp. 4386–4393). http://doi.org/10.1109/IROS.2017.8206302

[ROMAN16] Rakita, D., Mutlu, B., & Gleicher, M. (2016). Motion synopsis for robot arm trajectories. In 2016 IEEE Symposium on Robot and Human Interactive Communication (RO-MAN) (pp. 281–287). IEEE. http://doi.org/10.1109/ROMAN.2016.7745143

[ROMAN17] Liu, O., Rakita, D., Mutlu, B., & Gleicher, M. (2017). Understanding human-robot interaction in virtual reality. In 2017 IEEE Symposium on Robot and Human Interactive Communication (RO-MAN) (pp. 751–757). http://doi.org/10.1109/ROMAN.2017.8172387

[RSS18] Rakita, D., Mutlu, B., & Gleicher, M. (2018). RelaxedIK: Real-time Synthesis of Accurate and Feasible Robot Arm Motion. In Robotics: Science and Systems XIV. http://doi.org/10.15607/RSS.2018.XIV.043

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