NRI:FND: Communicating Physical Interactions

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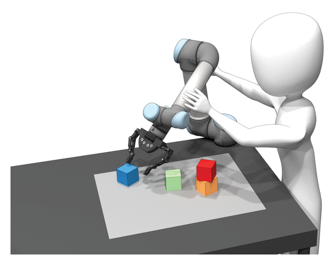
Goal

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.

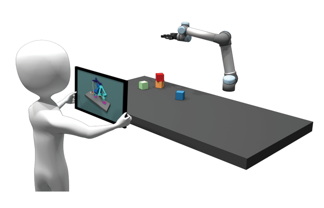
Communicating about physical interactions is hard enough for people:
- Unfamiliar quantities (forces, torques, compliance, …)
- Ranges of possibilities (compliances, degrees of freedom)
- Contingent behaviors (when to stop pushing or change direction)
- Need to know what not to do (as well as what to do)

But we must communicate with robots about physical interactions!

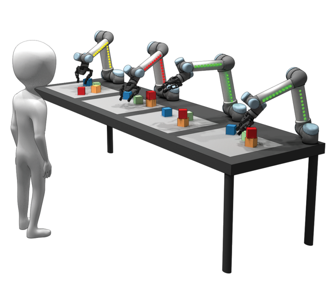


People must **specify** robot actions (e.g., teach or program robots)
How to specify the physical properties of an action conveniently?
Physical interactions are complicated to specify!
Can we make it feasible for non-experts to teach robots how to perform physical interactions?

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?

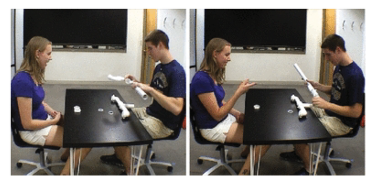


People must **monitor** robots while they perform physical actions.
How do we monitor the robot as it performs an action?
Actions may be complex, long-running, and have invisible properties.
Can we show users the current (and historical) state of a robot action so they can be sufficiently aware?

Plan

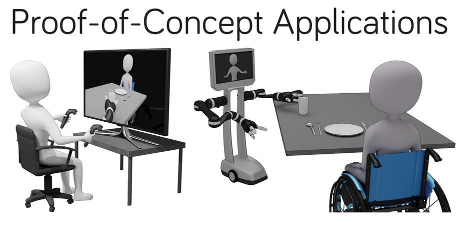
Develop strategies for more effective communication between people and robots focusing on physical interactions.

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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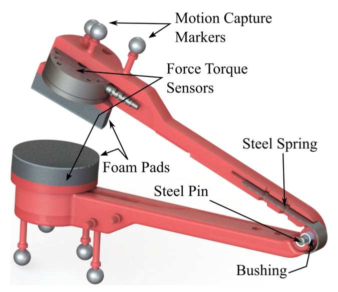
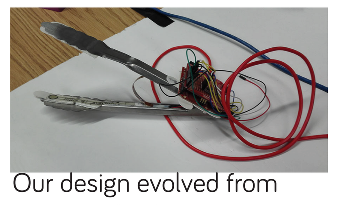
Instrumented Tongs

Obtain better demonstrations using a better input device.

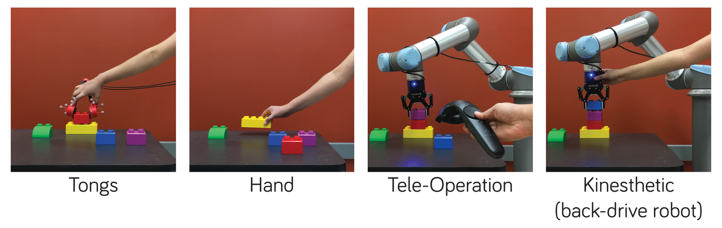


We obtain demonstrations with a device that is natural and familiar, yet more constrained than the free hand:
a pair of instrumented tongs.
Tongs are easy to instrument with position and force/torque sensors.

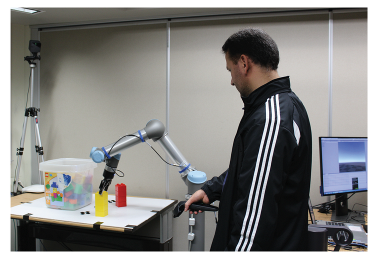


Our design evolved from common kitchen tongs

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)

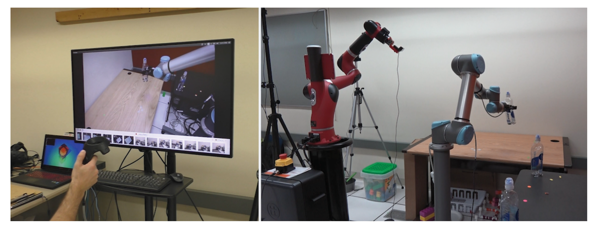


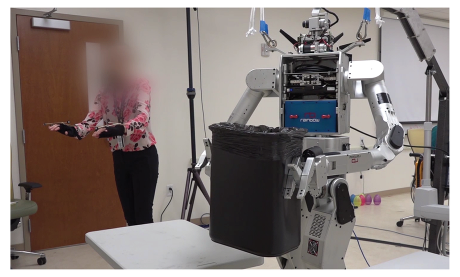
Mimicry-based Teleoperation



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]

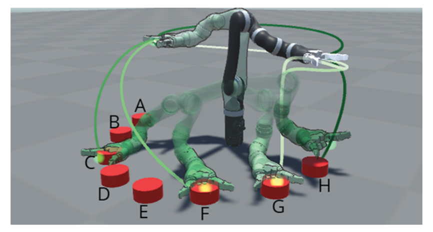




We have extended this work for bi-manual teleoperation [SciR19] allowing a user to control a pair of robot arms. To provide an effective interface, the system infers appropriate assistance modes based on the movements. Recent work also considers the effects of latency and robot speed on task performance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

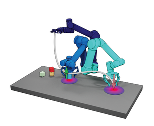
Visualization

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.

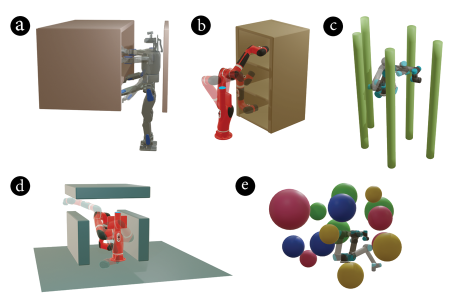


We are exploring the use of alternative displays, including Virtual Reality, Augmented Reality, and displays attached to the robot. Initial results suggest that VR offers different affordances for robot communication [ROMAN17]

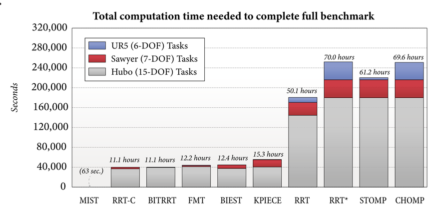
Efficient Planning

Memory and Information Sharing Trees (MIST) enable robust and efficient planning

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 MIST planner can create motions for single and dual arm systems much faster and more reliably than current approaches. [RSS20a]



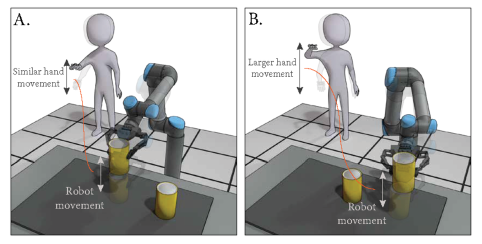
Extensions to MIST will allow us to create motions for high degree of freedom manipulators that consider physical constraints in cluttered environments.

Haptic Illusions

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

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

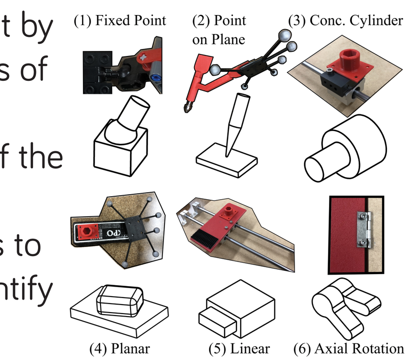
We are exploring how similar methods can be used as a general approach for conveying physical properties.

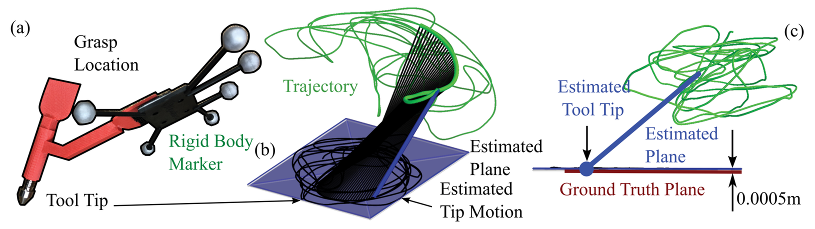


Constraint Inference

Infer constraints in a demonstration by analyzing forces and movements.

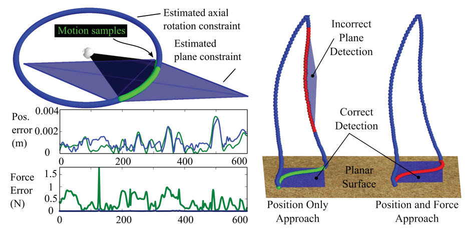
We infer what constraints are active in a demonstration segment by fitting observed motions and forces to the mathematical models of the constraints. [TRo20] [RSS20b] [CoRL18]
We use robust least-squares fitting over short sliding windows of the demonstration, and combine windows to identify constraints.
Choosing the constraint that best fits the observations allows us to select from a variety of constraint types. We can accurately identify constraint type, parameters, and timing.





We can determine the constraint type as well as its parameters:
e.g., when grasping a pen, we can infer the writing surface.
(markers on pen used to establish ground truth)
(in practice, we instrument the tongs)

We need force, moment and position information to determine constrained movements.
Positions alone are ambiguous: a free movement may happen to move in a planar or circular path.
Our methods check that both positions and wrenches (force/torques) fit the constrained model.

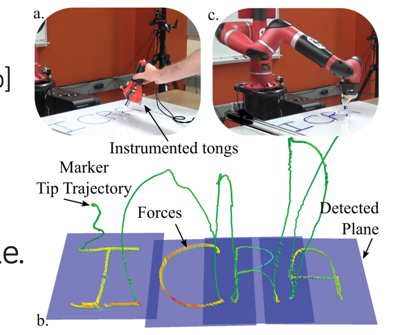


Robust Replay

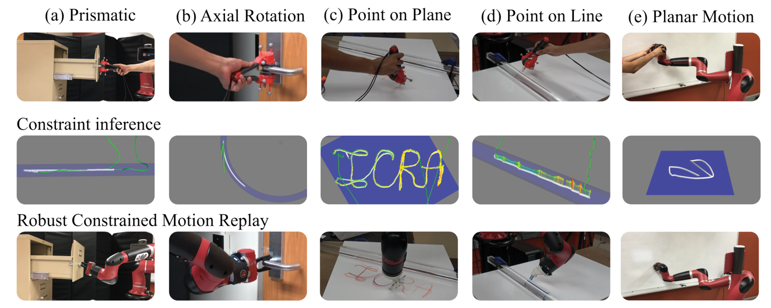
Use inferred constraints to create robot motions from a demonstration.

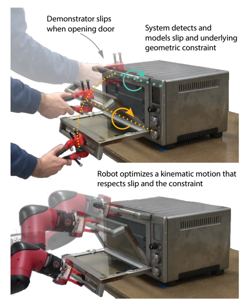
We use a demonstration, with its inferred constraints, to create robot motions that recreate movements and forces. [TRo20][RSS20b]

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

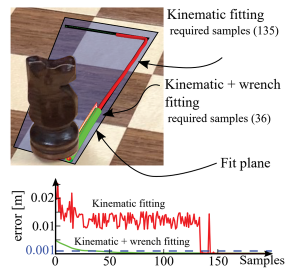


We have used the system on a variety of tasks, including opening drawers, drawing, and turning handles.
We have used both tongs and kinesthetic demonstration to obtain actions for the robot to execute.





By using constraint models, we are able to identify and parameterize common human strategies, such as slip on a handle, and leverage these strategies during replay to produce more favorable robot kinematics. [RSS20b]



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

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[RSS20b] Hagenow, Subramani, Zhang, Mutlu, Zinn, Gleicher. Recognizing Orientation Slip in Human Demonstrations. submitted Jan, 2020.

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Visual Computing Lab

Human Computer Interaction Lab