NRI:FND: Communicating Physical Interactions

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Michael Gleicher
Department of Computer Sciences
University of Wisconsin - Madison

Bilge Mutlu
Department of Computer Sciences
University of Wisconsin - Madison

Michael Zinn
Department of Mechanical Engineering
University of Wisconsin - Madison

Pragathi Praveena, Daniel Rakita, Guru Subramani

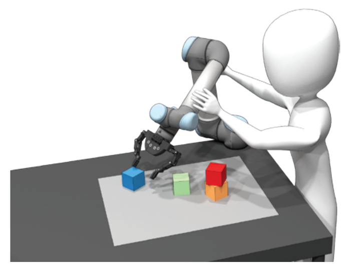
Goal

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.

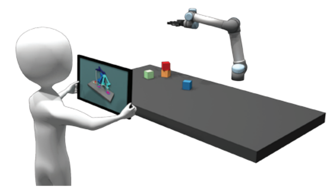
Communicating about physical interactions is hard enough for people:
- Unfamiliar quantities (forces, torques, compliance, ...)
- Ranges of possibilities (compliances, degrees of freedom)
- Contingent behaviors (when to stop pushing or change direction)
- Need to know what not to do (as well as what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

But we must communicate with robots about physical interactions!

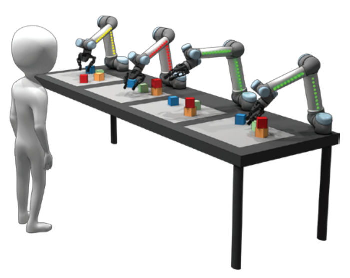


People must **specify** robot actions (e.g., teach or program robots)
How to specify the physical properties of an action conveniently?
Physical interactions are complicated to specify!
Can we make it feasible for non-experts to teach robots how to perform physical interactions?

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?

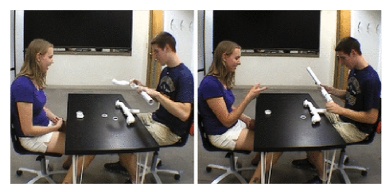


People must **monitor** robots while they perform physical actions.
How do we monitor the robot as it performs an action?
Actions may be complex, long-running, and have invisible properties.
Can we show users the current (and historical) state of a robot action so they can be sufficiently aware?

Plan

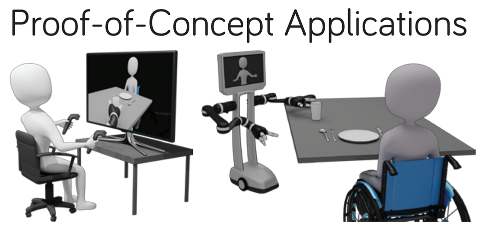
Develop strategies for more effective communication between people and robots focusing on physical interactions.

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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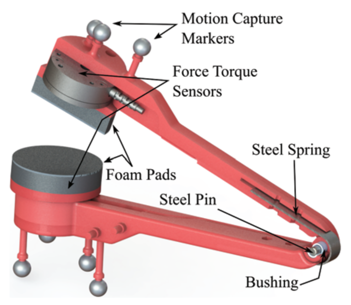
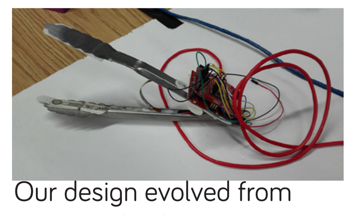
Instrumented Tongs

Obtain better demonstrations using a better input device.

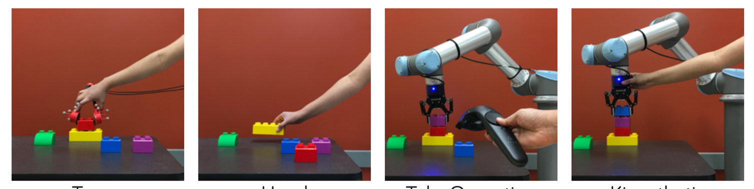


We obtain demonstrations with a device that is natural and familiar, yet more constrained than the free hand:
a pair of instrumented tongs.
Tongs are easy to instrument with position and force/torque sensors.

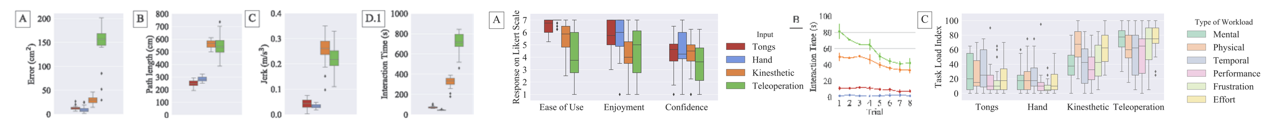


Our design evolved from common kitchen tongs

Experiment: compare tongs to common ways to obtain demonstrations [HRI19a]
Results: tongs are easy and provide good demonstrations (like hands) but provide feasible demonstrations (like tele-op or kinesthetic)

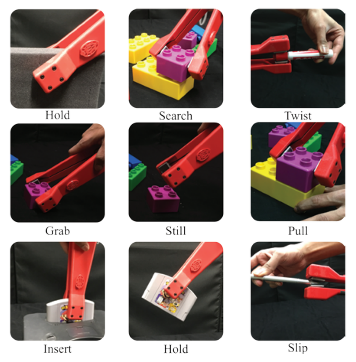


Tongs | Hand | Tele-Operation | Kinesthetic (back-drive robot)



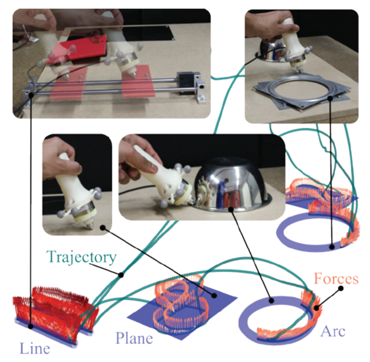
Segmentation

Break demonstrations into semantically relevant chunks using position and force information.



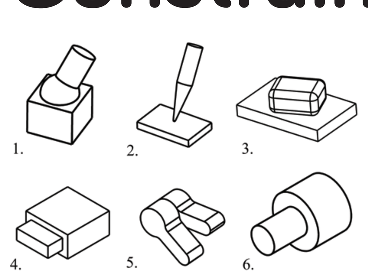
We divide demonstrations into semantically and physically consistent subsections by classification trained using wavelet features. [IROS2017]

Each segment can be described concisely.

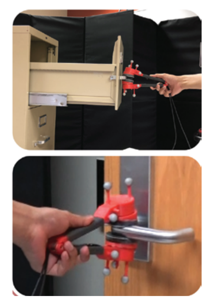


Constraints

We use mechanical constraints to represent movements, explaining why things happen and what should not happen.



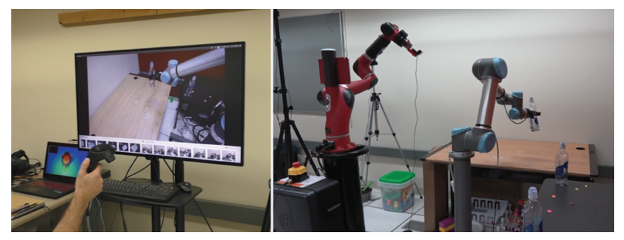
Mechanical constraints provide a concise description of physical interactions. They represent information that is not in the movement itself: information about the causes of the movement, and the limitations of it.



Mimicry-based Tele-operation

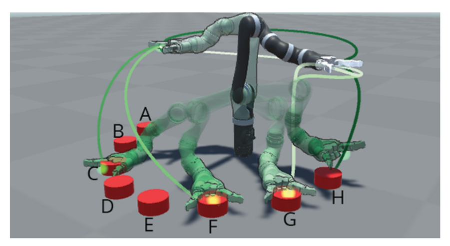
We create effective direct control interfaces by mapping from the user's movements to robot actions. [HRI17]
The mapping must preserve the feasibility of the robot motion while approximating the input movement.
We provide such mappings in a solver called *RelaxedIK* [RSS18].

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] [HRI19b]



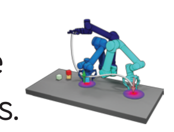
Visualization

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



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

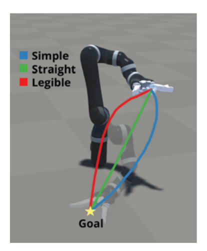
Future extensions will illustrate invisible aspects such as forces.



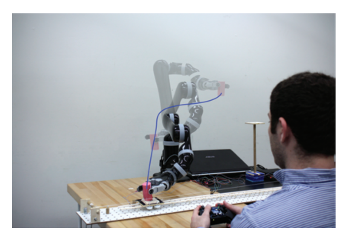
We are exploring the use of alternative displays, including Virtual Reality, Augmented Reality, and displays attached to the robot. Initial results suggest that VR offers different affordances for robot communciation [ROMAN17]

Movement Design

Robot movements can communicate action properties.



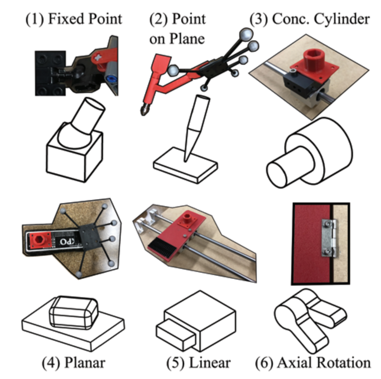
We have developed methods to synthesize robot movements that both achieve tasks as well as communicate goals to human observers. [IJRR18]
We will extend these methods to show invisible properties beyond robot intent.

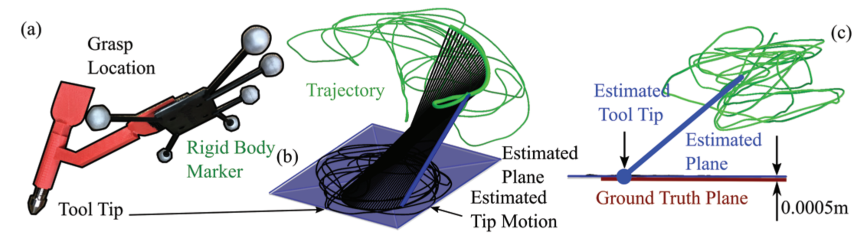


Constraint Inference

Infer constraints in a demonstration by analyzing forces and movements.

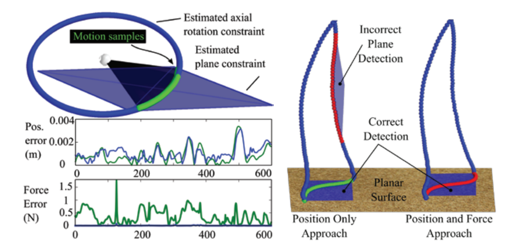
We can infer what constraints are active in a demonstration segment by fitting observed motions and forces to the mathematical models of the constraints. [ICRA/RAL18] [CoRL18]
We use robust least-squares fitting over short sliding windows of the demonstration, and combine windows to identify constraints.
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 statics fit the constrained model. [ICRA/RAL18] [CoRL18]

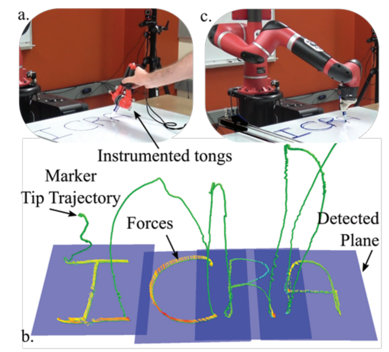


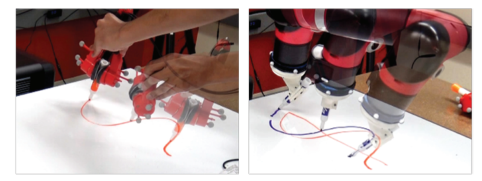
Robust Replay

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. [ICRA/RAL19]

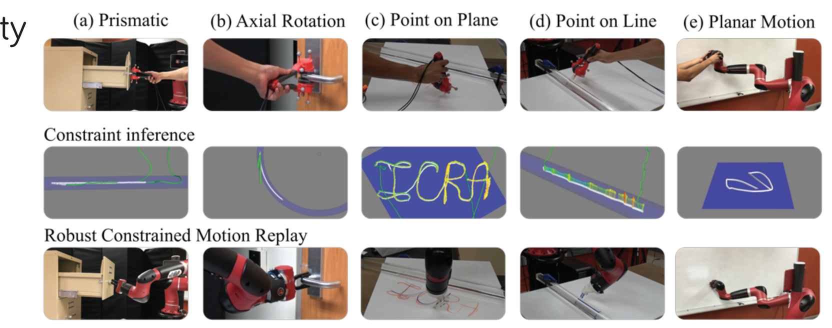
We use *force control* to "push" against the constraints as in the demonstration, matching the observed forces.
We use *position control* to mimic other aspects of the demonstration, matching positions as closely as possible.





The robot actions are robust to changes in the constraints (e.g., moving the surface)

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.



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