Inverted Trust Improves Shared Control of Complex Dynamic Systems

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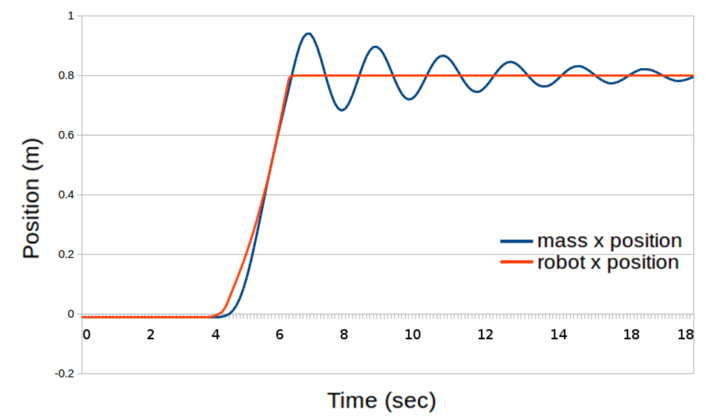
Motivation

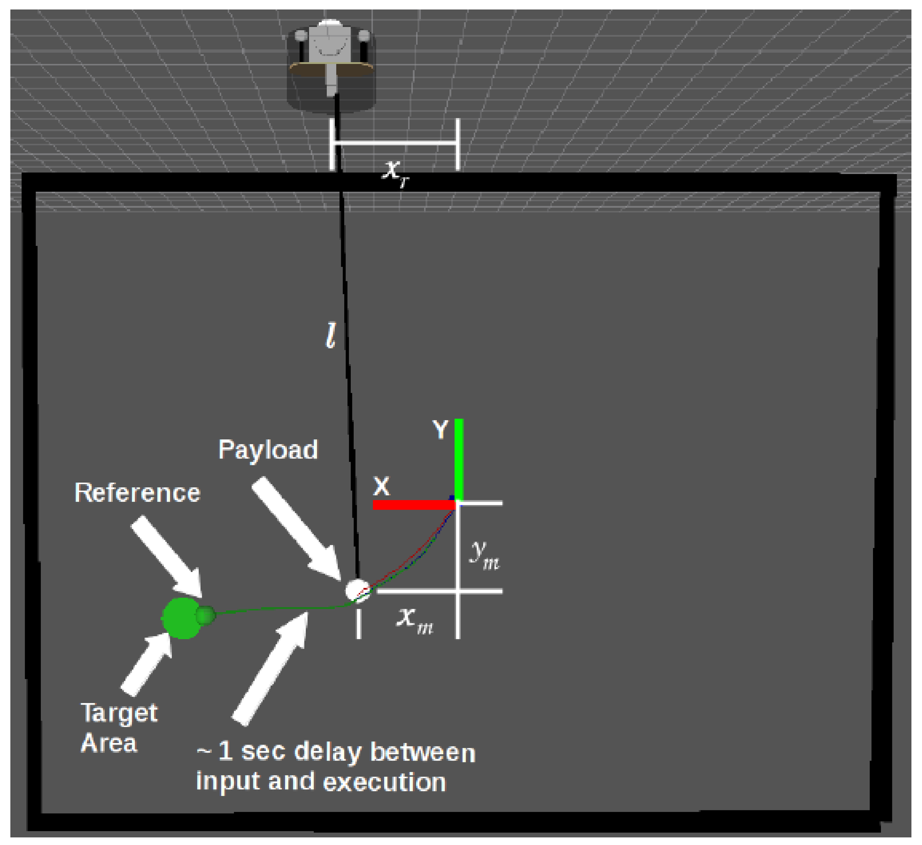
- Increasing pervasiveness of autonomous robots in human environments. Can we formalize the trust a robot has in a human?
- Need for control sharing that allows humans to interact with and shape robot behaviors, leveraging the strengths of the human and robot



- Control sharing improves general system utility by leveraging the strengths of the human and robot
- Essential attribute of shared control systems is an understanding of each by the other

Approach

- Automation good at controlling highly dynamic systems
- However, it requires a reference trajectory
- A human can provide the reference trajectory
- *But how much control should the user have?*



- System allocates control authority to the human user, based on a trust metric that represents human capabilities
- Aim : Trust metric improves system stability

Formulation of Trust

- Trust metric (τ) is inversely related to deviation (δ) from the reference trajectory:

$$\delta \sim N(\mu, \sigma^2)$$

Computed with Fréchet distance → δ; Mean and variance of an individual's deviation history → $N(\mu, \sigma^2)$

$$\tau_i = \tau_{i-1} + \gamma \cdot \mathscr{P}\{\delta = \delta_i\}$$

Updated trust → τ_i; Previous trust → τ_{i-1}; Learning rate → γ; Probability of most recent deviation → $\mathscr{P}\{\delta = \delta_i\}$

Modulation of User Input

- Modulation achieved through a combination of low-pass filter and scaling the input speed based on the trust metric :

$$\omega = (\omega_{max} - \omega_{min}) \cdot (\tau_i)^{\lambda} + \omega_{min}$$

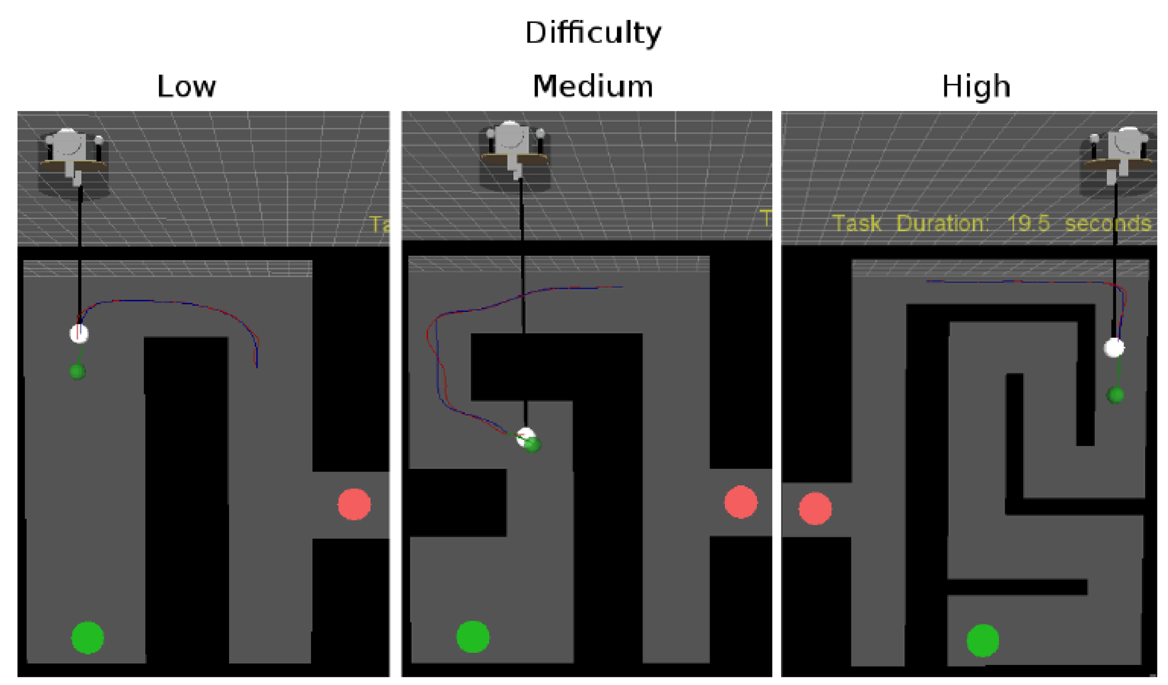
Low-pass filter → ω; Max. and min. cutoff frequency → ω_{max}, ω_{min}; Steepness parameter → λ; Updated trust metric → τ_i

$$\tilde{v}_i = \tau_i \cdot v_i$$

Scaled user input → $\tilde{v}_i$; Updated trust metric → τ_i; User input → v_i

Experimental Design

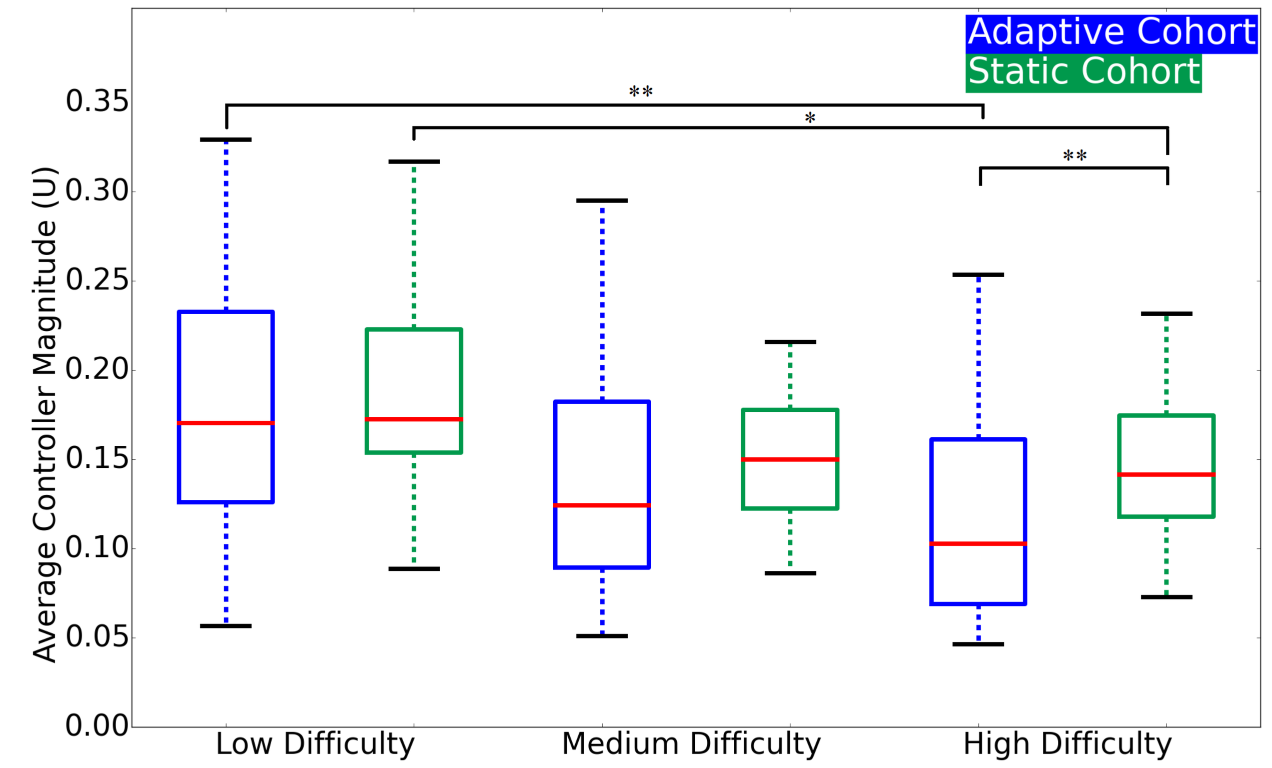
- Environment : Simulated planar crane system
- Task : Navigate series of 3 mazes



- 22 users randomly grouped into 2 cohorts
  - (1) Static: Trust level held static after initial training
  - (2) Adaptive: Trust level evolves during experiment
- Experiment: 5 trials of direct control followed by 5 trials of shared control, on each of the 3 levels of maze difficulty (20 trials in total)

Results

- Goal : Analyze system's ability to modulate user's input to produce more stable reference trajectories
- Metric : Average controller magnitude (U)



- Statistically significant **decrease in average controller magnitude** between low and high difficulty mazes in both cohorts
- Statistically significant **difference between Static and Adaptive cohorts** in high difficulty mazes
- No statistical evidence that either cohort is better in low and medium mazes

Conclusion

- Developed a control-theoretic formulation of the trust a robot has in a human partner.
- Demonstrate adaptive trust metric enables human operators to produce references trajectories that are significantly easier for the controller to track.
- Results reflect the system's ability to learn pertinent information about a user.

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