Caging in Time:

A Framework for Robust Object Manipulation under Uncertainties and Limited Perception

Gaotian Wang[1] *gw23@rice.edu*

Kejia Ren[1] *kr43@rice.edu*

Andrew S Morgan[2] *amorgan@theaiinstitute.com*

Kaiyu Hang[1] *kaiyu.hang@rice.edu*

[1] Department of Computer Science, Rice University, Houston, TX, 77005, USA

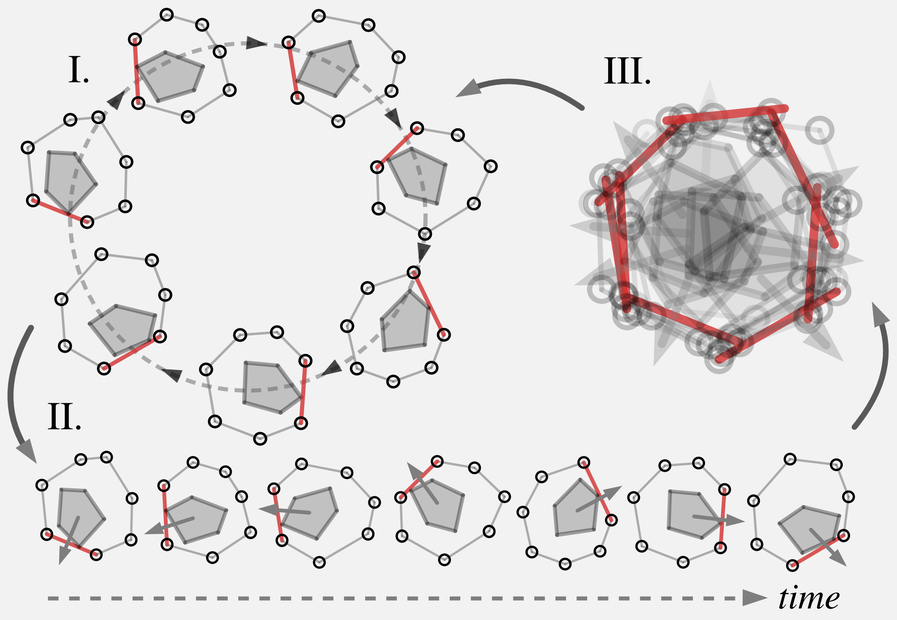
[2] The AI Institute, Cambridge, MA, 02142, USA

Video

Paper

Insights

I. Ideally **multiple robots** are needed to fully cage an object;
II. Only **one robot is effectively needed at a time** to ensure that the object doesn't escape from the cage;
III. Strategically built cage is possible with **only one robot in time.**

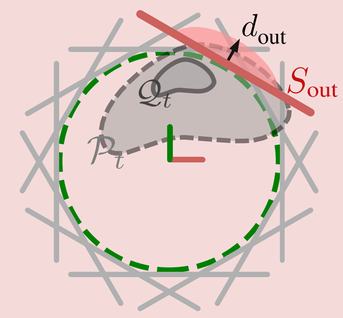


Contributions

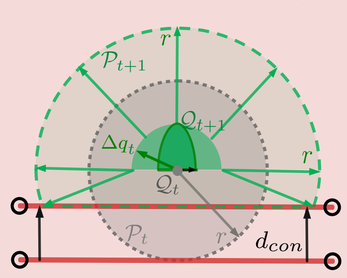
- A planning paradigm for robust robot manipulation that can **entirely remove the effect of perception uncertainties in an open-loop manner**;
- Broadening the traditionally narrowly scoped caging-based manipulation to **a more general manipulation framework** enabled by strategic robot motions;
- A possibility to precisely manipulate objects without sensing feedback, for the first time, to **support robust manipulation where perception is not reliable**

Quasi-static Pushing

Geometry-based Cage

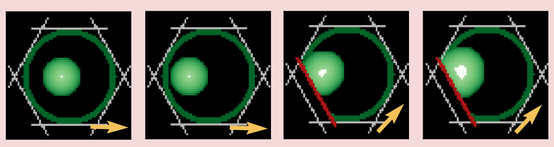


Potential State Set (PSS)



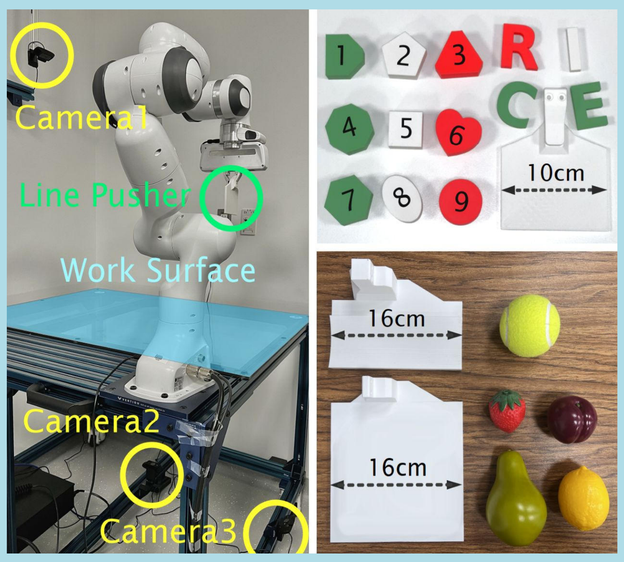
PSS is propagated to predict all possible motions for strategical actions for caging.

PSS propagation theory framework is built upon **Tangent bundle** theory



Pixel-based PSS propagation

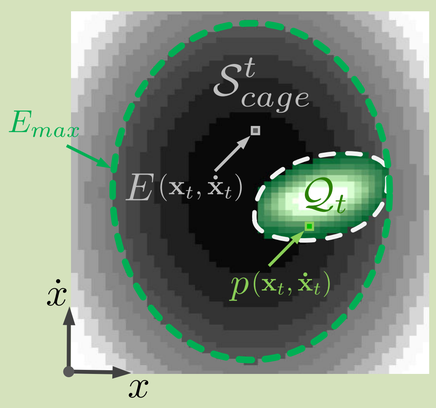
Experiment Setup

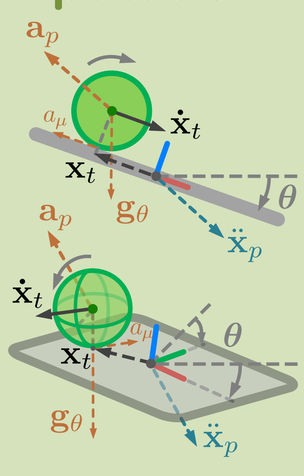


Cameras were only used for recording and visualizing trajectories

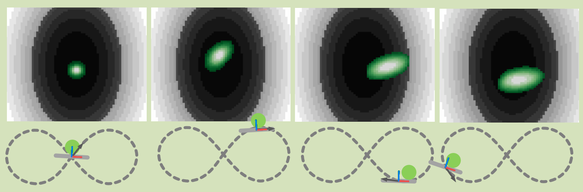
Dynamic Ball Manipulation

Energy-based Cage



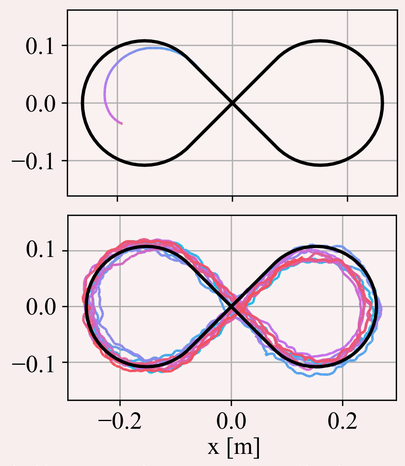


PSS can be defined with any state, and caged by any metrics



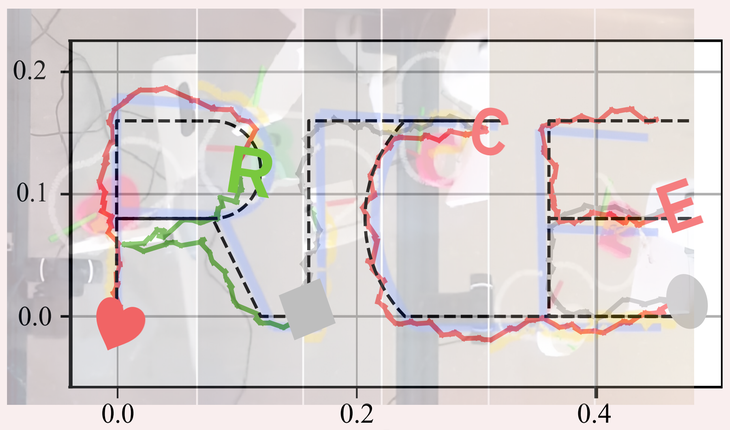
Pixel-based PSS propagation

Why Caging in Time?



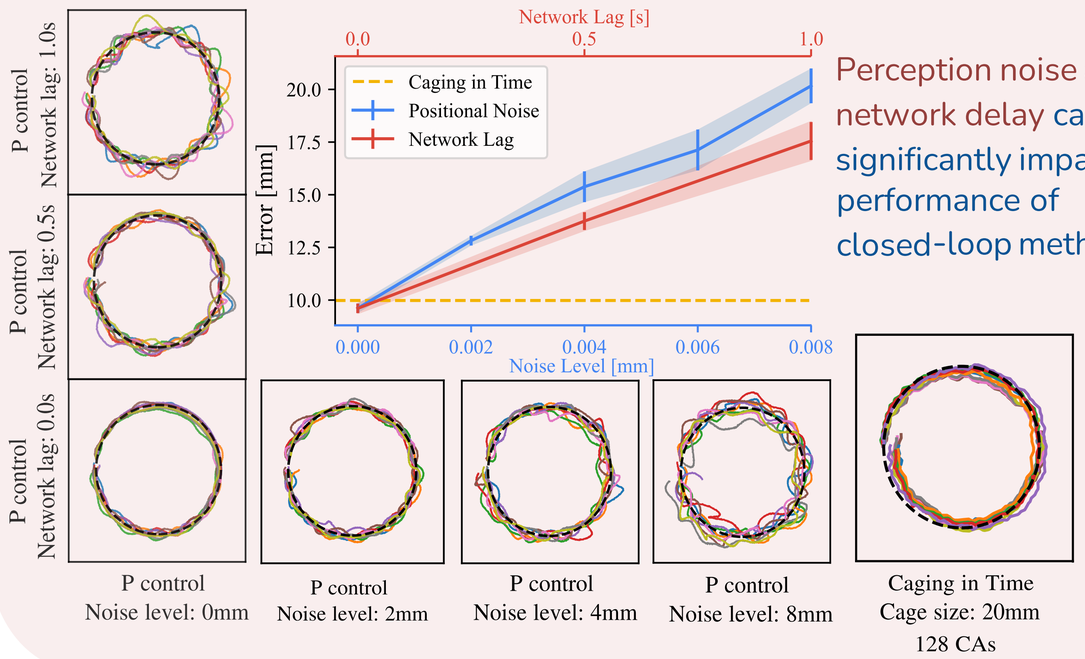
A line pusher can easily lose control of the object purely open-loop.

In-task Perturbations



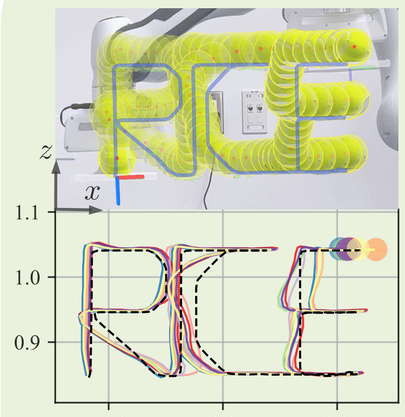
Unknown objects are sequentially inserted with random positions inside the current PSS

Why not Closed-loop?

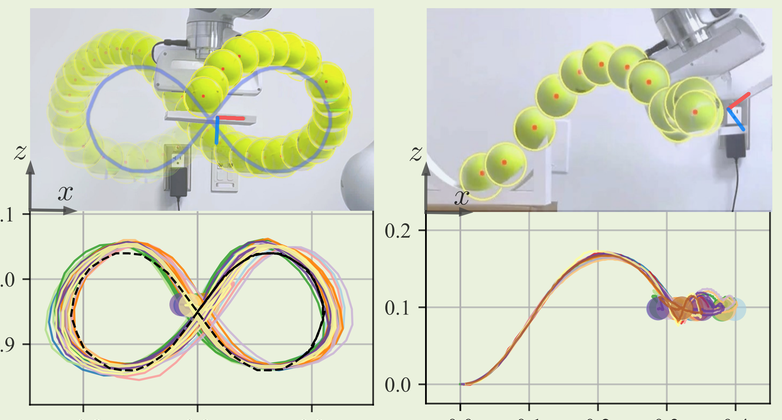


Perception noise and network delay can significantly impair the performance of closed-loop methods.

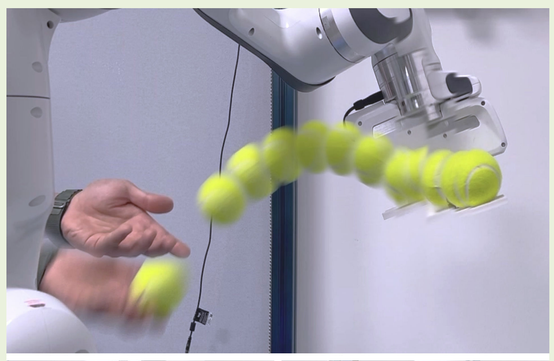
Ball Balancing (1D)

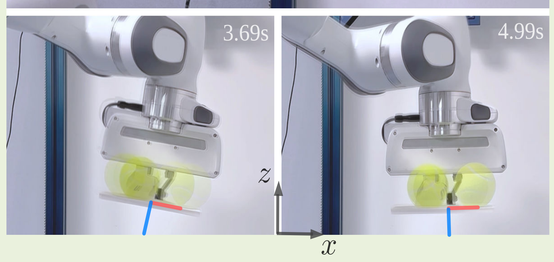


Ball Catching

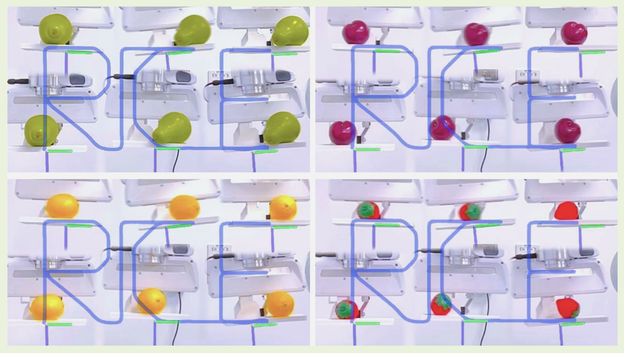


Ball Catching (Human Toss)

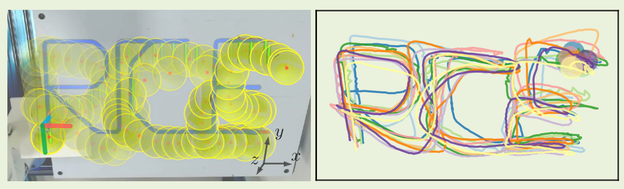




Fruits Balancing



Ball Balancing (2D)



With a suitable PSS propagation function, Caging in Time is also capable of robust manipulation for dynamic tasks in an open loop way