RF-Compass:
Robot Object Manipulation Using RFIDs

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Limitation of Today's Robotic Automation

Fixed-position, single-task robot

- Limited to large-volume production line
- Inability to change manufacturing process

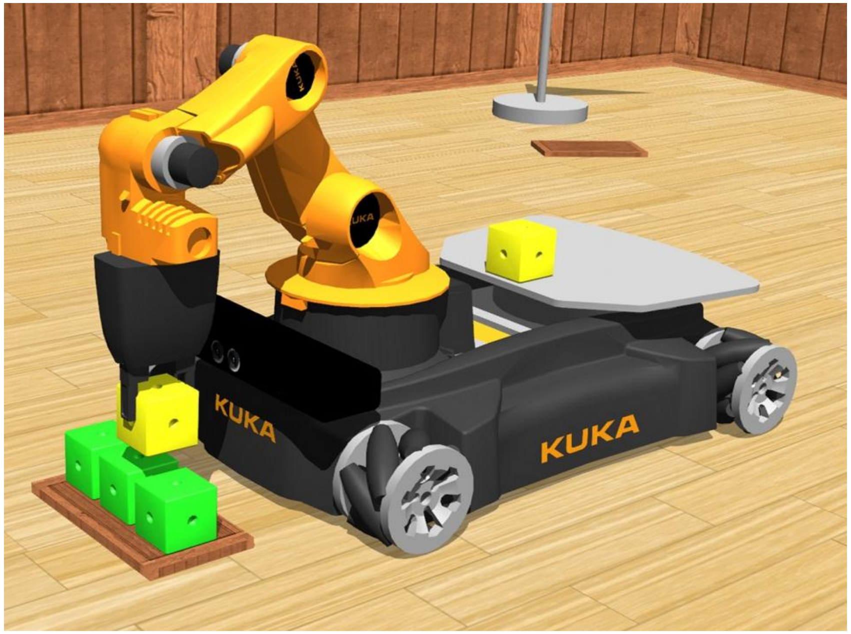
Toyota has been slowly backing away from heavy automation. The labor saved by robots was **wasted most of all by reprogramming robots**.

The potential for much broader industrial acceptance is tied to the development of robots that can **absorb data, recognize objects, and respond to information and objects in their environment with greater accuracy**.

This is the **future**. A new wave of robots, far **more adept** than those now commonly used by automakers and other heavy manufacturers.

Mobile Manipulation

Fetching, grasping, and manipulating objects



- Extend automation to small/medium factories
- Easy to reconfigure manufacturing process

Requirements for Mobile Manipulation

- Centimeter-scale localization, e.g., 2cm
- Minimal instrumentation → portable

Current Approaches

- Motion capture system, e.g., VICON
  - Sub-centimeter accuracy
  - Heavy instrumentation & Expensive

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- Imaging (e.g., optical camera, Kinect, LIDAR)
  - Needs prior training

or

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 or  ?

Do not work in NLOS/occlusion

Can RF localization help?

Current RF localization schemes are too coarse

- State-of-the-art WiFi localization: 23cm [*ArrayTrack*]

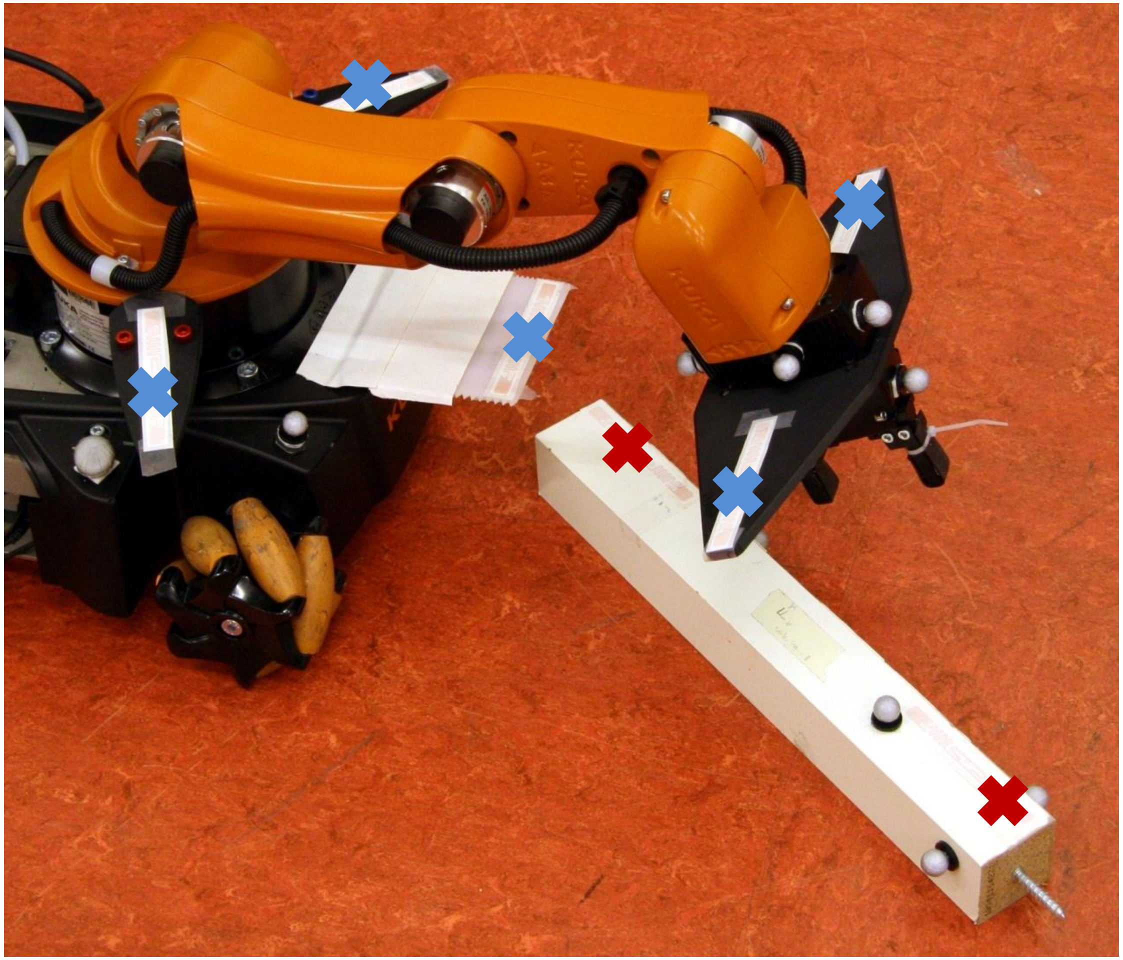
- State-of-the-art RFID localization: 11cm [*PinIt*]

  BUT requires a dense grid of reference tags

How to get a few cm accuracy without environment instrumentation?

RF-Compass

- Place RFID tags on both robot and objects
- No reference tags in the environment

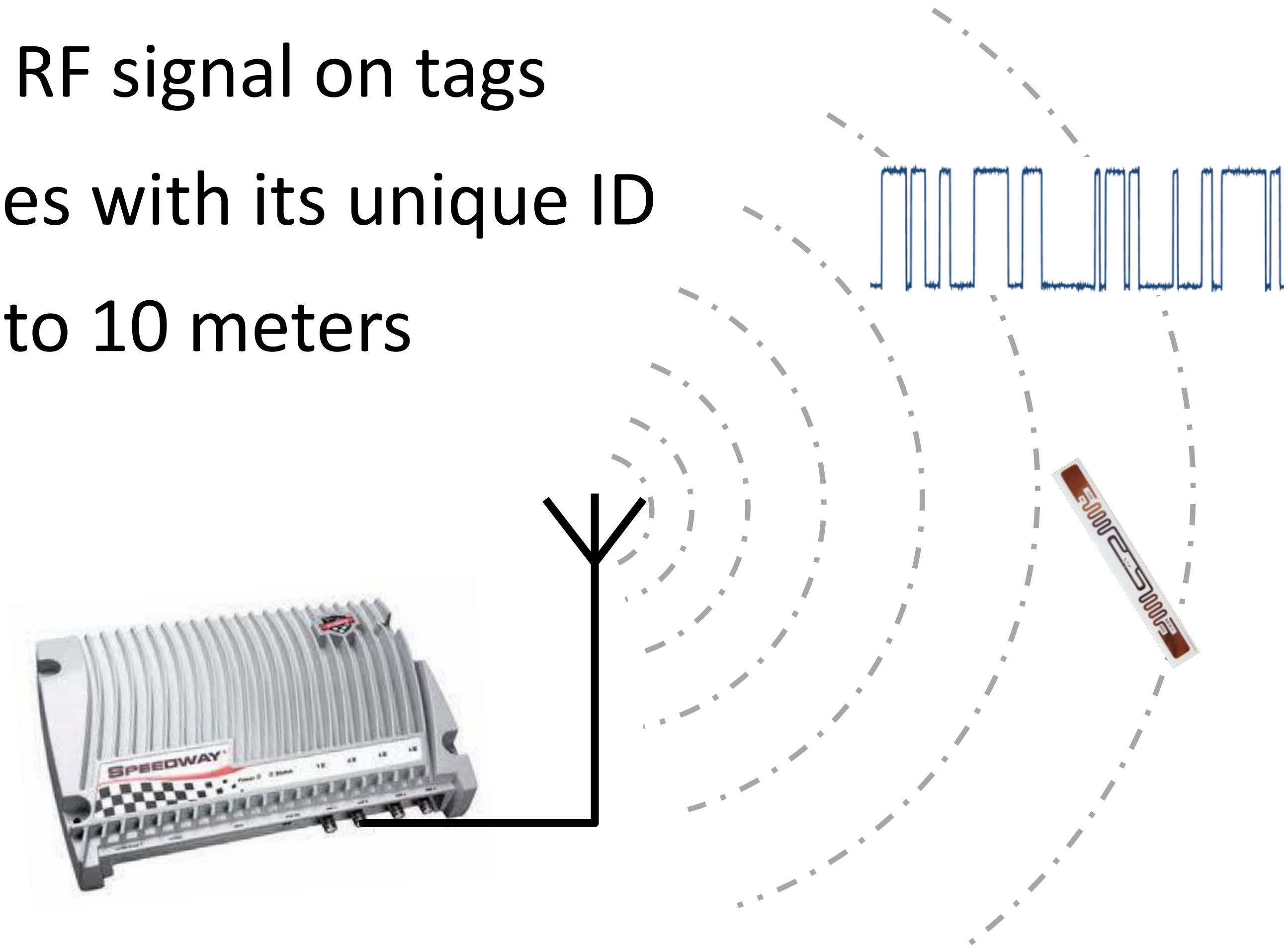


Identifying the Object

- RFID: a passive sticker – no battery, low cost
- Reader shines RF signal on tags

→ Each tag replies with its unique ID

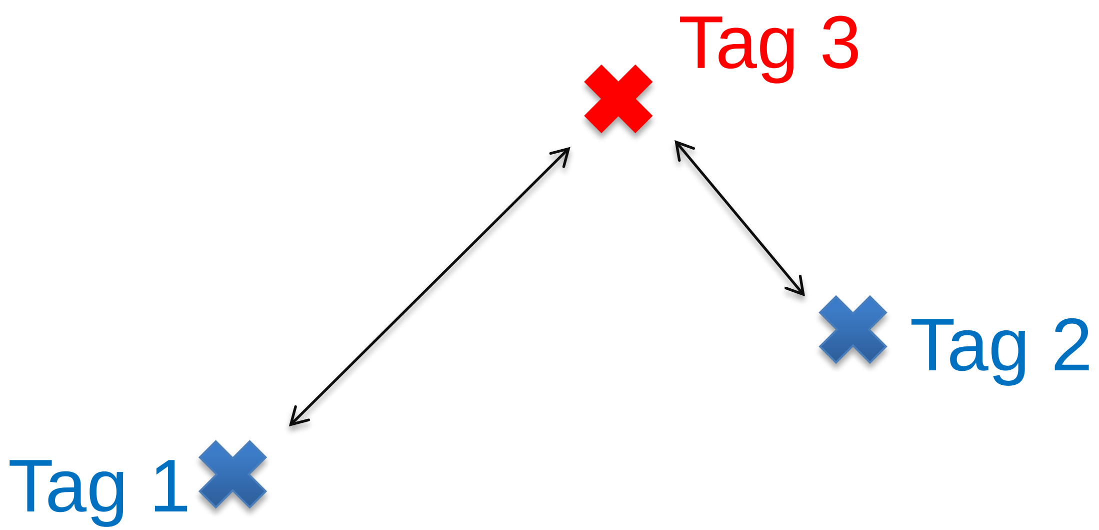
→ Works for up to 10 meters



How to get centimeter-scale accuracy?

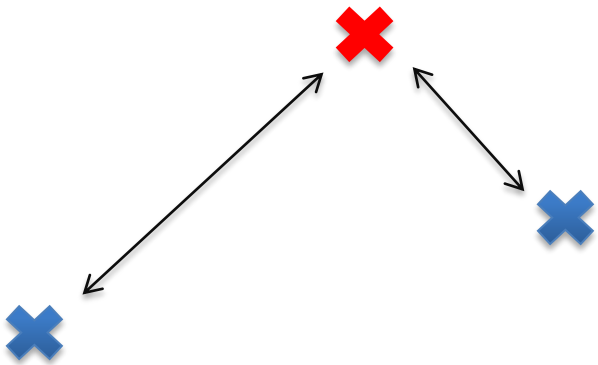
Building block: RF pairwise comparison

- Compare distances between RFIDs

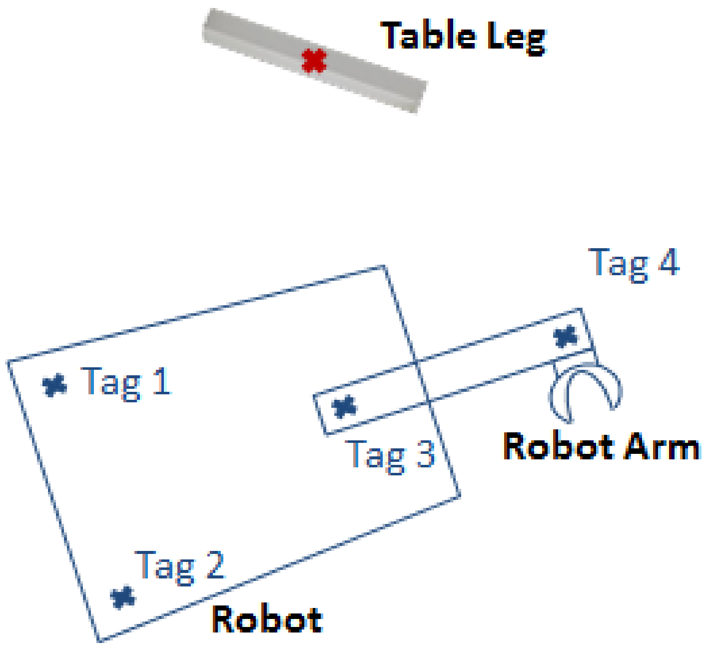


Distance ordering based on signal similarity [SIGCOMM'13]

Basic building block ? 2cm accuracy

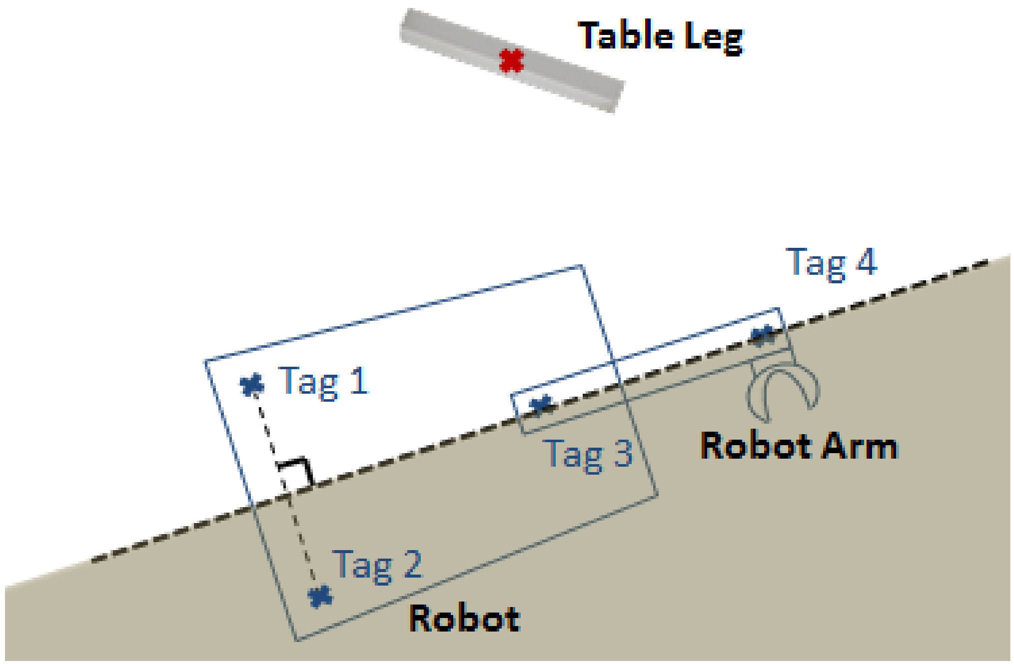


Basic Idea: Localization by Partitioning



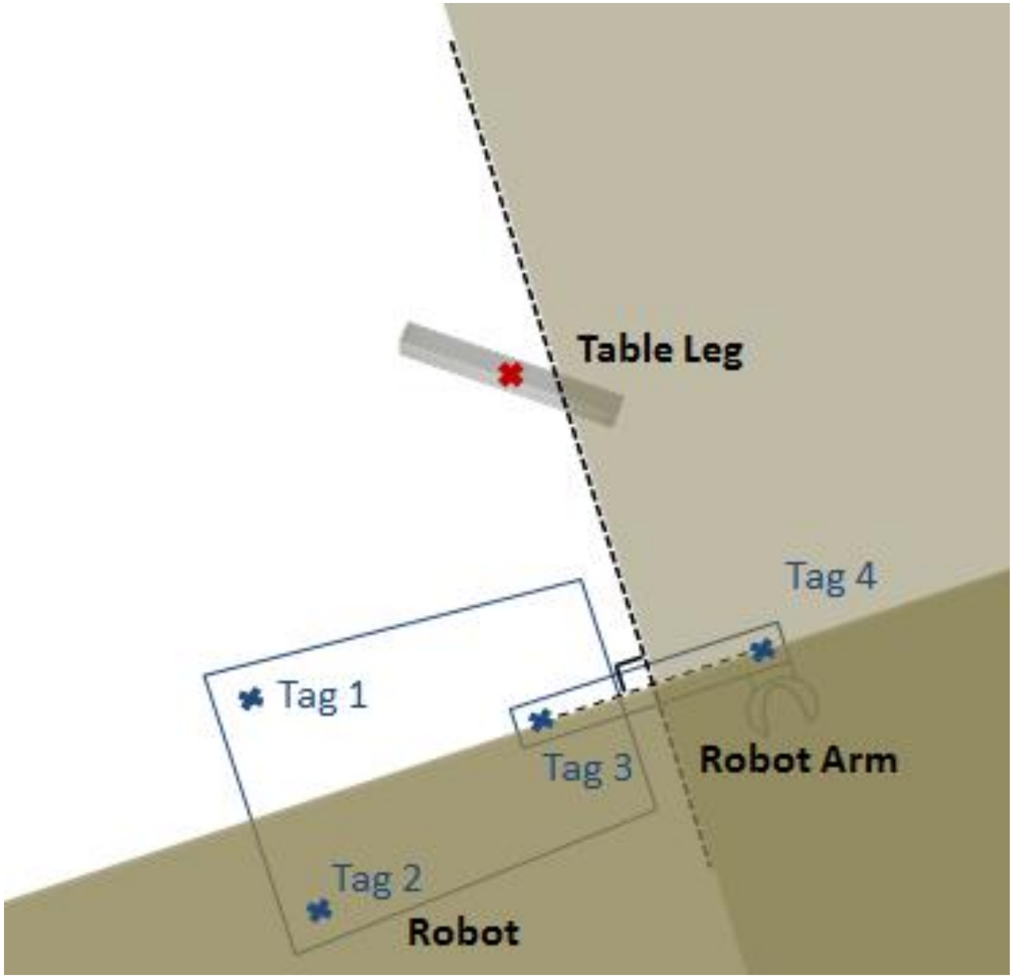
Is the red tag closer to Tag 1 or Tag 2?

Basic Idea: Localization by Partitioning



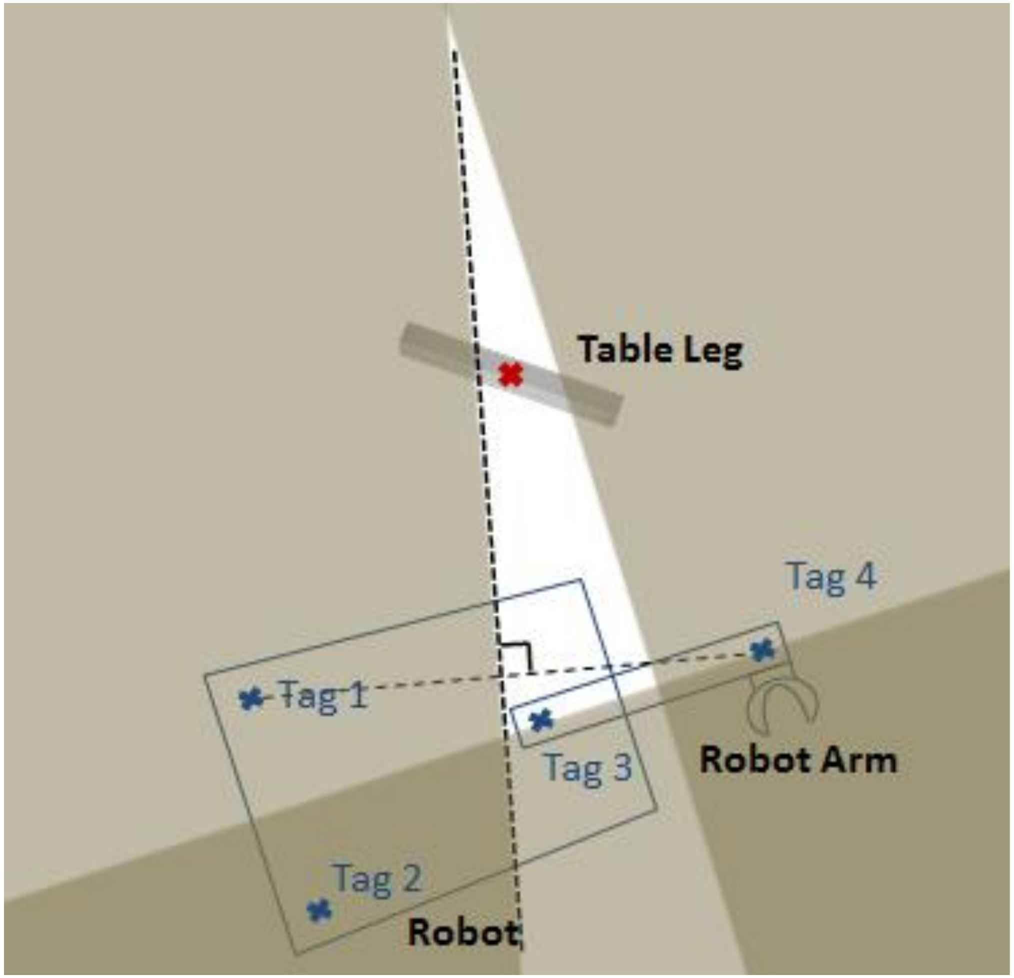
Tag 1 is closer than Tag 2

Basic Idea: Localization by Partitioning



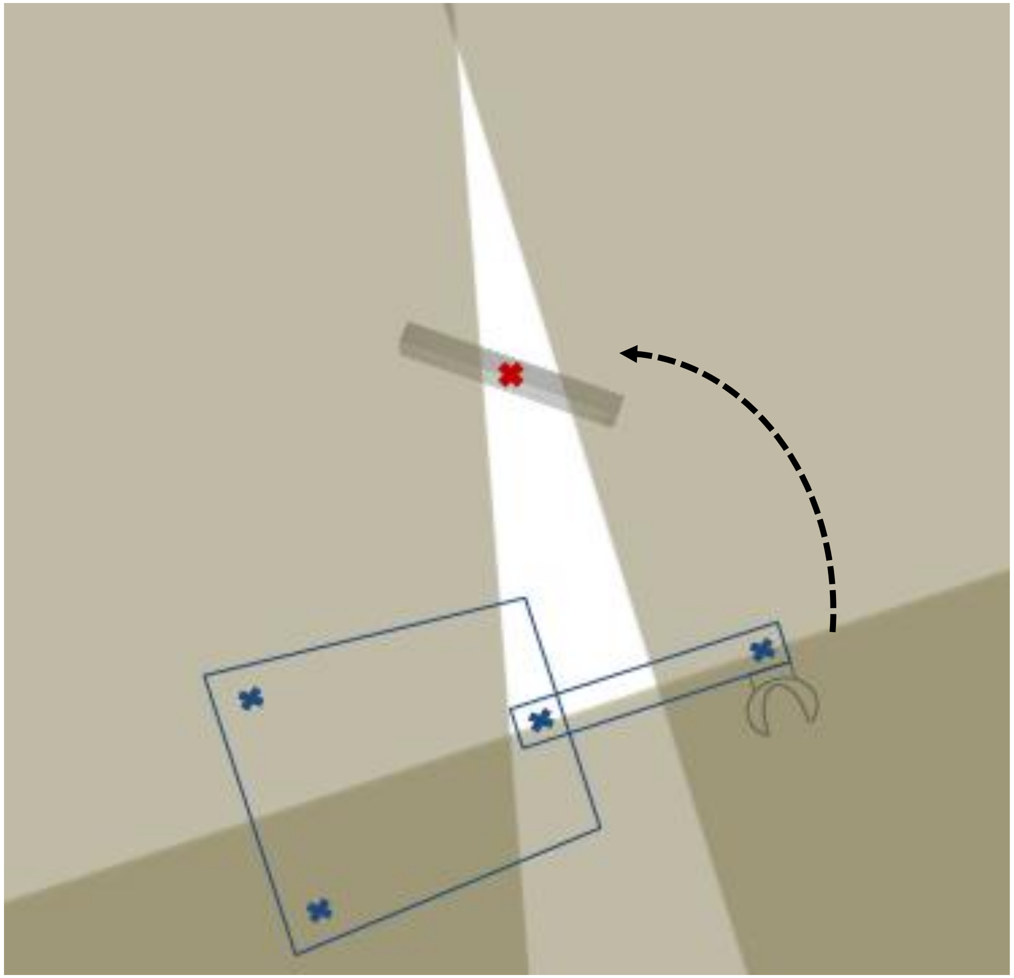
Tag 3 is closer than Tag 4

Basic Idea: Localization by Partitioning



Tag 4 is closer than Tag 1

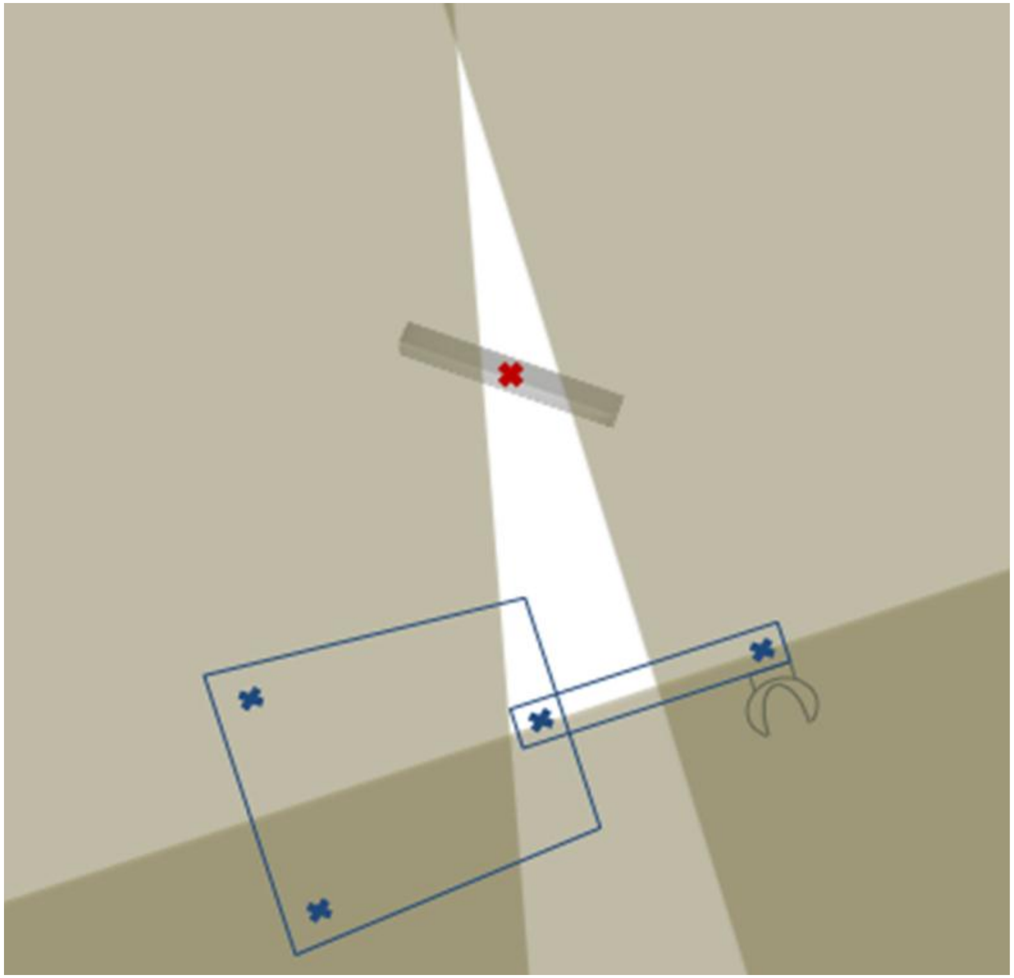
Basic Idea: Localization by Partitioning



But not yet centimeter accuracy

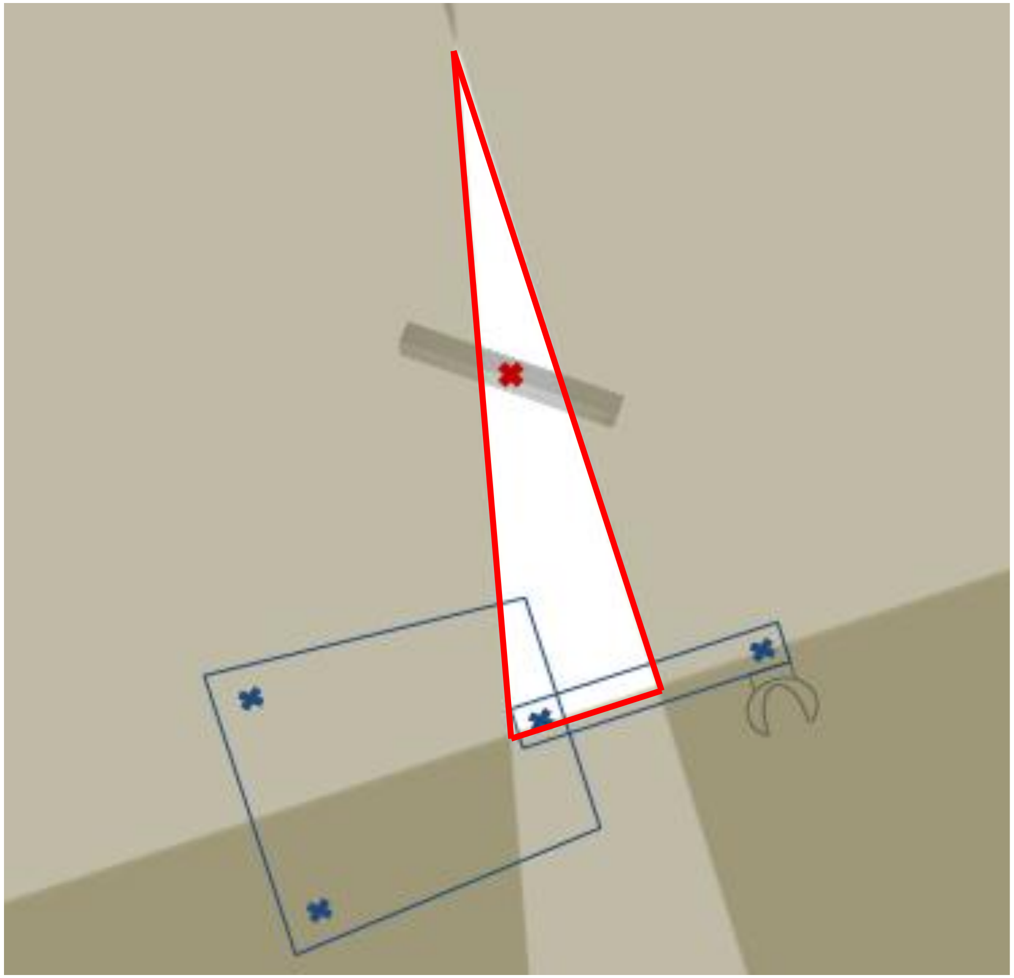
Basic Idea: Localization by Partitioning

- Partitions can be iteratively refined



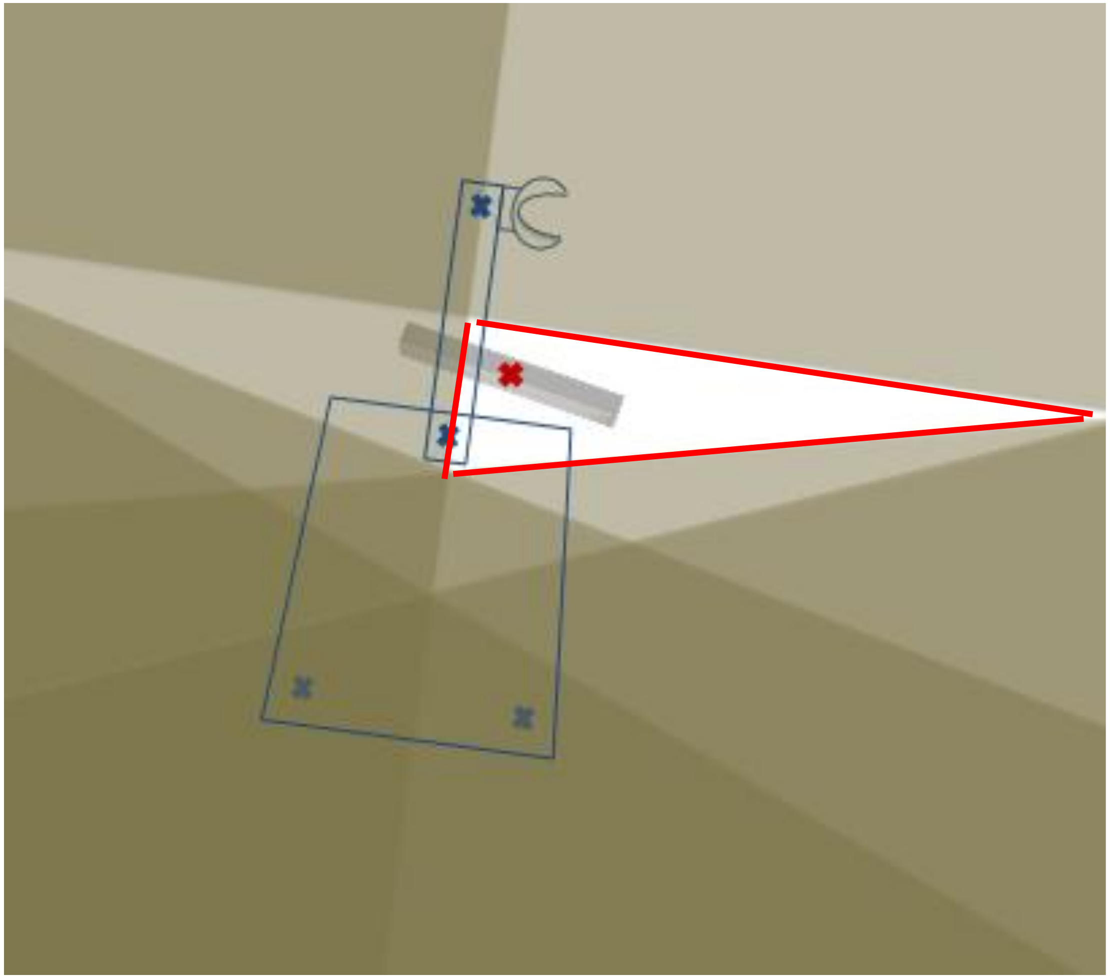
Iterative Refining via Robot Navigation

- Leveraging robot's consecutive moves



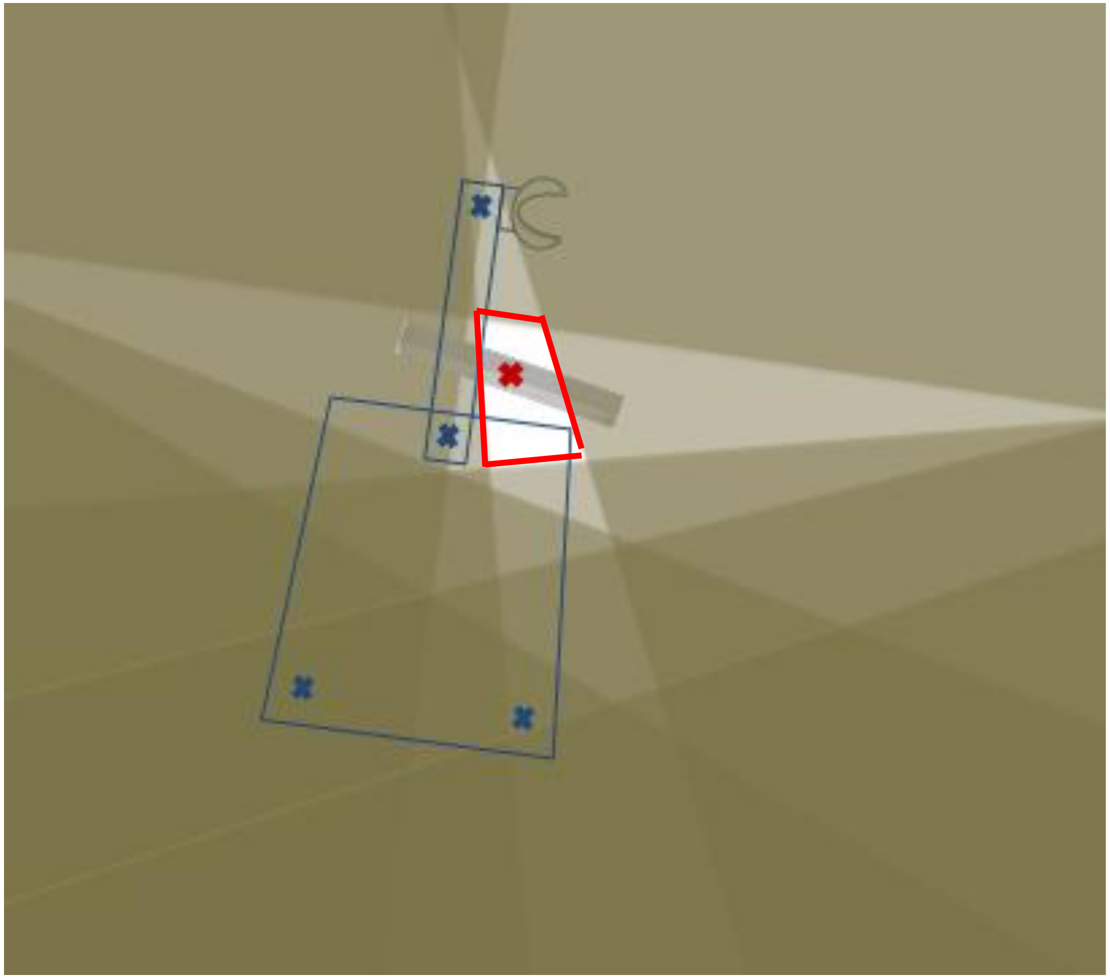
Iterative Refining via Robot Navigation

- Every robot move gives a new set of partitions



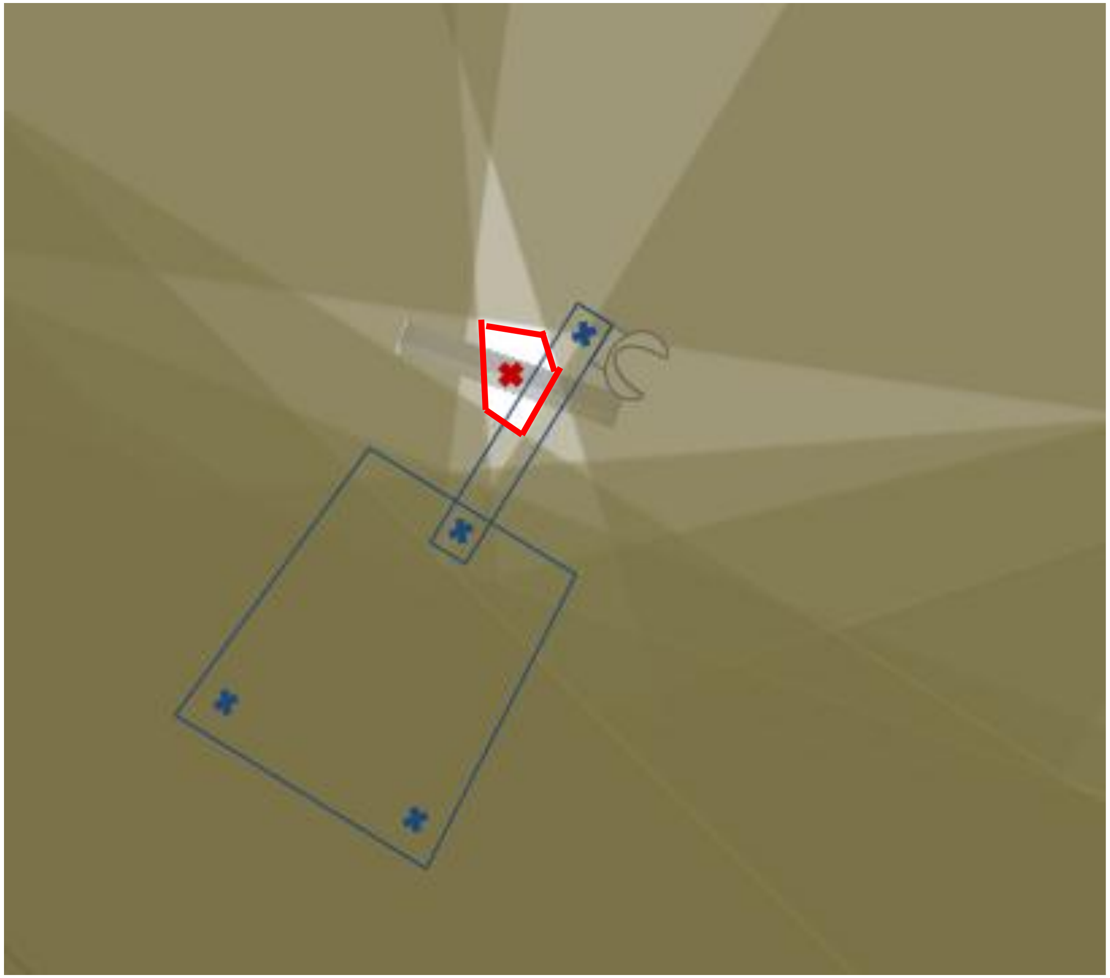
Iterative Refining via Robot Navigation

- Lay new partitions over old partitions to refine



Iterative Refining via Robot Navigation

- Keep refining until reaching centimeter accuracy



Iterative Refining via Robot Navigation

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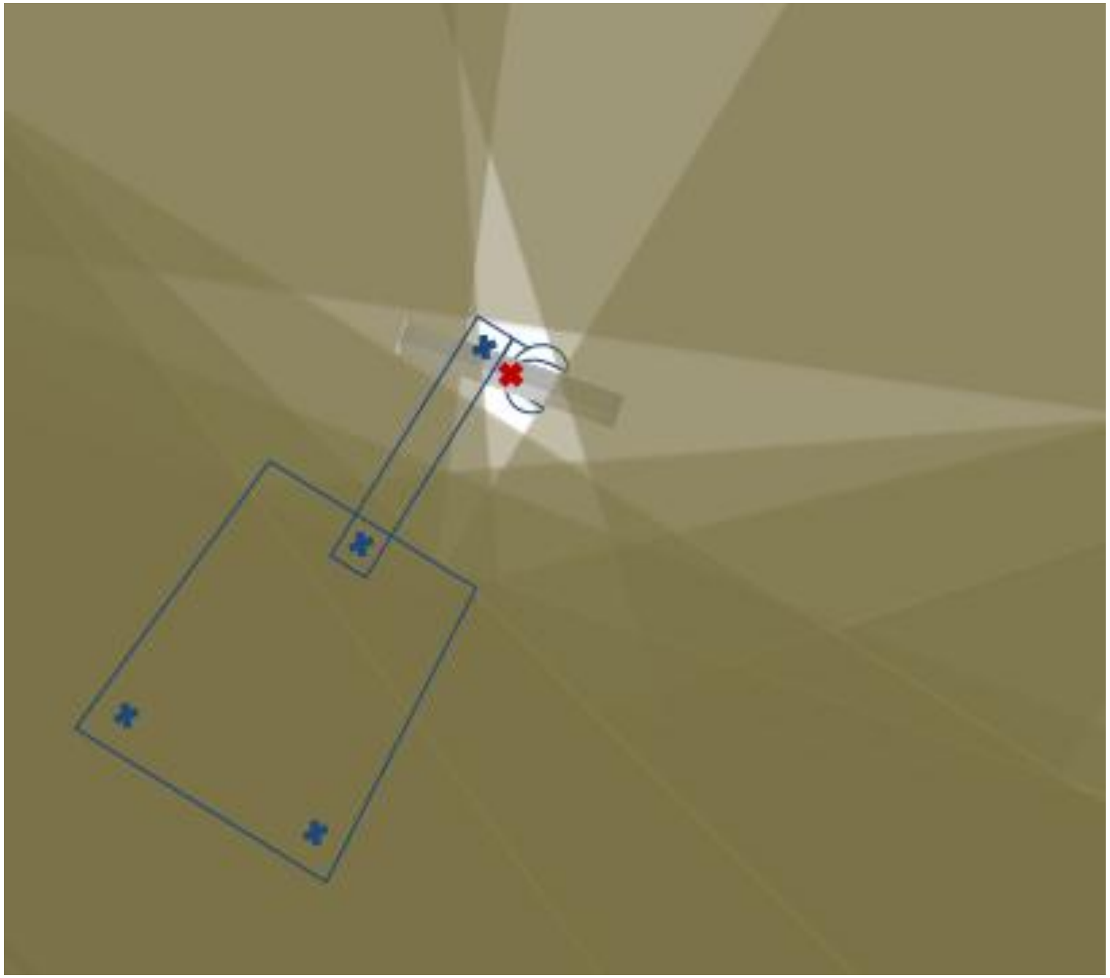
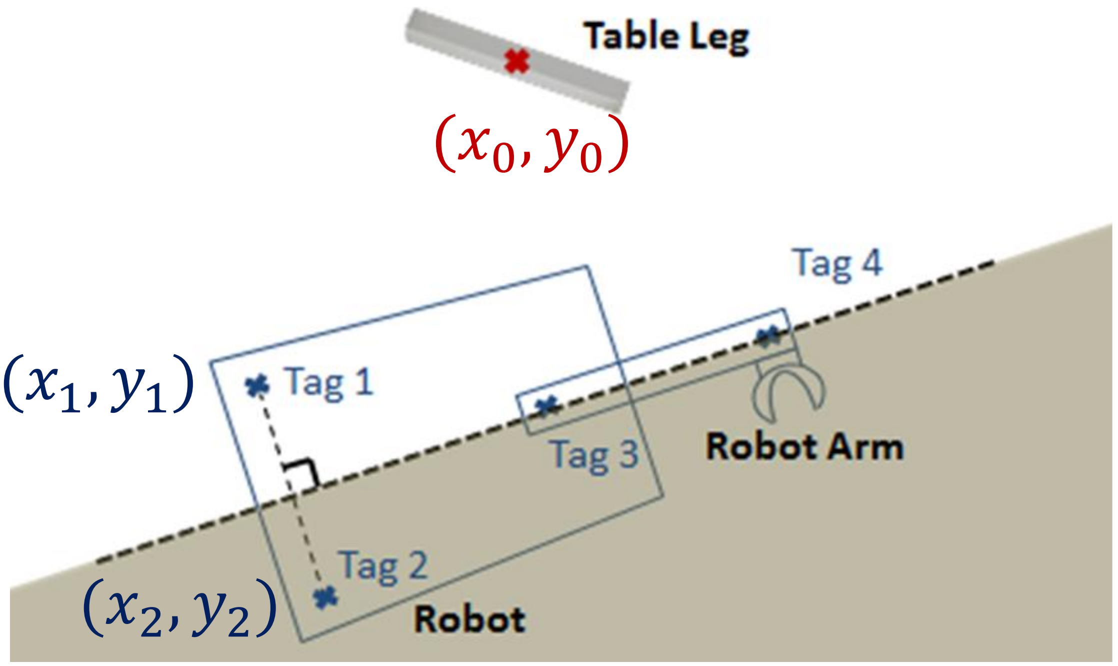


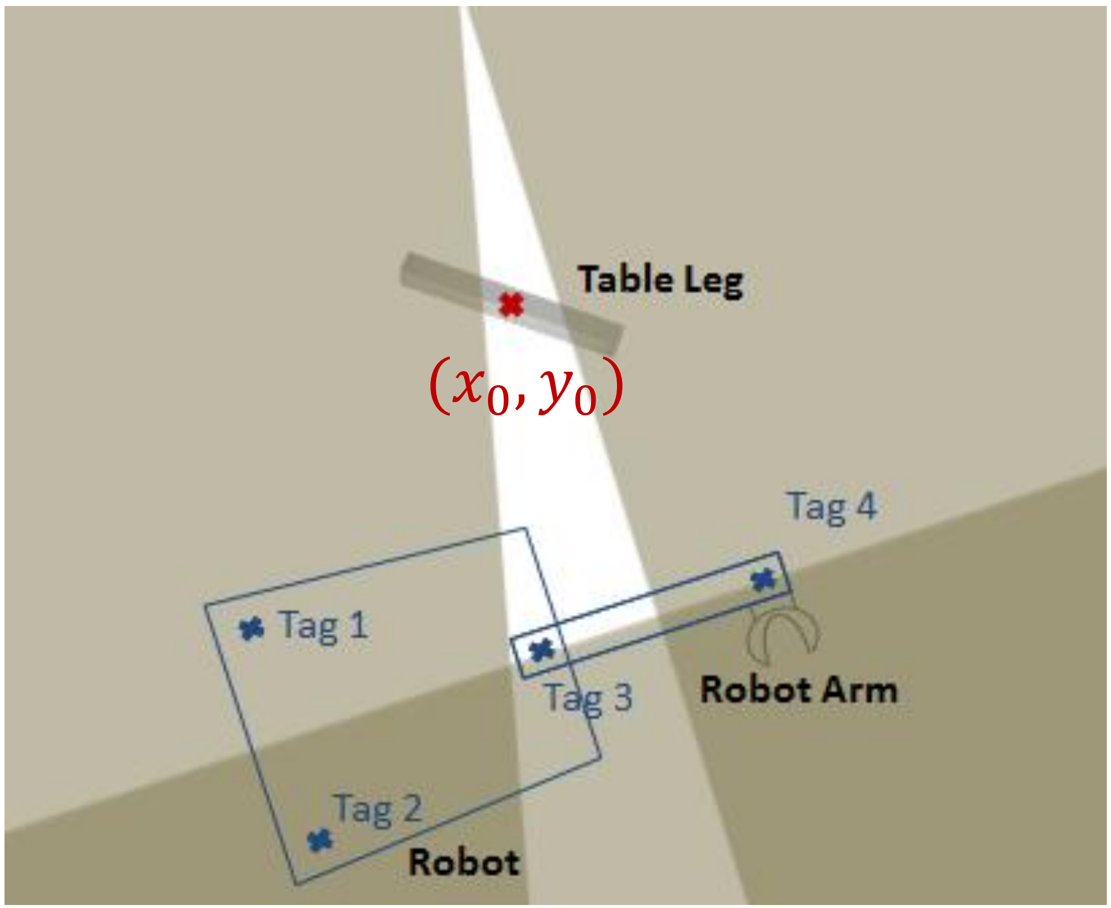
Formulation as an Optimization

$$[2(x_2 - x_1)\ 2(y_2 - y_1)] \begin{bmatrix} x_0 \\ y_0 \end{bmatrix} \leq x_2^2 + y_2^2 - x_1^2 - y_1^2$$



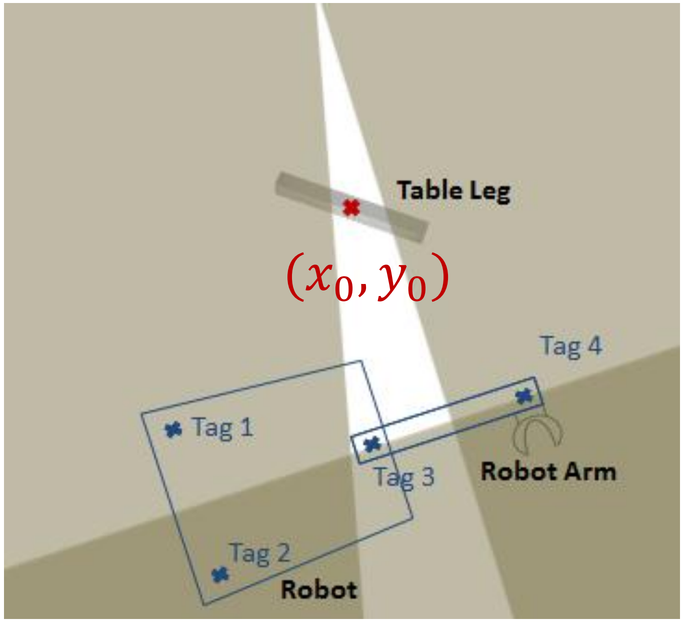
Formulation as an Optimization

$$\begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ \vdots & \vdots \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \end{bmatrix} \leq \begin{bmatrix} x_2^2 + y_2^2 - x_1^2 - y_1^2 \\ \vdots \end{bmatrix}$$



Formulation as an Optimization

$$\boldsymbol{A}\begin{bmatrix} x_0 \\ y_0 \end{bmatrix} \leq \boldsymbol{b}$$



- A feasibility problem with linear constraints
- Efficiently solved via convex optimization
- Over-constrained system

$$\downarrow$$

Robustness to errors & outliers

Works correctly even if randomly flipping 10% of pairwise comparisons, shown in paper

Orientation

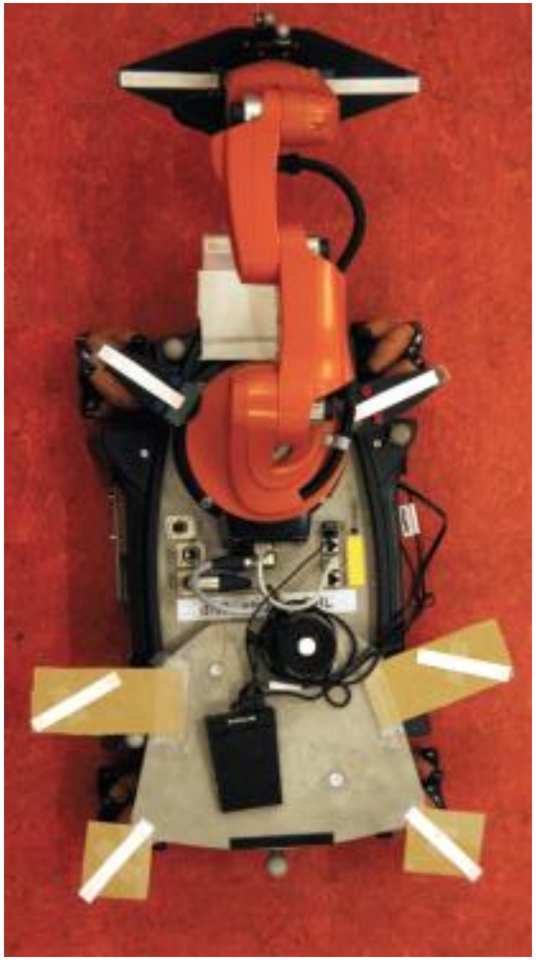
Problem: also need orientation for grasping

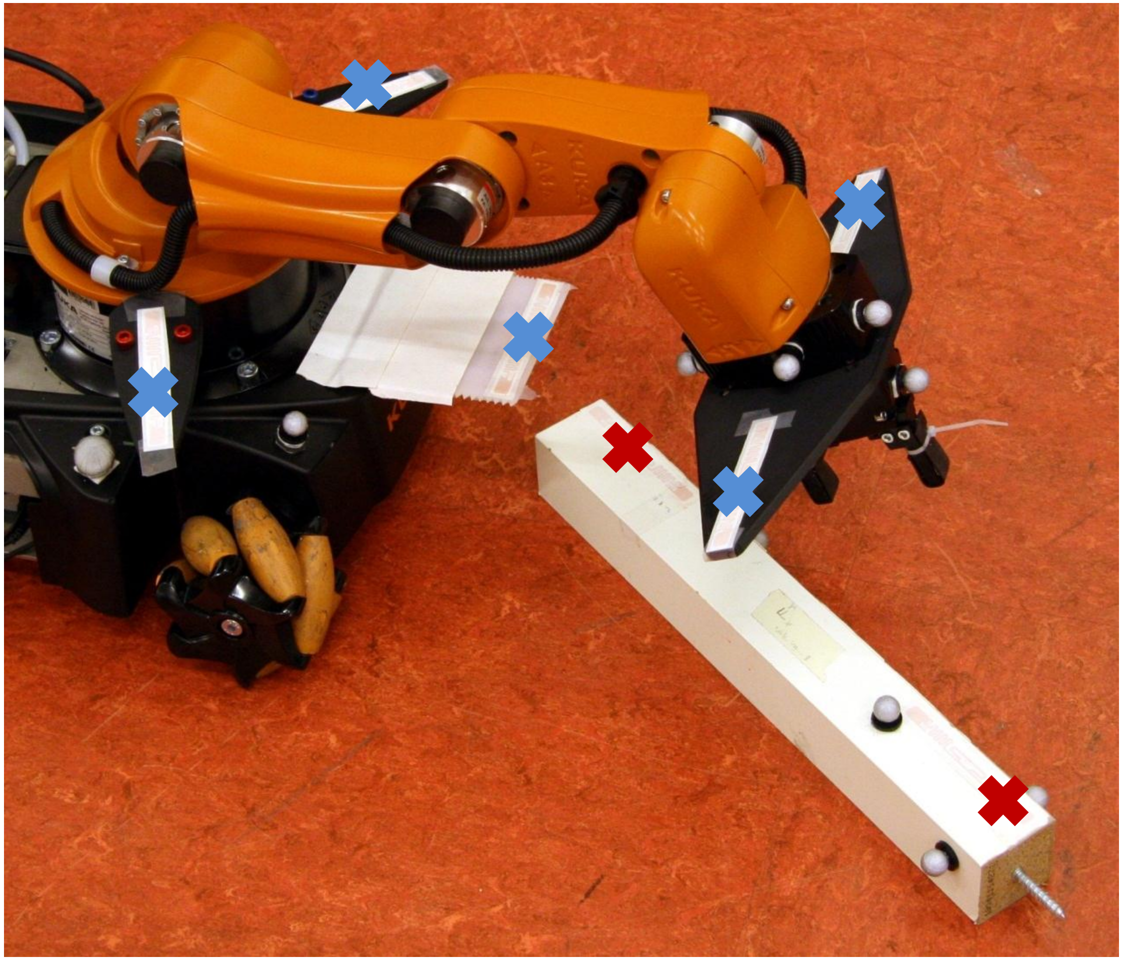
Solution:

- Multiple RFIDs on object
- Naïve approach: localize each RFID independently and find orientation
- Our approach: joint optimization using knowledge of their relative location

Evaluation

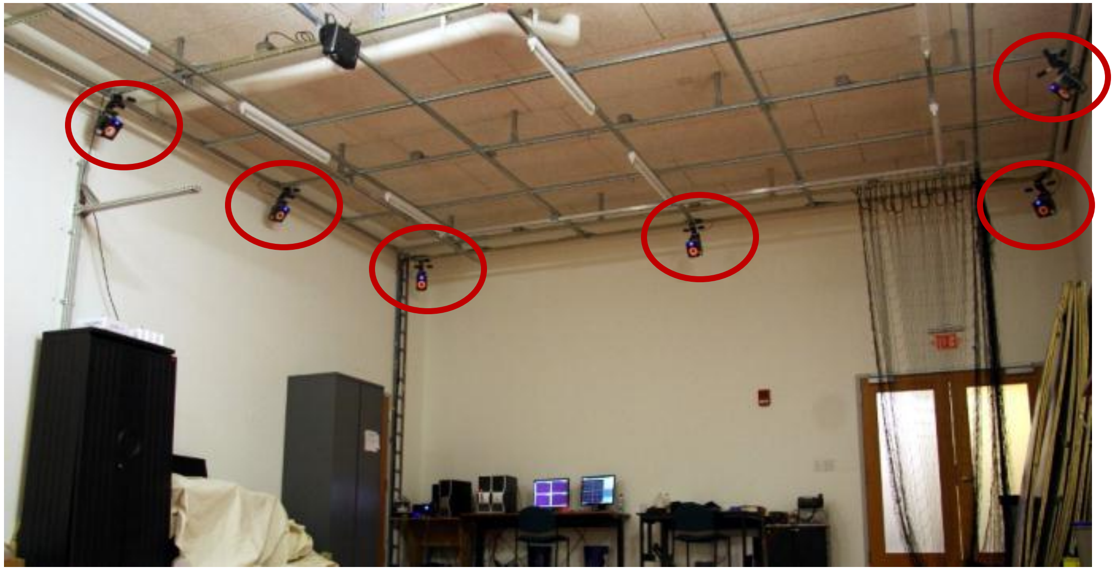
- Used a robot to fetch IKEA furniture parts
- 9 tags on robot, 1 – 4 tags on object

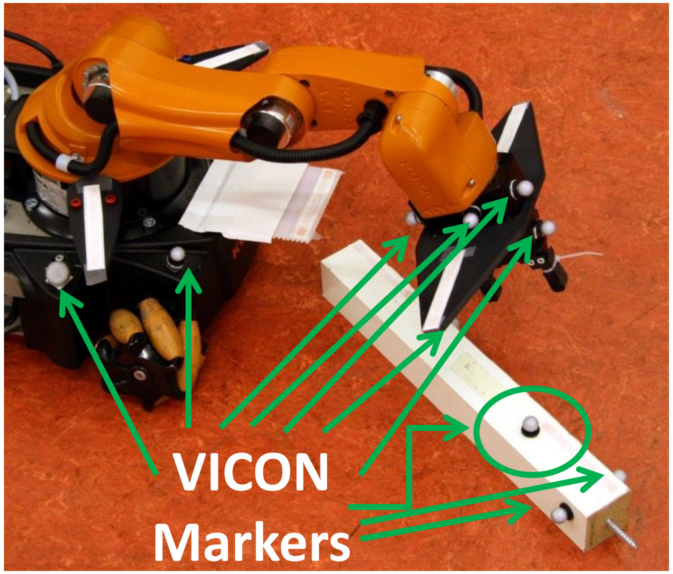




Baseline

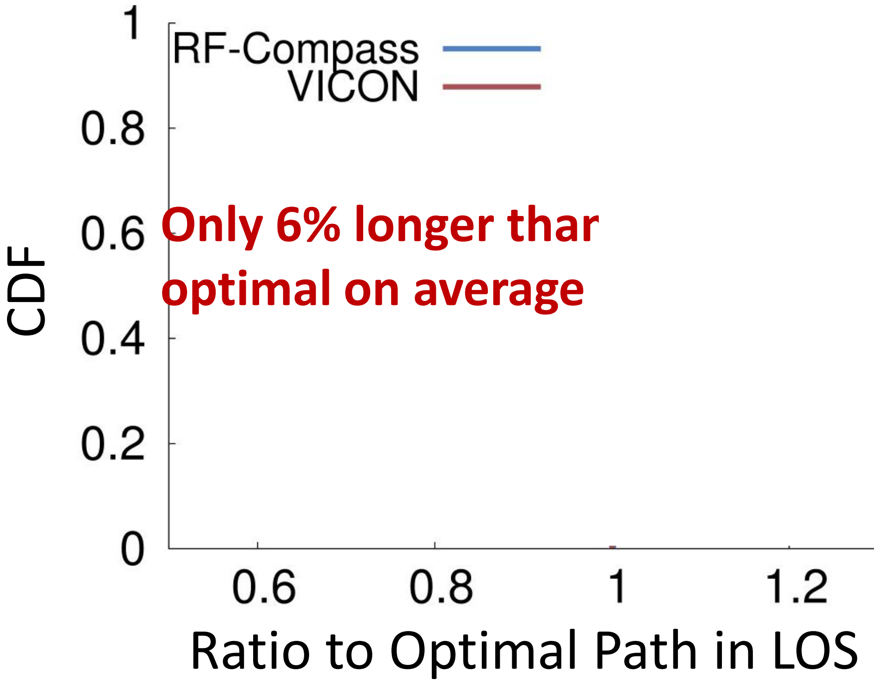
- VICON motion capture system
- Sub-centimeter accuracy
- Infrared cameras + infrared-reflective markers



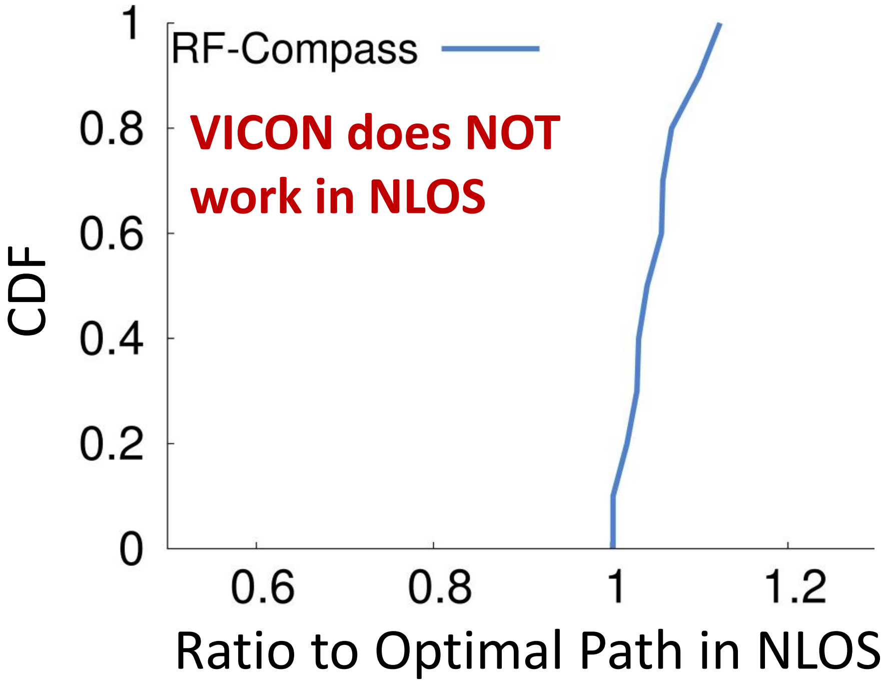


Navigation Performance

Direct line-of-sight

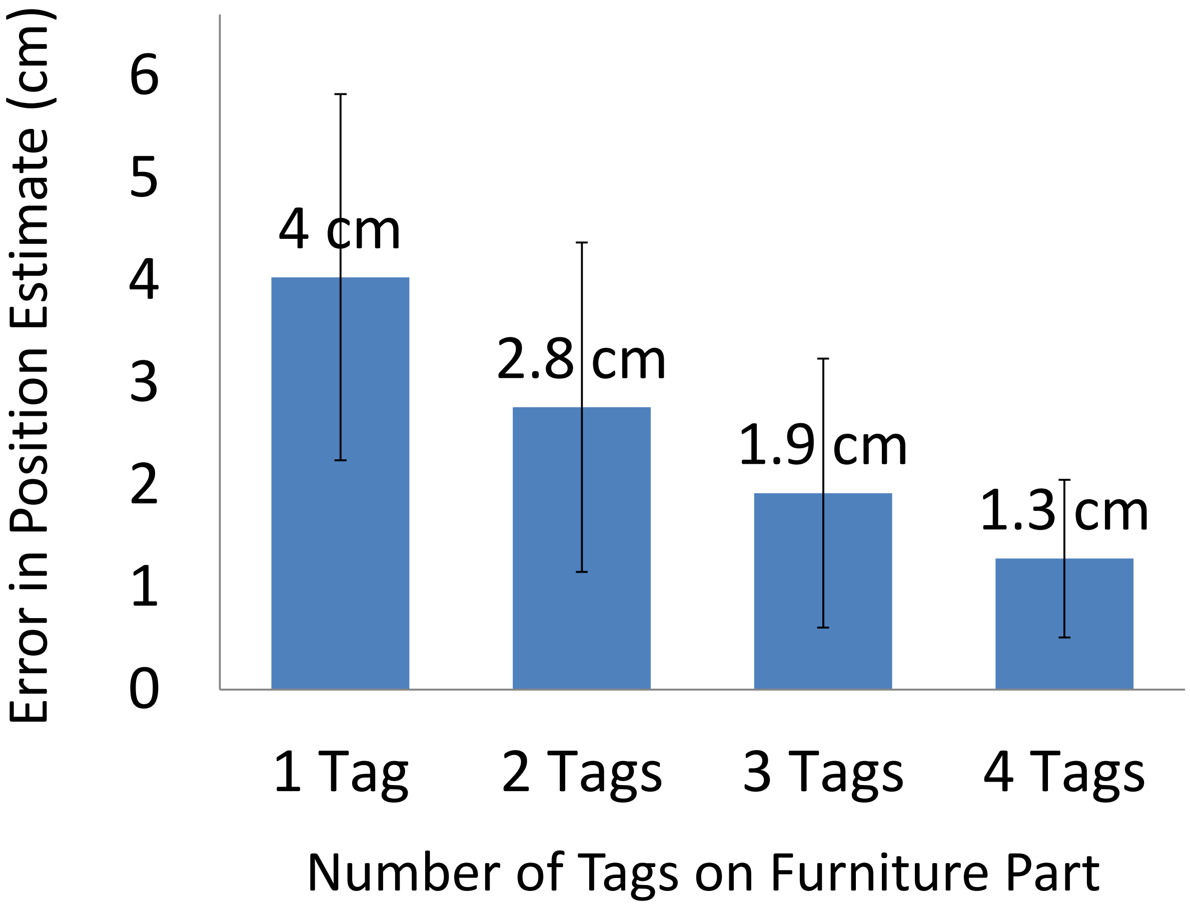


Occlusion and NLOS

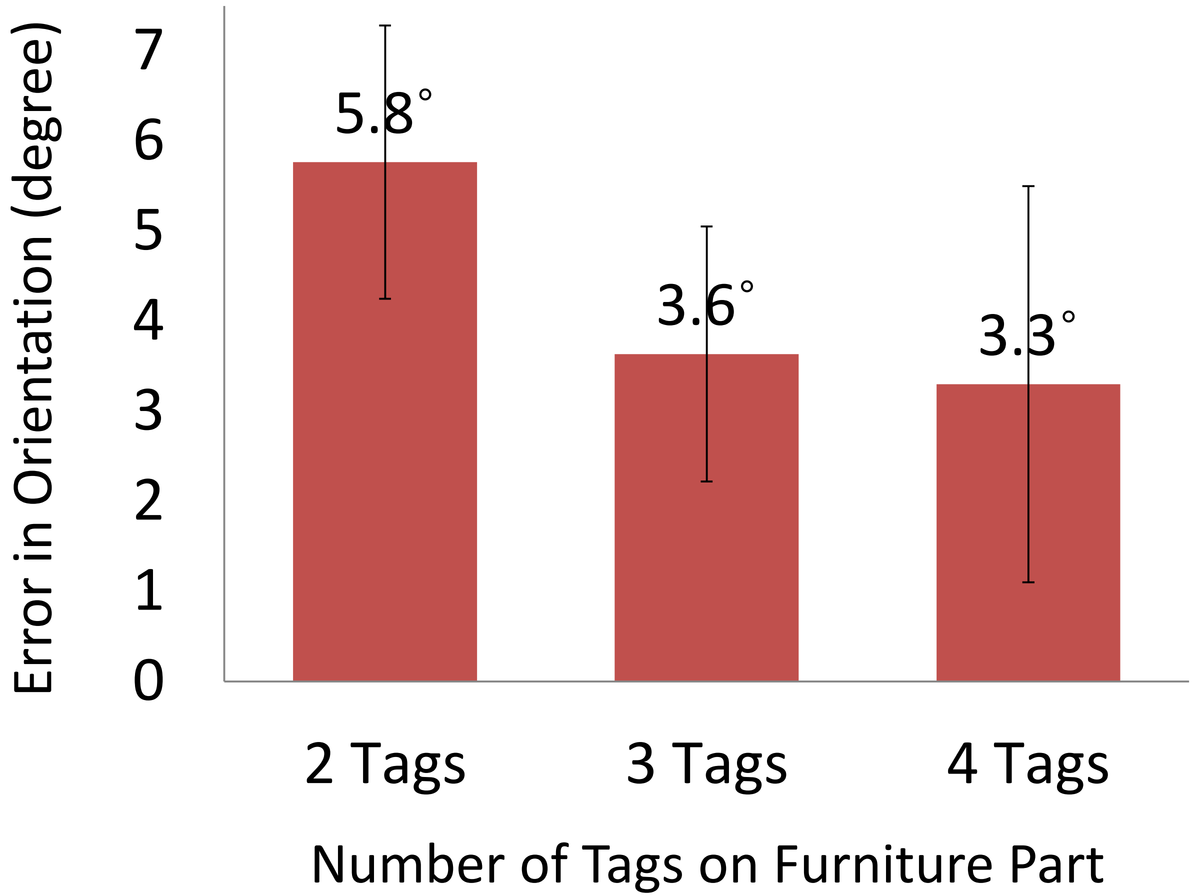


RF-Compass enables effective navigation in NLOS

Center Position Accuracy



Orientation Accuracy



Conclusion

- RF-Compass: accuracy of a few cm and degrees
- Iterative refining by leveraging robot's navigation
- Opens up opportunities for bridging robot object manipulation with RF localization