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RAPID CONSTRAINED OBJECT MOTION ESTIMATION BASED ON CENTROID LOCALIZATION OF SEMANTICALLY LABELED OBJECTS

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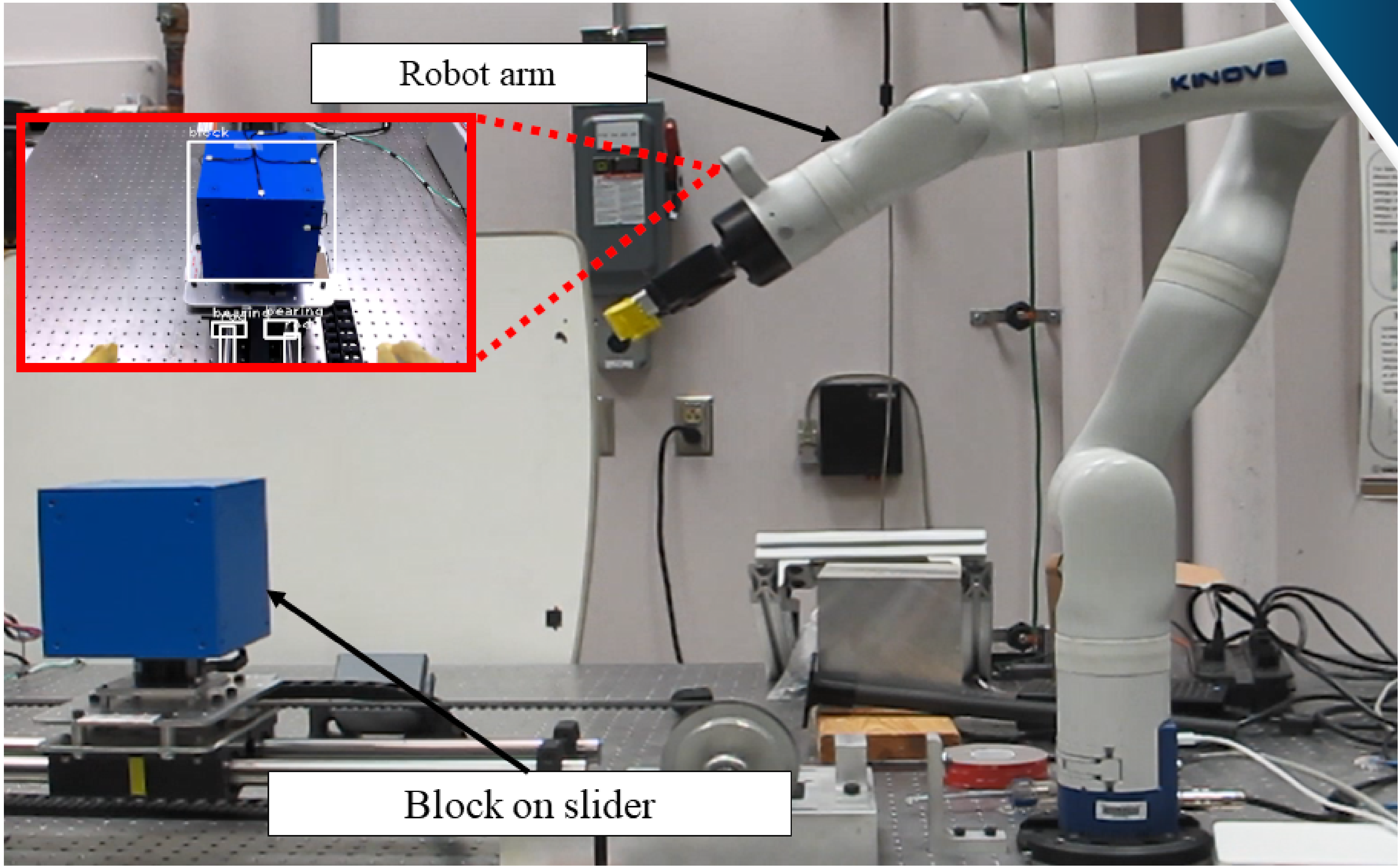
OVERVIEW

- Real time interaction with unstructured environment.
  - What things are.
    - Semantic labels.
  - Where things are.
    - Centroid estimation.
  - How things move.
    - Motion model estimation.
  - Enough speed for real-time use.
  - Small errors, or the ability to maneuver to a view with small errors.



Designed a real time and accurate method for locating objects and estimating potential motion

IMPORTANCE

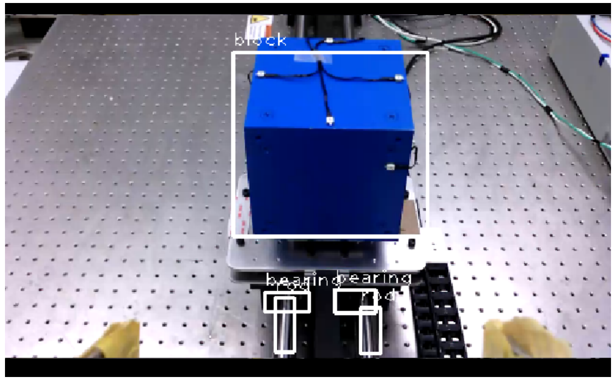
- To interact with the environment, we don't just care where something is, but also how it can move.
- Consider a typical indoor environment.
  - Everyday objects have a variety of ways to interact.
  - Design of the object informs how to interact with it before attempting.
    - Location of hinge or handle.
    - Slides vs hinges.
    - Symmetrical vs oblong.

BACKGROUND

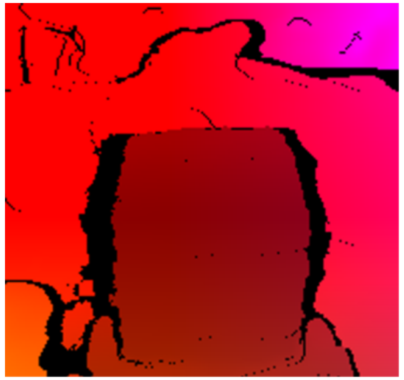
	Methods	Good Performance	Issues
Segmentation	Edged Based Graph Based Model Based	Real Time, Complex Scenes Real Time, Irregular Shape, Occluded Pose Estimation	Irregular Shape, Occluded Complex Scenes Real Time, Training
Localization	2D regressed MLP Network Model 3D Data	Only requires 2D data Leverages 3D data Position and pose Real Time	Training Training, Real Time Requires Model Occluded Sides
Model Estimation	In Motion	Estimates object motion between frames	Object must be in motion

- Segmentation.
  - Utilize edge based methods leveraging work from Uckermann et. all and Parikh et. all.
- Localization.
  - 3D data combined with simplified model in the form of a minimum bounding box.
- Model Estimation.
  - Develop novel motion model estimation based off of key features instead of observed motion.

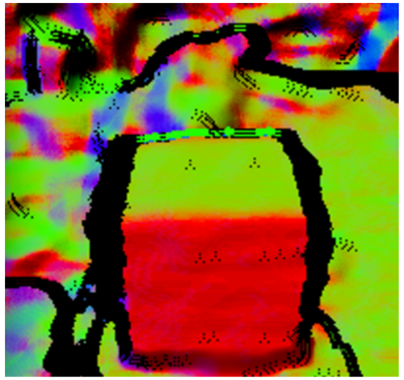
CENTROID ESTIMATION - VISION



Object Identification



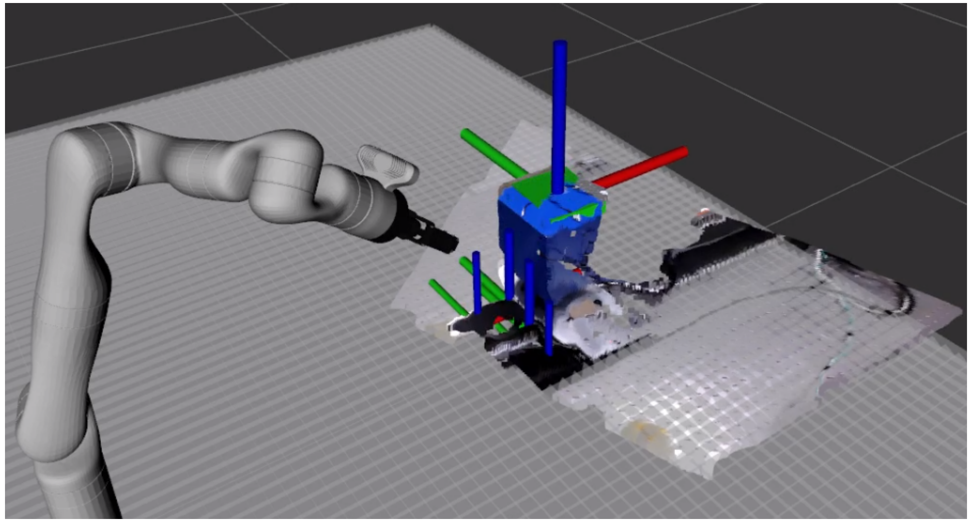
Segmented Depth



Normal Map

Edge Map

Surface

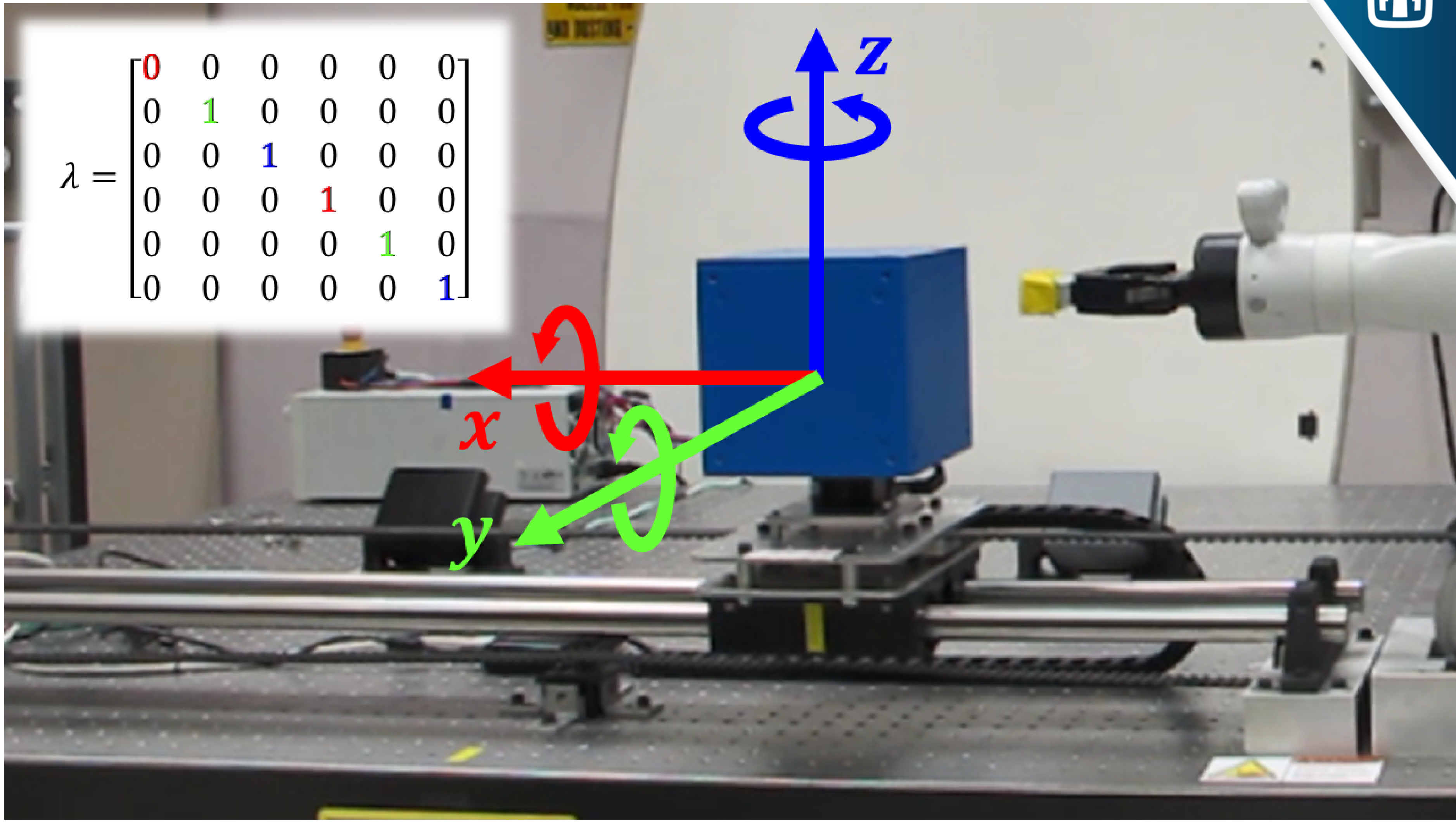


Minimum Orientated Bounding Box

- **Object Identification** – Yolo v3 with custom training set.
- **Segmented Depth** – Cut rectified depth image slightly larger than yolo bounding box.
- **Surface Normal** – Compute surface normals from depth data.
- **Edge Map** – Threshold change in normals to identify edges.
- **Surface Map** – Group surfaces based on edges.
- **Segmented Point Cloud** – Identify surface(s) that are at least 90% within bounding box.
- **Minimum Orientated Bounding Box** – Find the center of the smallest orientated cube that completely covers segmented point cloud.
- **Filtering** – Filter center of minimum orientated bounding box using size threshold and Kalman filter.

MOTION MODEL

- Lambda is a 6 x 6 diagonal matrix.
  - 0 is a direction fully open for motion.
  - 1 is a direction fully blocked from motion.
  - First three diagonal terms represent linear motion.
  - Last three diagonal terms represent angular motion.
- Equation shows linear motion only calculation.

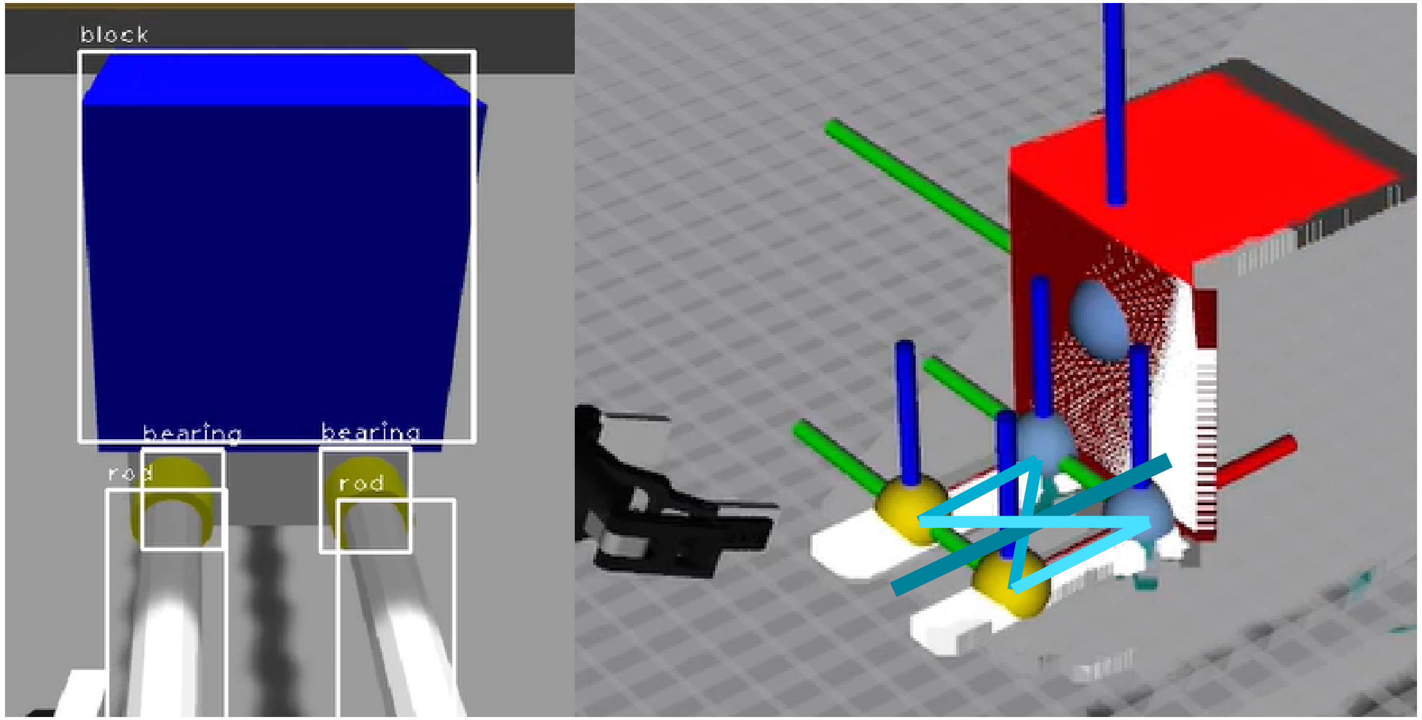


$$\lambda = \mathrm{diag}\left(1 - |v_1|, 1 - |v_2|, 1 - |v_3|, 1, 1, 1\right)$$

MOTION MODEL - CALCULATION

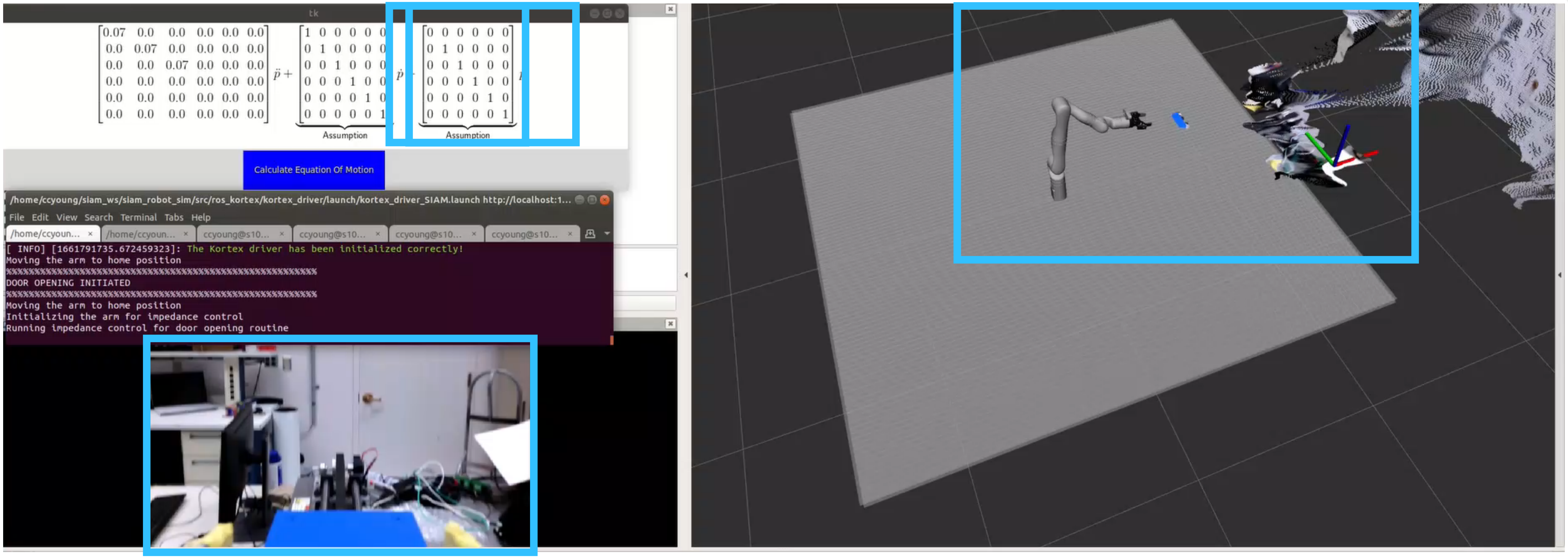
	1 Rod	2+ Rods
1 Bearing	Direct measurement.	Direct measurement of first seen rod.
2+ Bearings	Average line from rod to each bearing.	General case.

- General case.
  - Find lines from each bearing to all rods.
  - Consider all possible bearing to rod assignments.
  - Assign each bearing a rod so that the angle difference between all rod-bearing pairs is minimized.
  - Average the lines between all assignments to determine v.
  - λ is calculated from v.



IN MOTION

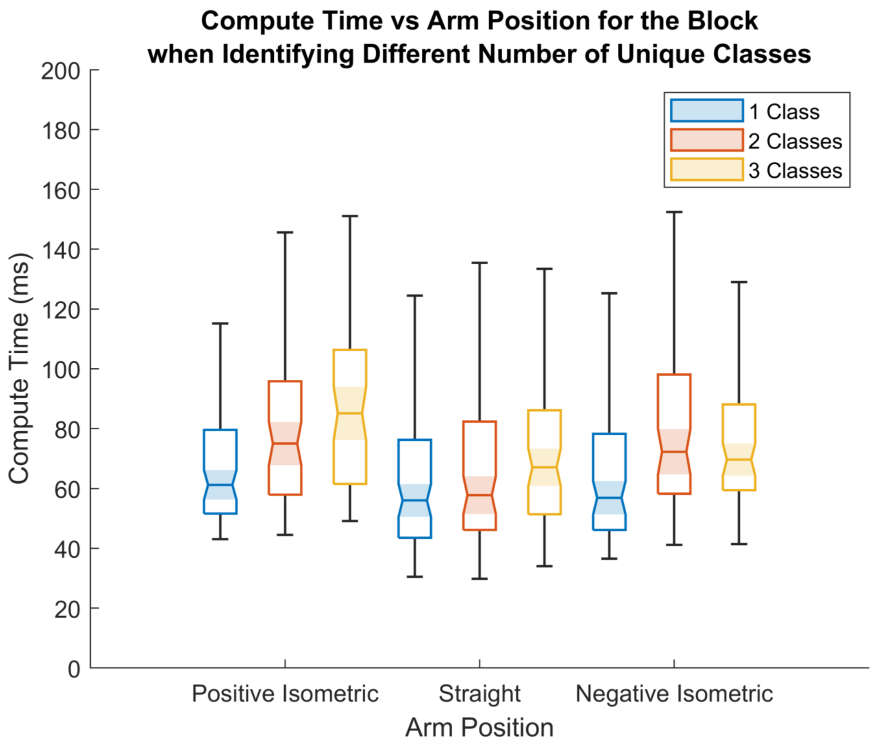
λ Centroid Estimation

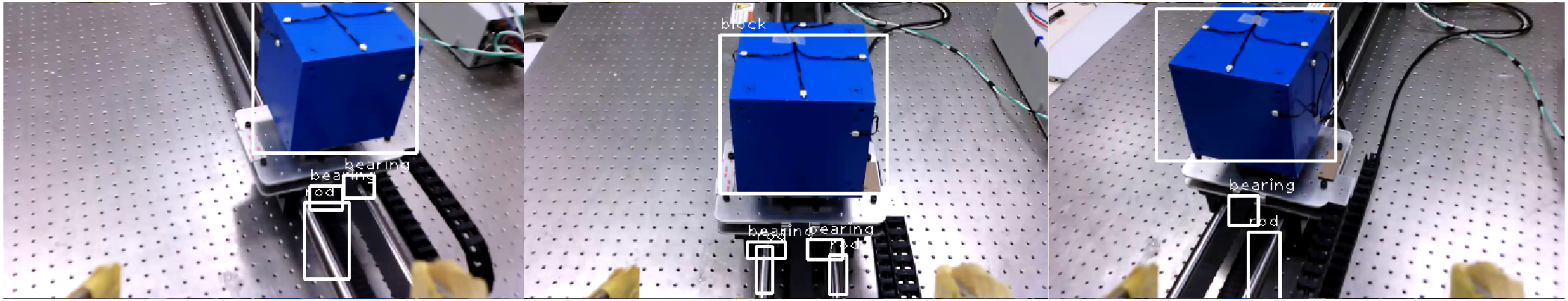


Object Identification

RESULTS - SPEED

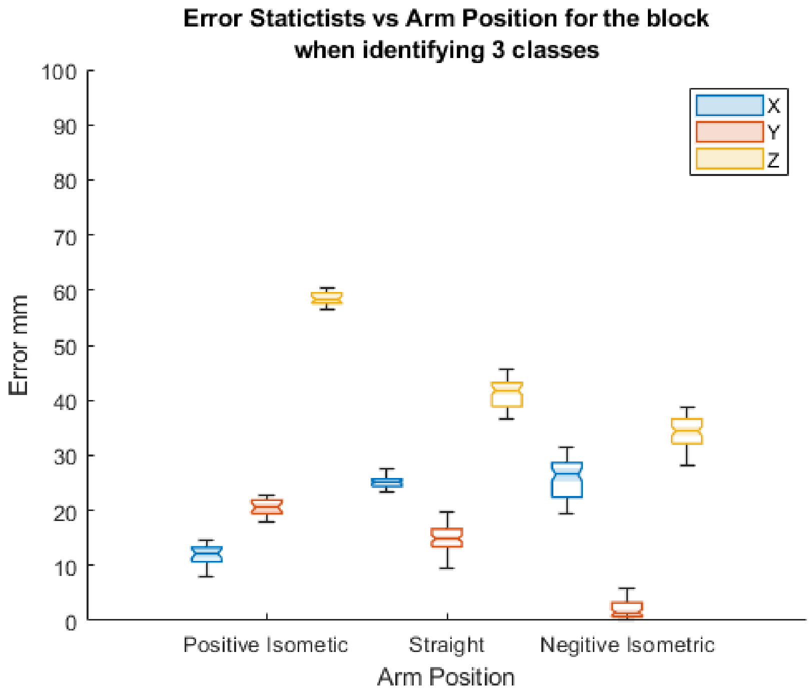
- Calculated without Kalman filtering for average end-to-end speed of 13.7 Hz.
- Using GPU enabled desktop computer.
  - 2 NVIDIA RTX A4000.
- As the number of classes increases, average computation time increases.
  - 10.3 ms from one to two classes.
  - 3.0 ms from two to three classes.
  - Sub linear growth rate.
- Compute time within range for real time identification.



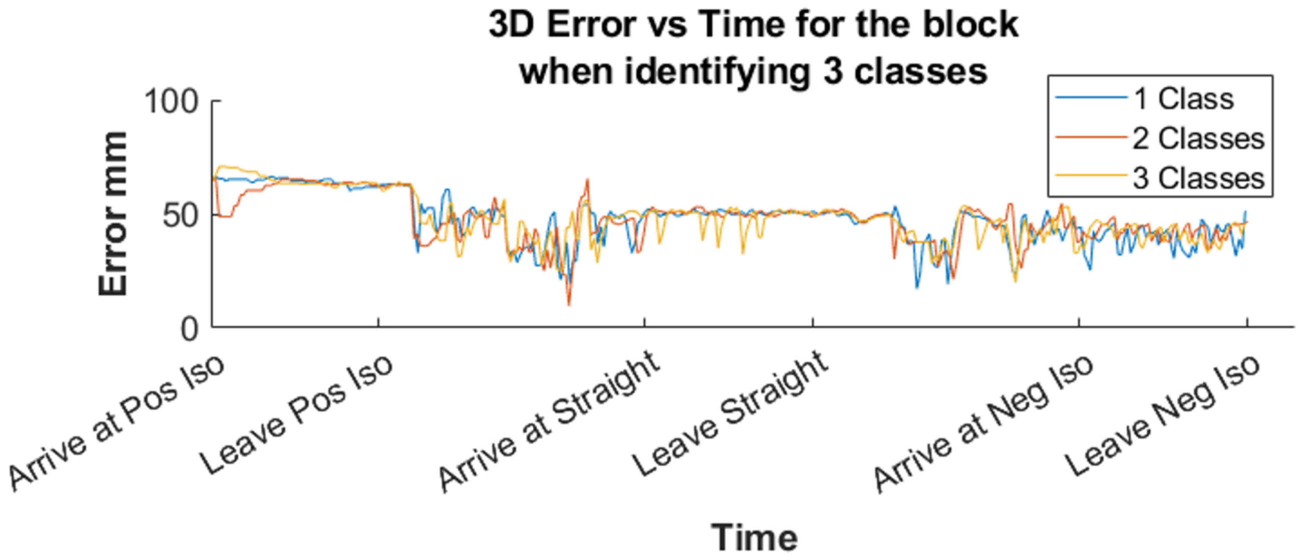


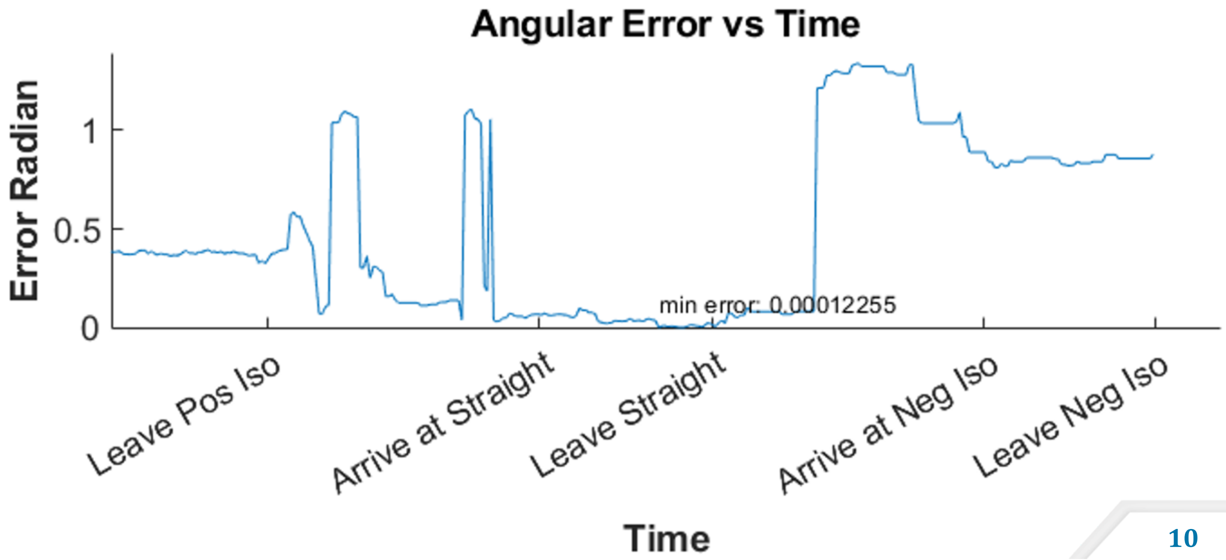
Positive Isometric Straight Negative Isometric

RESULTS - ACCURACY



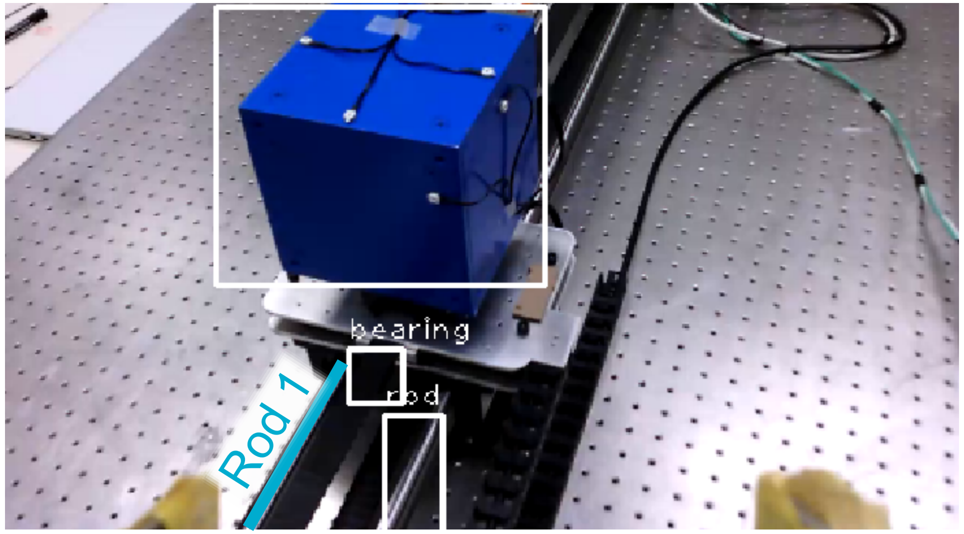
- Block centroid accuracy.
  - Dependent on arm pose.
  - Decrease of precision during motion.
- Motion model accuracy.
  - Dependent on arm pose.
  - Decrease in accuracy and precision during motion.
  - With appropriate pose, accuracy of 0.00012 rad.

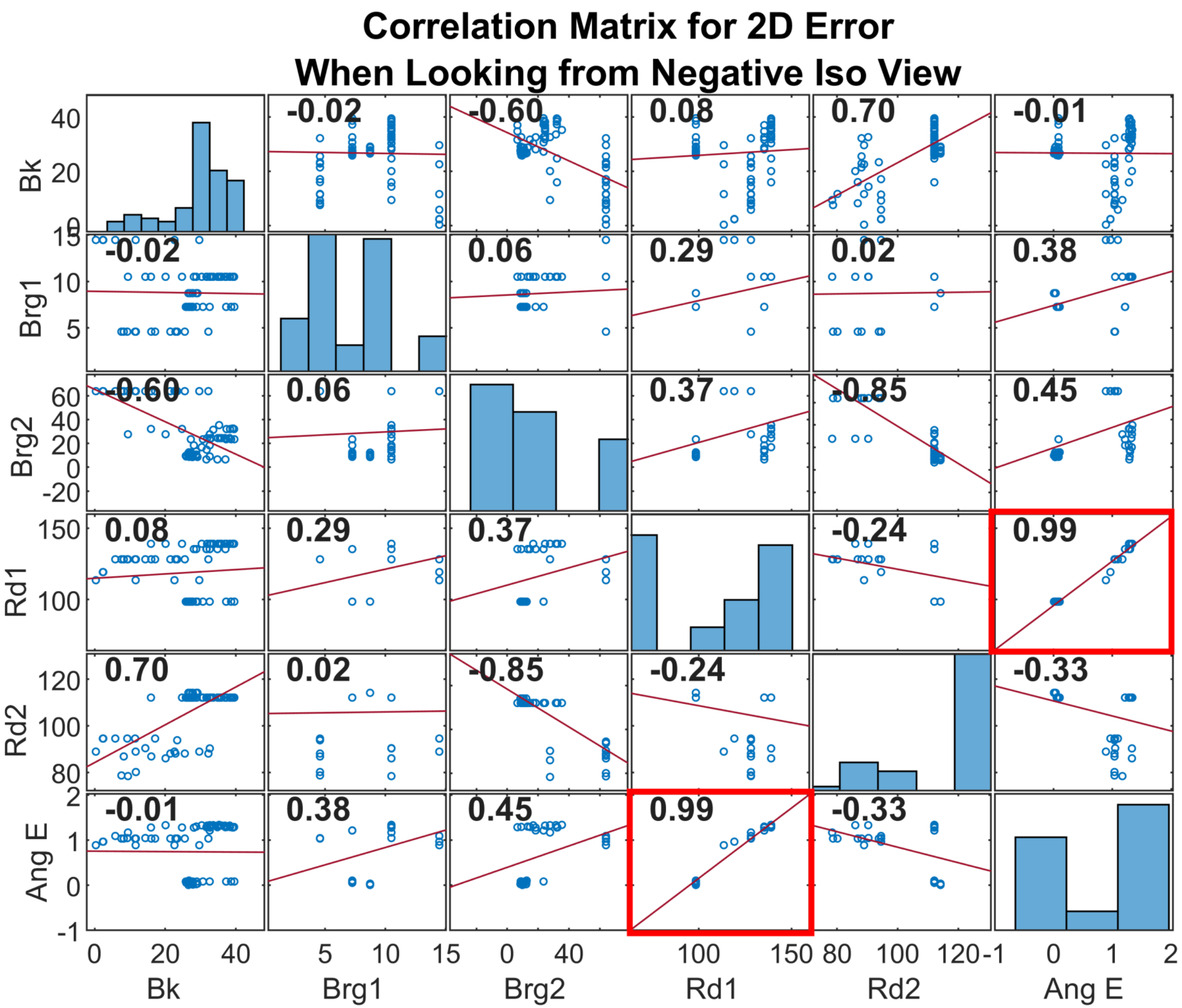




RESULTS - CORRELATION

- Strong correlation of error during worst performing pose for motion model estimation.
- Rod 1 is the rod that is most prominent during the positive isometric view, and not easily identifiable in the negative isometric view.
- An understanding of available features can inform reliability of motion model.





CONCLUSION

- A motion model for identifying permissible motions can be effectively generated through rapid centroid estimation of semantically labeled objects.
  - Average end-to-end speed of 13.7 Hz.
    - Indicates real time.
  - Sublinear slowdown when additional classes are present.
    - Indicates scalability.
  - Motion model estimation error as low as 1.23×10^{-4} rad.
    - Indicates high potential accuracy.
    - Possible performance increase with improved object tracking.

QUESTIONS

THANK YOU

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