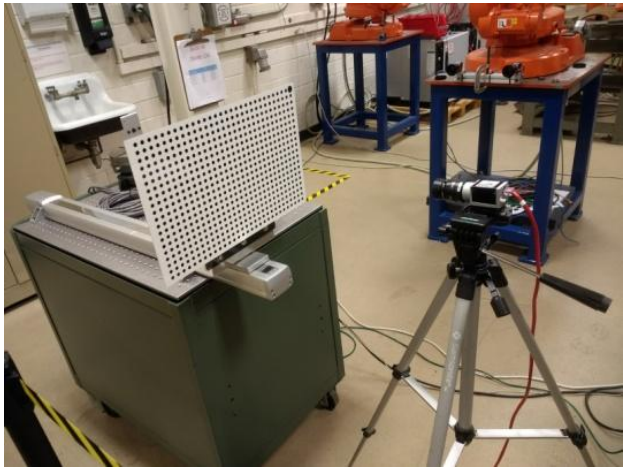
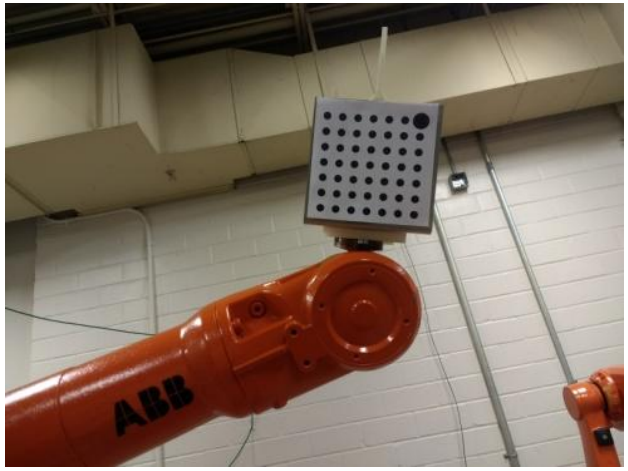
Where's My Camera?





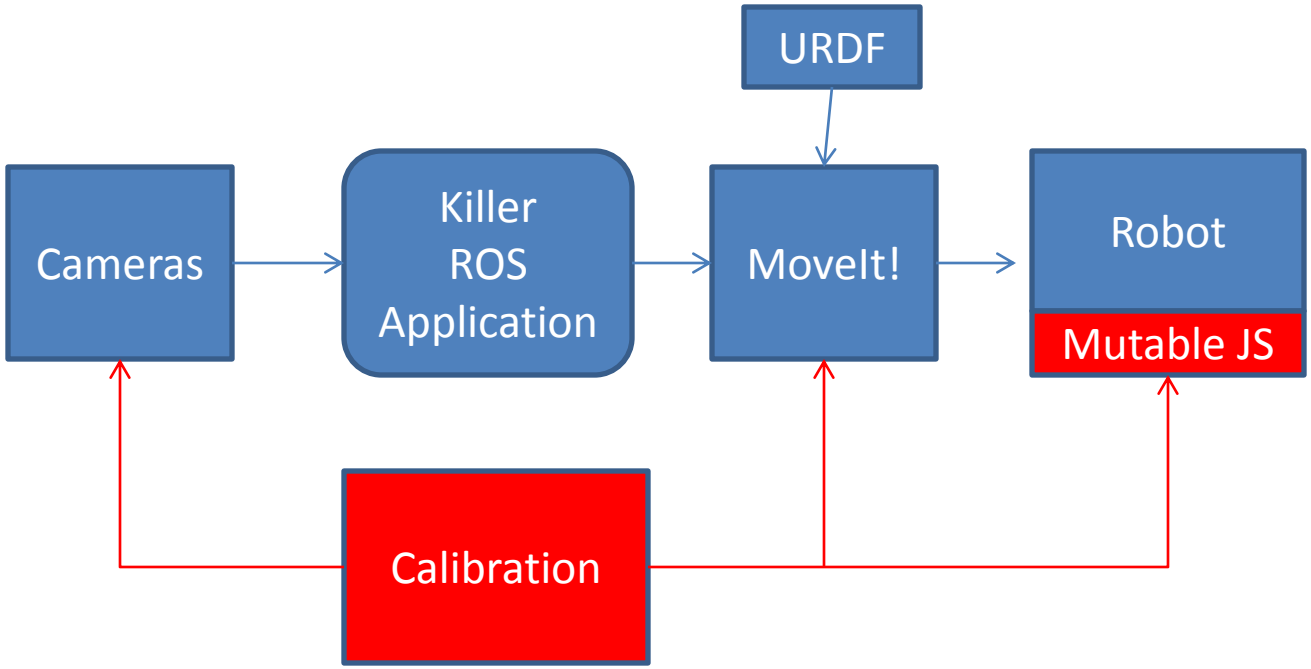
Chris Lewis

Jonathan Meyer

Southwest Research Institute

Library Original Goal

- Intrinsic and Extrinsic Calibration for Cameras in industrial robot Installations,(no user input)

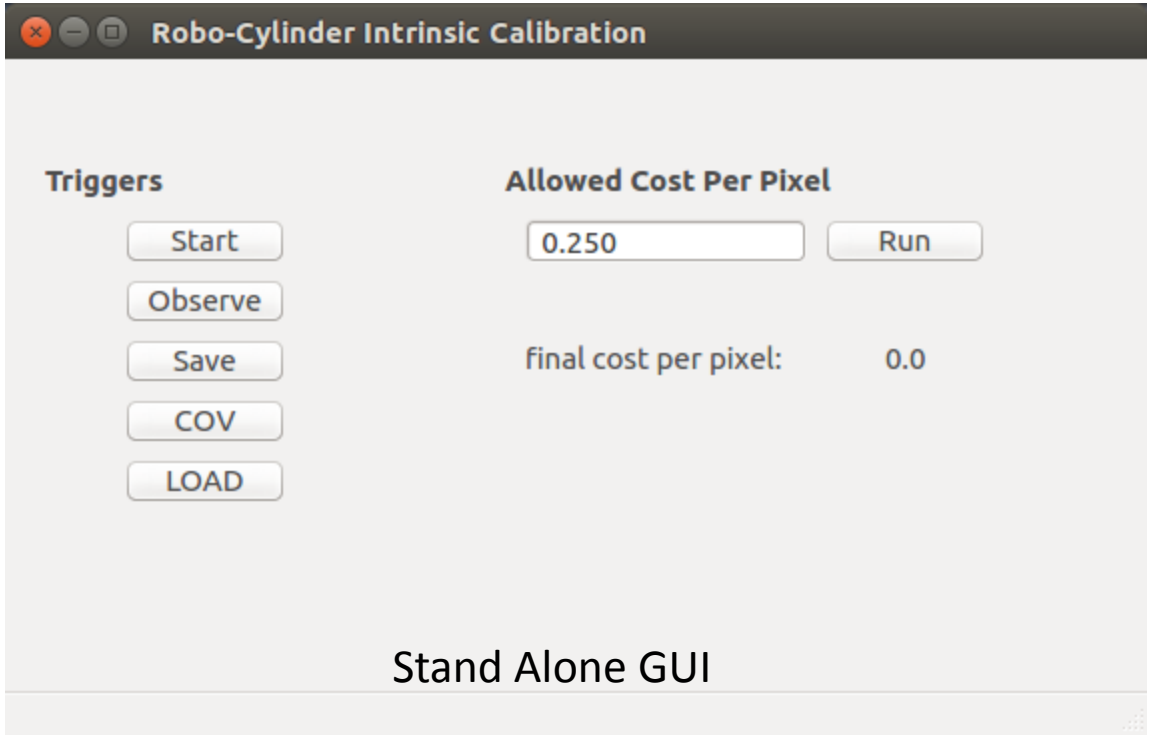


Why it was Awful?

- Virtually every flavor of intrinsic and extrinsic calibration in one node
- Massive Effort to Configure
  - Launch File/URDF madness
  - Yaml File Madness
    - Define every scene
      - Triggers
      - What camera sees which targets
      - Cost function for each observation
    - Define list of cameras and targets
      - Camera triggers
      - Transform interfaces

Minimize Configuration

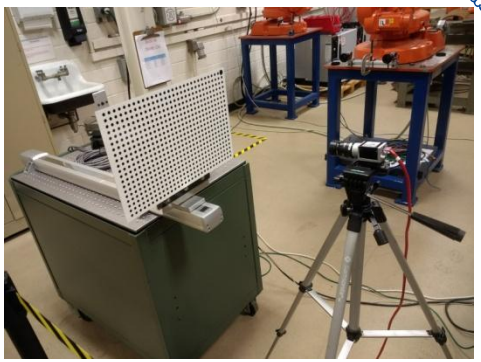
- Divorce calibration from motion and triggers
- Service Based Calibration

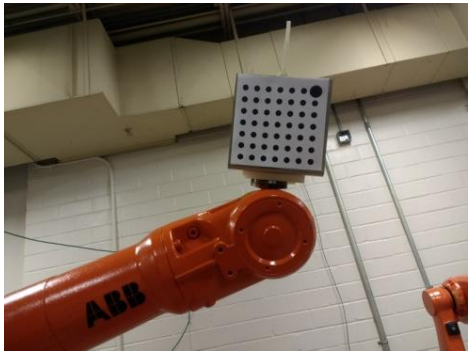


Stand Alone GUI

Dedicated Nodes

- Intrinsic
  - Rail
  - On Robot
    - Camera on Wrist
    - Target on Wrist
- Wrist
  - Camera on Wrist
  - Target on Wrist
- Stereo
  - Cameras on Wrist
  - Target on Wrist

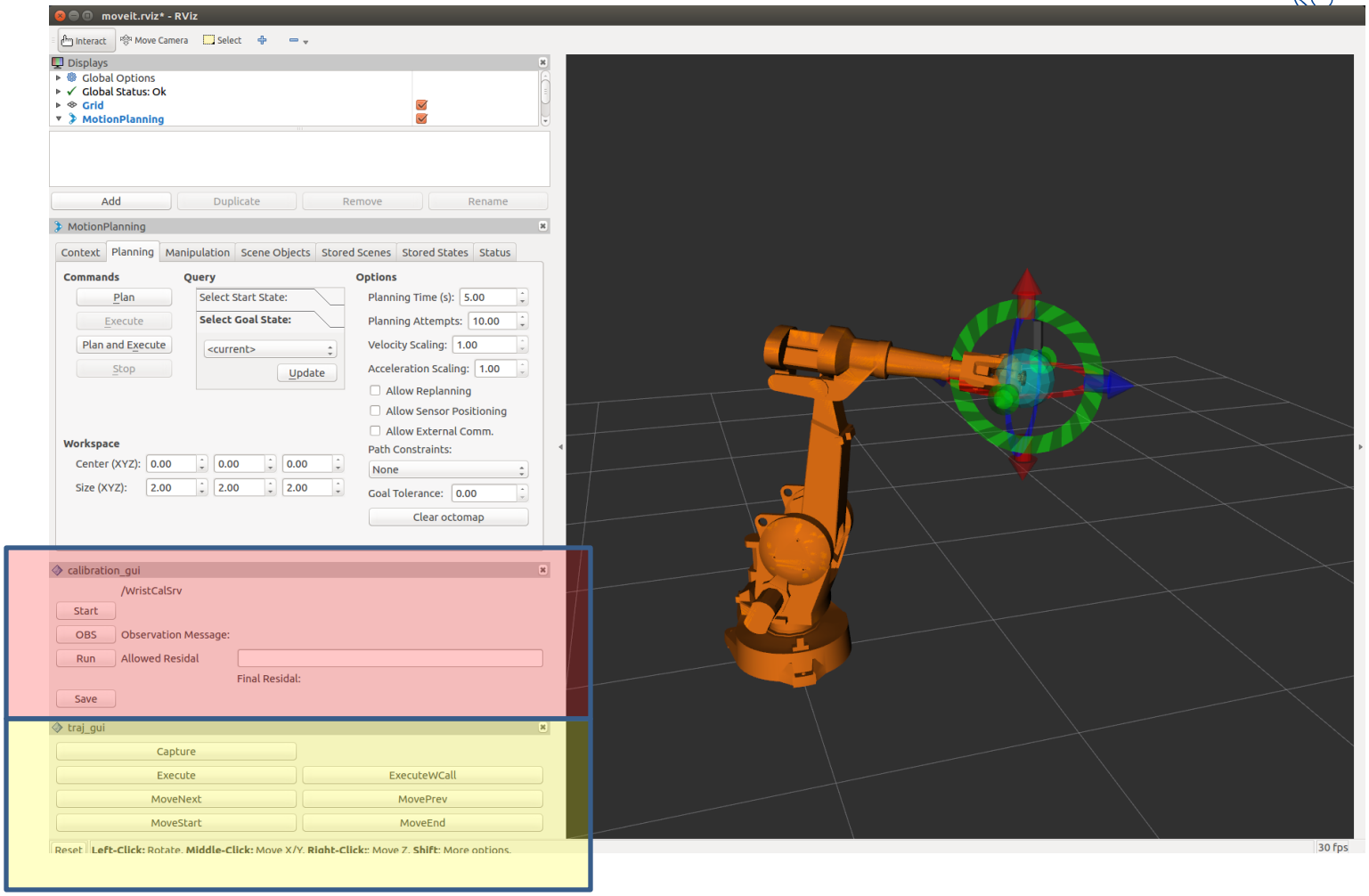




Load and Covariance

- Load
  - Add more data to existing calibration
  - Run with Any Method for Data Collection
  - Adjust Grid Finding Parameters
  - Remove troublesome images
- Custom Covariance matrix
  - Low Residual is no Guarantee
  - Enough Data
  - Diverse Data

GUI as an Rviz Plug in



Robo-cylinder Calibration

- 2 Passes Necessary
- Unknowns:
  - Pose to each Pass
  - Axis of Motion
  - Intrinsics
- Extruded grid
- Process forces measured motion to match observed motion

On Robot I-Cal

Repeatability and Accuracy

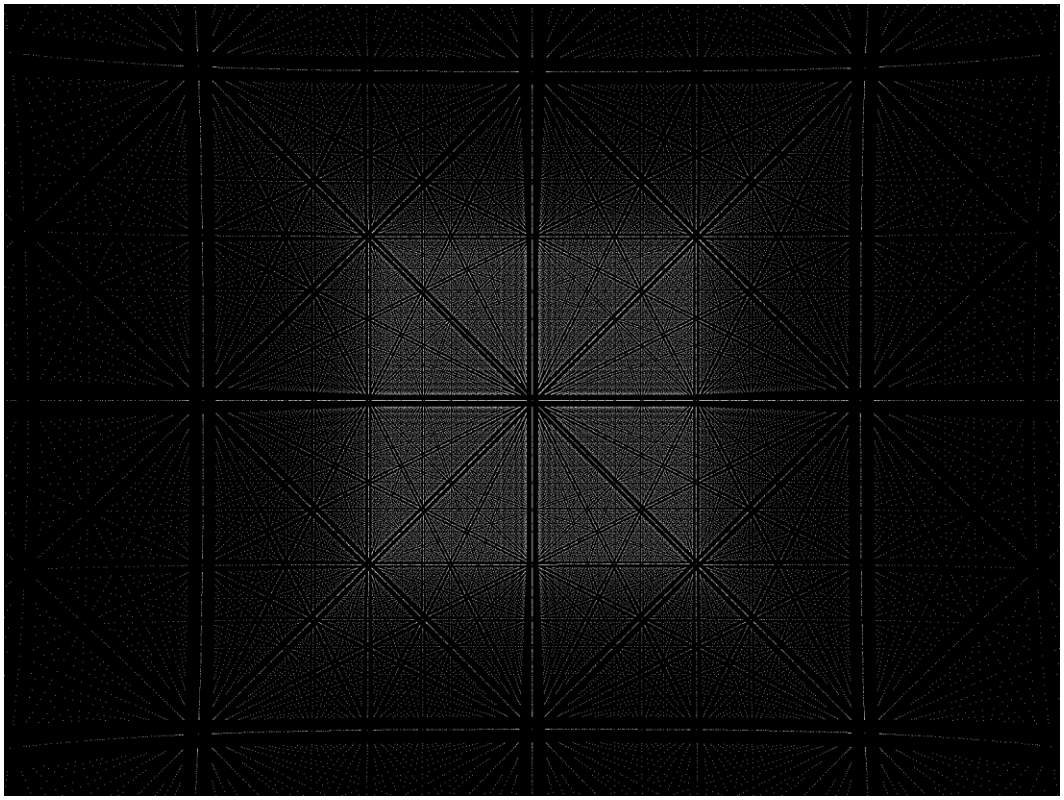
- Why do I get .25 per/pixel residual error, but 5-10 pixels variation in Cx, Cy, Fx and Fy?
- 1% σ in Fx corresponds to 1cm at 1meter
- Camera accuracy
  - Circles found with .01 pixel accuracy
  - Position Repeatable to .0254mm at 1 meter
- Is more data needed?
- Is the model redundant?

Covariance from Ceres

- Focal length correlated to radial distortion

  Fx,Fy ⇔ k1,k2,k3
- Principal point correlated to de-centering distortion Cx ⇔ p2 & Cy ⇔ p1
- k1 ⇔ k2 ⇔ k3

Ical w/data Everywhere



- Residual is low, Covariance Still High

Covariance Results

Full Model

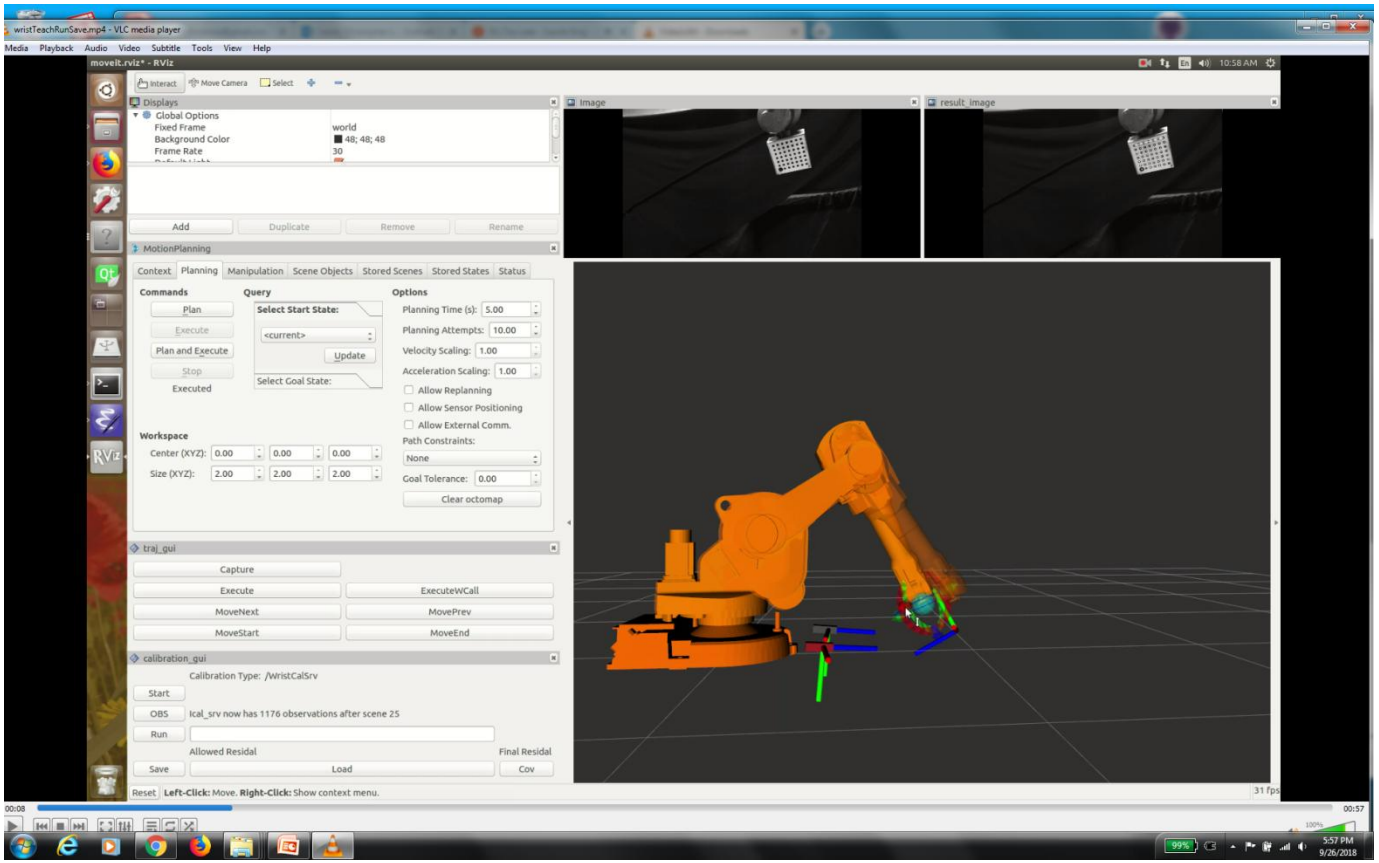
fx	fy	cx	cy	k1	k2	k3	p1	p2
0.01737	0.87709	-0.01683	0.00282	-0.80504	0.73464	-0.65705	0.00479	-0.01570
0.87709	0.01753	0.00157	-0.00464	-0.82091	0.75606	-0.67664	-0.00344	0.00295
-0.01683	0.00157	0.02018	-0.00058	0.00525	-0.01022	0.01526	-0.00060	0.92158
0.00282	-0.00464	-0.00058	0.01929	-0.00174	0.00171	-0.00166	0.88249	-0.00052
-0.80504	-0.82091	0.00525	-0.00174	0.00010	-0.96252	0.90466	-0.00536	0.00130
0.73464	0.75606	-0.01022	0.00171	-0.96252	0.00007	-0.98257	0.00319	-0.00781
-0.65705	-0.67664	0.01526	-0.00166	0.90466	-0.98257	0.00002	-0.00211	0.01221
0.00479	-0.00344	-0.00060	0.88249	-0.00536	0.00319	-0.00211	0.00002	-0.00048
-0.01570	0.00295	0.92158	-0.00052	0.00130	-0.00781	0.01221	-0.00048	0.00002

Reduced Model

f	cx	cy	k1	k2
0.01224	**-0.00063**	**-0.00433**	**-0.69724**	**0.68697**
-0.00063	**0.00786**	**0.00018**	**0.01022**	**-0.00075**
-0.00433	**0.00018**	**0.00910**	**0.01461**	**-0.01172**
-0.69724	**0.01022**	**0.01461**	**0.00004**	**-0.93120**
0.68697	**-0.00075**	**-0.01172**	**-0.93120**	**0.00001**

- Conclusion:
  - Probably shouldn't use K3,P1&P2

Create and Execute a Calibration Using MoveIt!



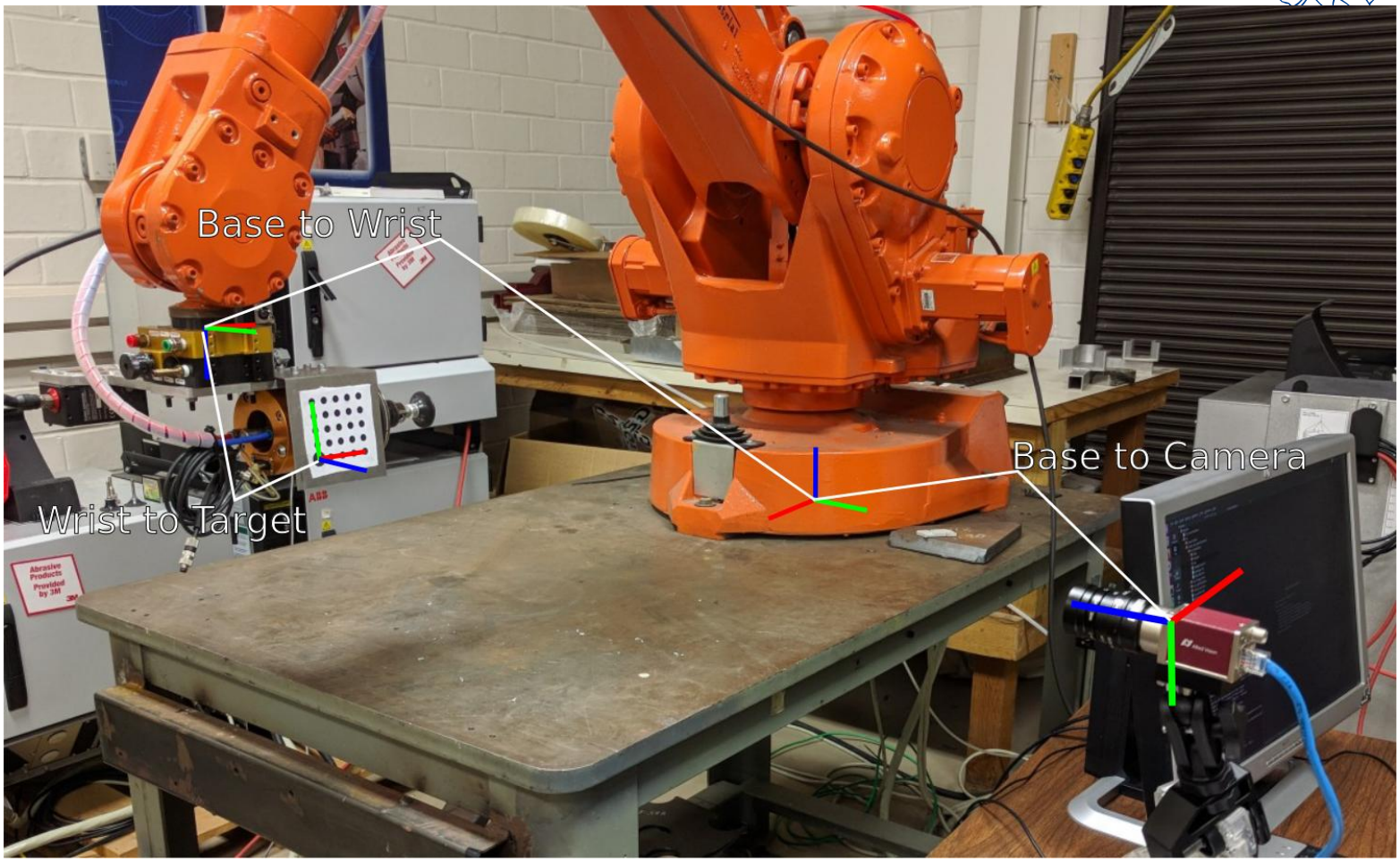
C:\Users\clewis\roscon2018\wristTeachRunSave.mp4

Stereo Calibration

Camera on Wrist Calibration

Target on Wrist Calibration

Robot_Cal_Tools



Robot_Cal_Tools

- *Industrial_calibration* works well but requires an eco-system to support it
- *robot_cal_tools* was made as a learning experience with a focus on *pure functions*
- Makes no assumptions about data collection or what you do with the answer
- Covers common calibrations
  - Intrinsic & extrinsic pinhole camera(s)
  - 3D (e.g. IFM) to 3D
- Hopefully useful for integrating into custom systems or as a basis for writing something custom

Robot Cal Tools (Contents)

- Core dependency: only Ceres (and Eigen)
- The API:

```
struct Problem {
        // Specify camera data, correspondences
};

struct Result {
        // Shows average cost, other convergence data
};

Result optimize(const Problem& params);
```

- Provides some tools for using OpenCV target finders
- Emphasis on documentation

Where Next

- Contributions welcome!
  - https://github.com/Jmeyer1292/robot_cal_tools
  - https://github.com/ros-industrial/industrial_calibration.git
    - (look for branch with 500 commits)
  - WE ARE HIRING
- Future plans:
  - Integrate robot_cal_tools into industrial_calibration
  - Provide experiments for robot kinematic calibration
  - Provide experiments for laser profile scanners
  - LiDAR?
  - Documentation with examples for Service based CAL