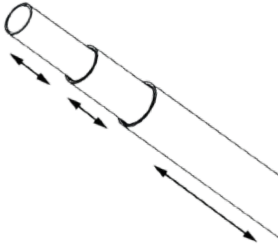
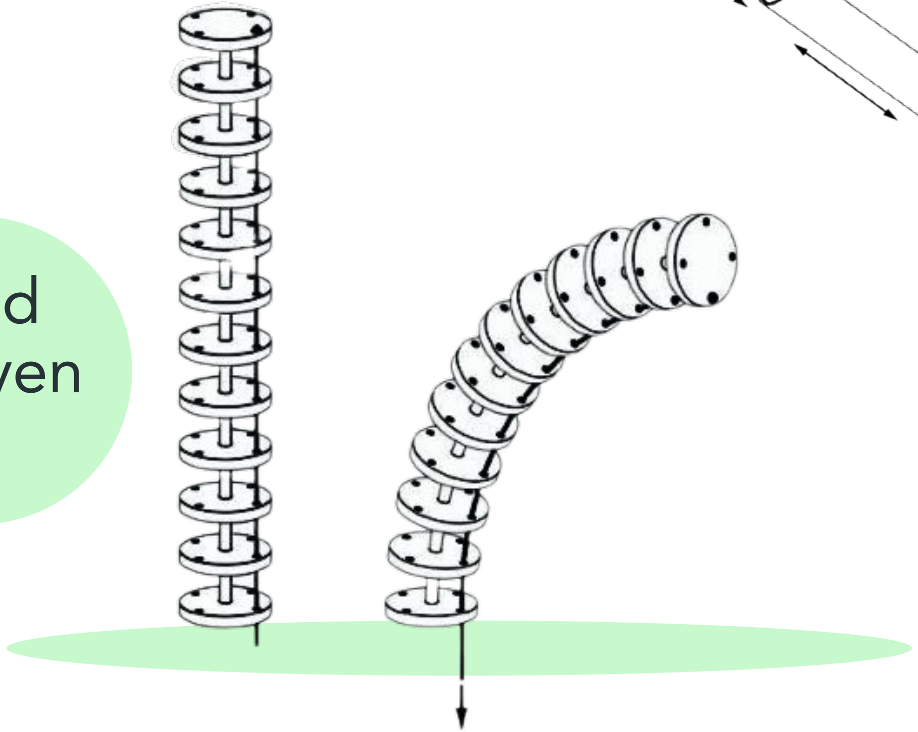


camera-based shape sensing and motion capturing of tendon-driven continuum robots

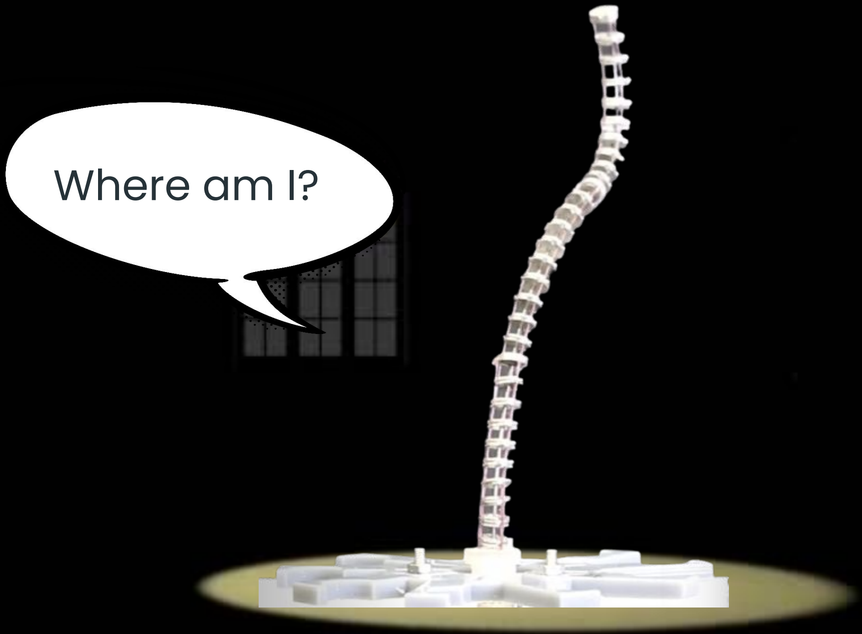


Supervisor: Priyanka Rao
Yasmeen Hmaidan

UNIVERSITY OF TORONTO
Robotics Institute

continuum robotics lab


proximity
distance
object
The Affordable Art Fair
AAF
The Affordable Art Fair
AAF
Syfy


Where am I?

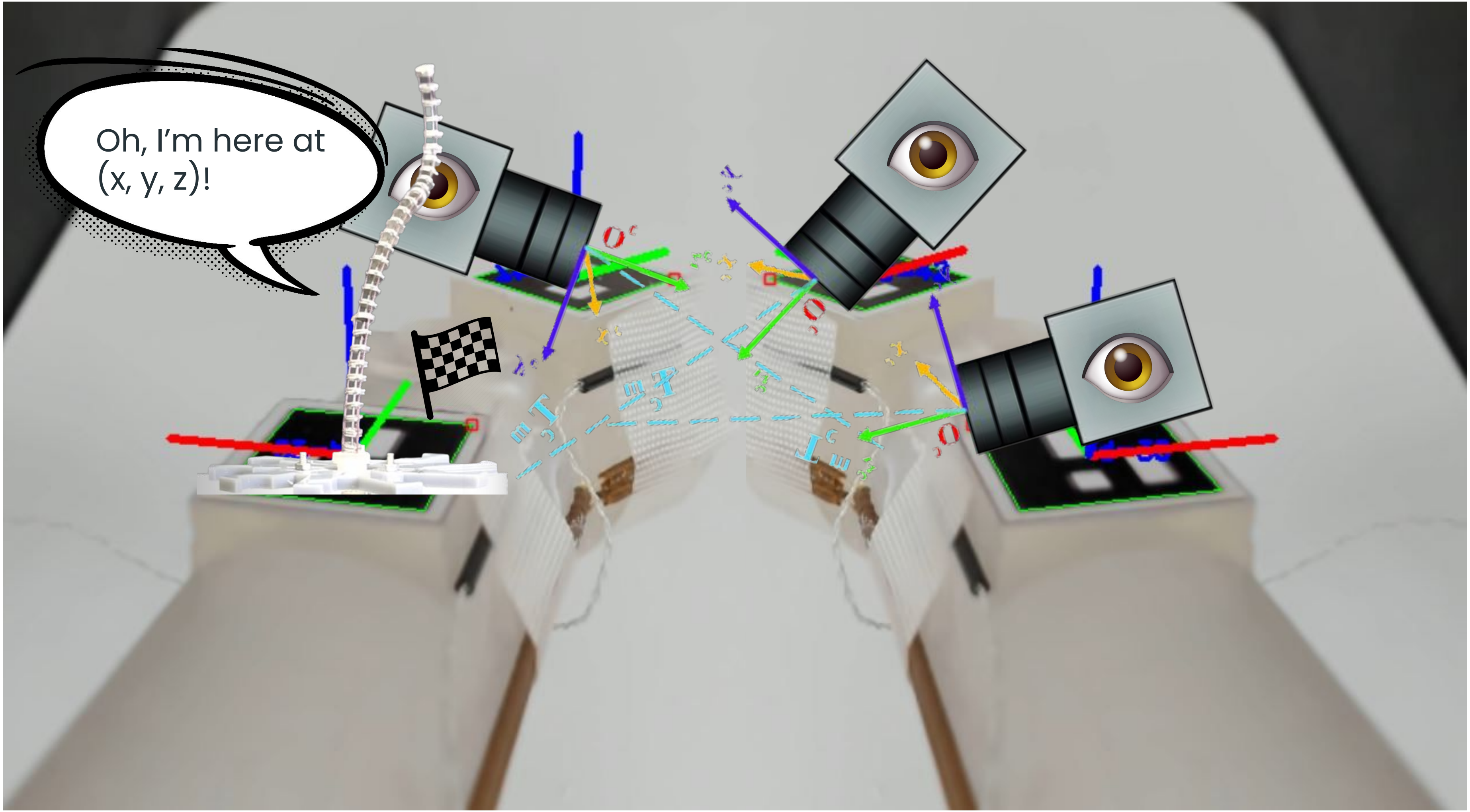
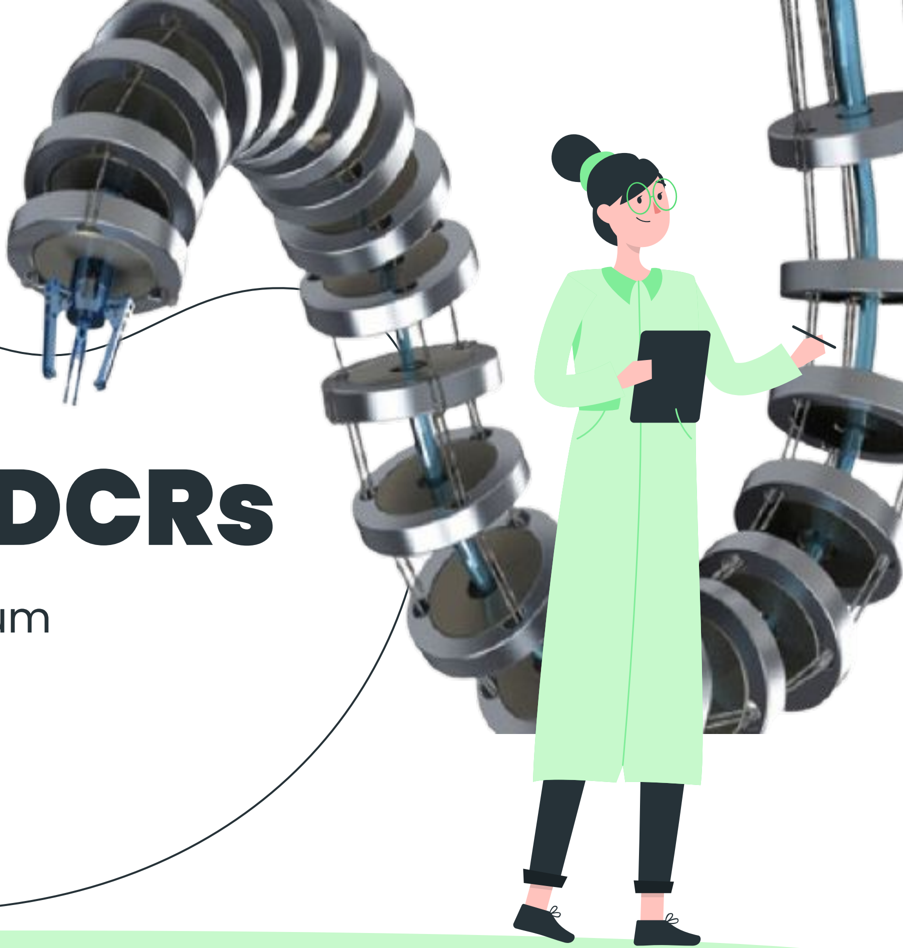

Oh, I'm here at (x, y, z)!

Table of Contents

1

Intro to TDCRs

Tendon Driven Continuum Robots



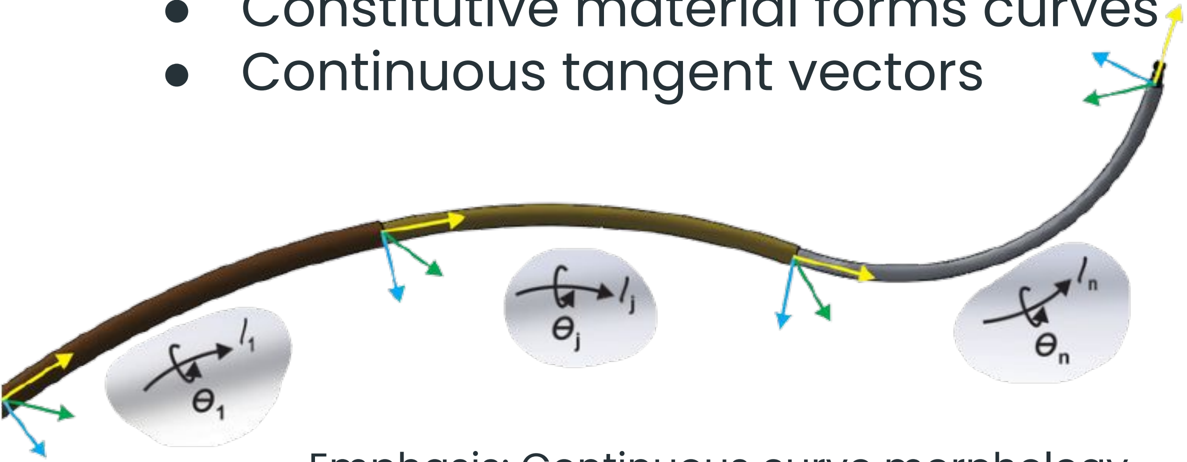
What is a Continuum Robot (CR)?

According to the Burgner-Kahrs, Rucker, & choset, 2015 definition:

- Actuatable structure
- Constitutive material forms curves
- Continuous tangent vectors

Note, <u>no</u> assumptions are made on:

- CR's actuation method
- Elasticity of composing materials



Pro: conformity
Con: less precise positioning (w/o discrete rigid links)

(CSC476, 2020)

Emphasis: Continuous curve morphology

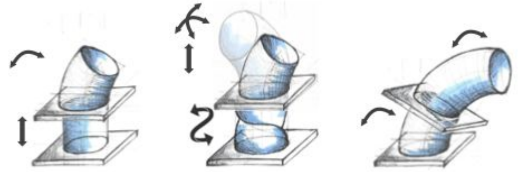
CR Elements

Ultimate Goal:

- Fully controllable continuously bending manipulator

Motion Primitives Set:

- Extension & Contraction
- Bending
- Twisting



range of motion $\propto$ # of stacked segments

Extrinsic Actuators:

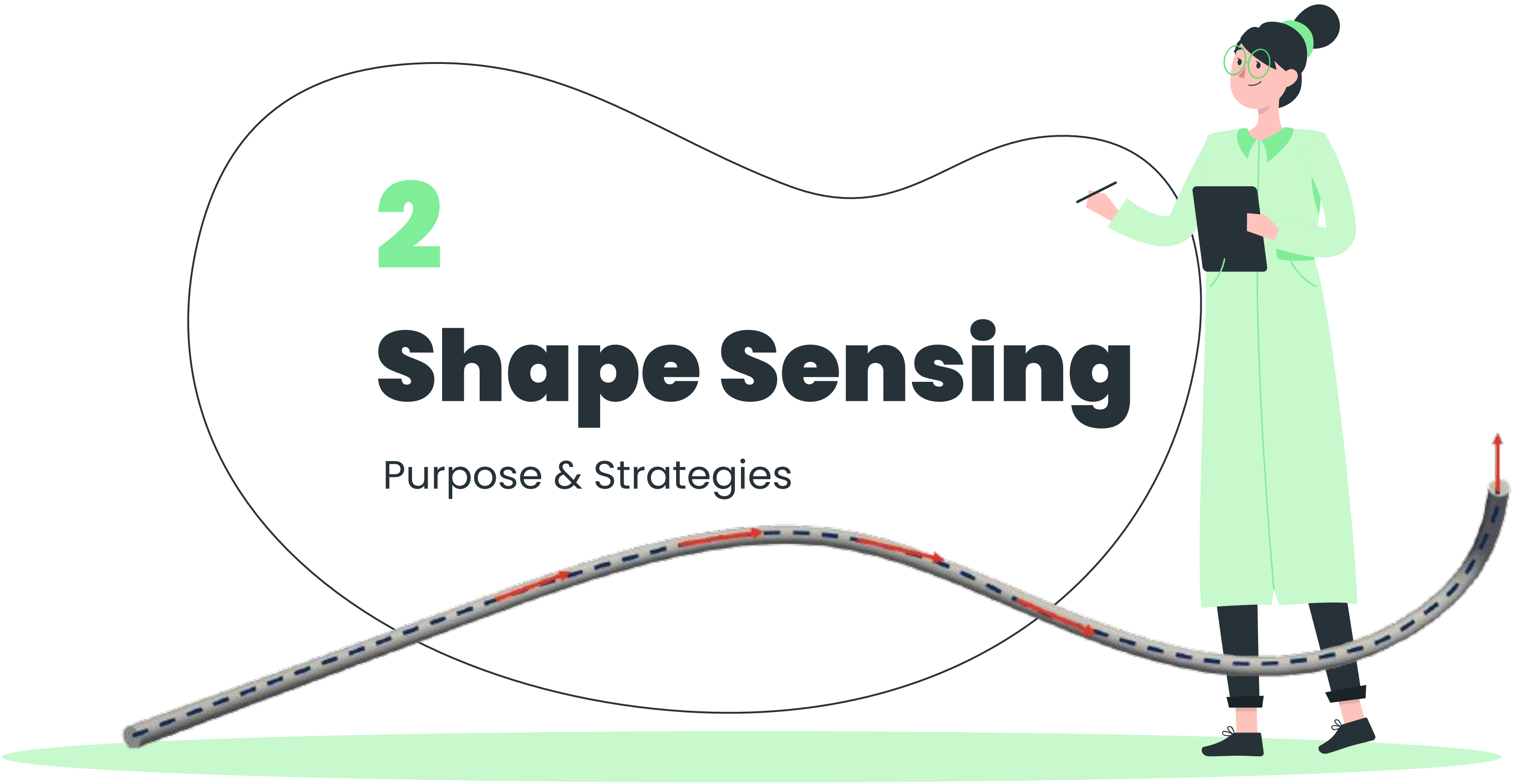
- Tendon/Wire-Actuated
- Telescoping Pre-Curved Tubes

(CSC476, 2020)

2

Shape Sensing

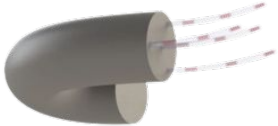
Purpose & Strategies



Shape Sensing Types

Embedded Sensors

- **Fibre-optic sensing**
  - Geometric fibres and sensor array
  - Pro: Real-time shape information
  - Con: Expensive



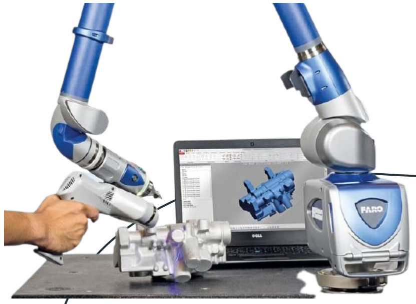
- **Electromagnetic sensing**
  - Locates objects with sensor coils
  - Real-time pose tracking
  - Pro: No line-of-sight restrictions
  - Con: Robot rigidity

(CSC476, 2020)

External Sensors

- **Mechanical probe**
  - Touches robot to measure tip position or shape
  - Pro: Measure multiple distinct locations
  - Con: Not contactless

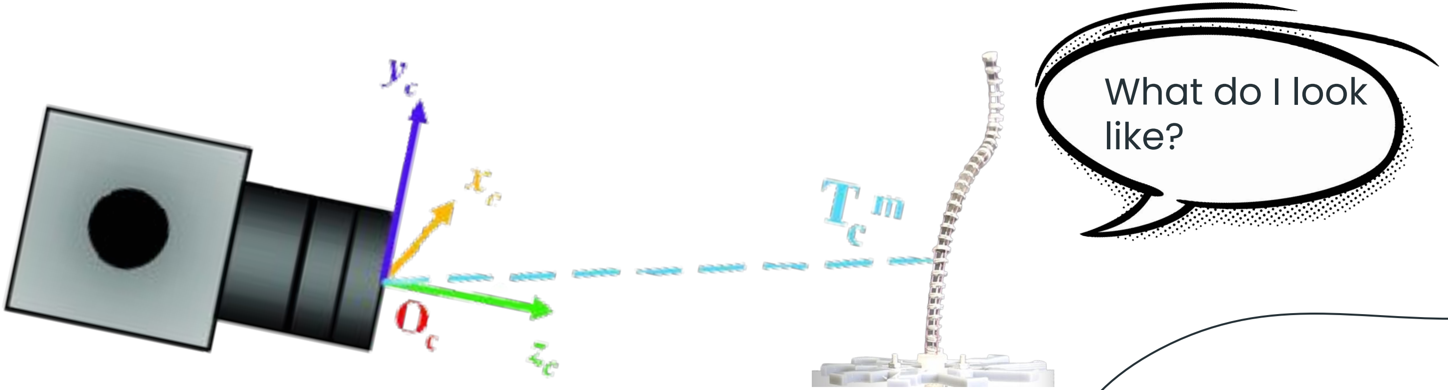
- **Laser probe**
  - Emits laser line that uses images from the camera along robot to get object distance
  - Pro: Dense point cloud of robot shape
  - Con: Time-consuming



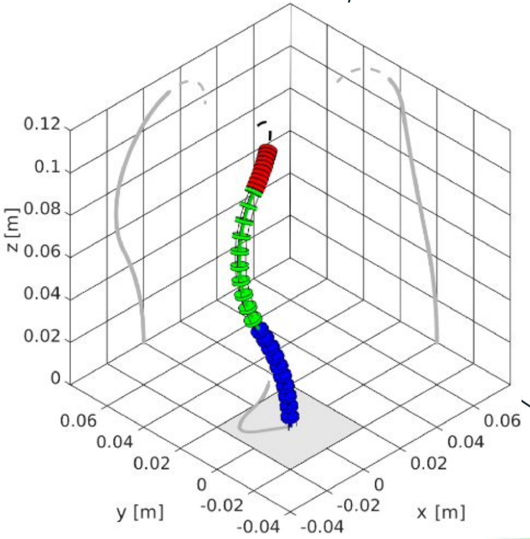
Shape Sensing Types

Ideal Choice: External image-based sensing

- Multiple **external cameras**
- **Contactless**
- Used in both **static** and **dynamic** TDCR applications
- Precise **3D reconstruction**
- Challenge: Direct **line-of-sight** (occlusions/partial views are processed)



(CSC476, 2020)



3

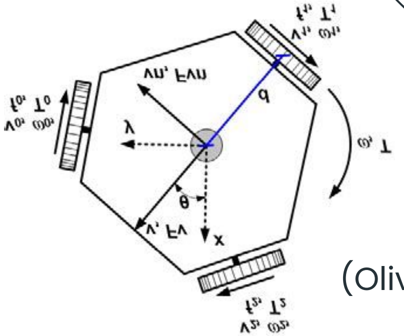
Depth Estimation (methodology)

Multiple-Camera system &
Computer Vision

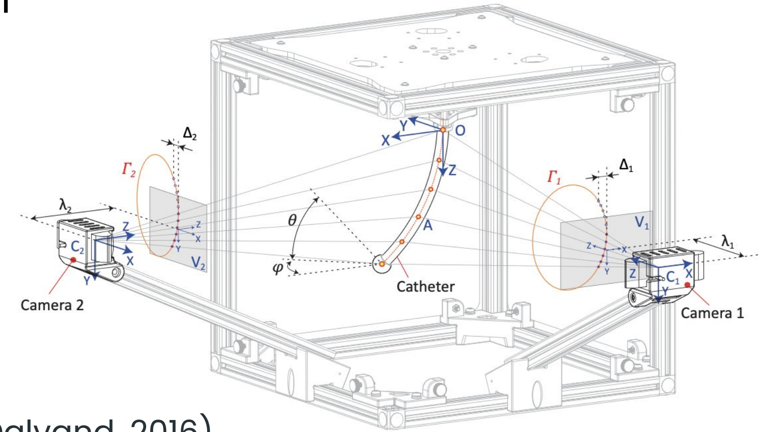
Multiple-Camera system

Main Project Goal:

- Orient **three cameras**
- Calculate **3D transformations** to '**global**' **coordinates**
- **Input:**
  - **Pixel** coordinates of detected object (per camera)
- **Output:**
  - **3D** coordinates in decided frame + the three axes (x,y,z)



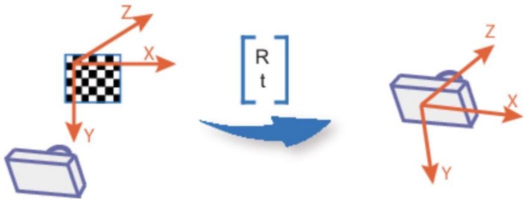
(Oliveria, 2008)

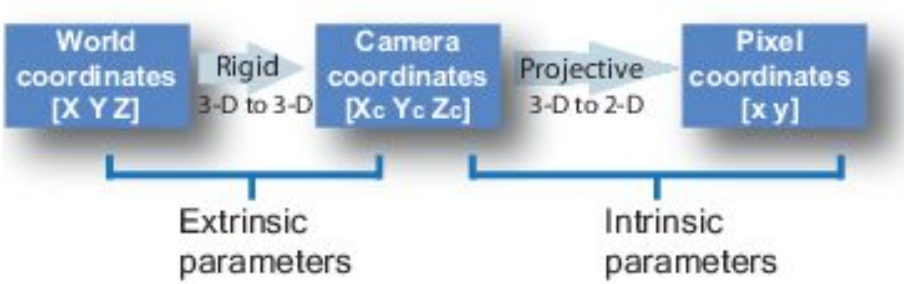


(Dalvand, 2016)

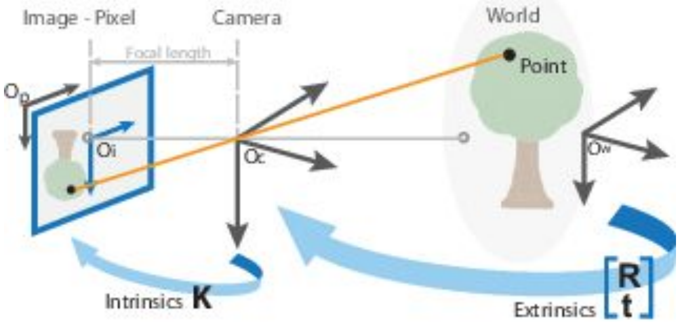
Camera Calibration Algorithm

- Calculates camera matrix (to detect object’s global location, size, etc.)
  - Two **parameters**



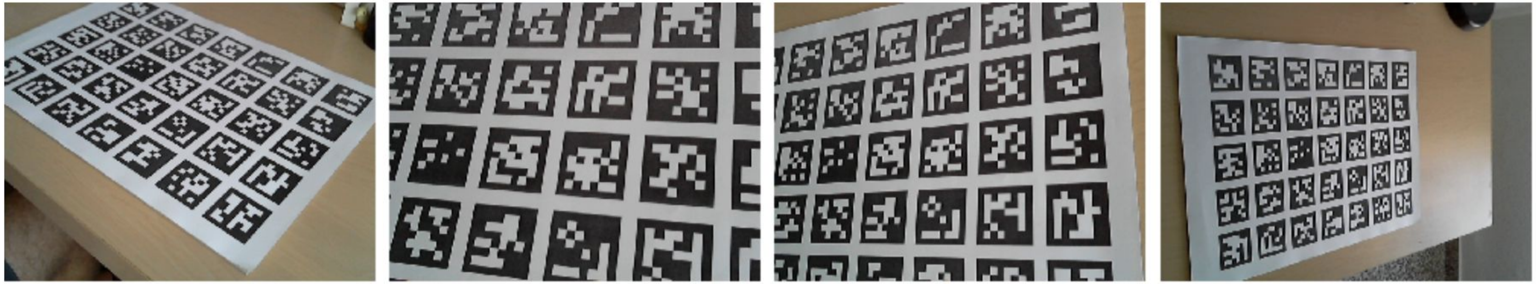


$$\begin{bmatrix} f_x & 0 & 0 \\ s & f_y & 0 \\ c_x & c_y & 1 \end{bmatrix}$$



(Mathworks, 2021)

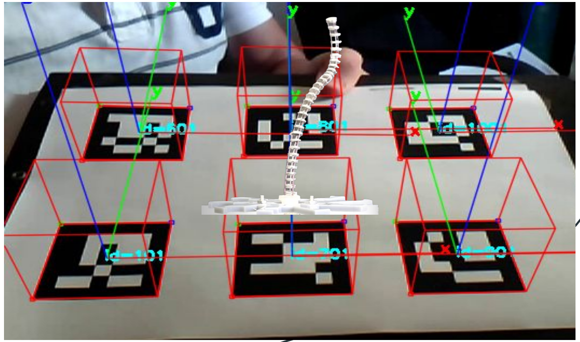
Camera Calibration: ArUco Module Markers



ArUco calibration viewpoints

A type of **QR code:**

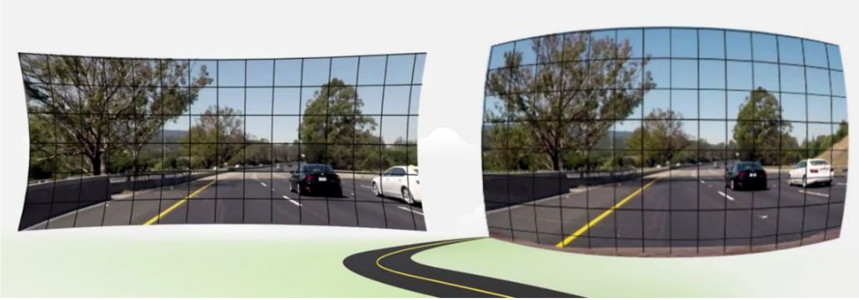
- **Black border** = fast image detection
- **Inner binary matrix** = identifier and detects + corrects distortion error
- **Output:** returns a list of detected markers



(OpenCV, 2019)

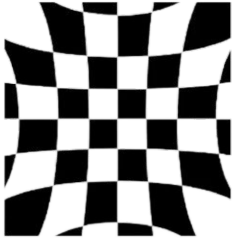
Calibration Challenges

Problem: camera **distorts images** when not parallel to the imaging plane.

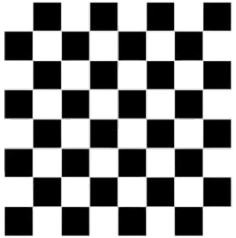


Radial Distortion: straight lines appear curved.

Tangential Distortion: some areas in the image look nearer.



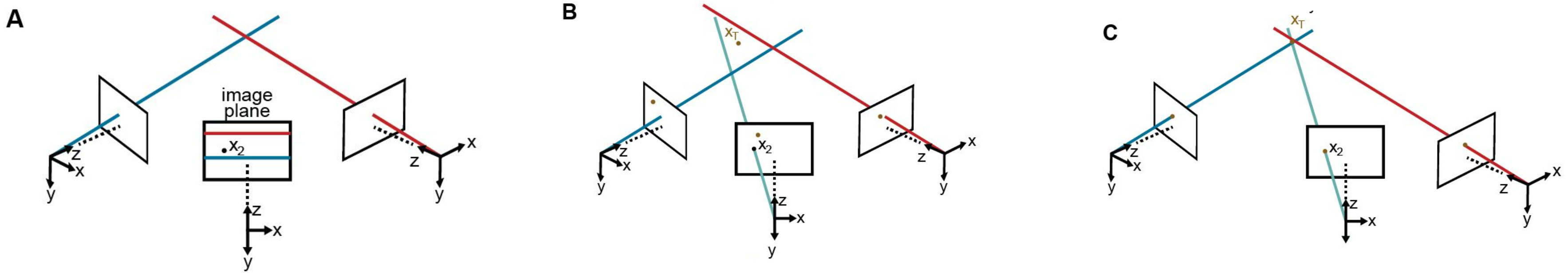
Pincushion Distortion



No Distortion

(OpenCV, 2019)

Calibration Challenges: Stereovision System



Correct 2D pose estimation by using epipolar relationships.

Triangulated point not synced and not accurate 3D position estimate.

Correct camera locations by **optimized orientation** & **location**.

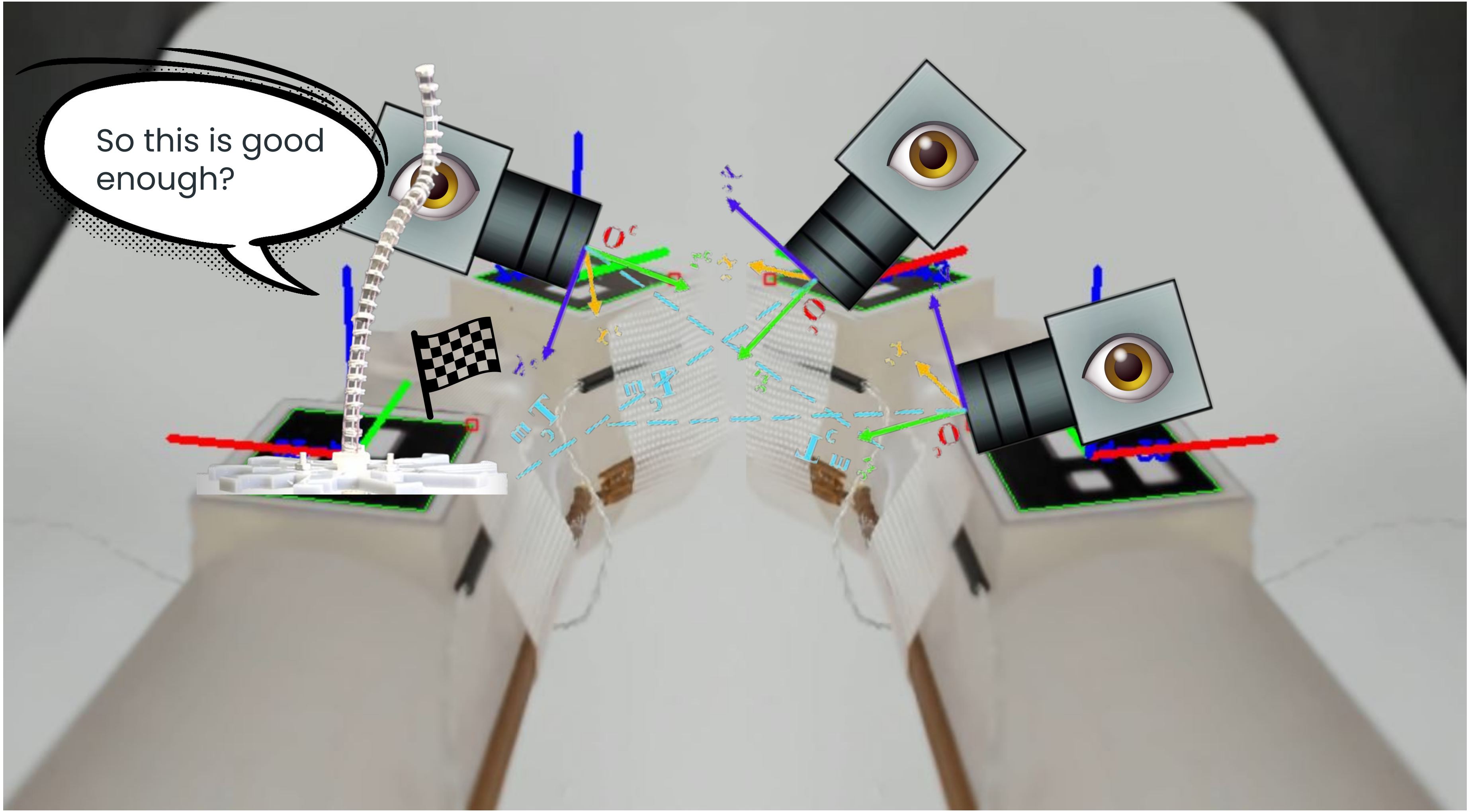
3D reconstruction accuracy of object: $\propto$ # of **cameras** and triangulated **angles** covered.

(DeepFly3D, 2019)

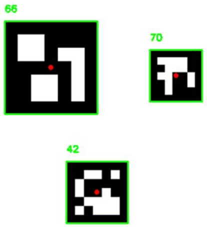
What does good camera calibration look like?

Good Camera Calibration = **accurate estimates** of objects in the **world** and where the **TDCR** is in this environment with no blind spots.

- **External** image-based sensing
- **Three-camera** system
- **Intrinsic** and **extrinsic** camera calibration **parameters**
    - ArUco Markers
- **OpenCV** distortion & calibration optimization methods


So this is good enough?

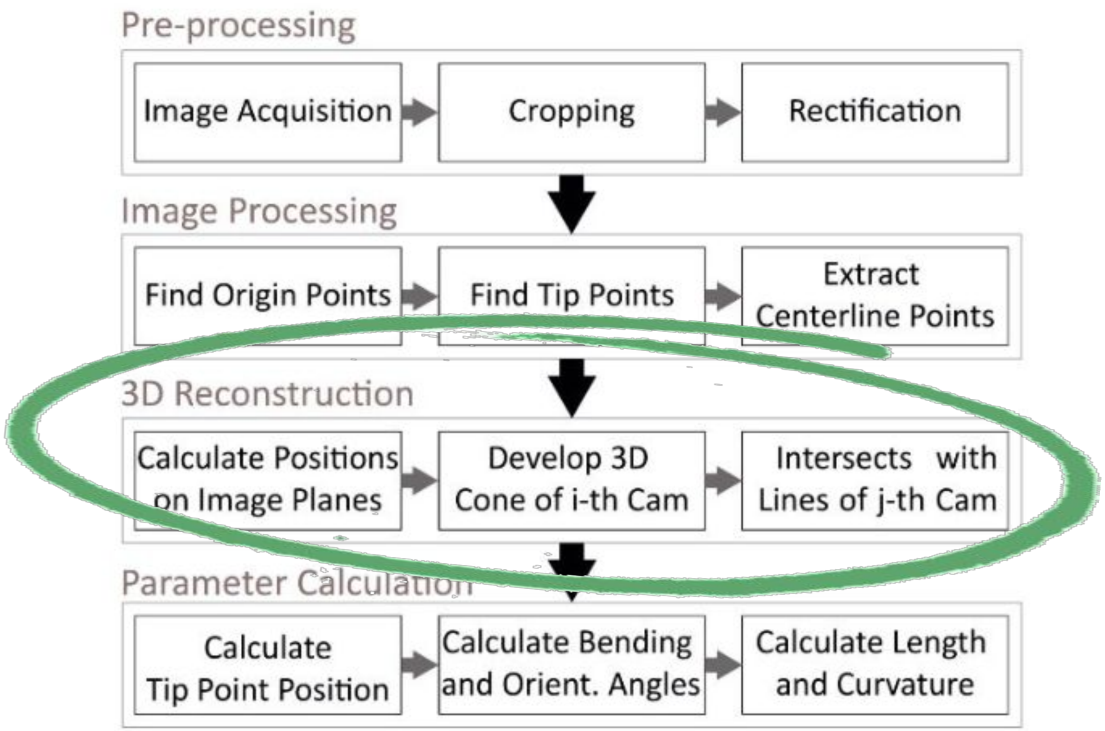
Research Plan



	Data	Application	Goal
ArUco Markers	First 10 markers of ARUCO_MIP_36h12	Rectangle robot base setup	Establish global coordinate system
Camera Setup	Live video feed to image collection	3 cameras in tandem orientation	Calculate extrinsic & intrinsic params
Computer Vision	OpenCV	Image processing pipeline	3D Reconstruction and transformation

OpenCV

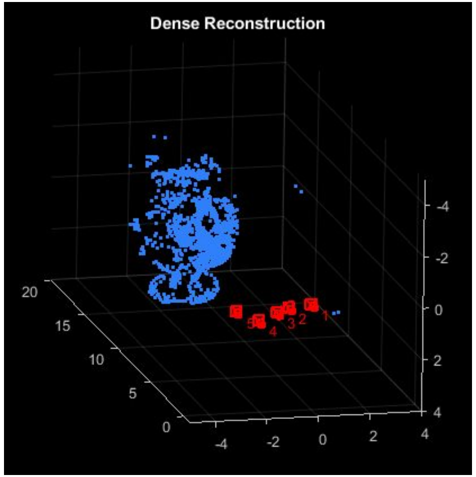
TDCR Image Processing Pipeline



(CSC476, 2020)

3D OpenCV Reconstruction:

- Segmentation
- Epipolar geometry
- Distortion reduction



(OpenCV, 2019)

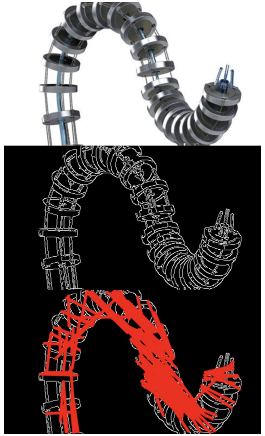
So what now?

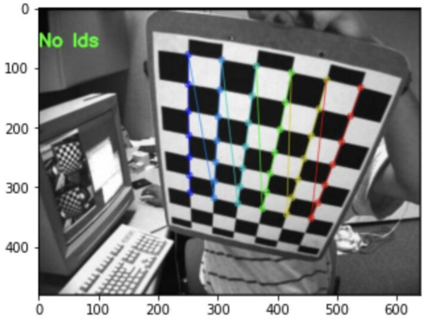
4

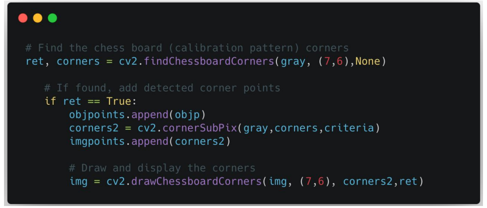
Project Timeline

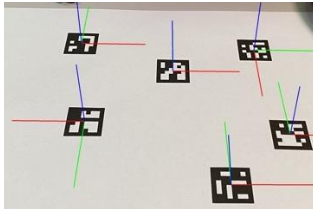
Workflow & Target Outcomes

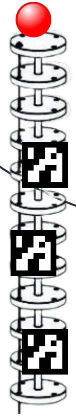
Project Timeline











weeks 1-2
OpenCV Tutorials + CSC476

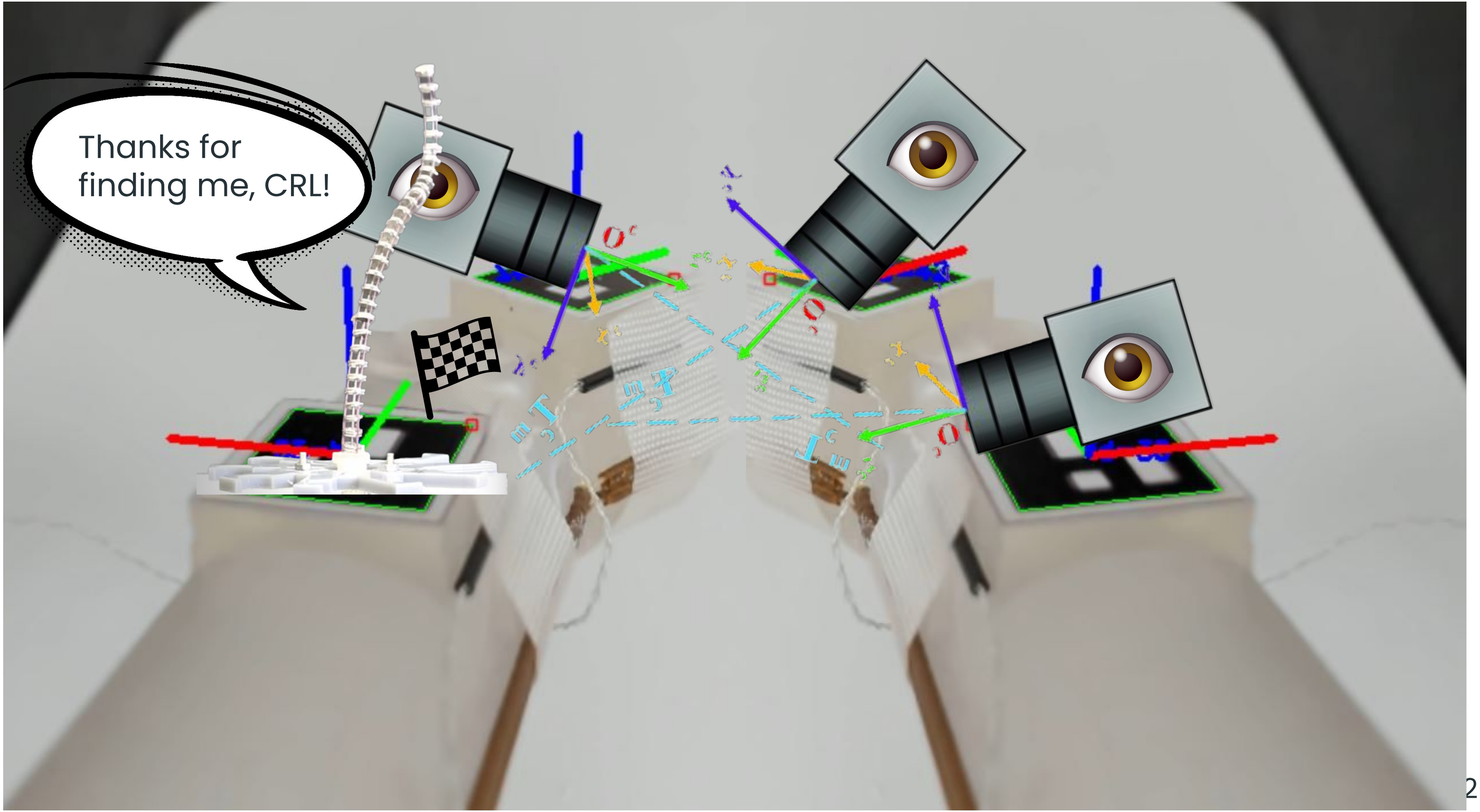
weeks 3-5
Camera calibration + Aruco markers

weeks 6-8
Set up camera system + 3D transforms

weeks 8-10
3D depth mapping + real-time tracking

weeks 11-12
Extra documentation + report writing

weeks 13-16
TDCR robot trial + GUI + ML joint to tip position mapping


Thanks for finding me, CRL!

References

https://www.researchgate.net/figure/Three-wheel-Omnidirectional-robot_fig10_256089781

https://april.eecs.umich.edu/software/apriltag.html

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http://biorobotics.harvard.edu/pubs/2016/ref_conf/MDalvand_SMC2016.pdf

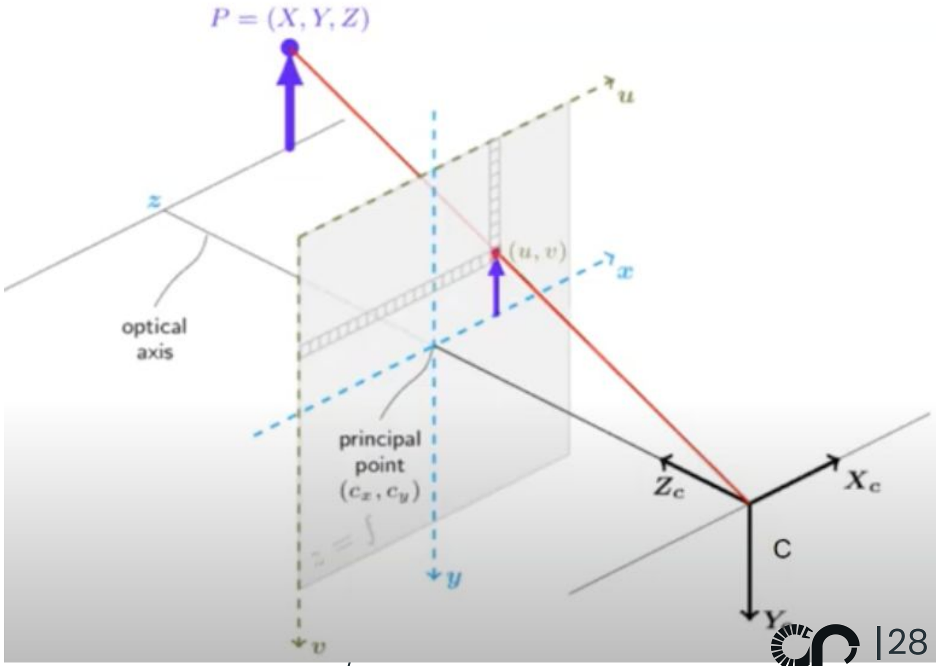
Calibration Types

Intrinsic Calibration

- Given a point **p** = (x, y, z) in camera frame
- Image coordinates calculated from top of frame in a live camera feed
- w.r.t camera center (principal point) and distance to image plane (focal length)
- PPM maps **p** to image coordinates **(u,v)**
- **Goal:** camera parameters

(Spartan Robotics, 2020)

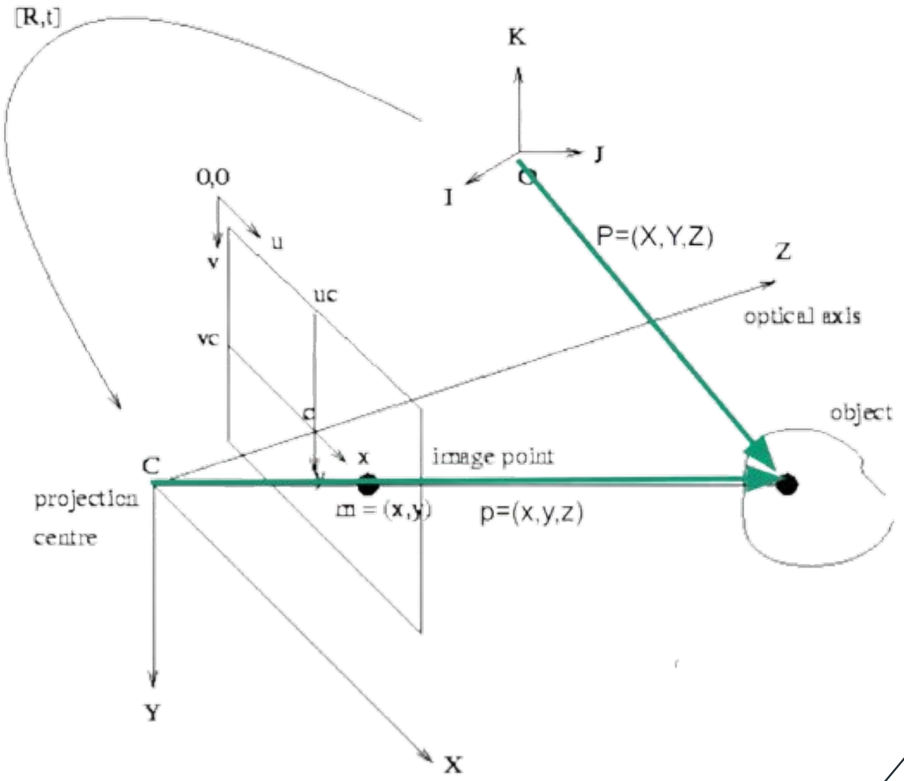
Perspective Projection Model (PPM)



Components

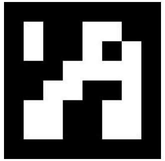
Extrinsic Calibration

- Maps where object is in **camera frame**
- Then, maps it to robot frame with **rotational translation**
- **Goal:** know where cameras are relative to TDCR in real-time



(Spartan Robotics, 2020)

Pros & Cons



ArUco Markers

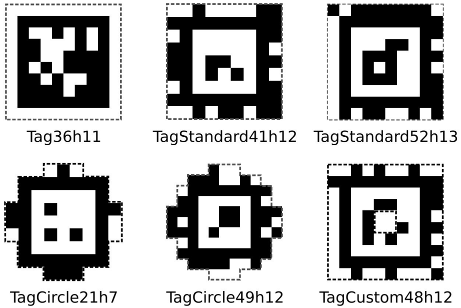
Pros

- Easier OpenCV implementation
- Available arUco marker generator
- Fewer false detection (w/ default)

Cons

- More computationally intensive
- Newer versions are GPL licensed, so opencv is older
- More tuning parameters

AprilTags



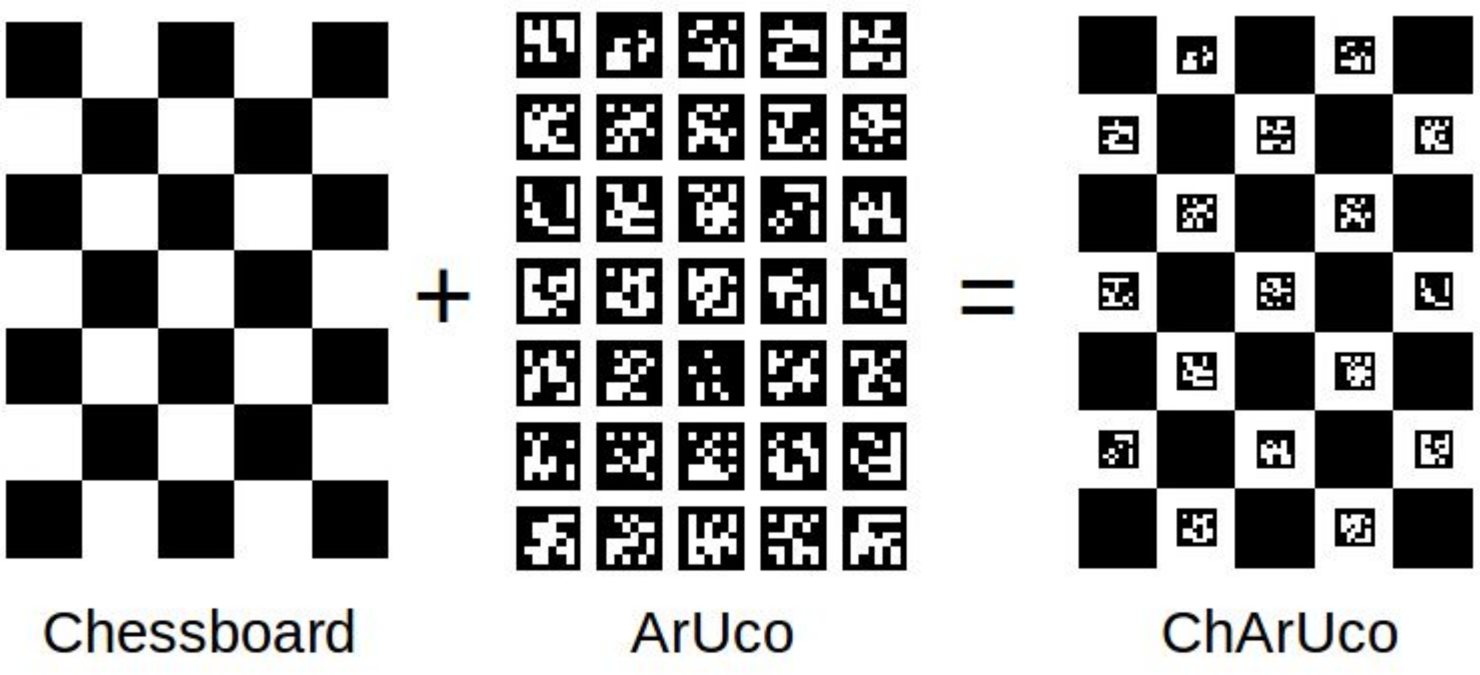
Pros

- BSD License
- Fewer tuning parameters
- Long distance compatibility
- More flexible marker design
- Less computation

Cons

- No opencv implementation
- More steps to obtain markers
- More false detection (with default parameters)

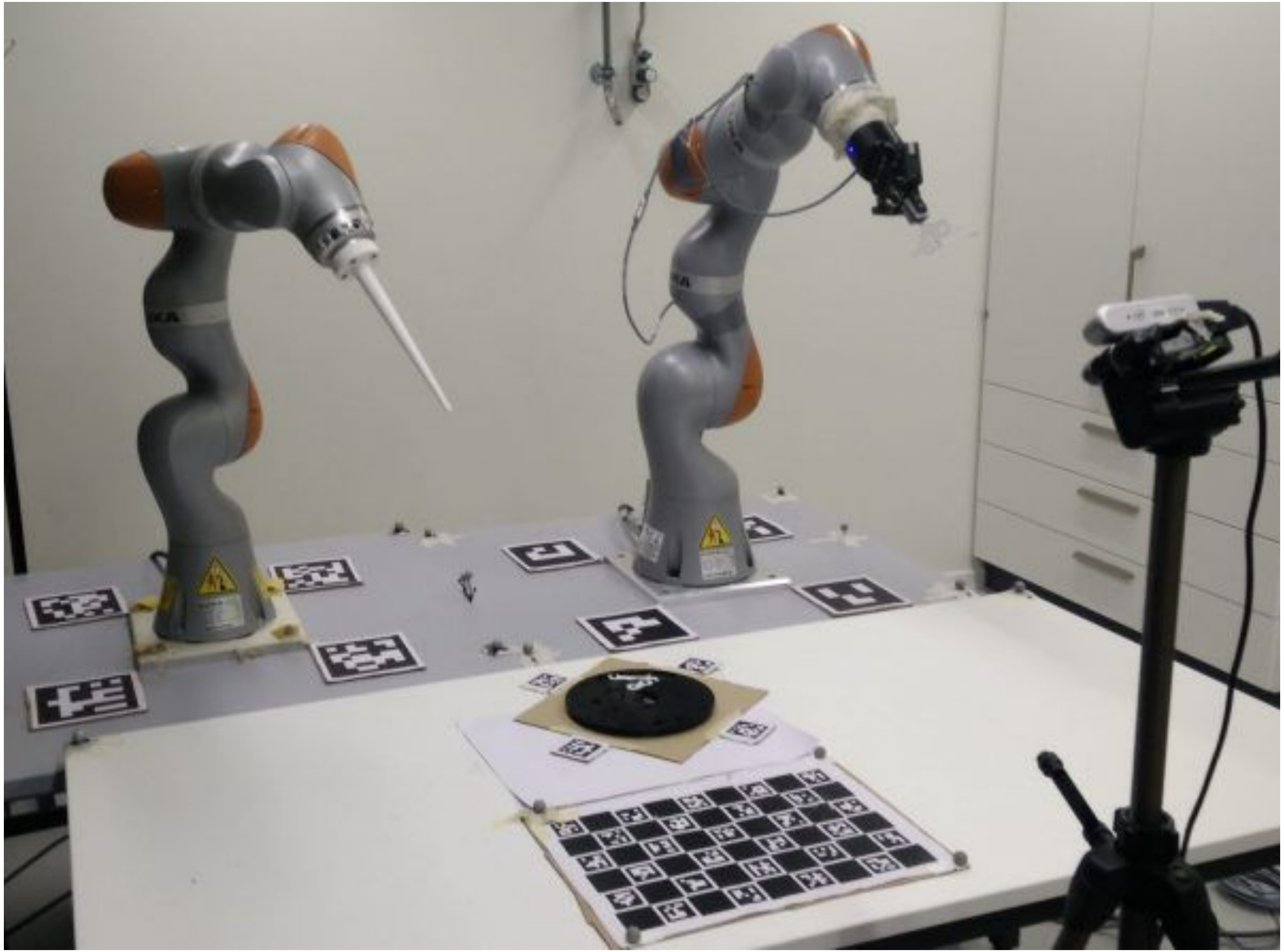
(OpenCV, 2019)



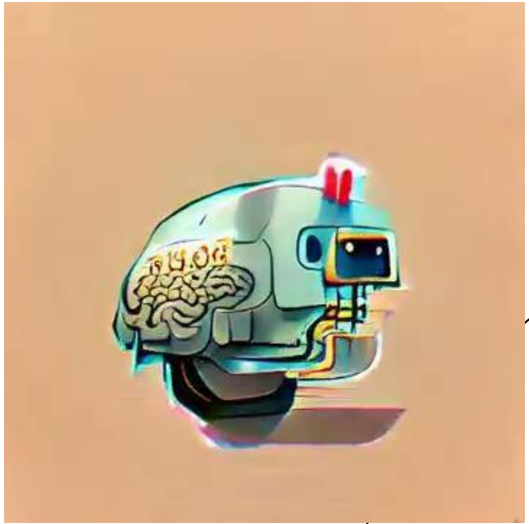
ChAruco boards > ArUco boards for camera calibration = more accurate marker corners.

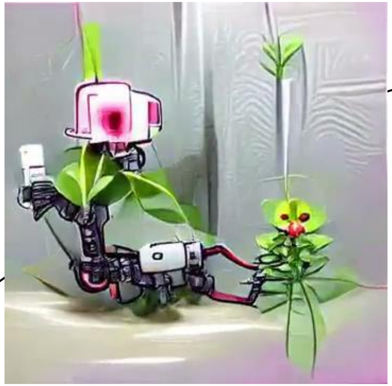
Benefits: occlusions and partial views are allowed, and not all the corners need to be visible in all the viewpoints.

(OpenCV, 2019)



(OpenCV, 2019)





thanks & some CRL art!