ME4101A Bachelor of Engineering Dissertation

Soft Robotics Competition 2

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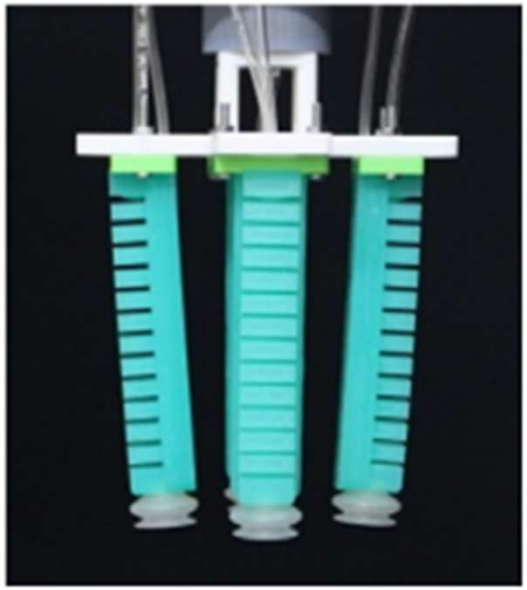
ROBOSOFT
Singapore · 3-7 April 2023

Manipulation Challenge

Layout for RoboSoft 2023 Competition [1]

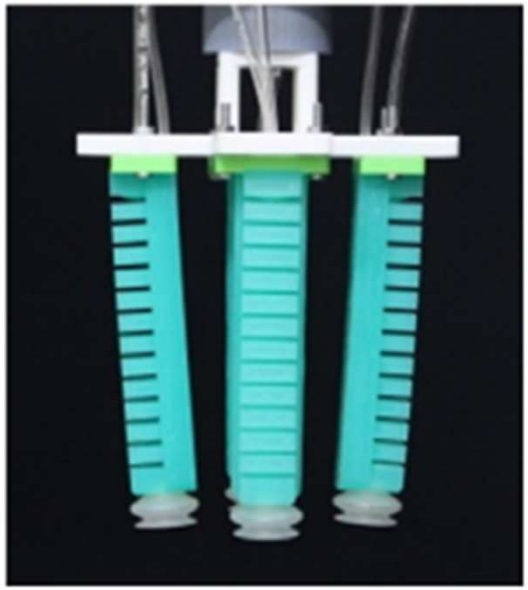
Soft Finger Configuration

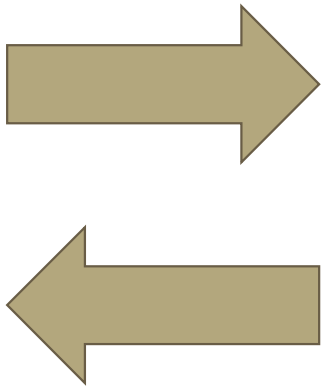


Perpendicular [2]

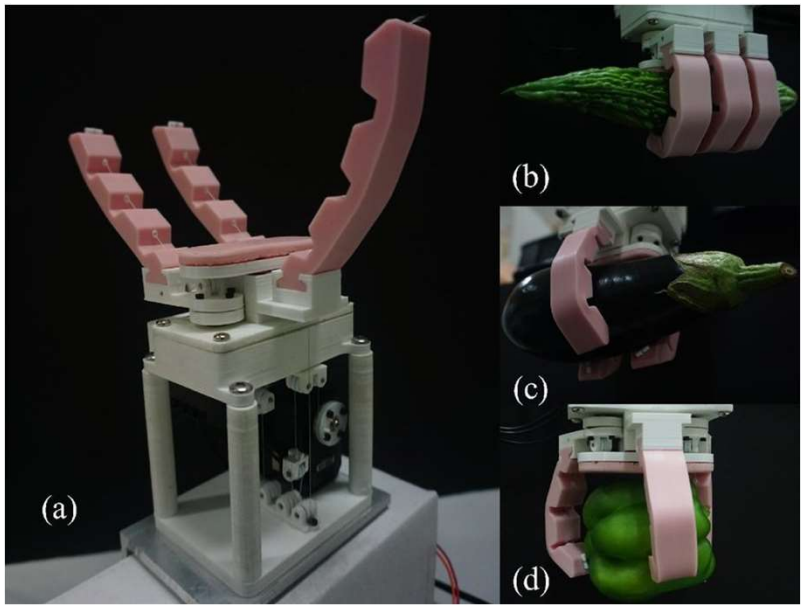
Parallel [2]

Automatic Dual-Mode Pneumatic (ADMP) Gripper

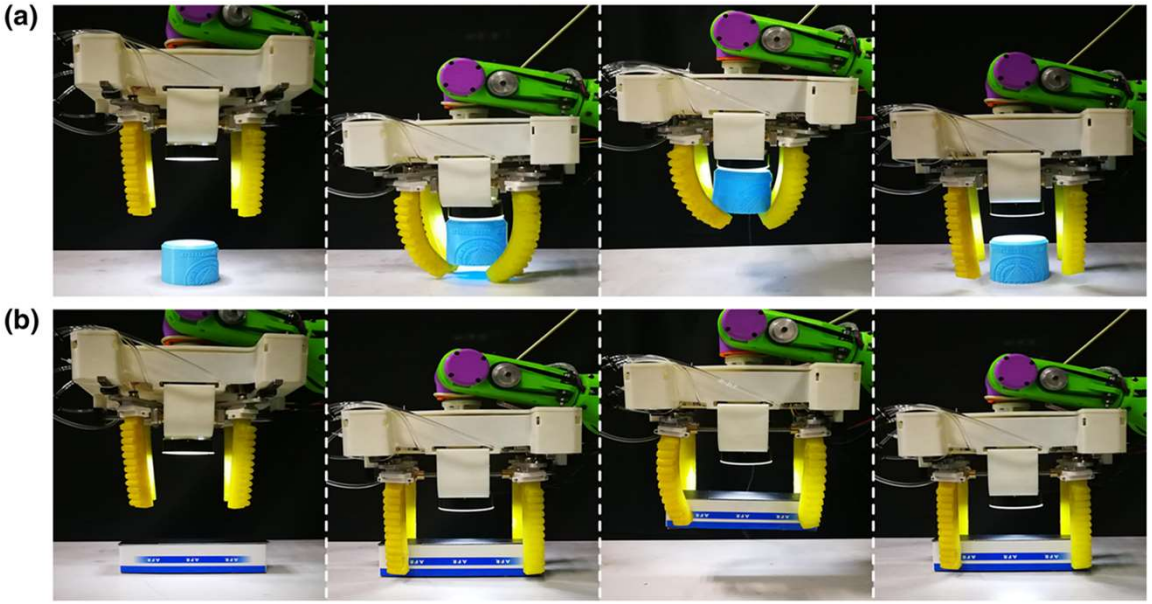




Current configurable soft grippers



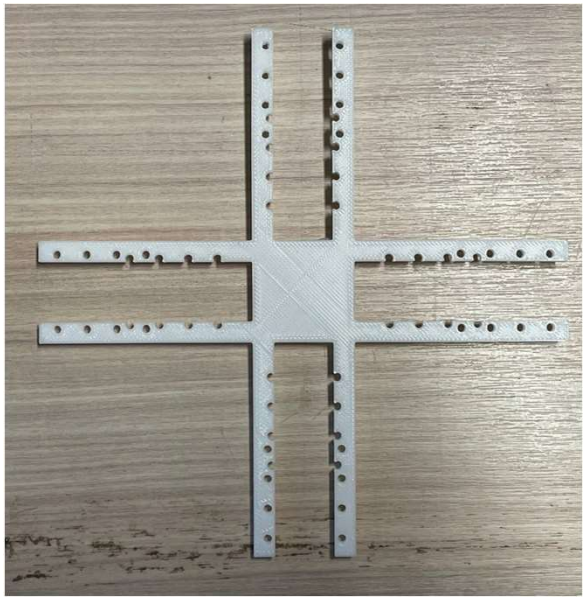
Gripper developed by
Mathew et. al [3]



Gripper developed by
Yuan et. al [4]

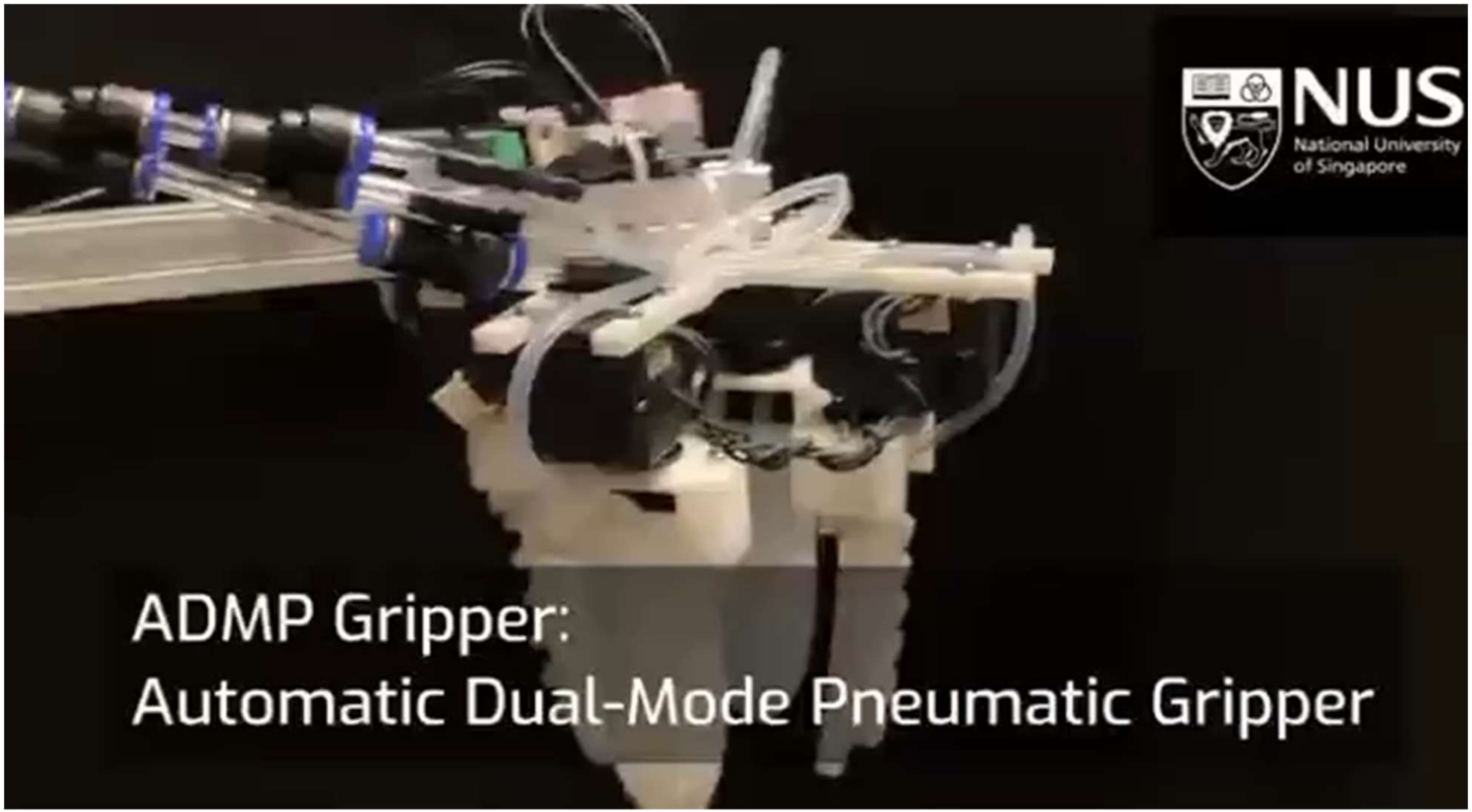
Reconfiguration mechanism

Servo motor [5]

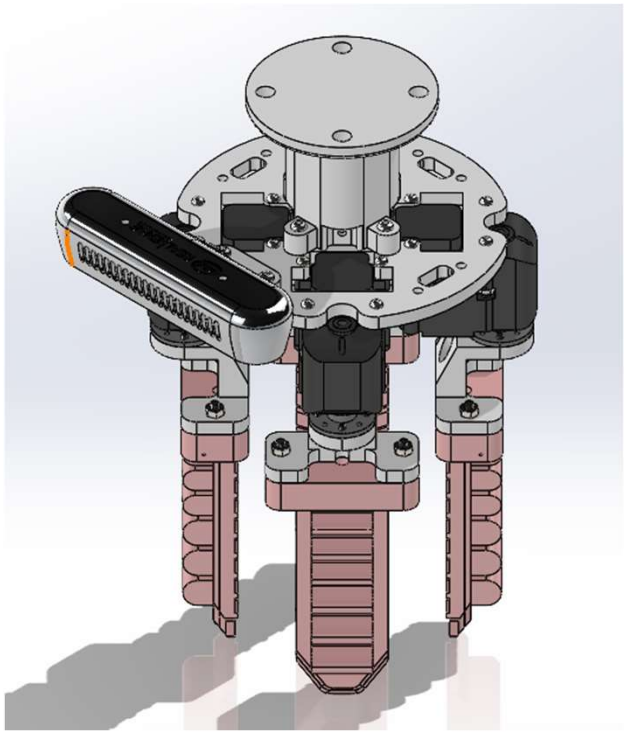


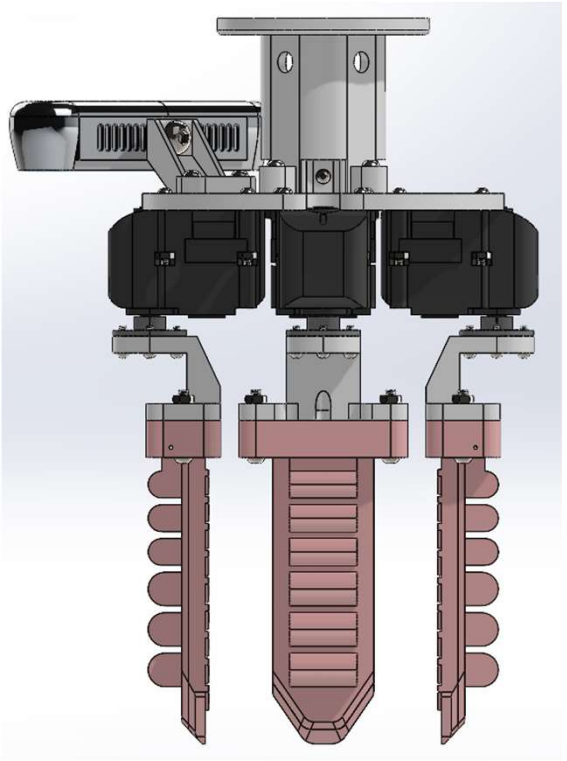
Modified
gripper base [2]

Competition Submission Video

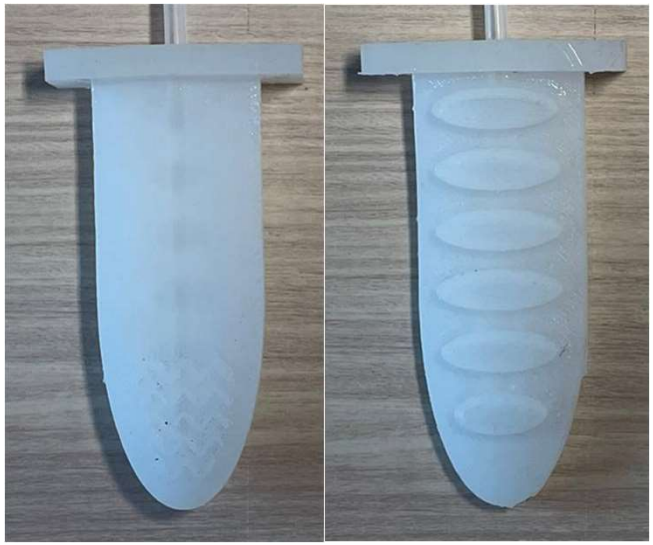


Version 2 of ADMP Gripper





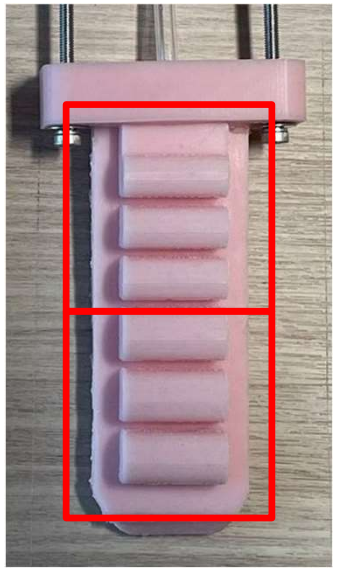
Version 2 Soft Finger



Version 1

Grip pattern extended

Wider finger tip

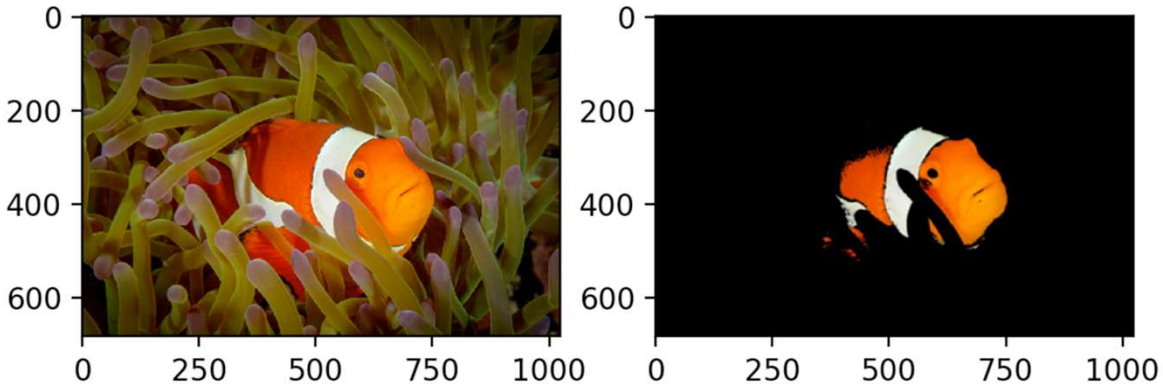


Air chambers larger closer to the base

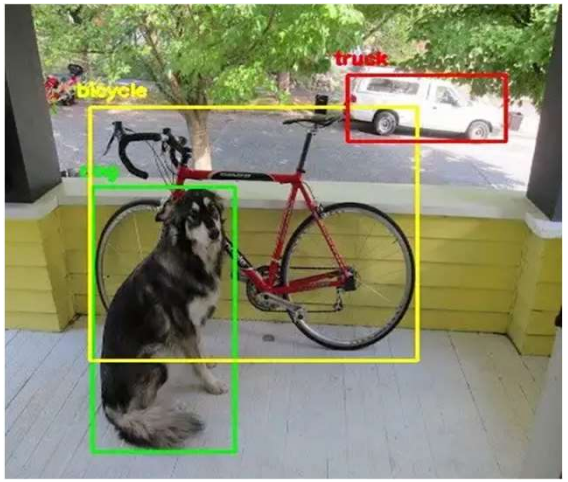
Vision System Camera

RealSense D415
Depth Camera [6]

Vision System



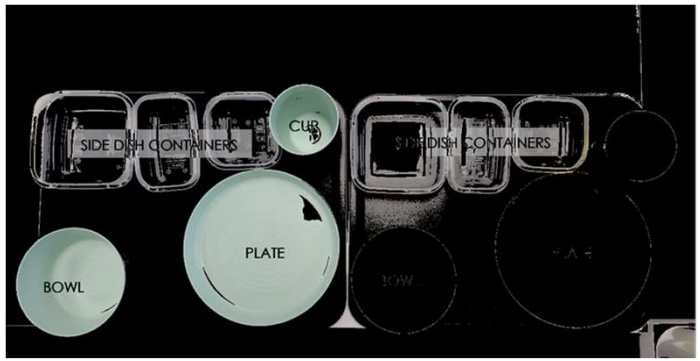
Colour segmentation

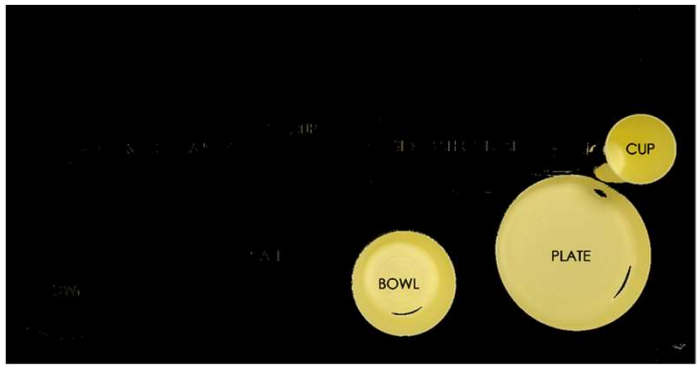


Object Detection System

Colour segmentation

Plates, bowls, cups and containers on the assembly table [1]





Output of Colour segmentation

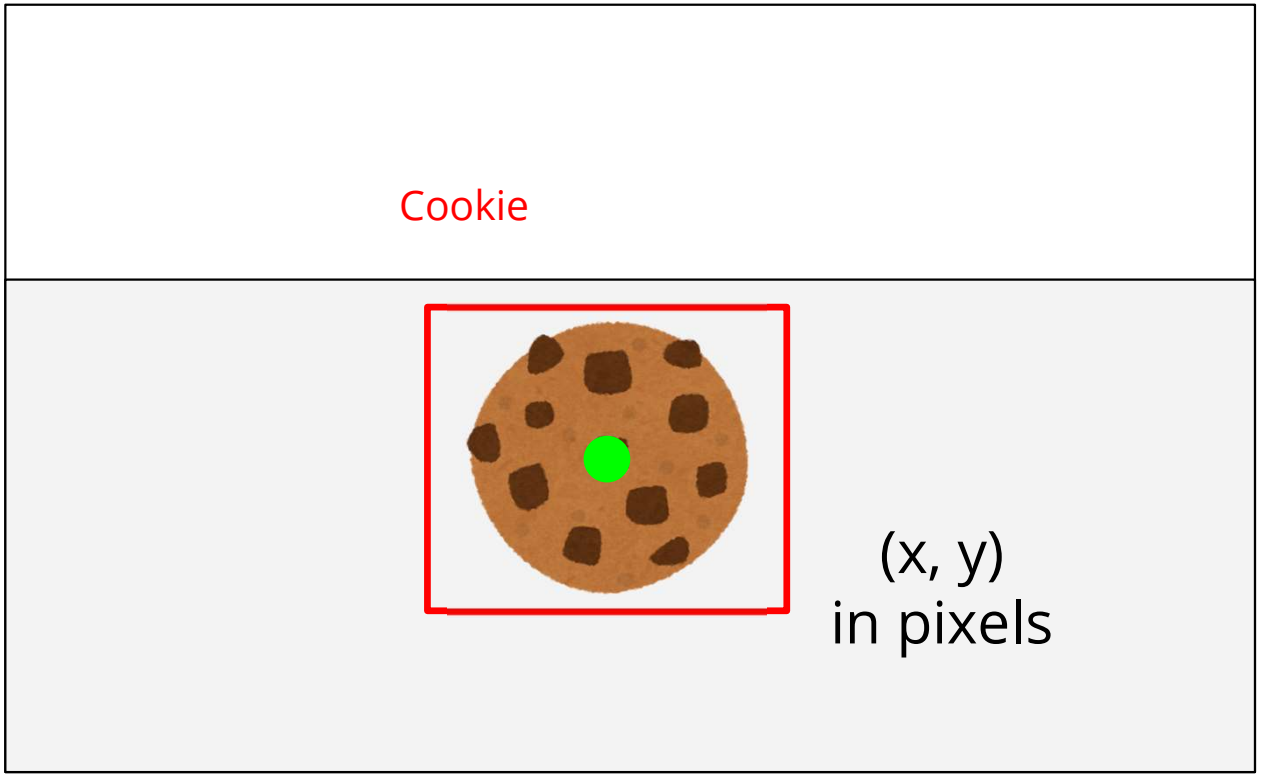
Finding containers

Thresholding would not work
in low light conditions

You Only Look Once (YOLO) detection system

Version of YOLO being used in this project [7]

Pixel location from YOLO

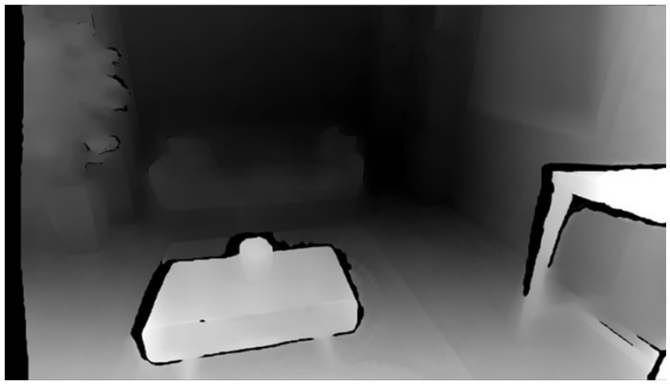


Conversion from pixels to metres

Things needed to convert pixels to meters [8]:

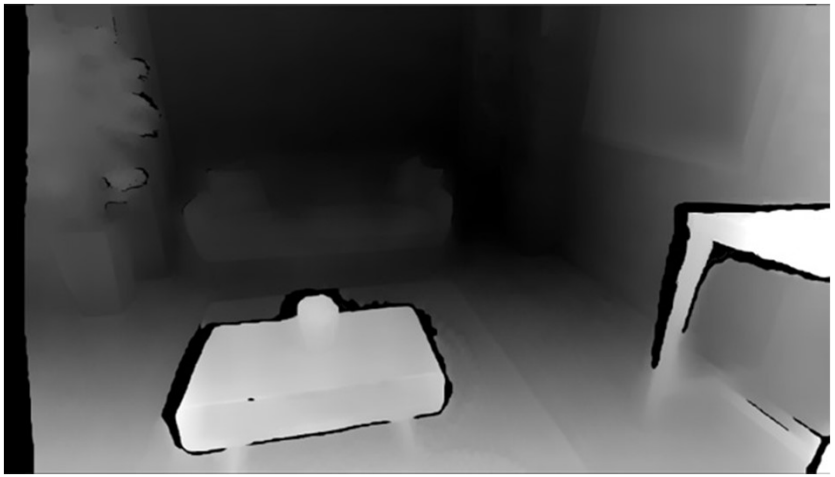
$$\begin{pmatrix} f_x & 0 & W/2 \\ 0 & f_y & H/2 \\ 0 & 0 & 1 \end{pmatrix}$$

Camera's intrinsic matrix

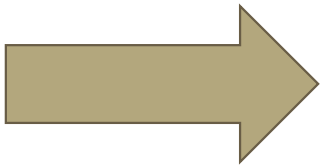


Depth map

Z coordinate

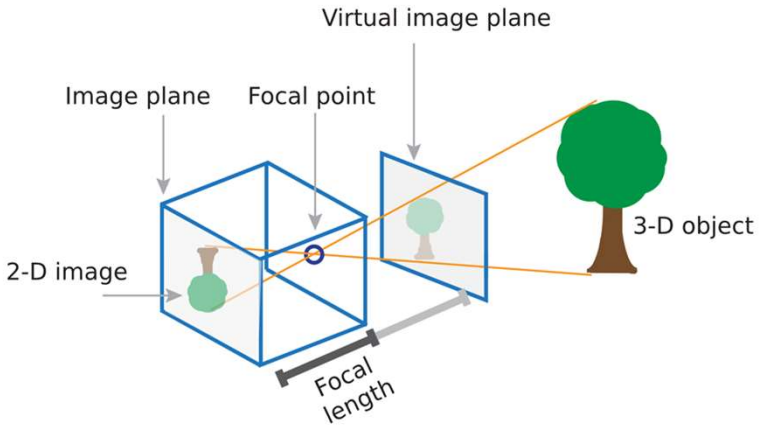


Depth value at
(x, y)



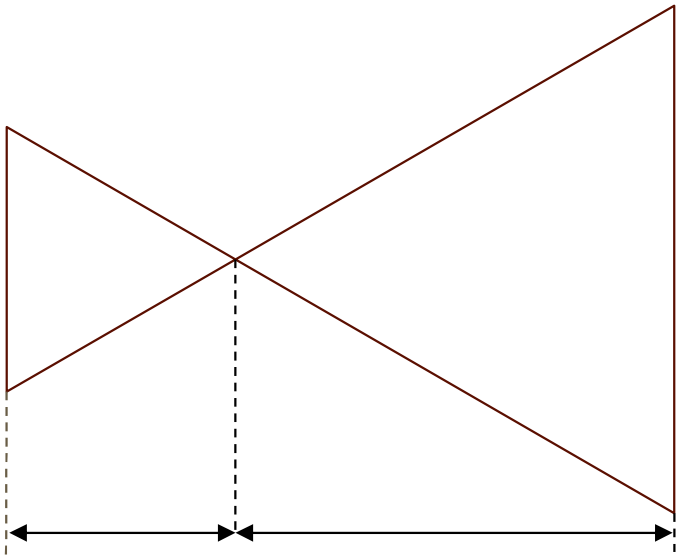
Z
coordinate

Conversion ratio



$$\begin{pmatrix} f_x & 0 & W/2 \\ 0 & f_y & H/2 \\ 0 & 0 & 1 \end{pmatrix}$$

Due to similar triangles, conversion ratio can be obtained [8]



Focal length f_x and f_y

Depth value

X and Y coordinate

$$\begin{pmatrix} f_x & 0 & W/2 \\ 0 & f_y & H/2 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\left(\text{X coordinate (in pixels)} - \text{Principal point in x direction (in pixels)}\right) \times \frac{\text{Depth value (in metres)}}{\text{Focal length (in pixels)}} = \text{X coordinate (in metres)}$$

$$\left(\text{Y coordinate (in pixels)} - \text{Principal point in y direction (in pixels)}\right) \times \frac{\text{Depth value (in metres)}}{\text{Focal length (in pixels)}} = \text{Y coordinate (in metres)}$$

Orientation

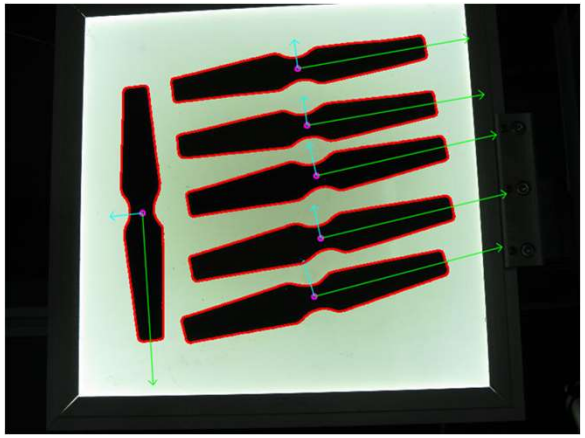
As the object lies on the table, the food items' orientations will be rotated about the **z-axis**.

Rotation matrix about the z-axis [9]:

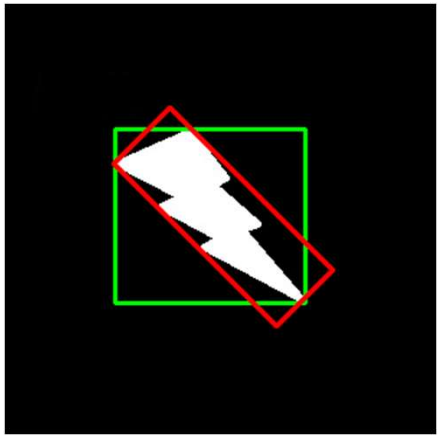
$$Rot_z = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Methods to find angle of rotation

YOLO



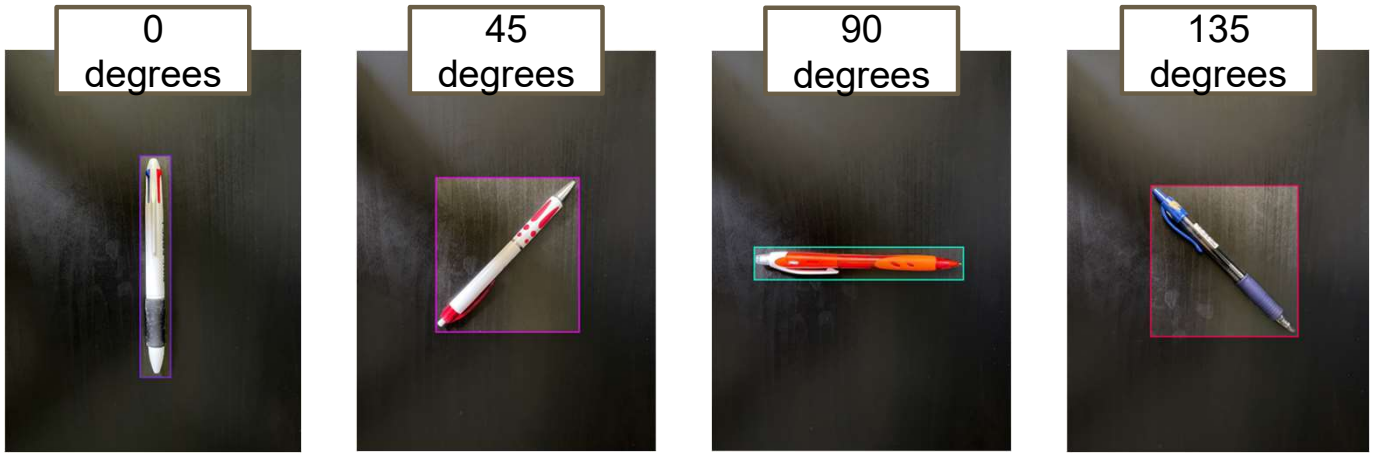
Principal Component Analysis (PCA) on a point cloud



Angle of smallest rectangle that contains all contours

YOLO

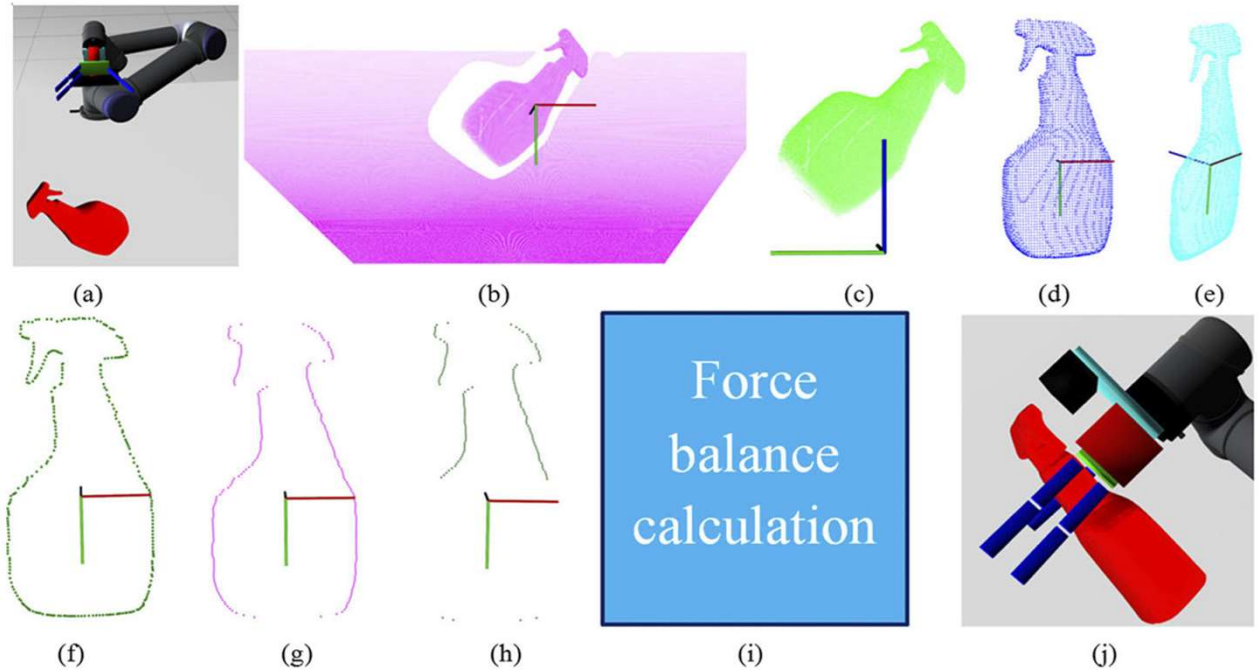
Dataset of pens at differents orientations:



Model	size (pixels)	mAP^{val} 50-95	mAP^{val} 50	Speed CPU b1 (ms)	Speed V100 b1 (ms)	Speed V100 b32 (ms)	params (M)	FLOPs @640 (B)
YOLOv5n	640	28.0	45.7	45	6.3	0.6	1.9	4.5
YOLOv5s	640	37.4	56.8	98	6.4	0.9	7.2	16.5
YOLOv5m	640	45.4	64.1	224	8.2	1.7	21.2	49.0
YOLOv5l	640	49.0	67.3	430	10.1	2.7	46.5	109.1
YOLOv5x	640	50.7	68.9	766	12.1	4.8	86.7	205.7

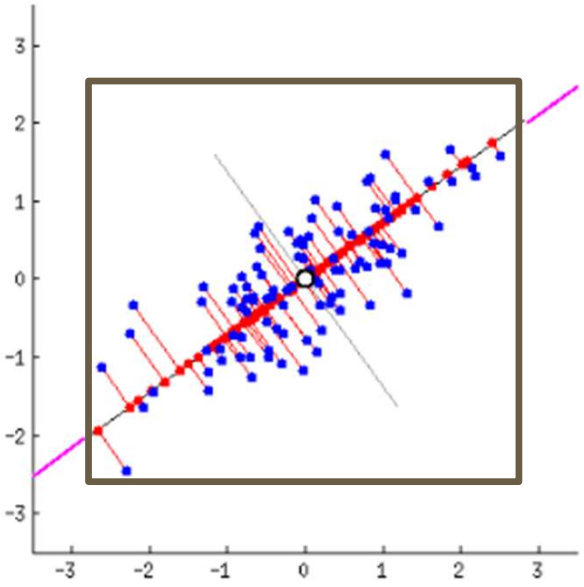
Weights used to train YOLO on [7]

Principal Component Analysis on Point Cloud

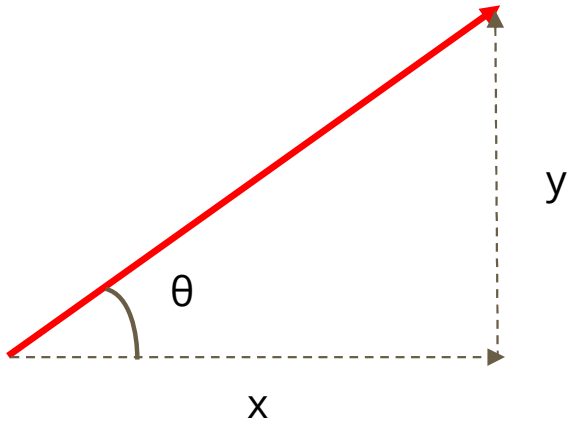


Lei et. al method to grasp objects using PCA on a single-view partial point cloud [10]

Principal Component Analysis on Point Cloud

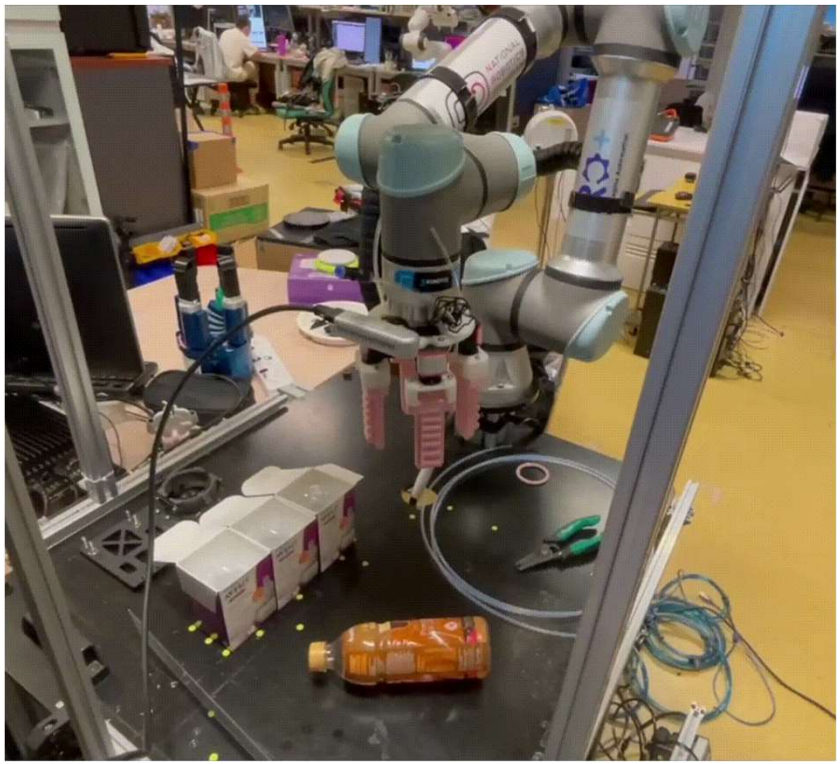


Largest eigenvalue gives us the eigenvector along the axis with the **largest variance** [11]

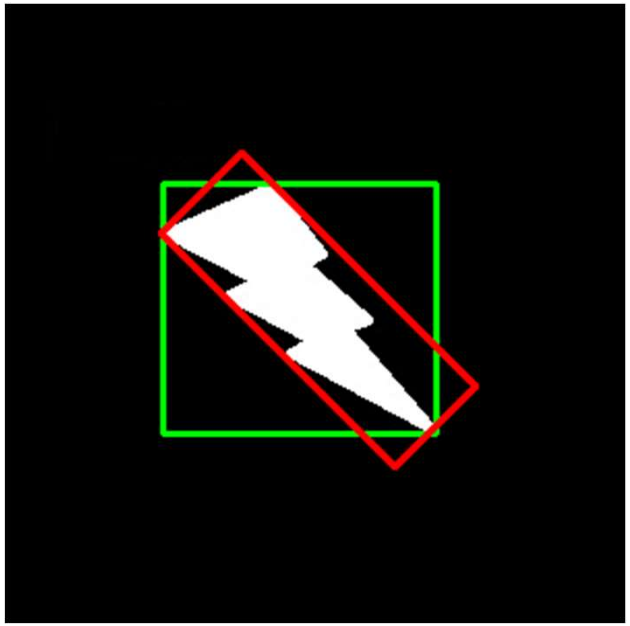


$\theta = \arctan(y,x)$

Principal Component Analysis on Point Cloud

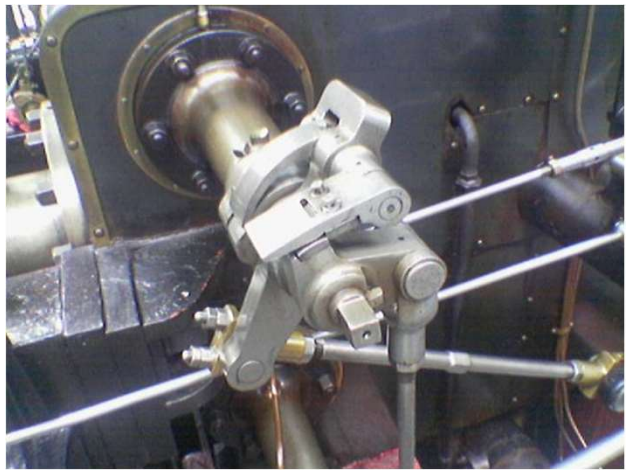


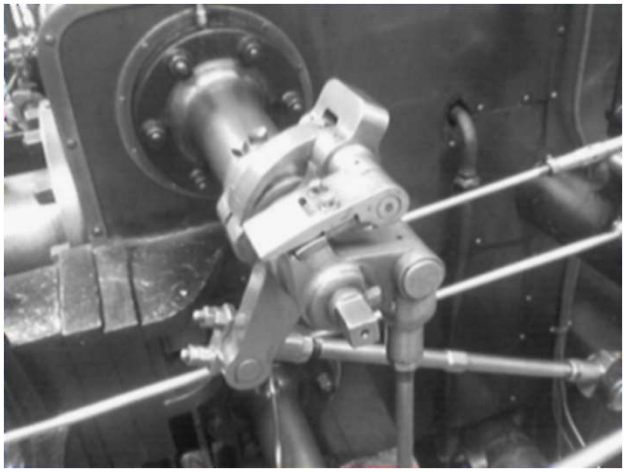
Angle of smallest rectangle that contains all contours



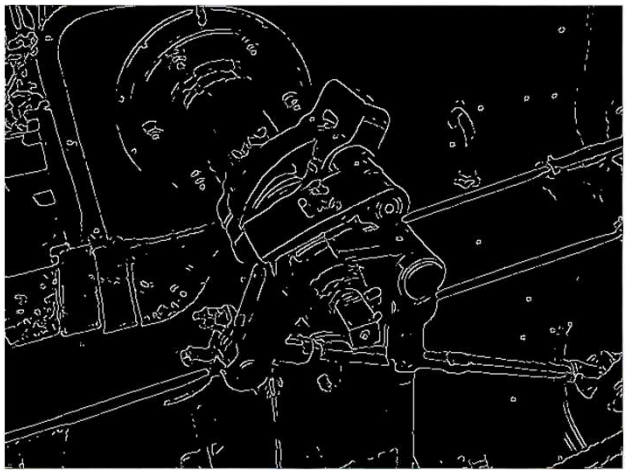
cv2.minRectArea [12]

Angle of smallest rectangle that contains all contours

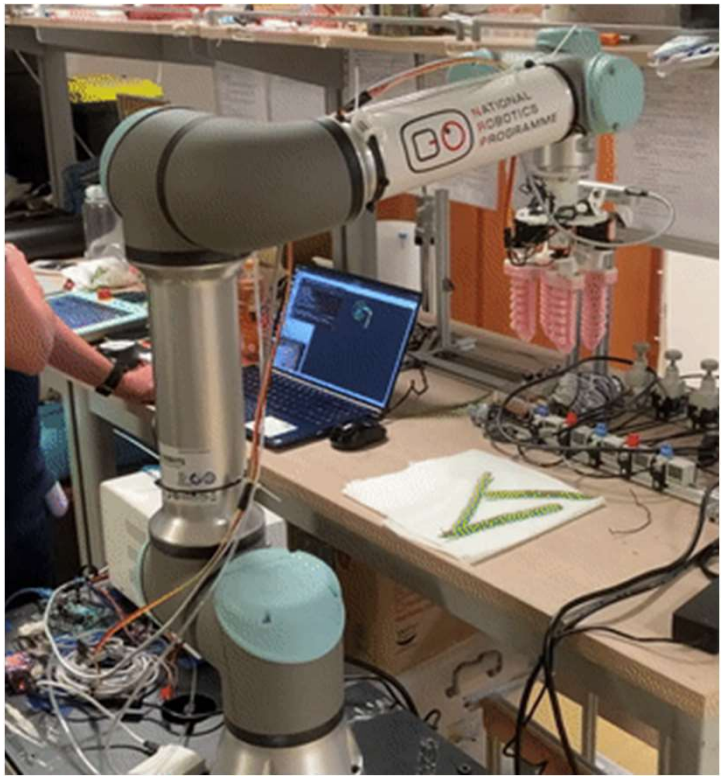




Canny Edge Detection using cv2.Canny [13]



Angle of smallest rectangle that contains all contours



Transformation to Base of Robot Arm

$$T_{object}^{camera} = \begin{bmatrix} R_{object}^{camera} & P_{object}^{camera} \\ 0\ 0\ 0 & 1 \end{bmatrix}$$

Reference frame needs to be changed from the **camera** to the **base** [9]

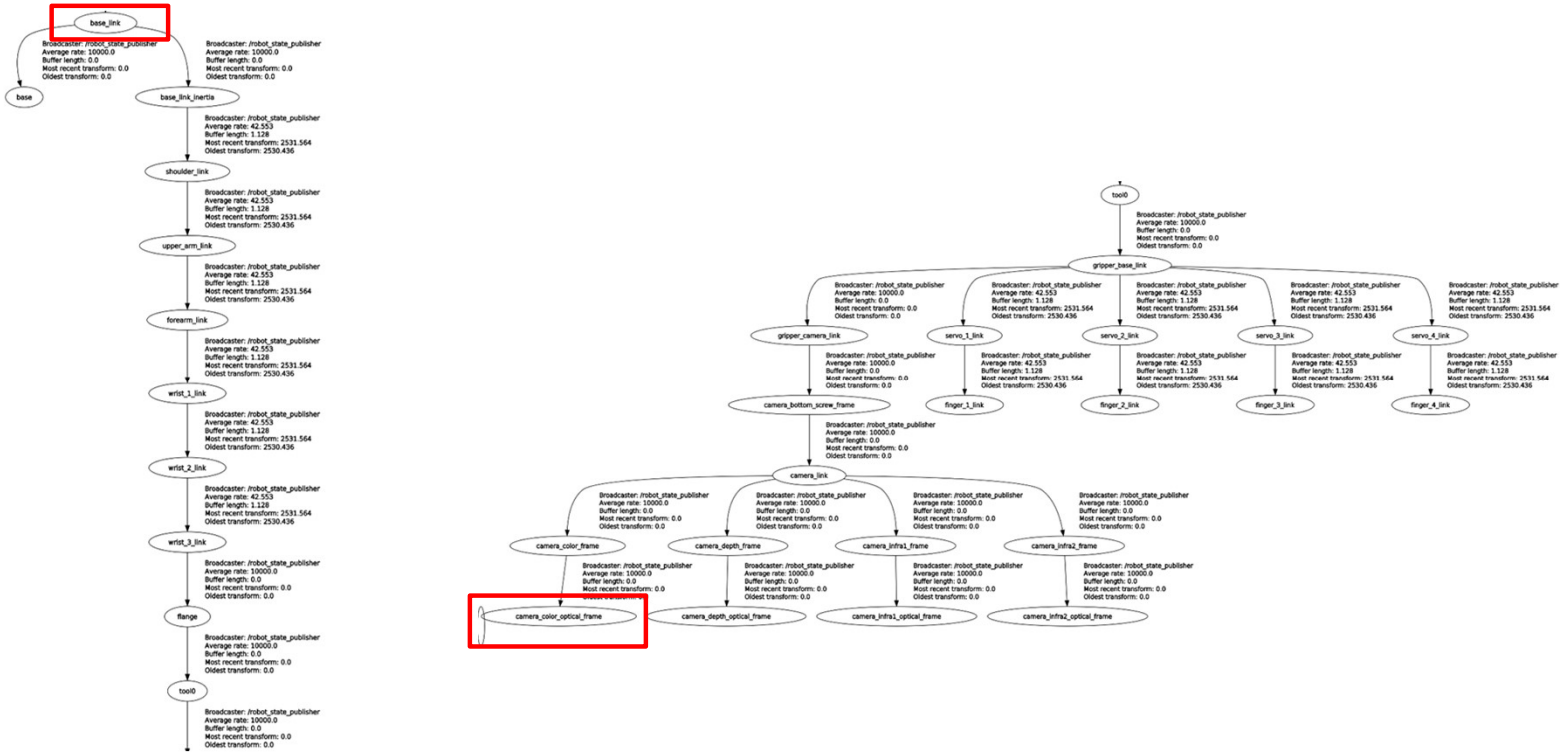
$$T_{object}^{base} = T_{camera}^{base} \times T_{object}^{camera}$$

Transformation to Base of Robot Arm

into the tray. These cameras and sensors cannot be mounted, placed nor connected to the tables. Participants may choose to mount sensors onto the robot or separate holders (like tripods) that can be positioned around the table; these sensors holders should not block view or access to either the tables, the containers, shelf, and the trays.

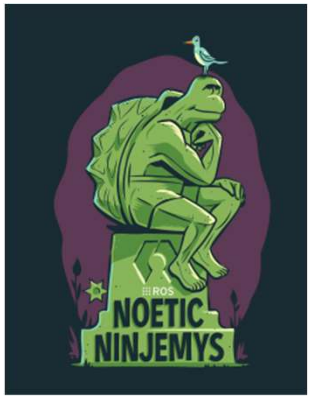
Rules for the competition [1]

tf2 ROS package



Connection from base link to the camera's reference frame using tf2 ROS package [14]

Robot Operating System (ROS)



High Level ROS architecture for simulation

D415
depth camera

Colour and
depth
image

YOLOv5

Detections and
their poses

Colour
Segmentation

Pose of
blue plates

Pose of red
plates

PickNPlace
Control

Colour and
depth
image

Scene
captured
by camera

Gazebo with
Robot Arm

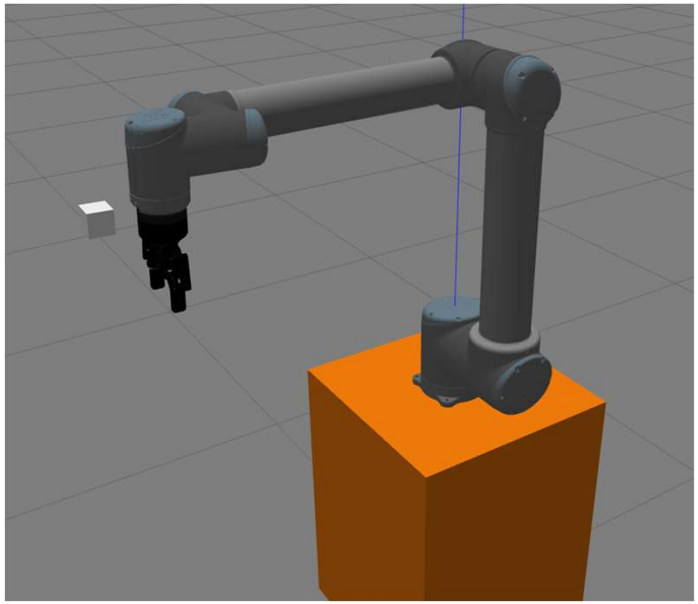
Joint states

MoveIt
Move Group

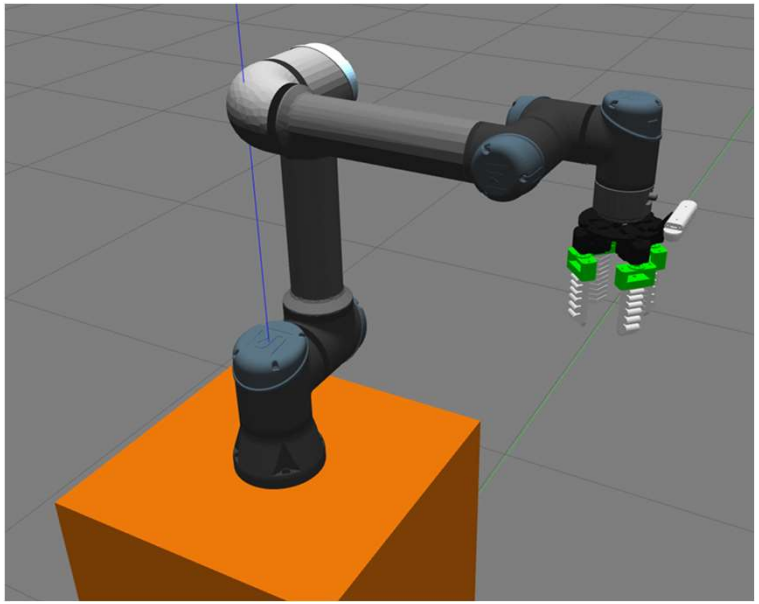
Pose &
Joint
values

Trajectory

Robot Arms



- UR10 robot arm [15]
- Robotiq 2F-85 gripper [16]
- Kinect camera



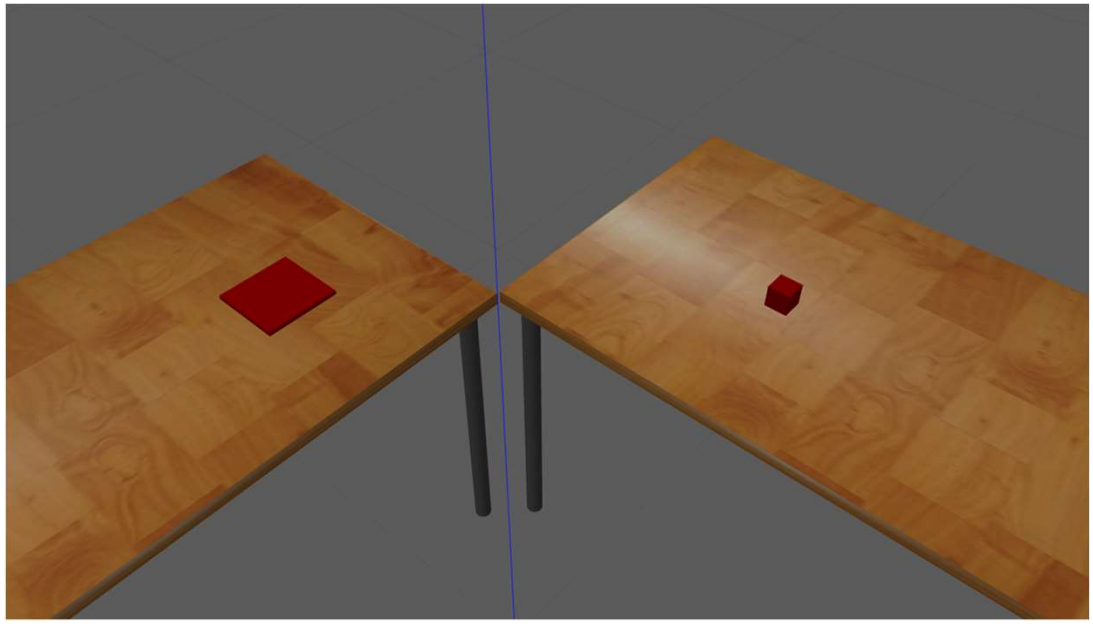
- UR5e robot arm [15]
- ADMP gripper
- D415 depth camera [17]

YOLO

Trained YOLO on a dataset of 3D shapes [18]

Weights:
yolov5s

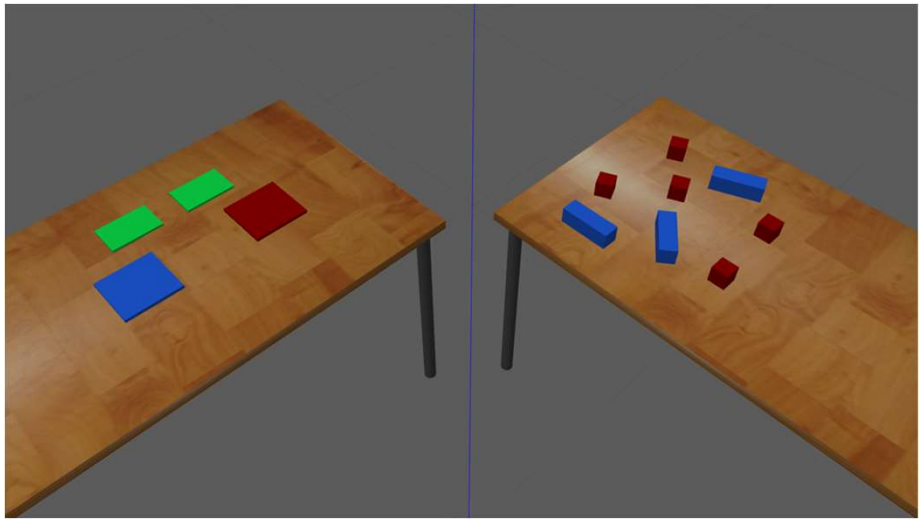
Simulation Environment

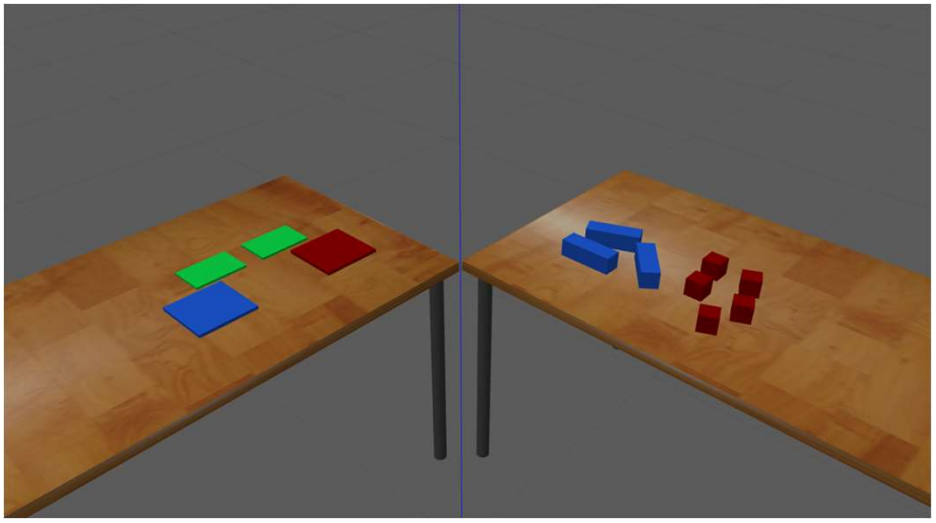


1st Environment

Task: Pick up a **red cube** from the source table and place it onto the **red plate** on the assembly table.

Simulation Environment



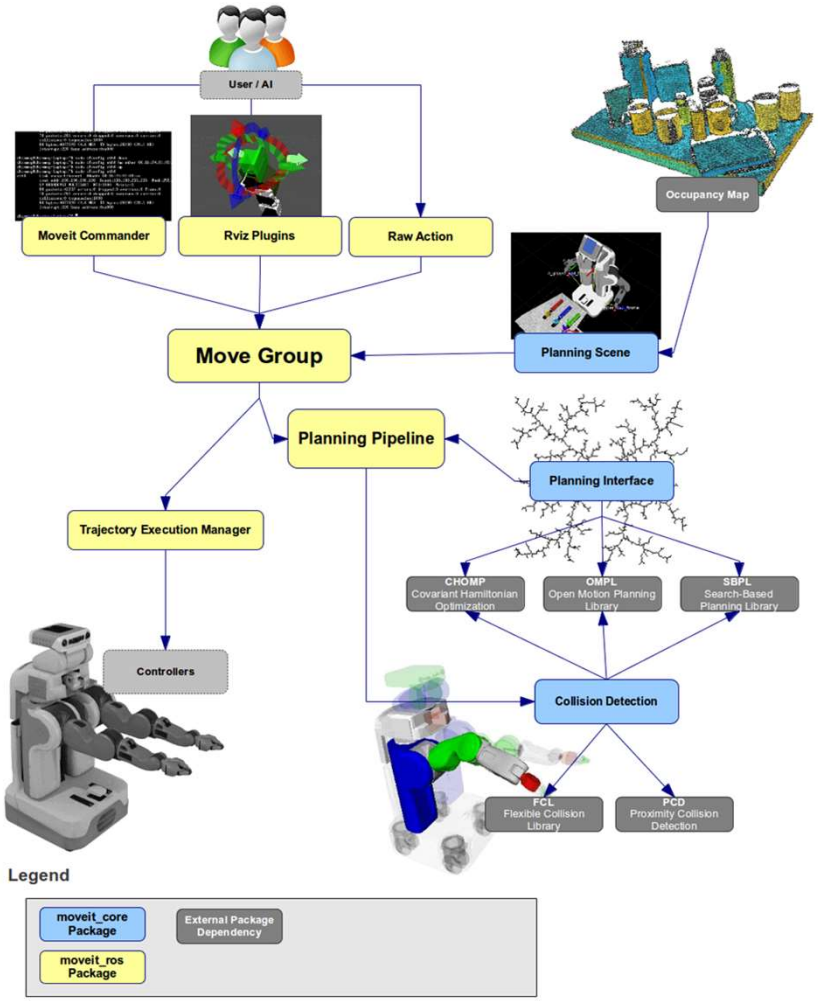


2nd Environment

Task: To place two **red cubes** on both the **red** and **blue** plates
and a **blue cuboid** on each of the **green plates**.

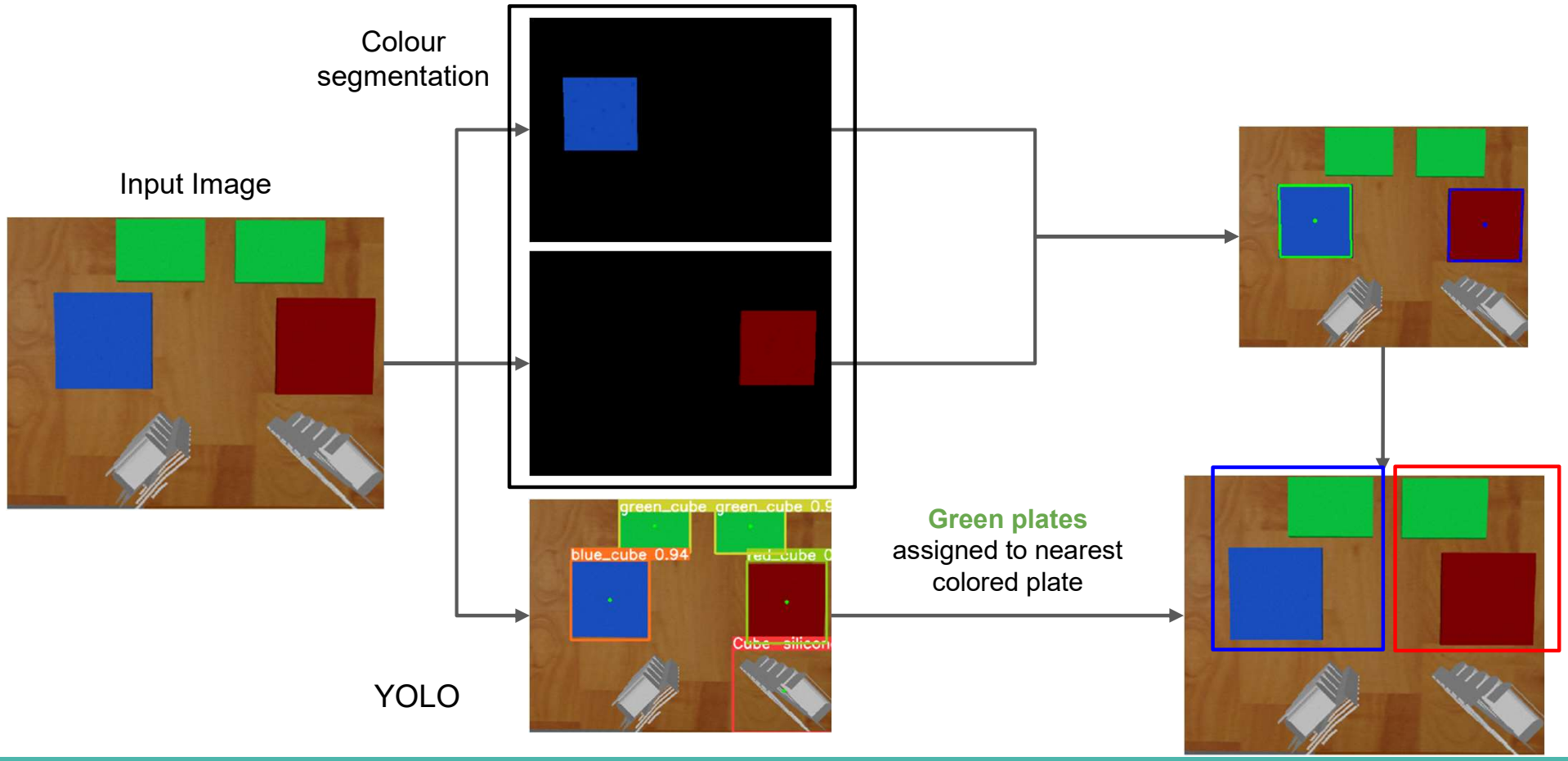
MoveIt

- Allows inverse kinematics calculations [19]
- Can control robot arm with a Python file using MoveIt commander [20]

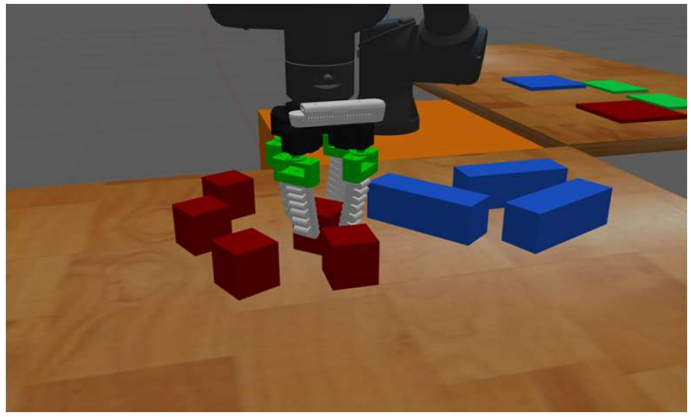


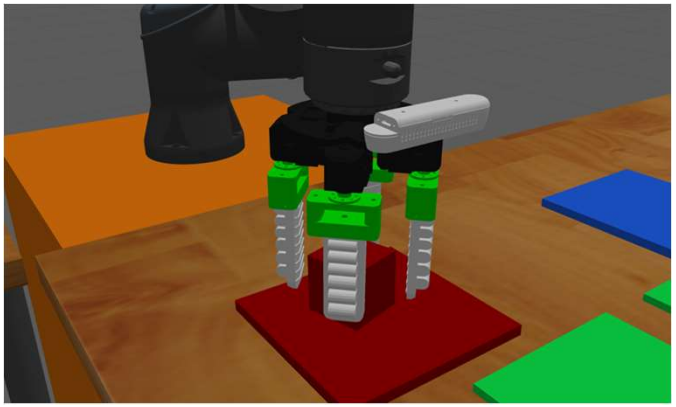
High Level Diagram of MoveIt [20]

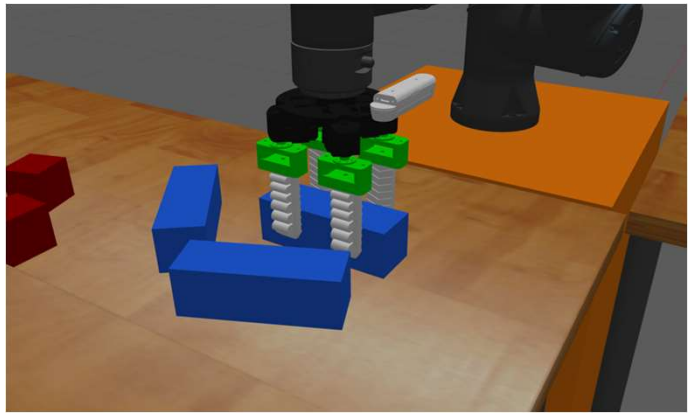
Control File For Complex Pick and Place Task

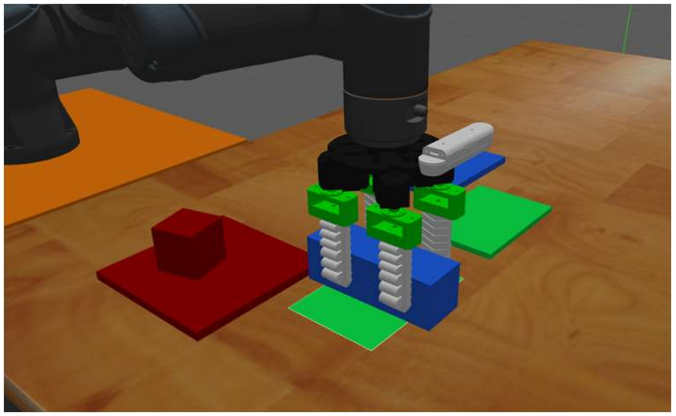


Control File For Complex Pick and Place Task

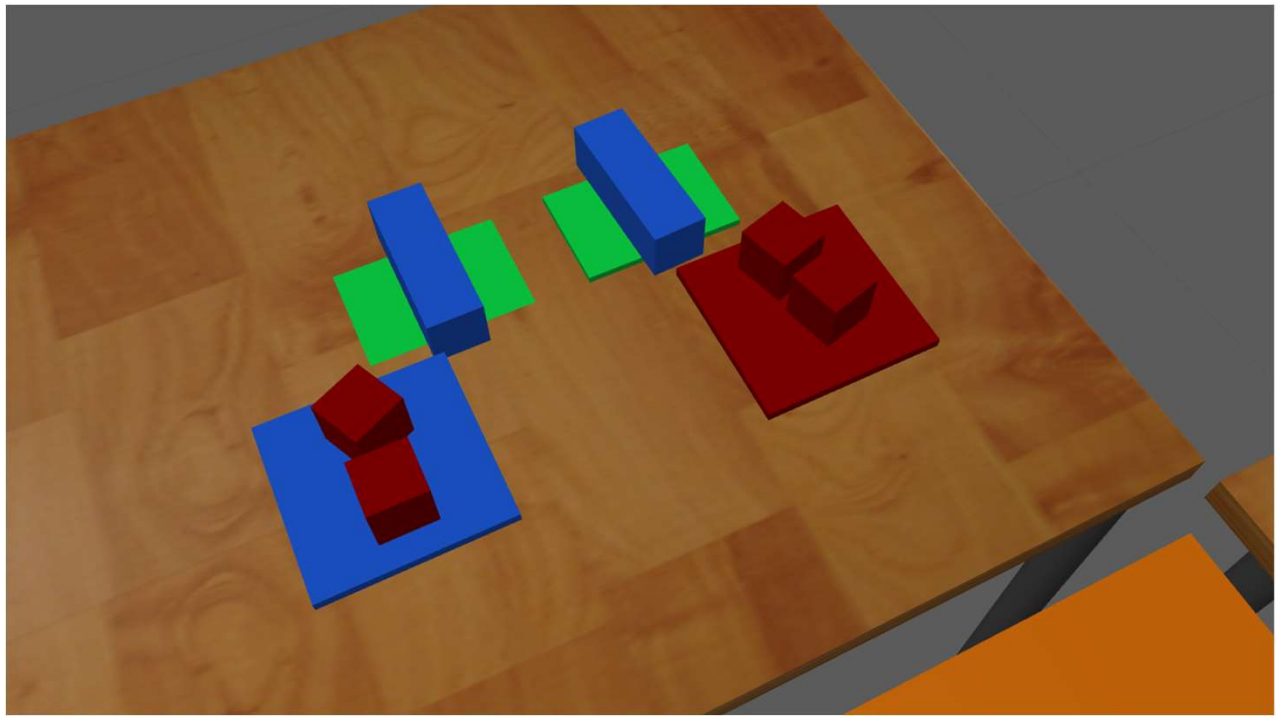








Control File For Complex Pick and Place Task



Control File For Complex Pick and Place Task

pick_count : {“**red_cube**”: 2, “**blue_cube**”: 1}

place_count : {“**red_cube**”: 0, “**blue_cube**”: 0}

Code will run until all classes in
pick_count == place_count

High Level ROS architecture for Competition

D415
depth camera

Colour and
depth image

YOLOv5

Detections and
their poses

Controller
and servos

Colour
Segmentation

Colour and
depth image

Pose of
yellow and
green plates

PickNPlace
Control

0/1

0/1

Robot Arm

Joint states

MoveIt
Move Group

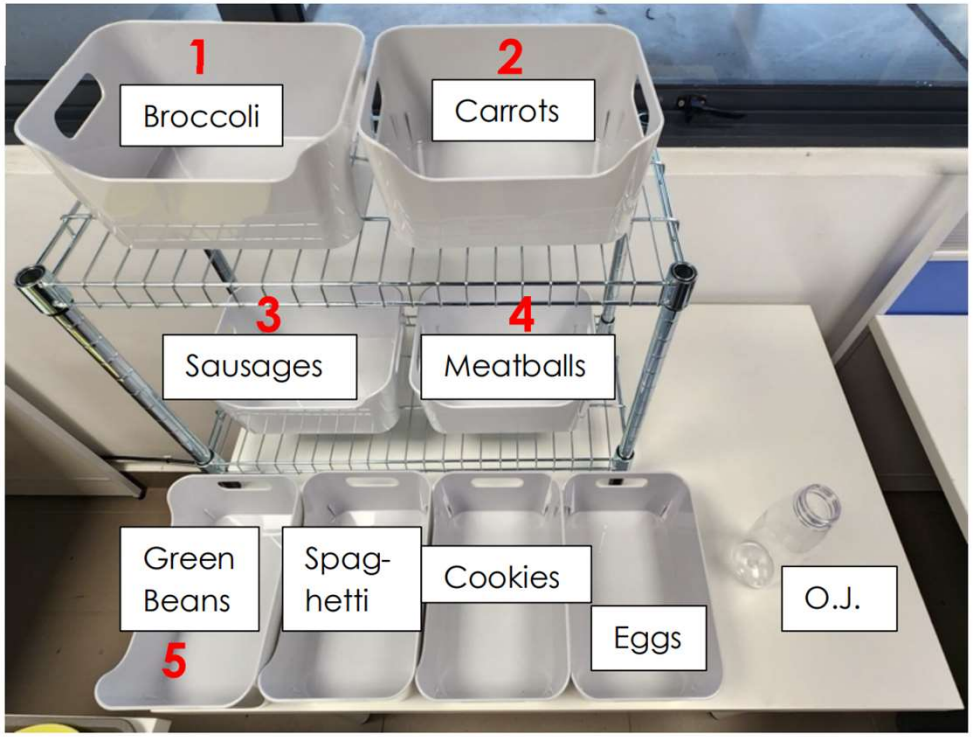
Trajectory

Pose &
Joint values

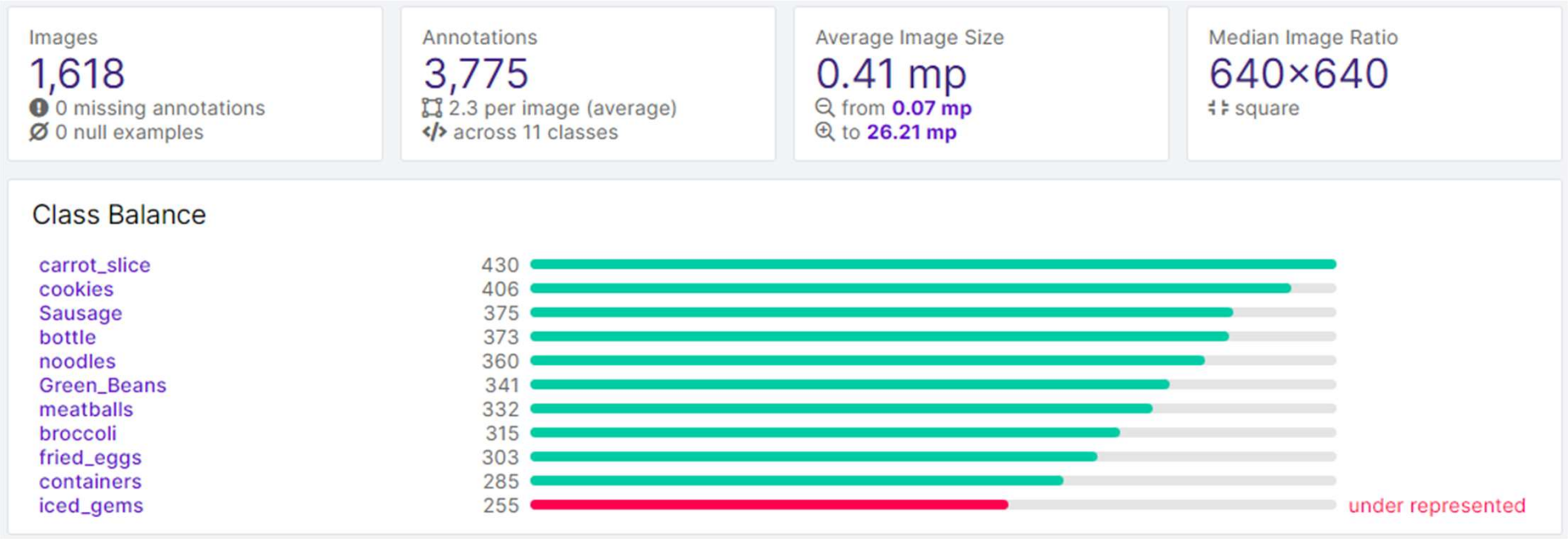
Arduino and
electric valve

Testing before Competition

Iced Gems Biscuits

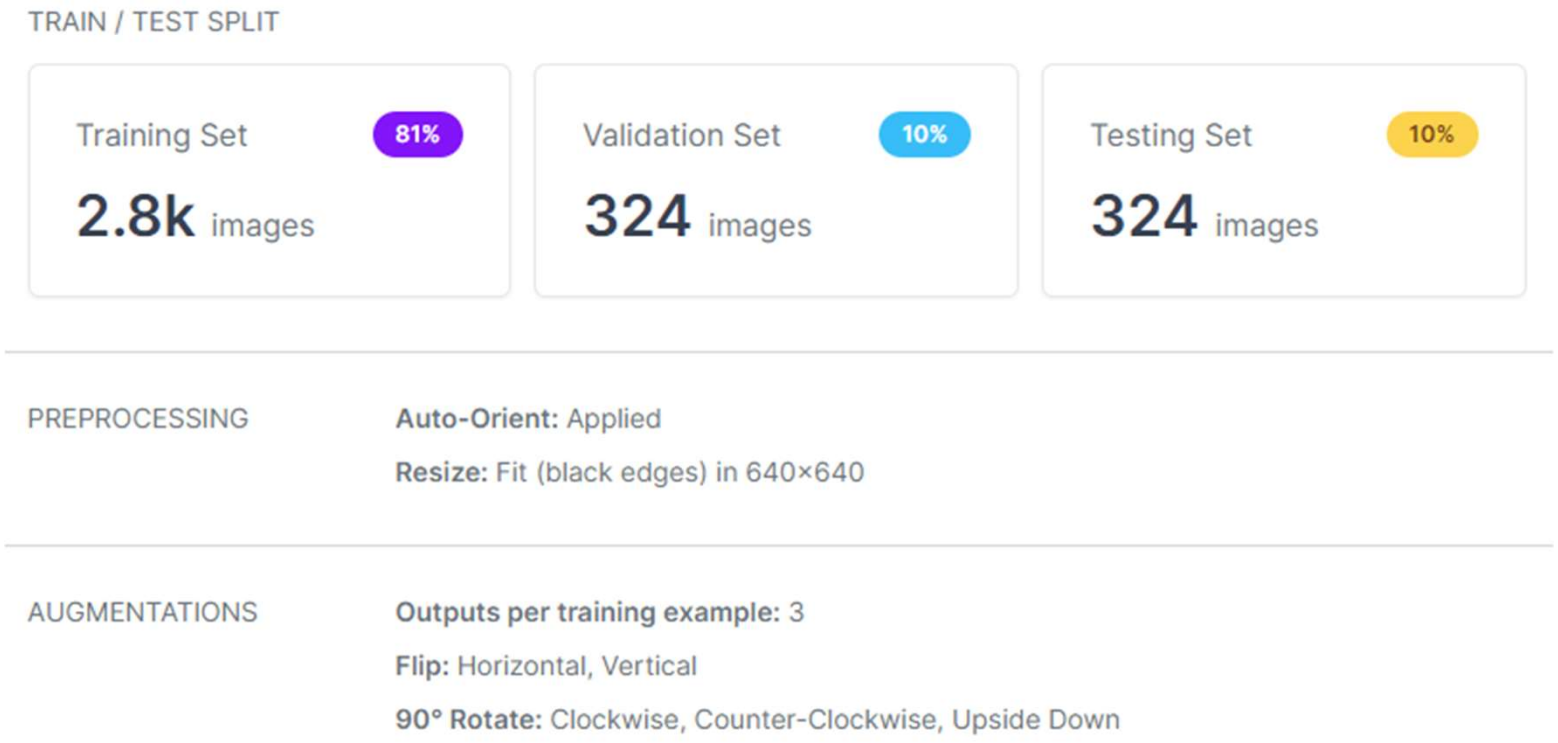


Dataset for YOLO



Number of images in dataset with how many classes are present [21]

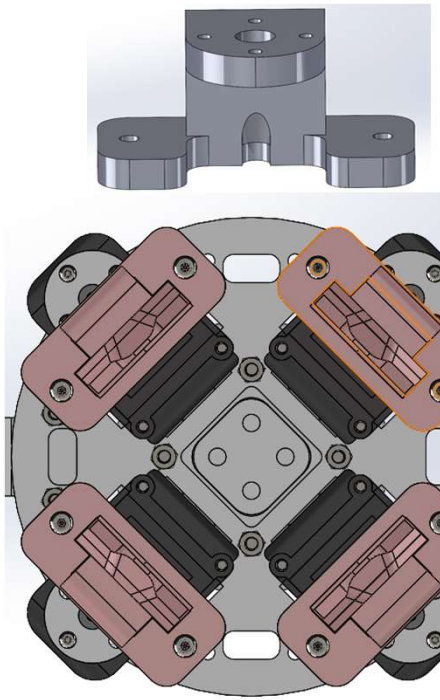
Dataset for YOLO



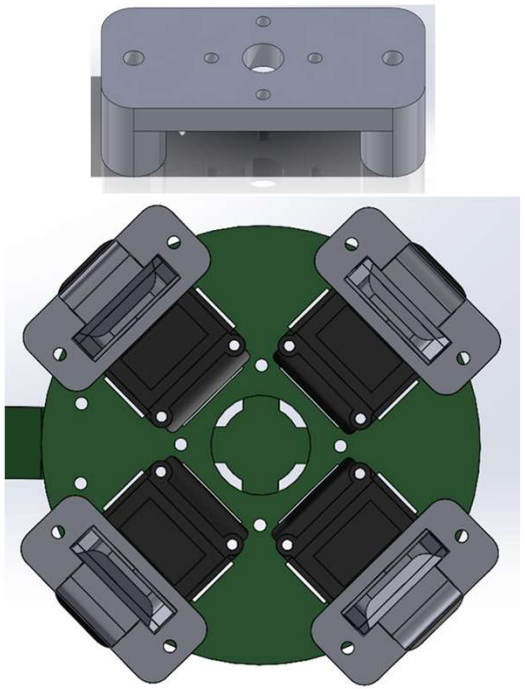
Training Set with augmented images, Validation Set and Testing Set [21]

Test Run

Reason for inability to pick up the sunny side egg



7cm gap
Too narrow, Cannot pick up bottle



9cm gap
Can fit but unable to pick up small items

Issues with YOLO detections

Misidentify as
- Carrot slices
- Bottle

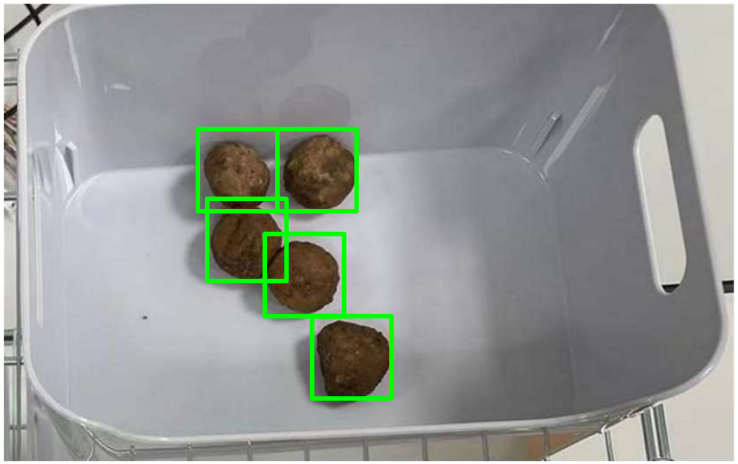
Correctly identifies when light is shone on it

Solution: Camera looks at 1 tray at a time

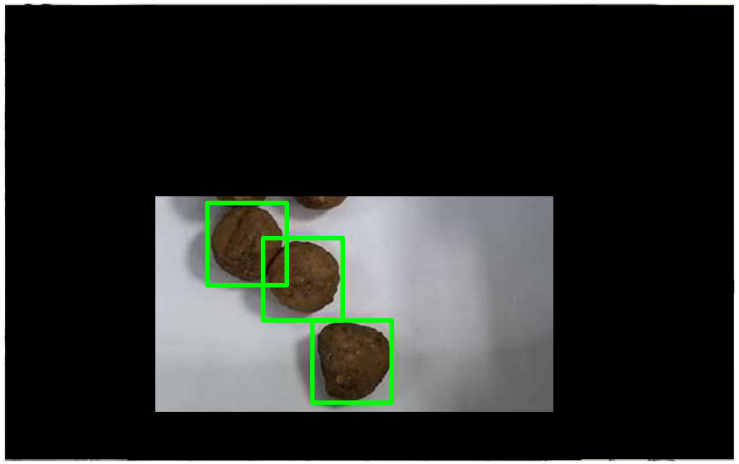
Arrangement of food on tray

Containers are sorted by the **area** and **height** of the bounding box

Collision with the tray walls



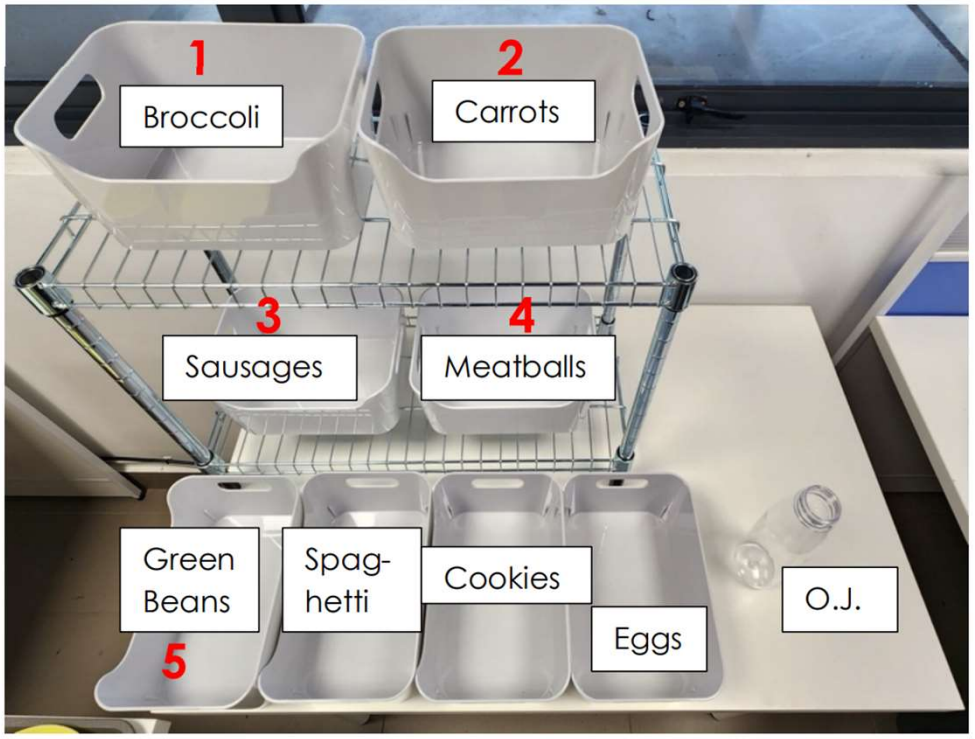
Food items near the wall will cause the gripper to **collide with the tray wall**



Apply a mask so that only the food items near the middle are detected

Competition Run

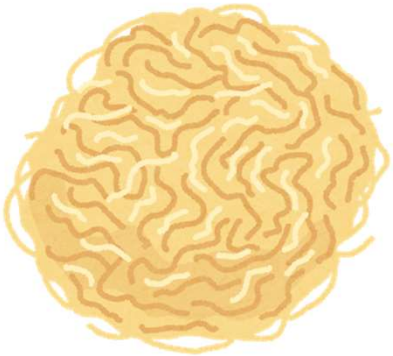
Replaced No.5: Green Beans



Competition Run

Results

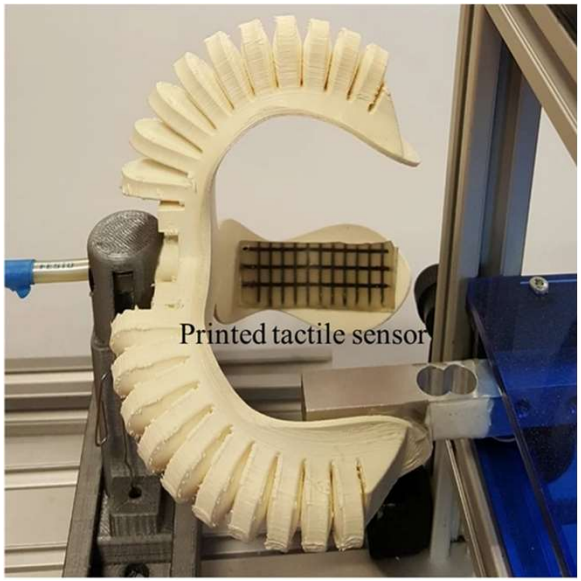
Food placed on the tray



Score: 30 points

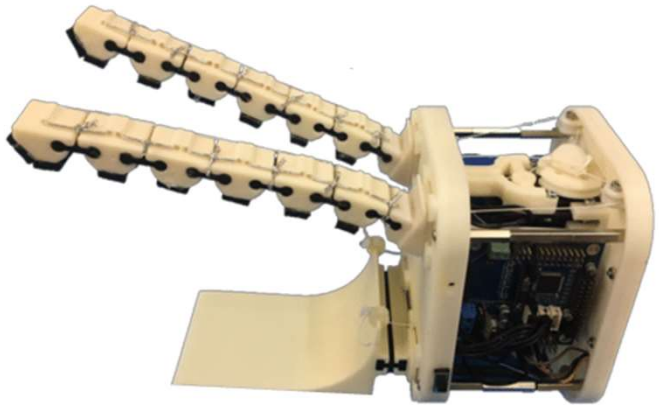
Placed 4th among the 6 teams

Improvements on ADMP Gripper



Tactile sensors to detect if an item is grabbed [22]

Vacuum pump to widen the gap between the fingers



Each finger individually controlled for different gripping patterns [23]

Improvements on Vision System

Newer version of YOLO [24]

Model	size (pixels)	mAP^{val} 50-95	mAP^{val} 50	Speed CPU b1 (ms)	Speed V100 b1 (ms)	Speed V100 b32 (ms)	params (M)	FLOPs @640 (B)
YOLOv5n	640	28.0	45.7	**45**	**6.3**	**0.6**	**1.9**	**4.5**
YOLOv5s	640	37.4	56.8	98	6.4	0.9	7.2	16.5
YOLOv5m	640	45.4	64.1	224	8.2	1.7	21.2	49.0
YOLOv5l	640	49.0	67.3	430	10.1	2.7	46.5	109.1
YOLOv5x	640	50.7	68.9	766	12.1	4.8	86.7	205.7

Larger and more accurate weights run on stronger graphics card

Conclusion

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End of Presentation

Thank you