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College of Engineering

Enhancing Robotic Operations through Digital Twin and AI Integration

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Mission

In this capstone project, our team focused on the development and enhancement of a digital twin system for a robotic arm. The goal was to create a comprehensive digital representation of the robotic arm that allows for real-time monitoring and control. Our work built upon an existing digital twin system and aimed to integrate advanced computer vision and artificial intelligence (AI) technologies to enhance functionality. Its functions were to include the following:

- Identify objects by color and/or shape.
- Only pick up specific objects determined by the user.
- Drop off objects in a designated location.

Concept Development

In this project, we were given the opportunity to make improvements upon a robotic arm which was given to us by the previous capstone team. This eliminated our design phase since our job was only to consider how the robot arm would operate. This consisted of:

- The movement of the arm.
- The detection of objects.
- The classification of objects.
- The capability of a grabbing motion of the arm's 'fingers'

The general concept we decided on would accomplish the following: First, the object would be detected by the cameras, as well as their relative location in space. Second, an optimal path would be calculated, and it would pick up the object. Finally, the arm would move to a designated area and drop off the object.

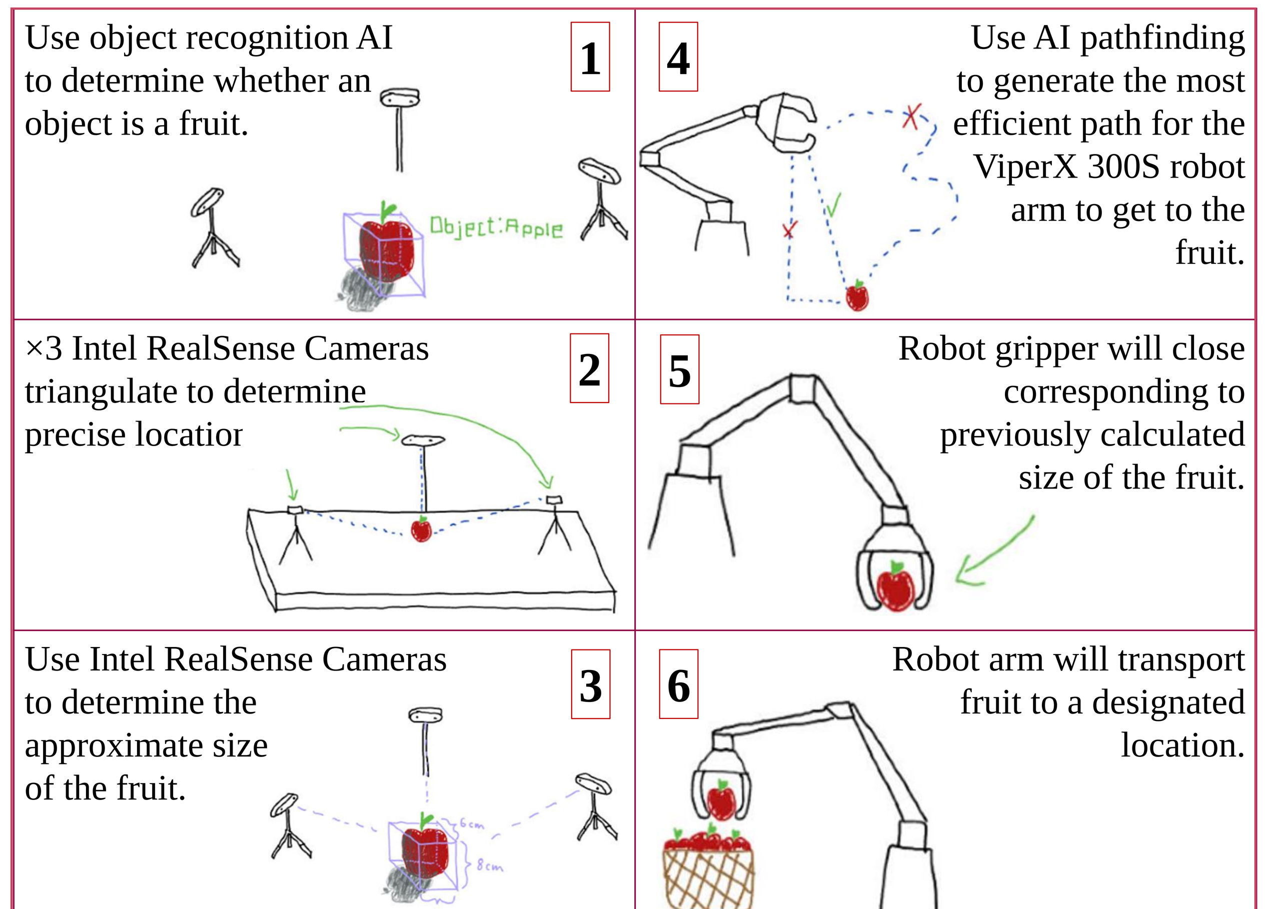

Figure 1. Concept Development

Final Design

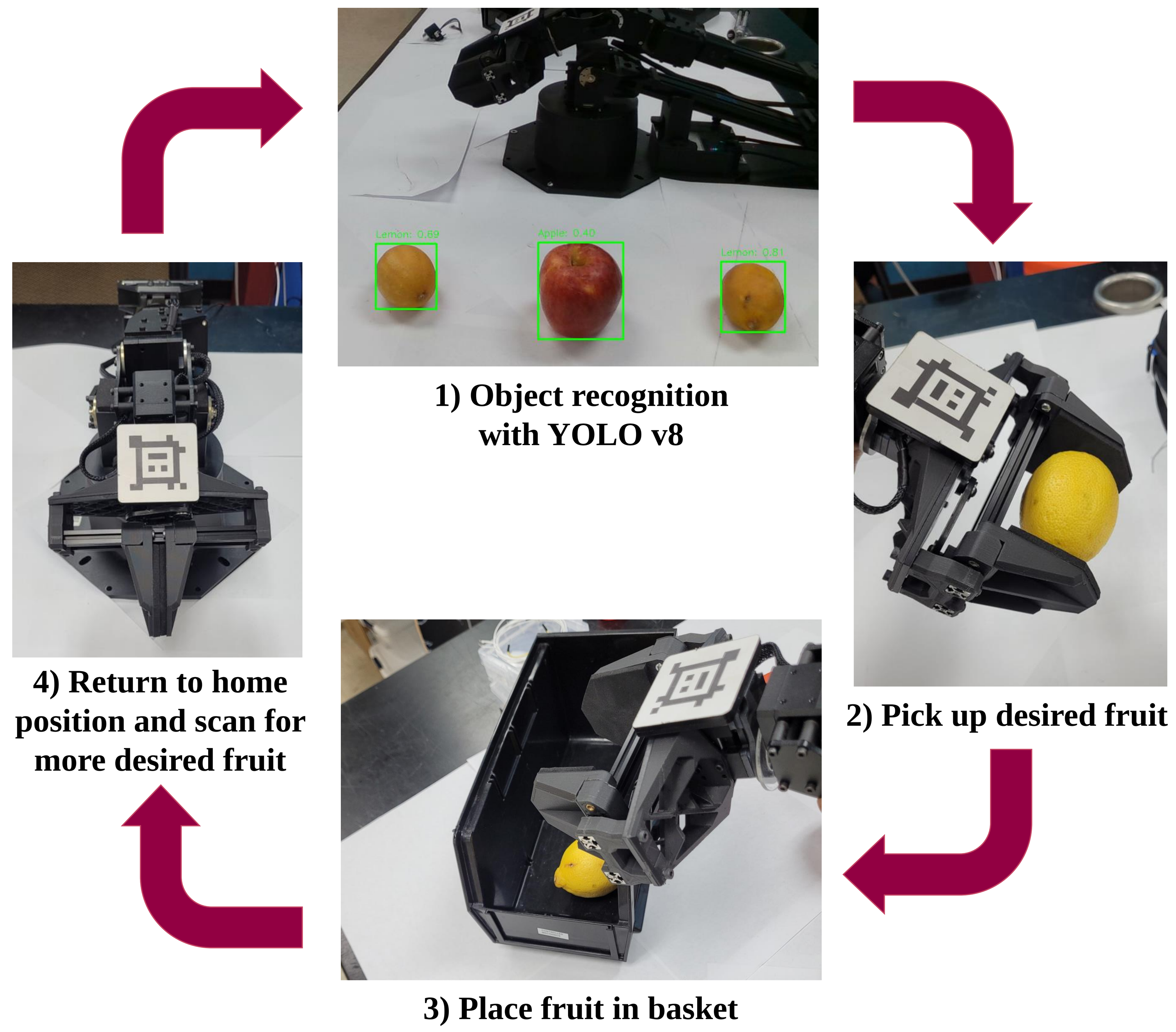

Figure 2. Steps in fruit retrieving system

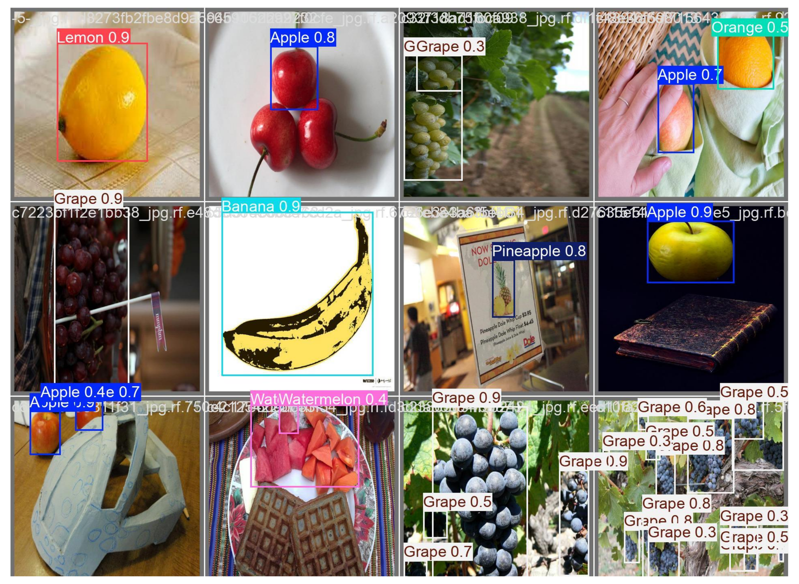

Figure 3. Images used for training the YOLO v8 model

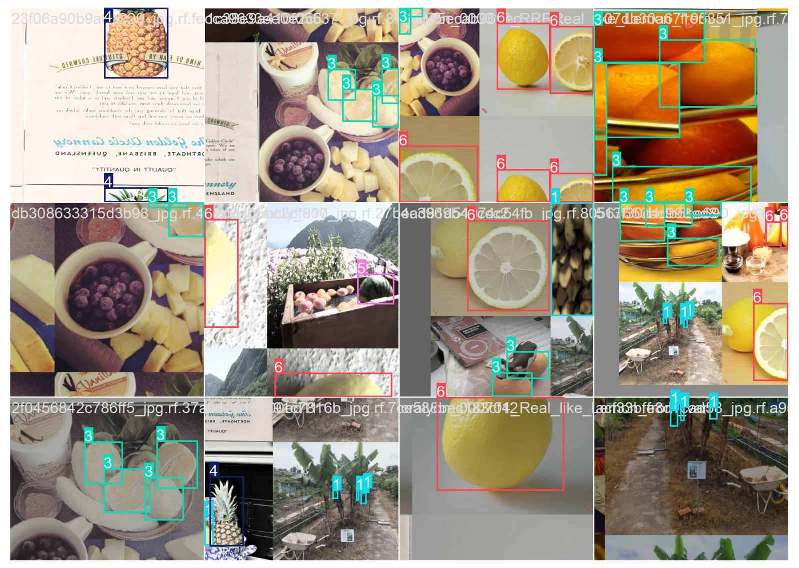

Figure 4. 'Class' labels applied to the images

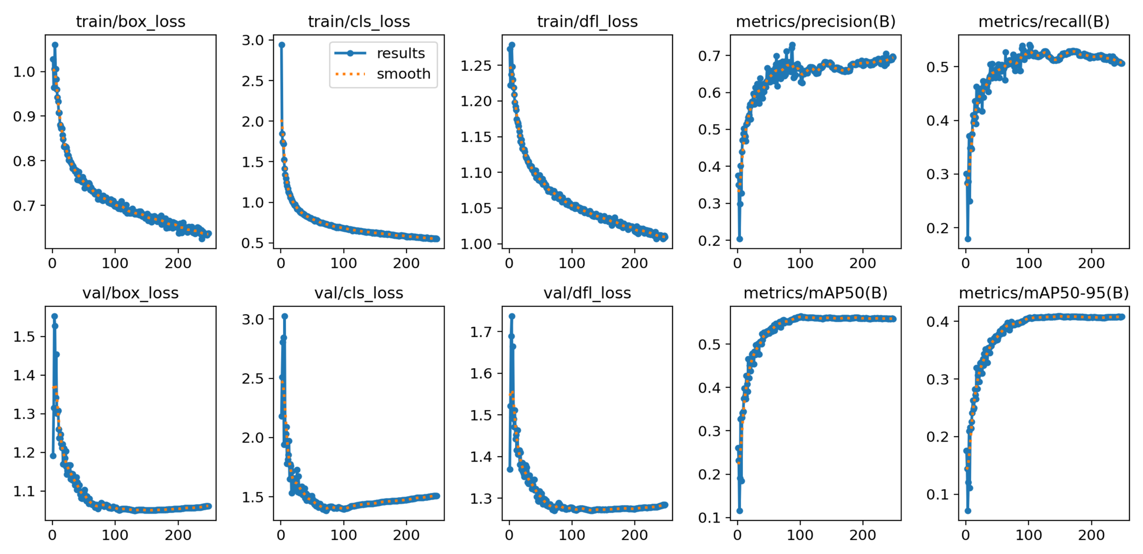

Figure 5. Results

Various improvements made when we trained our object detection model. Such as the loss, precision and mAP50 of the model in for both the training and validation data sets.

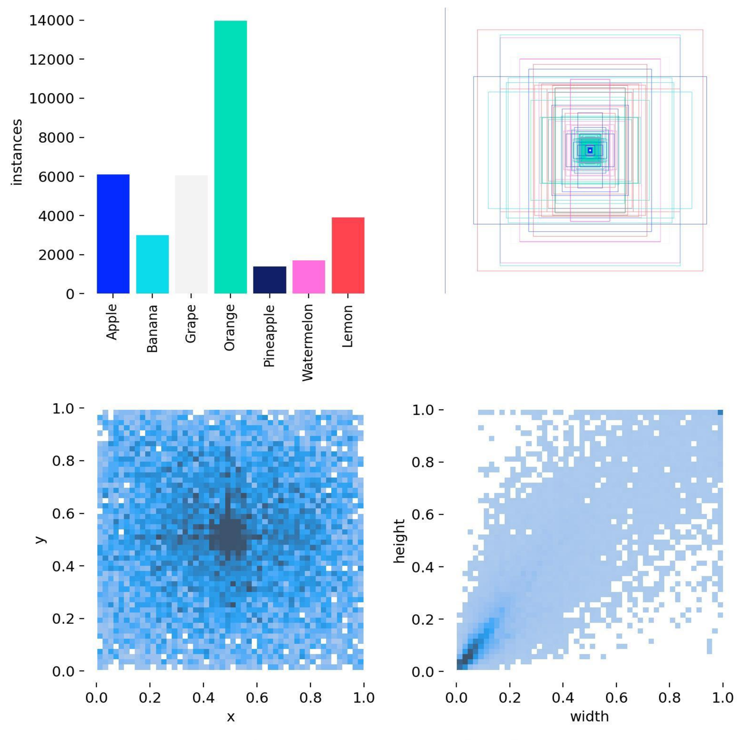

Figure 6. Labels

This image demonstrates the correlation process during training. Such as the bounding boxes and their relative locations, the identification of the object and the number of times it appeared during the training session, and its position.

The P Curve displays the precision of the trained model for each training class (in this case: fruits) based on the confidence of each class. Overall, the model seemed to be the most confident in identifying lemons, which was helpful because this was the fruit we chose for the robot to pick up.

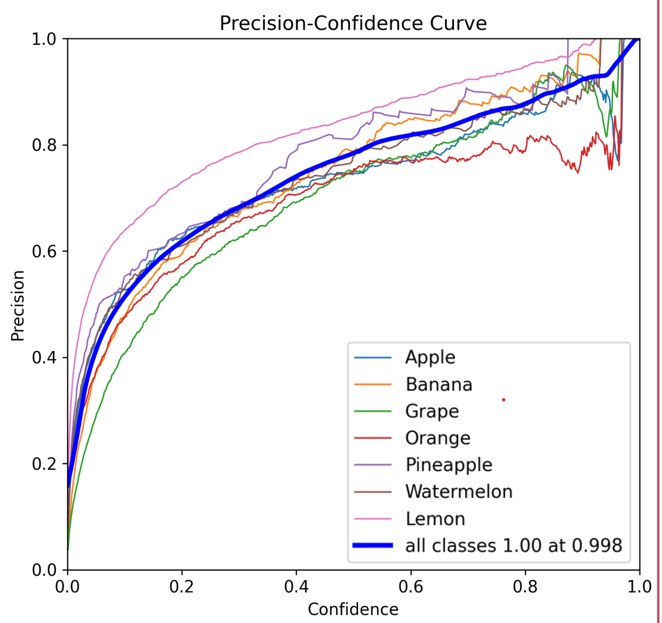

Figure 7. P Curve

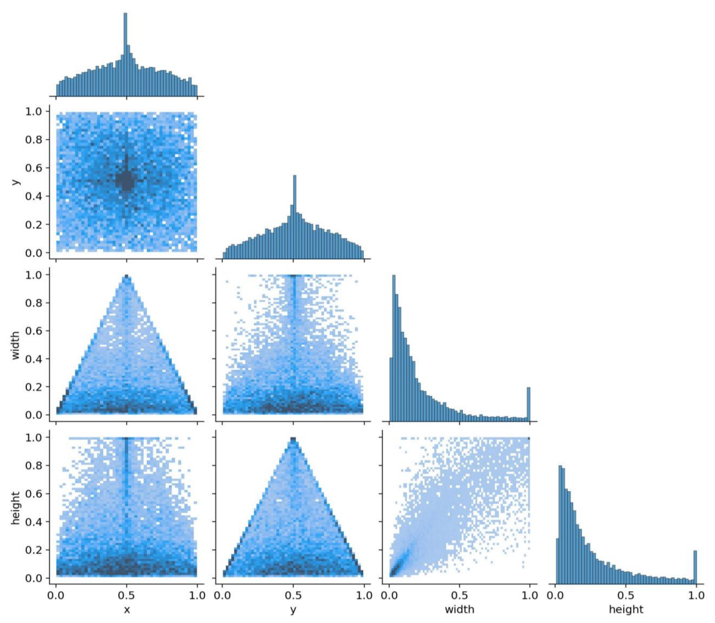

Figure 8. Labels Correlogram

On the left is a group of plots called the Labels Correlogram. The Labels Correlogram displays how the x, y, width and height values of the bounding boxes for each of the images, correlate with each other.

Research

Table1. ViperX 300 S Specifications	
Degrees of Freedom: 6 Degrees	**Works with Gazebo:** ✓
Reach: 750mm	**Works with Python-ROS:** ✓
Span: 1500mm	**Servos:** 6X XM540-W270-T | 2X XM430-W350-T
Repeatability: 1mm	**Communication Hub:** DYNAMIXEL U2D2
Accuracy: 5-8mm	**Power Supply:** 12 Volt - 20 Amp
Working Payload: 750g	**Parallel Gripper Kit:** ✓
Interbotix: ✓	**Tools and Bolts:** All Included
Works with ROS 1/2: ✓	**Wrist Rotate:** Yes
Works with MoveIt: ✓	**Weight:** 3.6kg / 8lbs

Table 2. Intel® RealSense™ D415		
Features	**Use environment**: Indoor/Outdoor **Image sensor technology:** Global Shutter	**Ideal Range:** .6 m to 6 m **Inertial measurement unit:** Bosch BMI085
Depth	**Depth technology:** Stereoscopic **Minimum Depth Distance (Min-Z) at Max Resolution:** ~52 cm **Depth Accuracy:** <2% at 4 m(1)	**Depth Field of View (FOV):** 87° × 58° **Depth output resolution:** Up to 1280 × 720 **Depth frame rate:** Up to 90 fps
RGB	**RGB frame resolution:** Up to 1280 × 800 **RGB frame rate:** 30 fps **RGB sensor technology:** Global Shutter	**RGB sensor FOV (H × V):** 90 × 65° **RGB sensor resolution:** 1 MP
Major Components	**Camera module:** Intel RealSense Module D415	**Vision processor board:** Intel RealSense Vision Processor D4
Physical	**Form factor:** Camera Peripheral **Length × Depth × Height:** 99 mm × 20 mm × 23 mm	**Connectors:** USB-C* 3.1 Gen 1* **Mounting mechanism:** – One 1/4-20 UNC thread mounting point. – Two M3 thread mounting points

References

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