Friday, May 4th

AUBO Robotics

SENIOR DESIGN: Spring 2018

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Overview

- Introduction
- Initial Research and Analysis
- Functions and Requirements
- Conclusions and Recommendations
- Lessons Learned
- Next Steps

Introduction

The scope of this project is to integrate an AUBO-i5 collaborative robot with both a gripper and camera vision system into a conveyor tracking application.

The manipulator’s goal is to pick and then precisely place parts from a conveyor belt.

Because the AUBO-i5 is a collaborative system it will also integrate a lidar for reduced speeds and safety zones.

Initial Research and Analysis

- Vision Recognition
  - OpenCV
- Gripper
  - Pneumatic actuator already present; little to no research done
  - See Functions and Requirements for further details
- Safety System
  - Premade systems
    - Costly
    - Felt we could implement in-house
      - Contributes towards goal of Senior Design
  - Ultrasound, infrared, and lasers
    - Infrared is short-range and ultrasound less accurate
      - Both require auxiliary systems (rotation for 360 degree view)
    - Lasers allow easy setup and control of safety zone
      - Initial concept from group

Initial Research and Analysis

- General Setup
  - 2 USB compatible, high speed communication cameras
    - Logitech HD Pro Webcam C920
    - Wide-Lens for larger work area
    - One above work area for general detection, one attached to Robot for when arm blocks first camera
  - Attachment to robot for gripper and second camera
    - Metal piece already made to build on
    - Attachment modeled to build from base up
      - Model not toleranced and fit needs to be adjusted
  - First camera overhang
    - Design with calibration of vision system in mind for ease of transport and setup

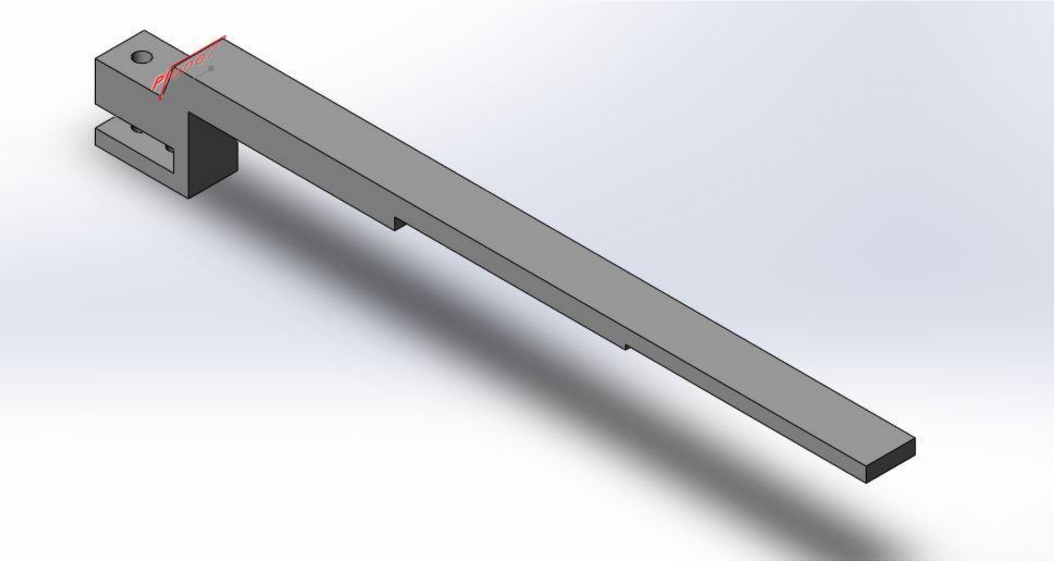
Functions and Requirements: Mechatronic Parts, Fall Review

Mechatronic Parts

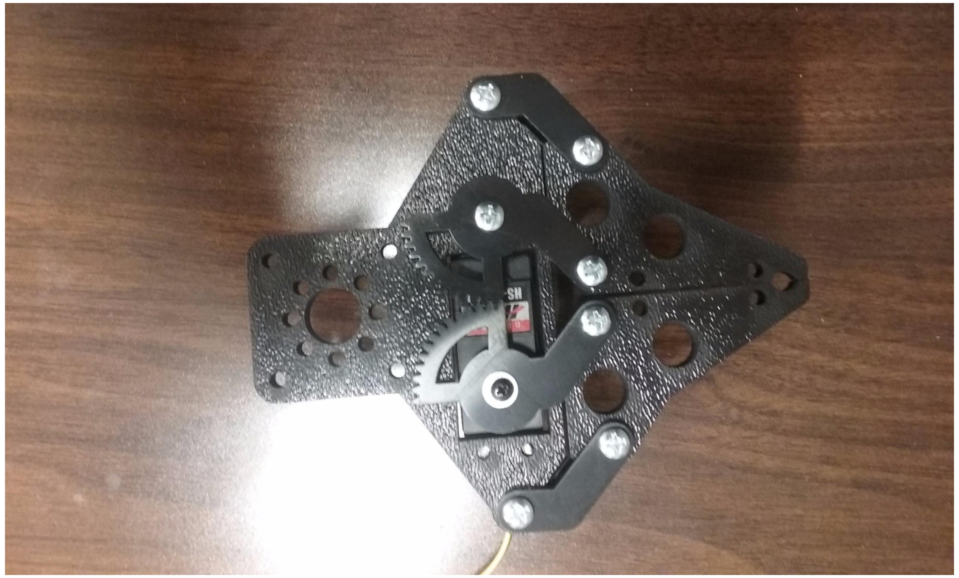
- Gripper, 2 options
  - Pneumatic
    - 2 state pneumatic lock system
    - Cheaper and "faster"
      - Already obtained
      - 3D printed vices
    - Difficulty controlling
    - Less versatile
  - Servo Run Parallel Vice Grip
    - Controlled via force sensors
      - Sensor acts as resistor
      - Voltage across read
      - Low threshold

- Safety System--Tripwire
  - Laser Light (Cat Toy)
  - Photoresistor
  - Mirrors used to bounce light and determine safety area
  - Current Protocol: flipping a switch upon exiting safety area
    - Other protocols applicable

Functions and Requirements: Grippers, Fall Review



Initial Gripper Concept
Pneumatic

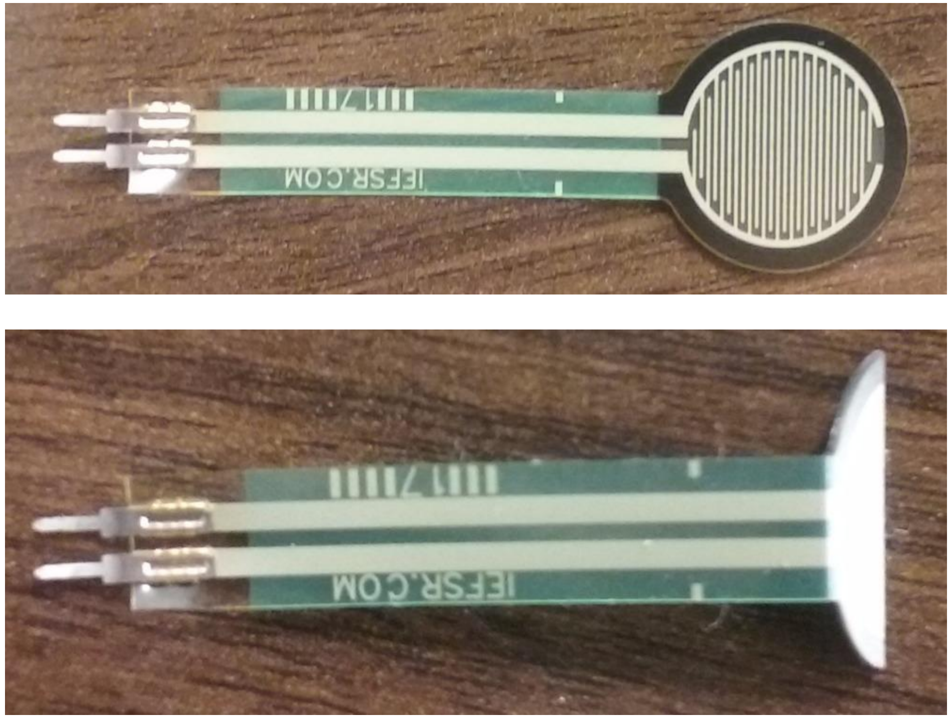


Current Gripper Concept
Electric

Demonstration

Shown to the right is a video of the gripper closing onto the desired object.

Functions and Requirements: Sensors, Fall Review



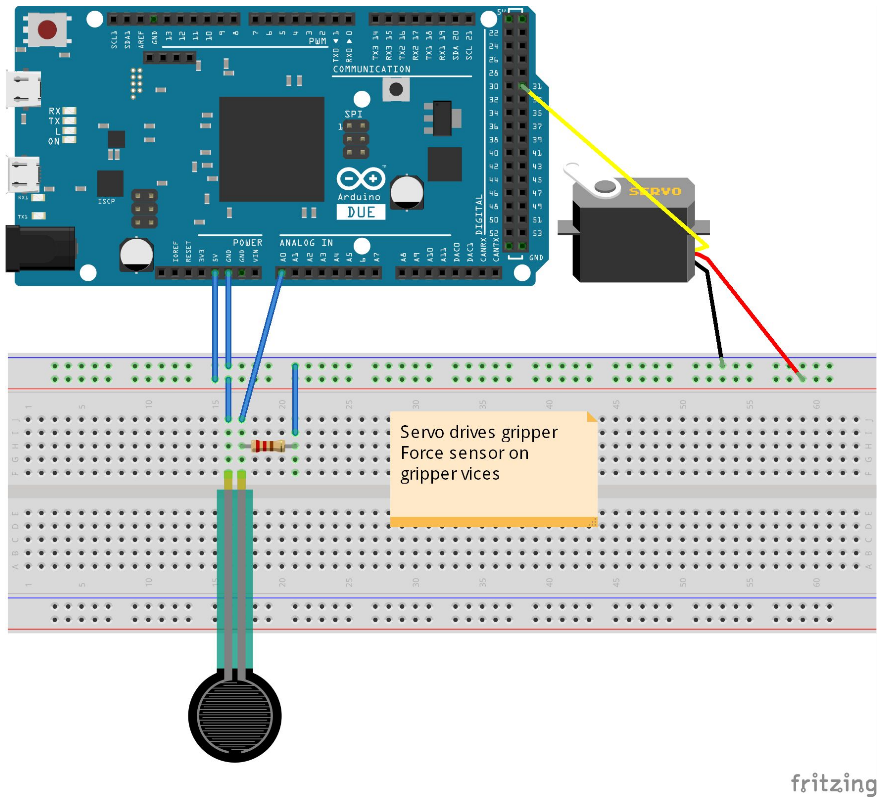
Force Sensors: Work when cut

Photo resistor for Safety System

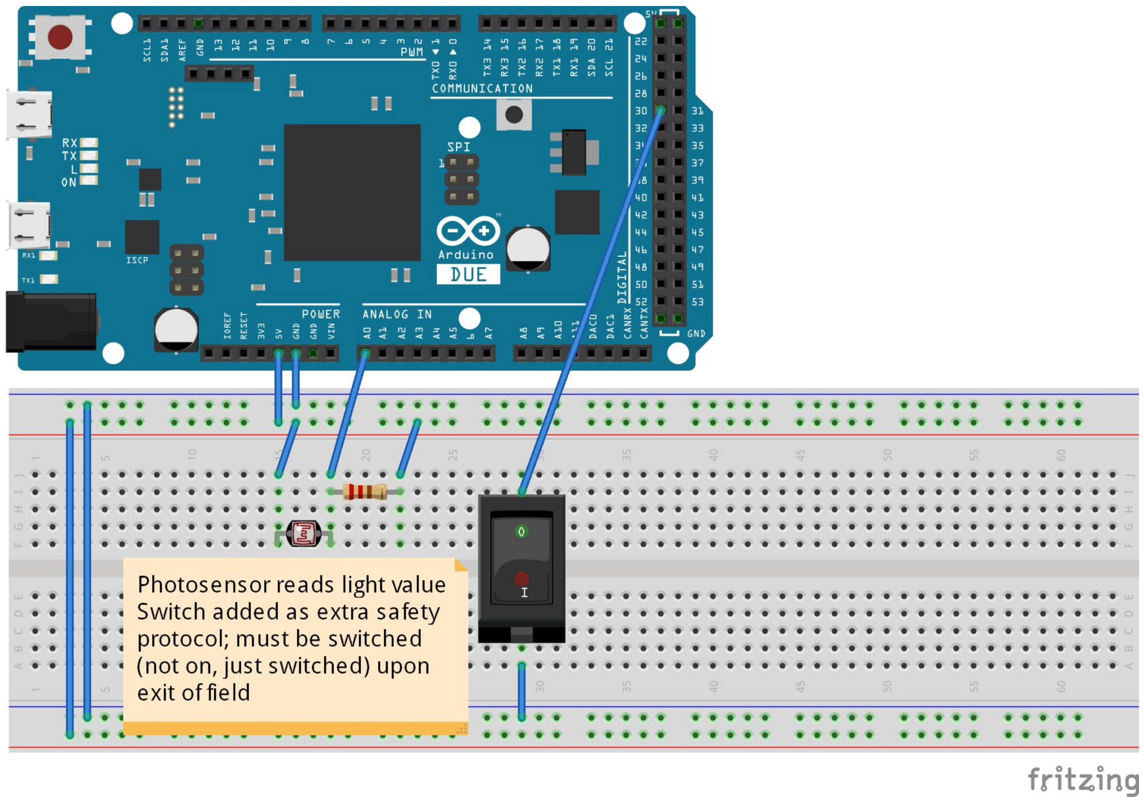
Demonstration

Shown to the right is a video of the gripper working in conjunction with the safety system. The gripper stops when the system detects a "person"

Functions and Requirements: Circuit Diagrams, Fall Review



Gripper Circuit*



Tripwire Circuit*

*Made using Fritzing

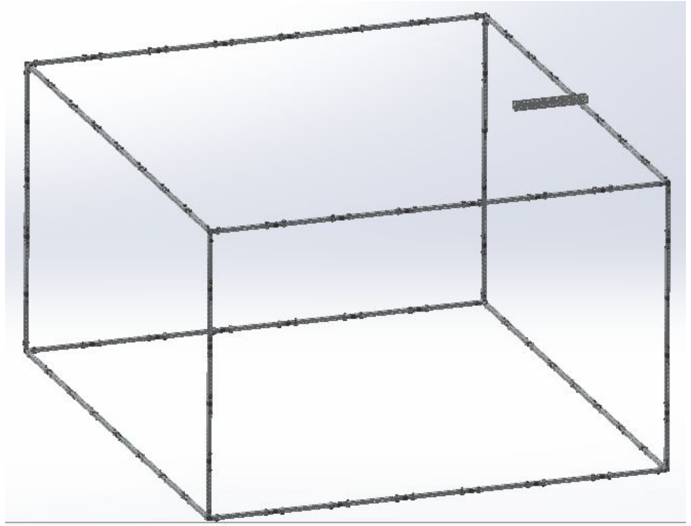
Demonstration

Shown to the right is a video of the trip wire registering the presence of a "person" (represented by a yellow light) and then resetting (green light).

Functions and Requirements: Work Cell

Work Cell

- Constructed using aluminum square beams purchased from Tetrix Robotics
- Enclosure surrounded robotic arm as well as conveyor belt
  - Dimensions: 1776 mm x 2044.38 mm x 1268.57 mm
- Design incorporated a c-channel beam to support overhanging vision attachment

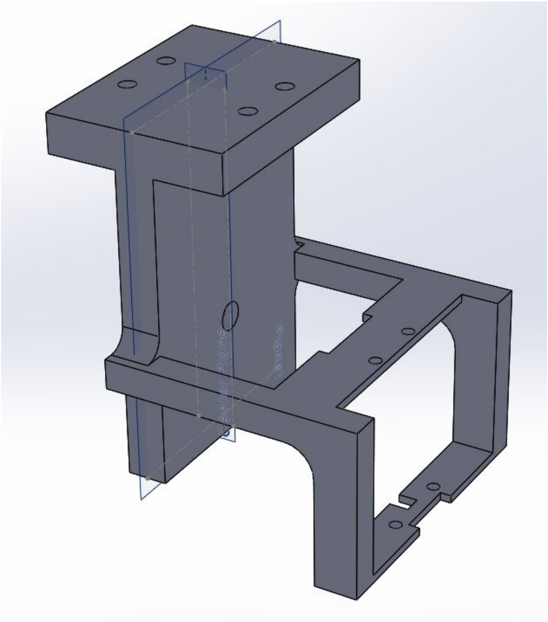


Functions and Requirements: Grippers

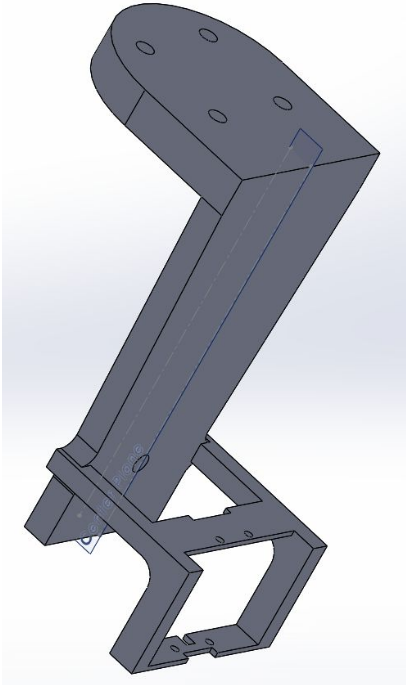
- ROBOTIQ
  - Separate gripper purchased by AUBO
  - Attached directly to AUBO Arm
  - Old parallel gripper shelfed
  - Camera mounts designed around use of new grip

Functions and Requirements: Vision Attachments

Attachment to Work Cell

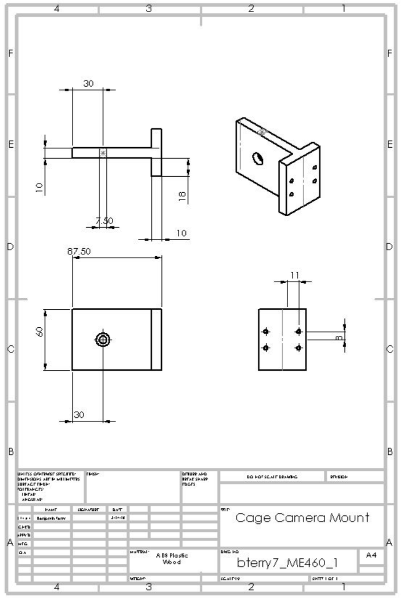


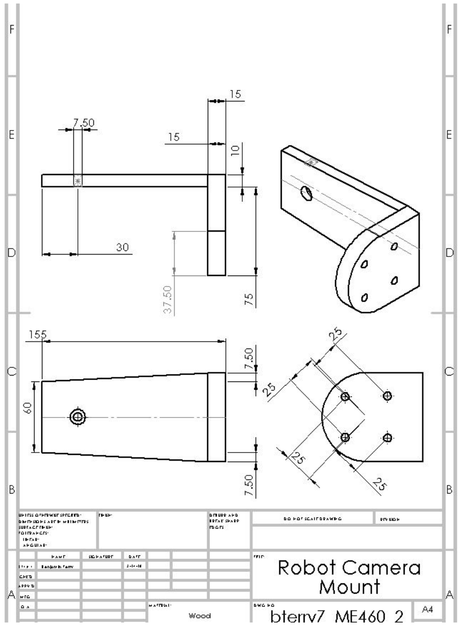
Attachment to Robotic Arm



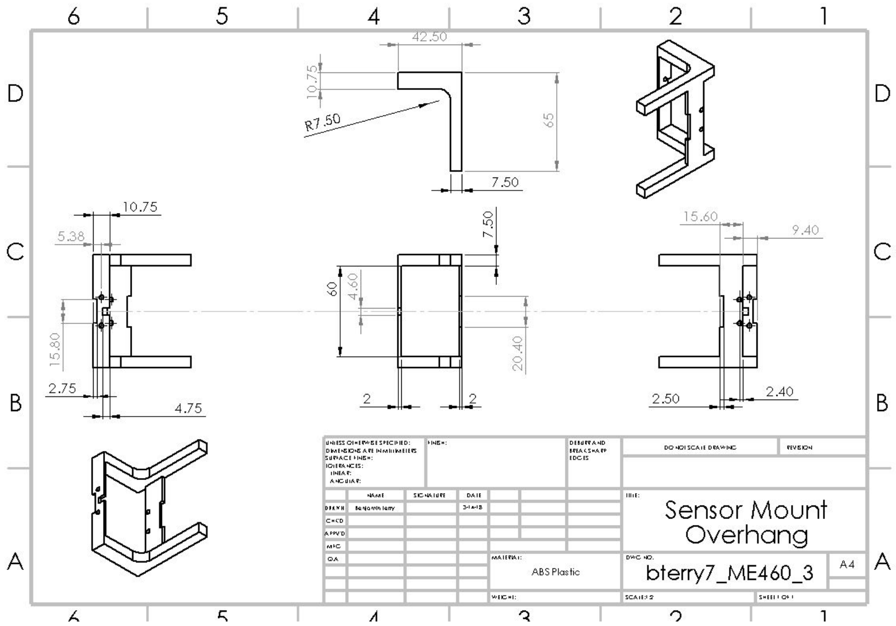
Functions and Requirements: Vision Attachments

External Mount Drawings





Sensor Mount Drawings



Functions and Requirements: Vision Attachments

External Mount

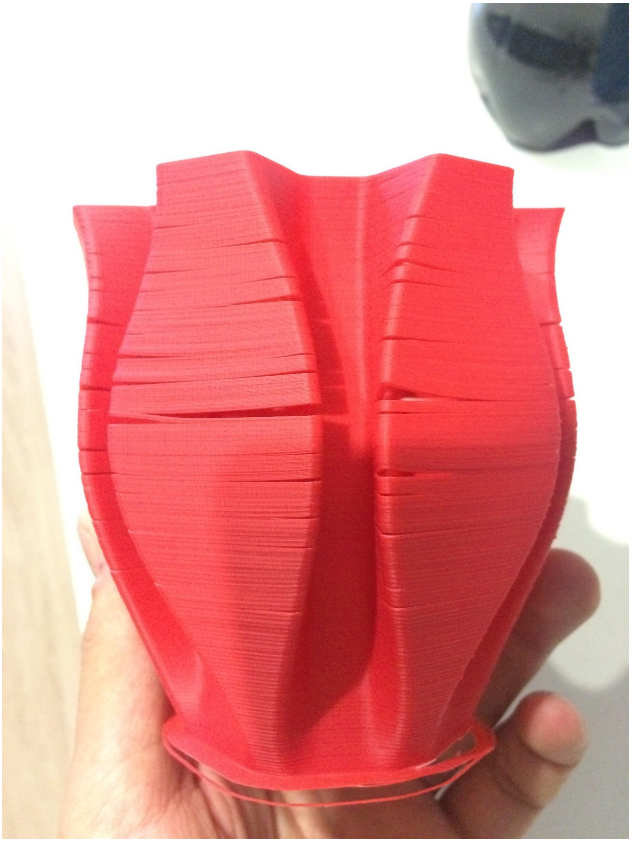
- Part that attached to Cage or Arm
- Designed to match dimensions of camera and attachment point
  - Upper flanges for Cage Mount
  - Between grip and arm for Robot Mount

Sensor Mount

- Held sensors in known place relative to camera
- Designed to match dimensions of sensors
  - No dimensions given
  - Holes left for soldering
  - Filed to final form
  - Vinyl layer between screws and sensors, if needed
- 5 millimeter fillet between
  - But that didn't matter because…

Vision Attachments: Processes and Problems

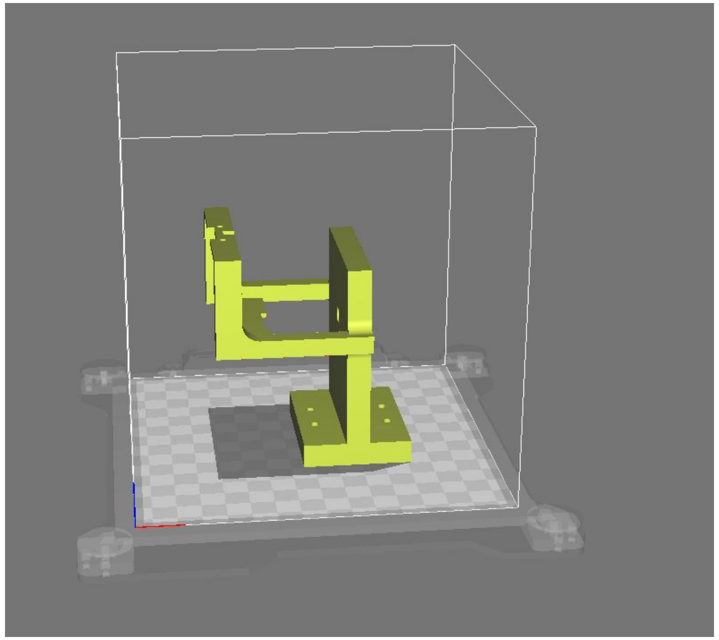
- Original Plan: 3D printing
  - Innovation and Collaboration Studio (ICS)
  - Tolerances not considered
  - Multiple failed prints
    - ABS is poor material
      - Very brittle and temperature dependent
      - Fluctuations in temperature and motion of nozzle cause breaks
      - Exacerbated by long print time
    - Too much support material
    - Multiple Orientations tried
    - Enclosed Environment tried
- Next Plan: 3D print sensor mount, fabricated external mounts from wood



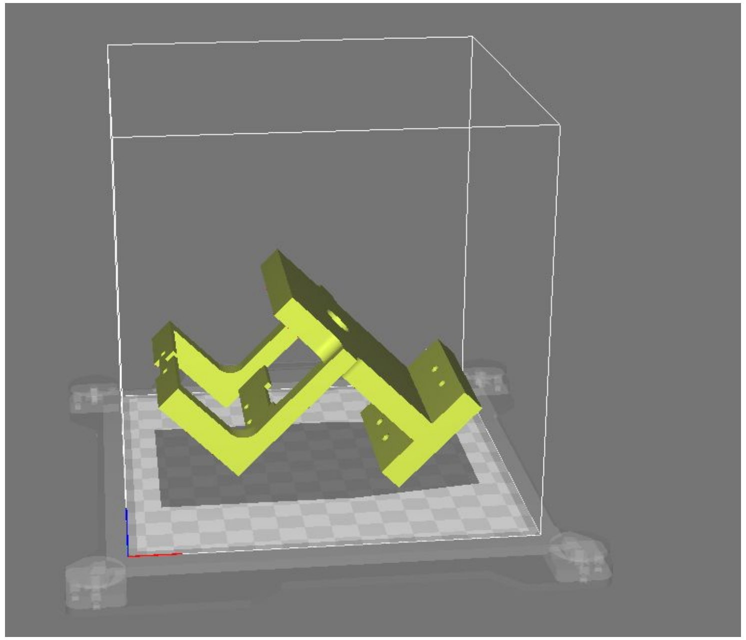
Example of bending and flexing in large ABS print

Vision Attachments: Different Print Orientations

Print Orientation 1

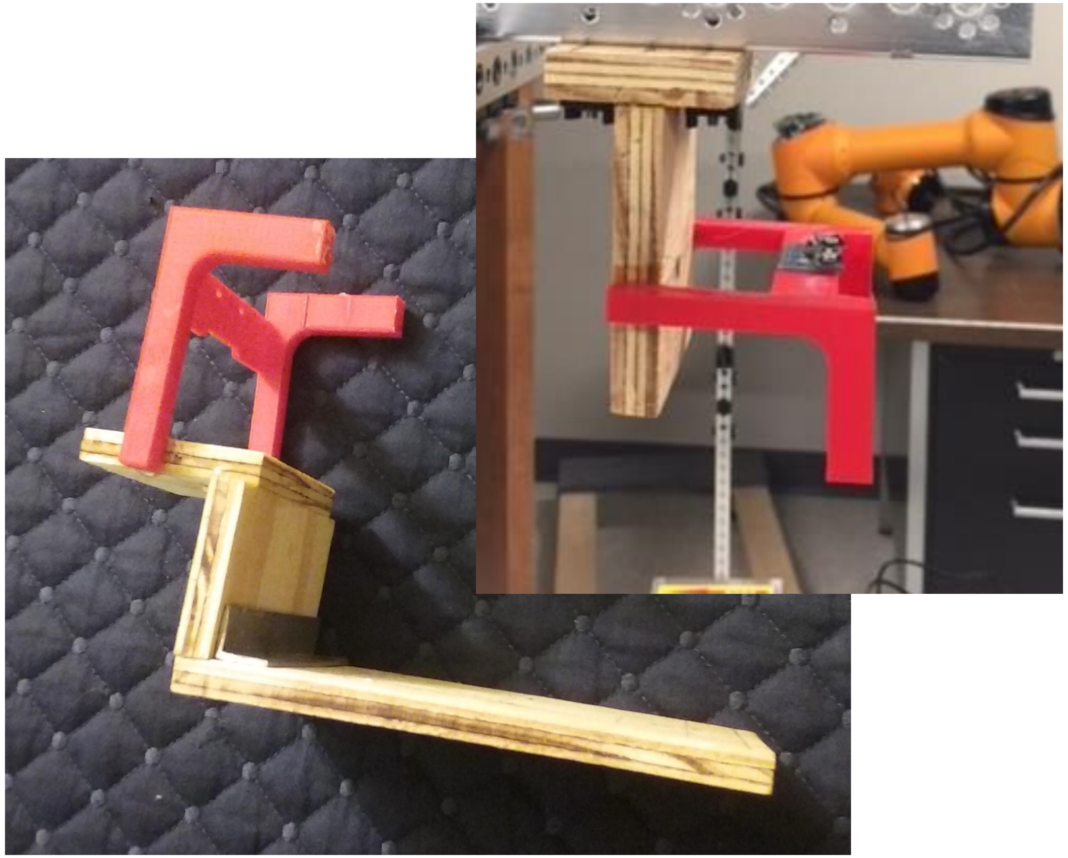


Print Orientation 2



Vision Attachments: Split into ABS and Wood

- External mounts were simple enough to be made out of wood, even by an amateur (i.e. me)
  - Would reduce total material/time needed for print
  - Overhang could be printed with less support→ less failure opportunity
- 3D printed overhang
  - Still failed at least once
  - Unknown cause→ part should've printed without issue
  - ABS really is not a good material without a fully sealed chamber
  - Final print still had to be glued together
- Pieces epoxied together after separate fabrication



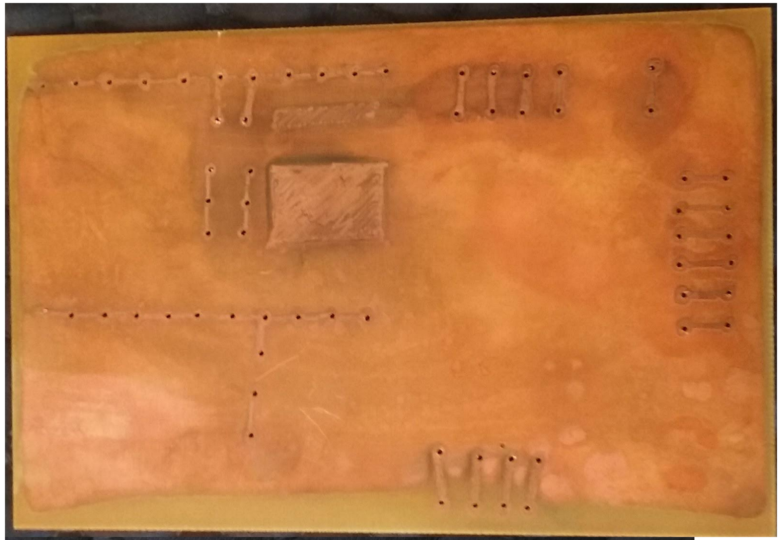
Vision Attachments: More Problems

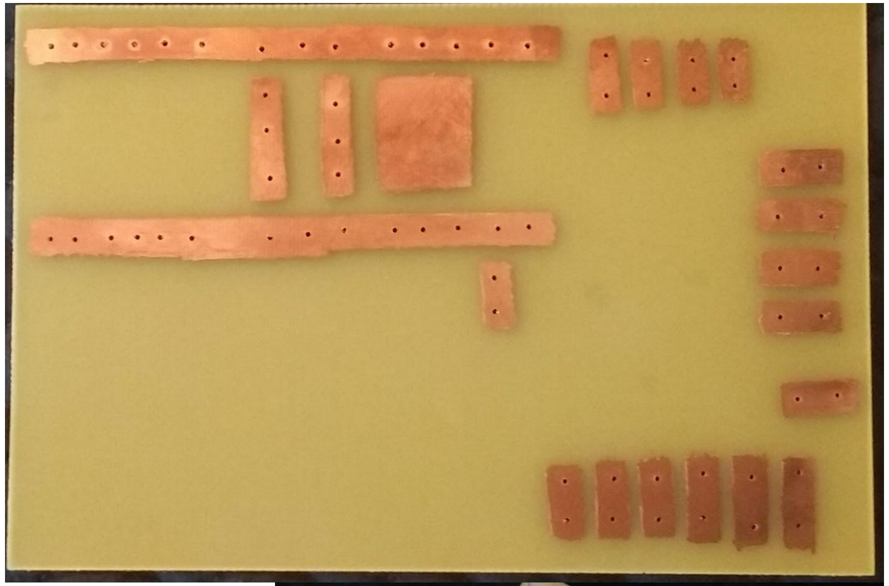
- But wait, that part isn't what was designed?
  - Original design was for the ROBOTIQ arm purchased independently by AUBO
  - Difficulty communicating with ROBOTIQ (in conjunction with all the other pieces)
  - Fall back to old plan of using parallel gripper
  - Short design and fabrication time
- Other Issues
  - Misunderstandings
    - Based on cage design and communication, thought camera would be in center of conveyor belt, pointing straight down and relying on wide view to see all objects
    - Would actually be at end, and would need to be placed at an angle
  - Vibration
    - Slight movements could shift camera angle
    - Assumed internal damping was enough
    - Unstable Cage

Functions and Requirements: Printed Circuit Board

- Goal was to incorporate Printed Circuit Boards (PCBs) for sensors and mechatronic parts
  - Fabrication of other pieces took longer than expected
  - Etching process took longer than expected
  - Ultimately successful etching, but not incorporated
- PCB Etching Process
  - Copper laminate substrate
  - Imprint circuit onto laminate
    - Ironed on design from laser jet printer
    - Drawn on using sharpie
      - Remove at end with toothpaste
  - Cut to size so as not to waste material
    - Difficult with hand drawn design→ can't compress as much and keep detail
  - Submerge in Ferric Chloride
    - Ideally heated via bath
    - ~10 minutes for a small piece in heated solution
    - ~90 minutes for a large piece in room temperature solution
  - Dispose of Ferric Chloride
    - Chemical Waste Disposal
    - DO NOT RINSE DOWN DRAIN

Functions and Requirements: Printed Circuit Board





Far Left: Ferric Chloride
Left Top: Failed Etch
Left Bottom: Microdrill “bits;” note broken bits-->use a drill press
Right Top: Successful Etch
Right Bottom: Gloves

Functions and Requirements: Software & Programming

Software/ Programming

- Visual recognition software
  - Language used (C++)
  - Free source openCV library
  - Camera calibration
    - Chessboard calibration using multiple pictures at different distances and angles
    - Calibration matrix
  - Object tracking
    - Aruco markers detection
    - Object information contained in aruco markers
    - Location using distance coefficients at a particular aruco marker

- Robot Communication and Scripting
  - AUBO Script
  - Script editor provided by AUBO
  - Communication with control box
    - IP communication using ethernet connection
    - Configure computer's IP to match control box
  - Script for robot control
    - Writing in AUBO Script to control individual joint angles

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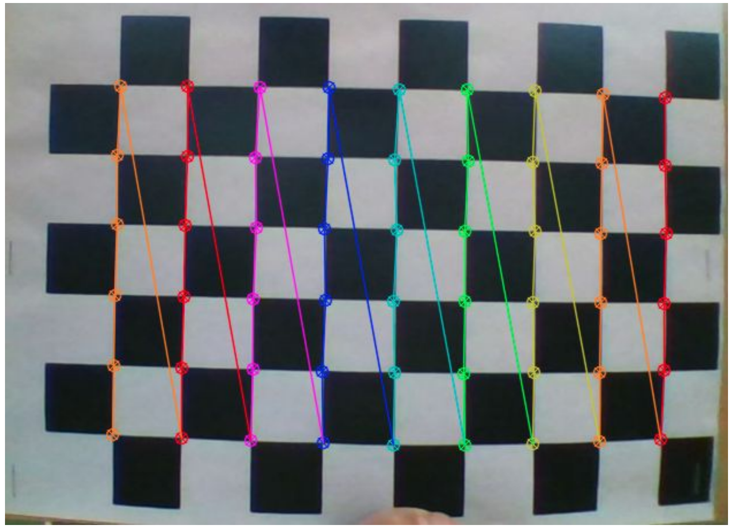

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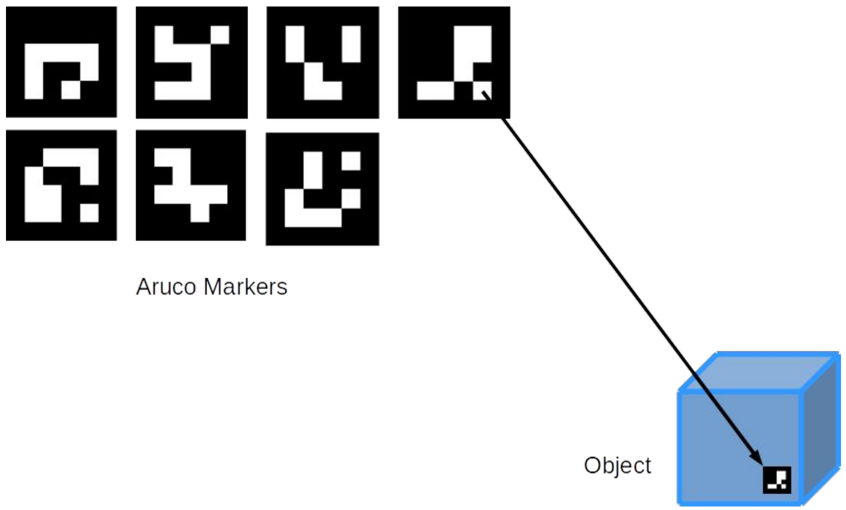

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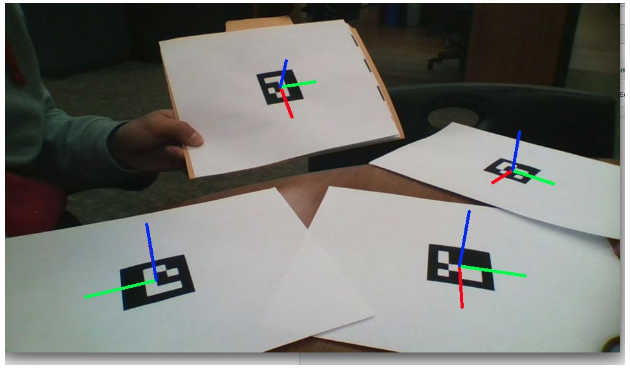

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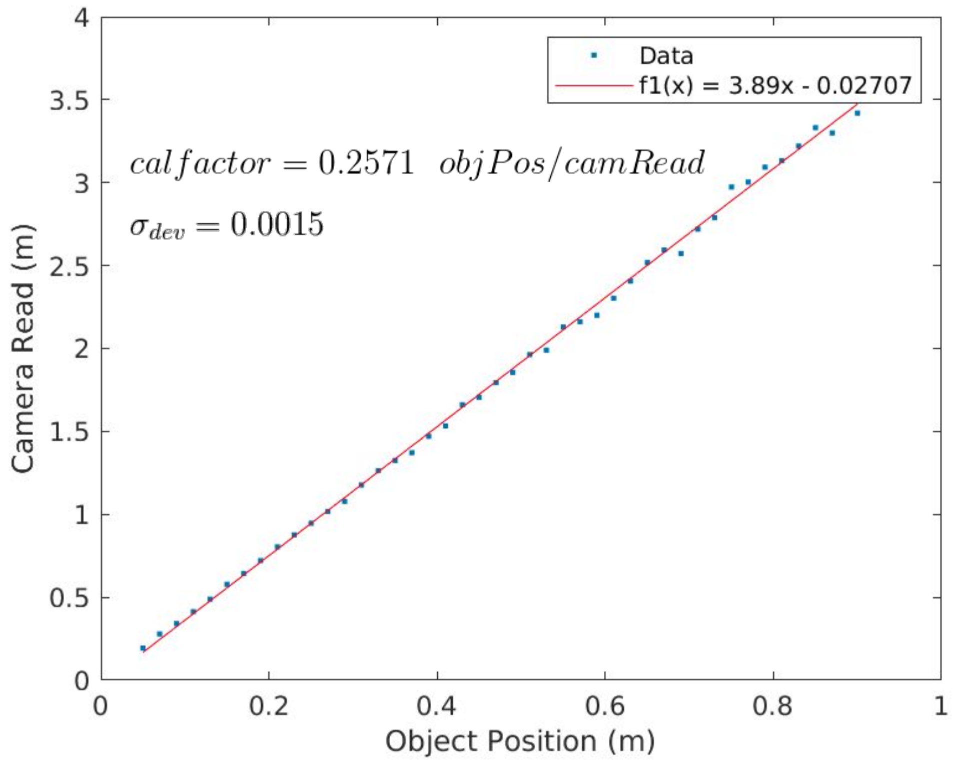

Fig.1 Linear fit to obtain calibration factor

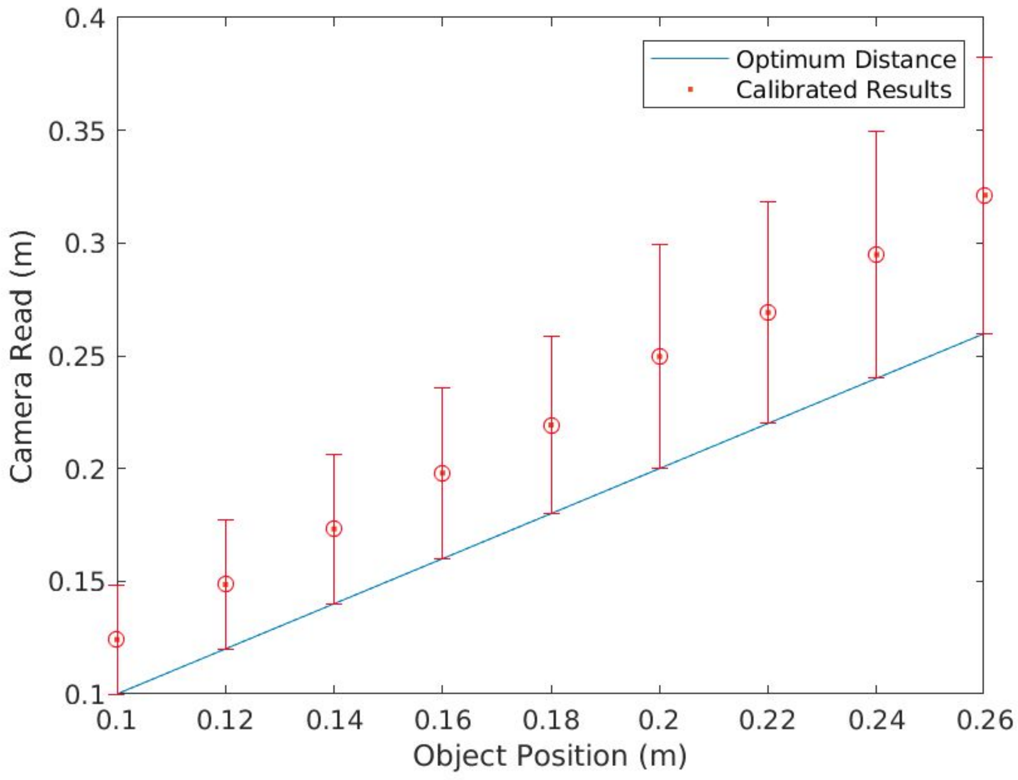

Fig.2 Calibrated camera distance

Functions and Requirements: Software & Programming

Software/Programming

- Robot Communication and Scripting
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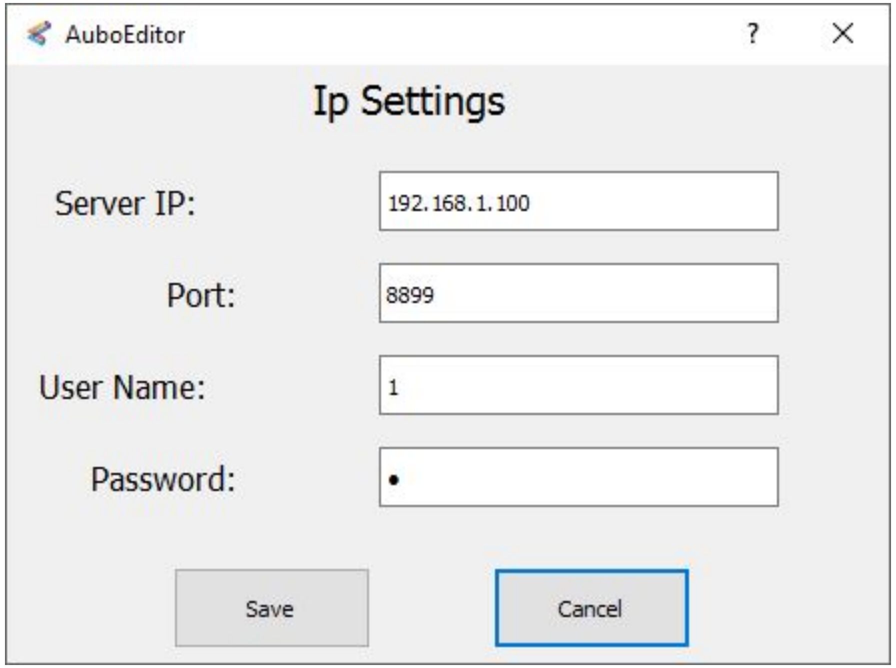
    - Writing in AUBO Script to control individual joint angles



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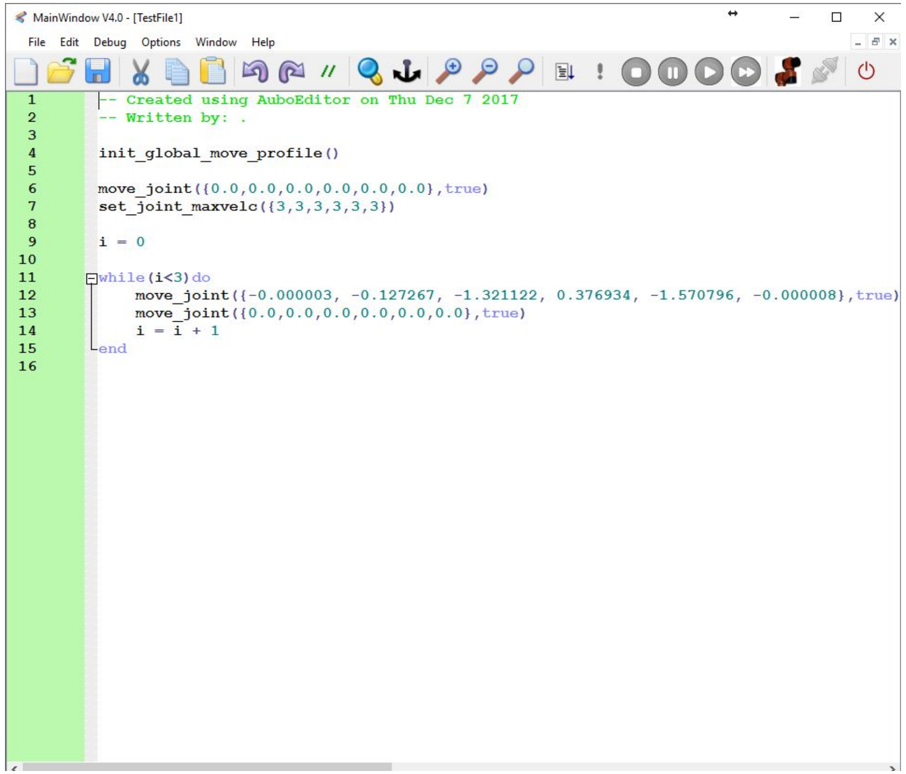
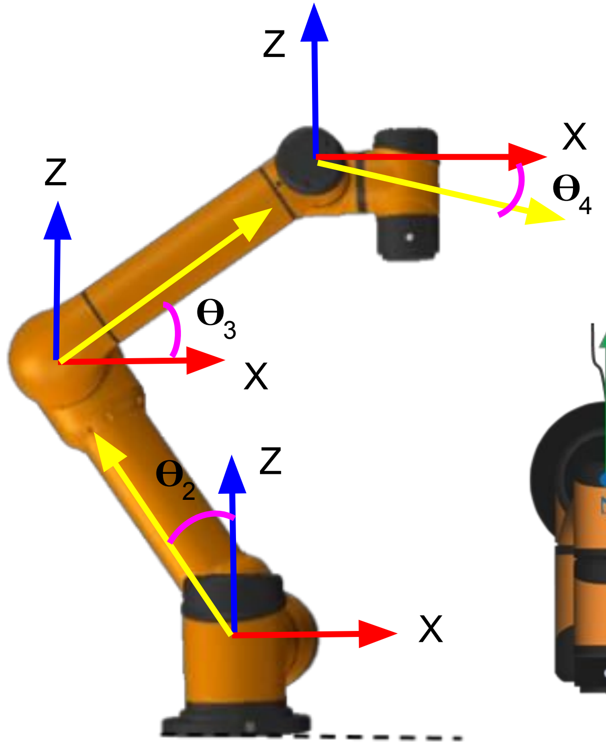


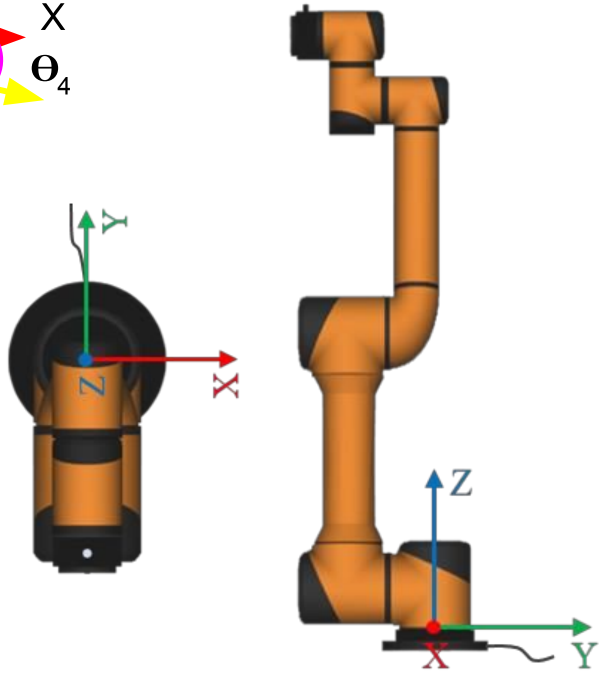
Functions and Requirements: Software & Programming

Software/Programming

- Development of mathematical algorithm to determine joint angles using C++
  - Loop equation until convergence of angles reaches a pression of 0.00001
  - Angles are calculated with respect to an absolute coordinate system
  - Resultant angles are transformed into angles that are measured with respect to each moving joint.
  - Angle for joint 1 is transformed to cylindrical coordinate.
  - Angles for joint 5 and 6 use the angle coefficients obtained from the object recognition software.

Functions and Requirements: Software & Programming





$$\theta_{2,abs} = cos^{-1}\left[\frac{x - r_3 - r_2cos(\theta_2)}{r_1}\right] \qquad (1)$$

$$\theta_{3,abs} = sin^{-1}\left[\frac{r_1sin(\theta_1) - z}{r_2}\right] \qquad (2)$$

$$\theta_1 = tan^{-1}(y/x) \qquad (3)$$

$$\theta_2 = -(90^o - \theta_{2,abs}) \qquad (4)$$

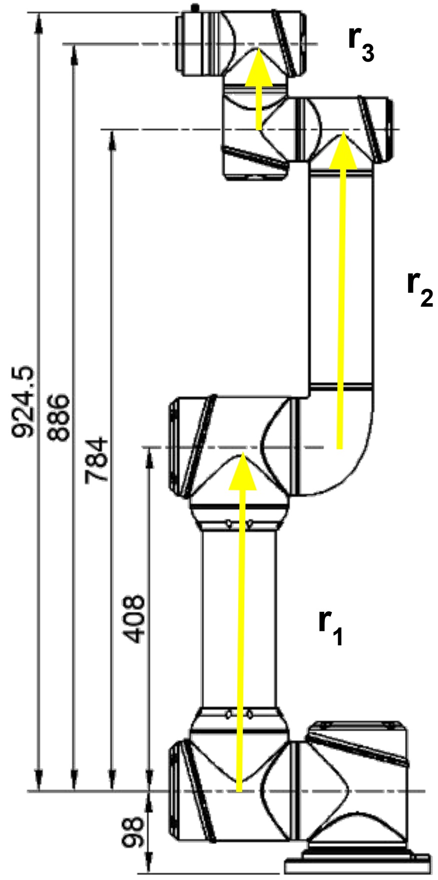
$$\theta_3 = \theta_{2,abs} + \theta_{3,abs} \qquad (5)$$

$$\theta_4 = -(90^o - \theta_2 + \theta_3) \qquad (6)$$

$$\theta_5 = angle_{coeff} \qquad (7)$$

$$\theta_6 = angle_{coeff} \qquad (8)$$

$R = (x, y, z)$
$r_1 = 0.408\ m$
$r_2 = 0.376\ m$
$r_3 = 0.102\ m$



Functions and Requirements: Software & Programming

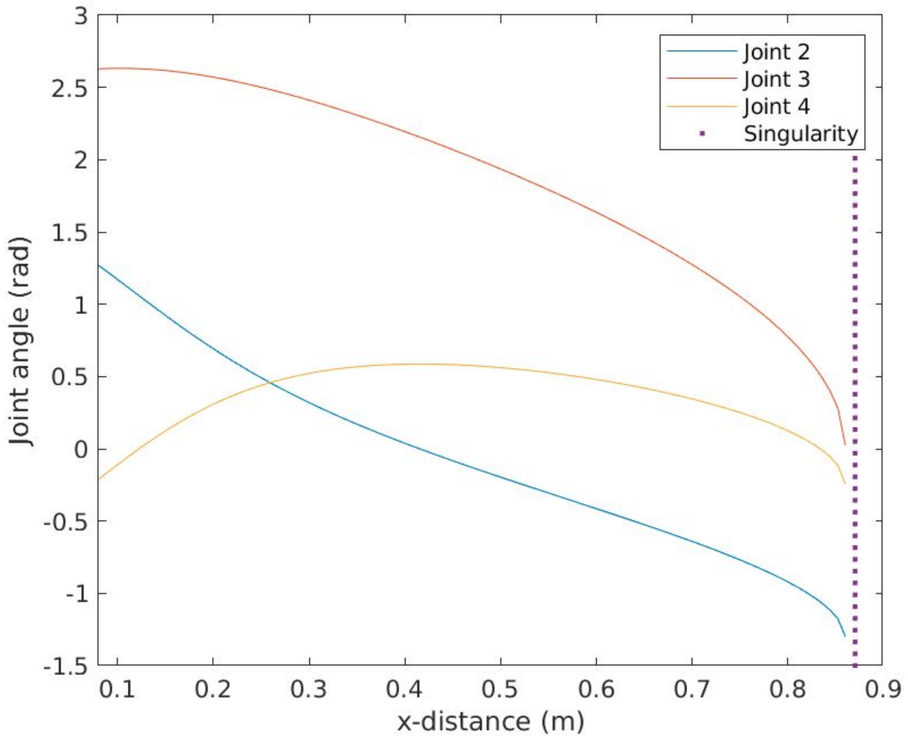


Fig.1: Joint angular distribution at constant z-distance = 0.2m from Joint 1

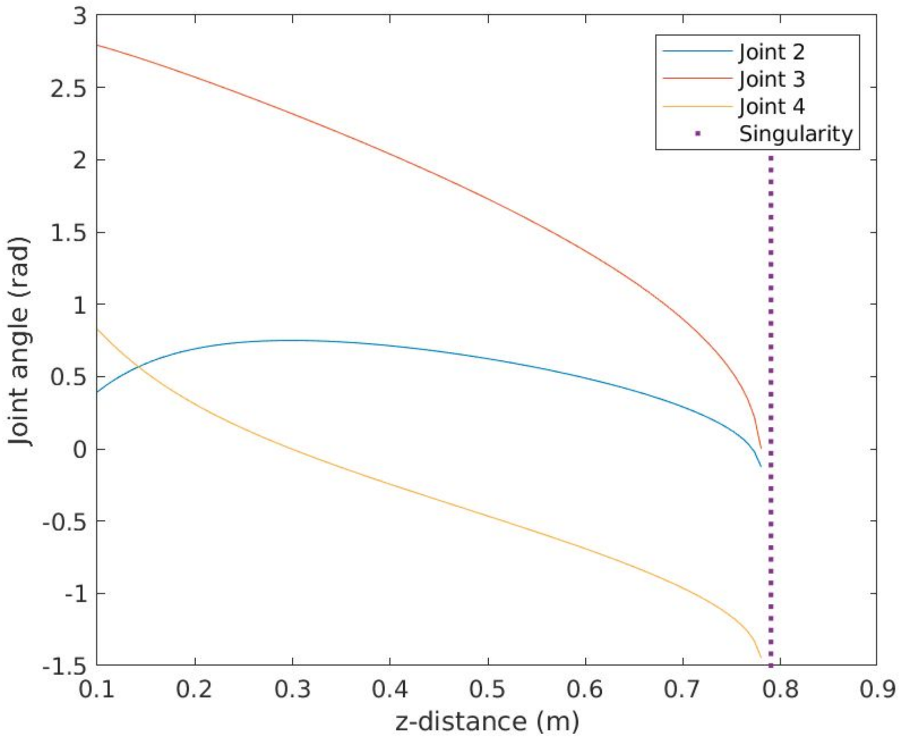


Fig.2: Joint angular distribution at constant x-distance = 0.2m from Joint 1

Functions and Requirements: Software & Programming

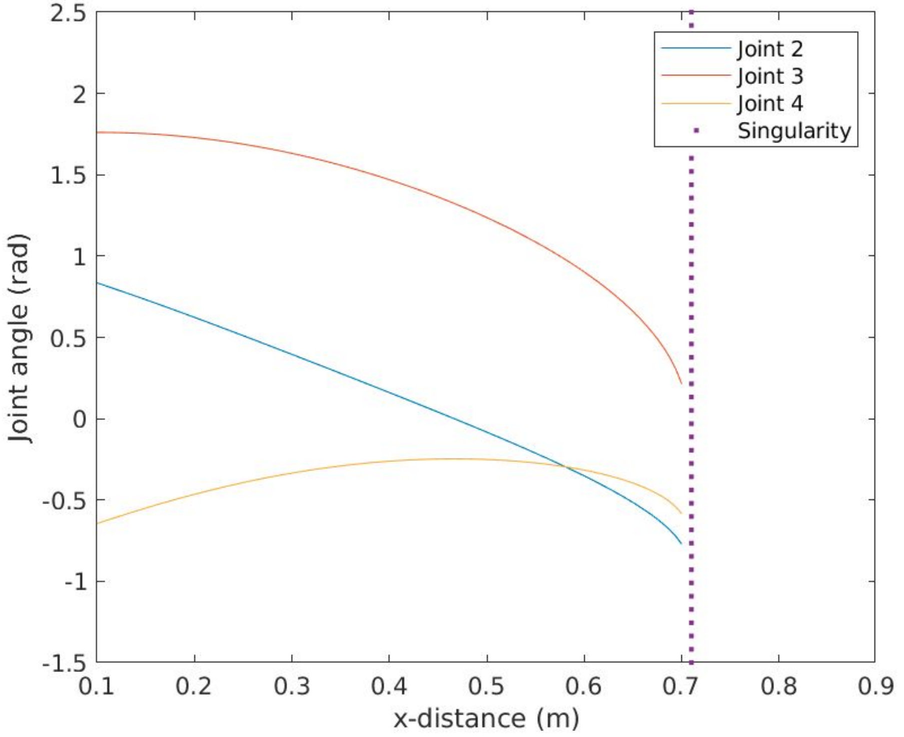


Fig.3: Joint angular distribution at constant z-distance = 0.5m from Joint 1

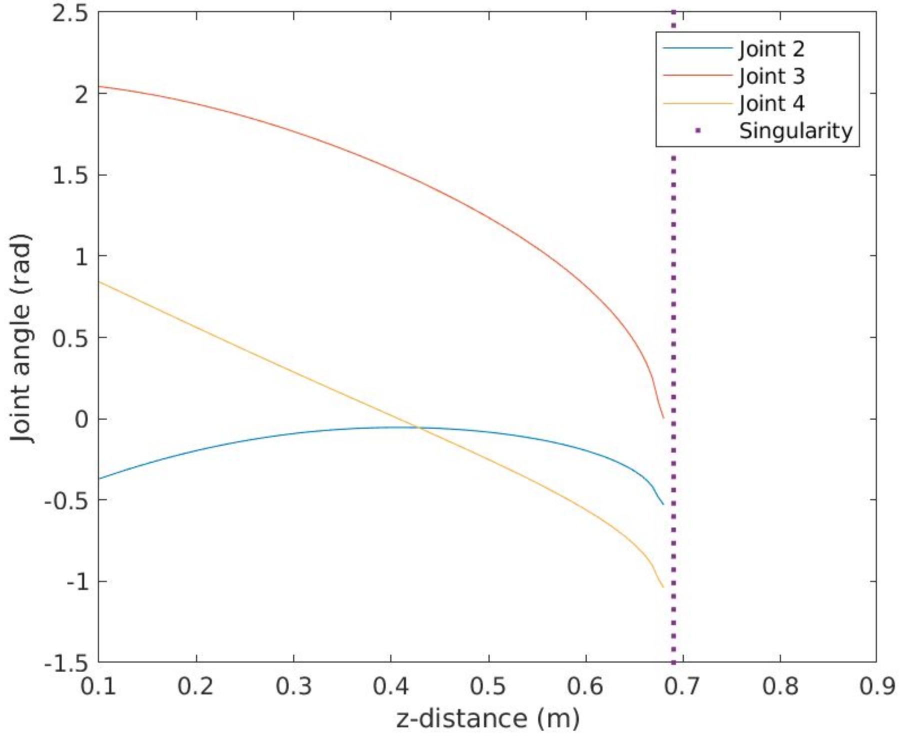


Fig.4: Joint angular distribution at constant x-distance = 0.5m from Joint 1

Functions and Requirements: Software & Programming

File	Size (bytes)
clien_aubo.cpp	843
aubo_main.cpp	3289
camCalibration.cpp	2020
angles.h	680
tcp.h	1561
readAngles.h	307
writeFile.h	173
posDetection.h	7590
posCalibration.h	4643
joint_move.aubo	1363
Total	22469

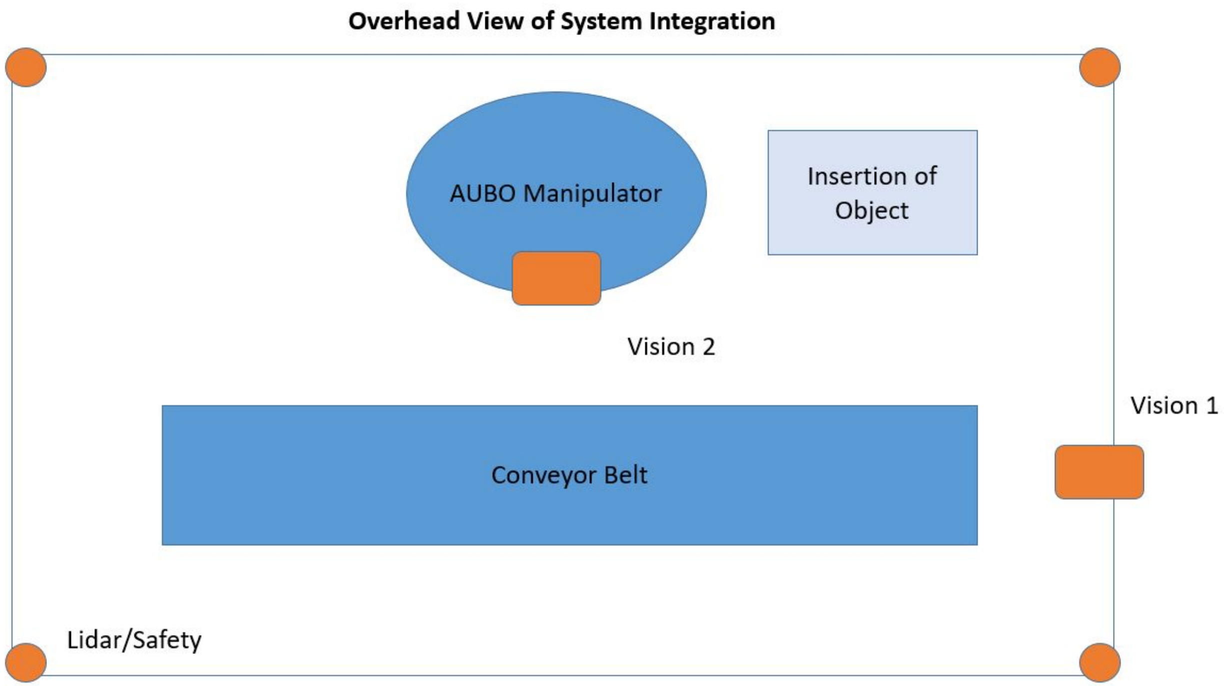
C++ File Size = 22.47 kB
Executable File Size = 151.7 kB
txt File Size = 54 bytes

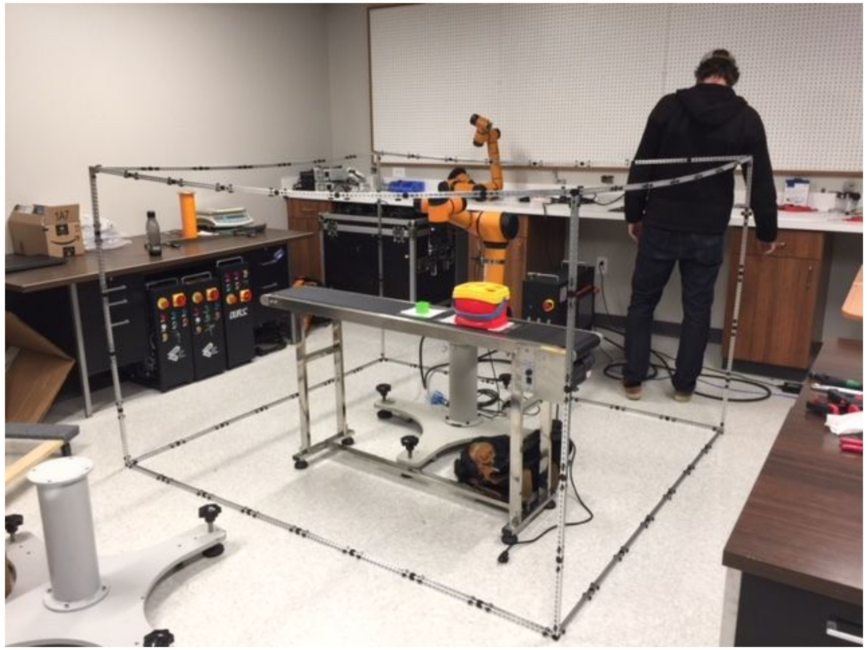
Total Software Size = 175.5 kB

Demonstration

Shown to the right is a video of the AUBO robot responding to commands given by computer.

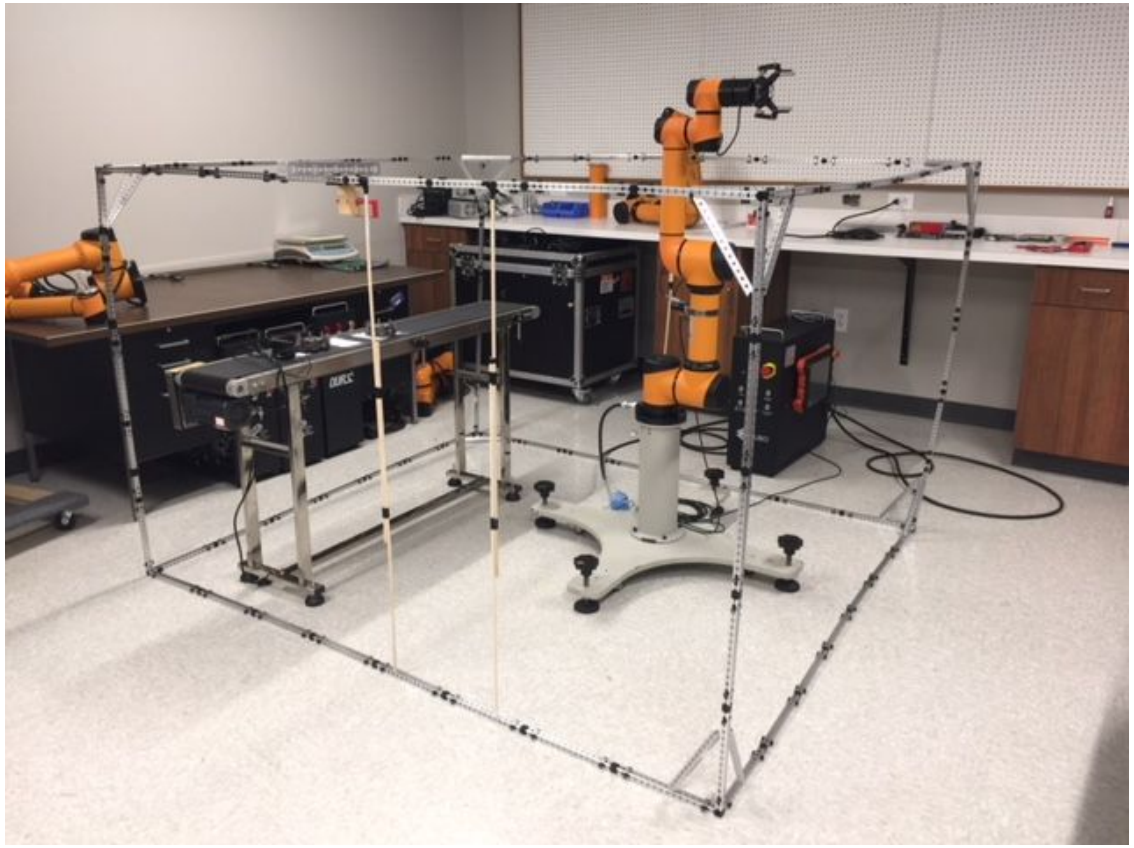
Conclusions and Recommendations: System Setup





Conclusions and Recommendations: Work Cell

- Enclosure was not as rigid as expected
  - Used excess tetrix parts to create trusses
  - Utilized wood to provide extra support
- Recommend using longer pieces of wood to create trusses across entire cage
- Stability is important because of the safety system



Conclusions and Recommendations: Vision Attachments

- Don’t use ABS
  - Complexity of design needed to match other parts still warrants 3D printing
  - Use PLA and/or more advanced, fully enclosed printer
- Wood was chosen for ease of access and timing
  - Could have used aluminum→ specialist machining or more training required
  - Advantages of rapid prototyping lost→ less time to readjust
- Ensure understanding of mechanical needs

Conclusions and Recommendations: Mechatronics Parts

- Extended development of other pieces and poor time management meant these were not implemented
- PCB
  - Use heated Ferric Chloride and ironed on circuits
  - Microdrill bits may break
  - Safety
- Individual systems still work as individual systems
- More fully design full system from start

Conclusions and Recommendations: Software & Programming

- Gripper Communication
  - Arduino serial communication is a bit slow
  - May consider switching to TCP/IP in later iterations
- AUBO Script
  - Gripper Control
    - Script could use functionality for direct gripper control
  - Arm Positioning
    - Script provides functions for exact joint positioning but not cartesian coordinates
    - Results in creating custom positioning functions for each project
- Camera System
  - Distance Calibration
    - In later iterations two or more cameras should be used to determine distance
    - A single camera cannot determine object positions within the tolerance needed to pick them up
  - Field of View
    - The field of view of the cameras used was not quite as wide as would be prefered
    - In the future cameras with a wider view range should be used

Lessons Learned

Spring 2018

- Planning
  - Difficulties ordering and receiving parts in a manner that agreed with pre-scheduling
  - Fabrication of parts proved longer than expected due to failures
- Communication with Robotic Arm
  - Unforseen communication difficulties arose and delayed coding progress

Despite incorporating an extra week into the schedule, we still found ourselves overwhelmed by unforeseen circumstances.

Having this experience gives us a better understanding of realistic timelines and a myriad of potential solution paths for this type of project.

Next Steps (Fall 2018)

Looking Forward

- The next team that works on this project will have to focus on incorporating the dynamic component for this system.
- They will also have to work on the safety system and making sure to integrate it into the system as well.
- Furthermore, the team will have to achieve the functionality part of this project so that it is complete and they are able to optimize and deliver a finished product.

Questions & Discussion

Bill of Materials Link:

https://docs.google.com/spreadsheets/d/1sGuwYoi6w41bW_Qs5Qa0oNcsMnsE2yJ3QFXYwl5N7rE/edit?usp=sharing