Preliminary Design Review

Advisor: Dr. Neogi

Members: Jordan Abell, Peter Amorese, Bruce Barnstable, Lindsay Cobb, Alex Ferguson, Marin Grgas, Kyle Li, Nick Miller, Jett Moore, James Tiver, Brandon Torczynski, Logan Vangyia

10.21.2020

Outline

1. Project Description
    a. Definition, objectives, ConOps, and FBD
2. Baseline Design
    a. Critical Project Elements
3. Evidence of Baseline Feasibility
    a. First-level Feasibility Analysis
    b. Additional Evidence
4. Summary

Section 1

Project Description

Presenters: Kyle Li and Lindsay Cobb

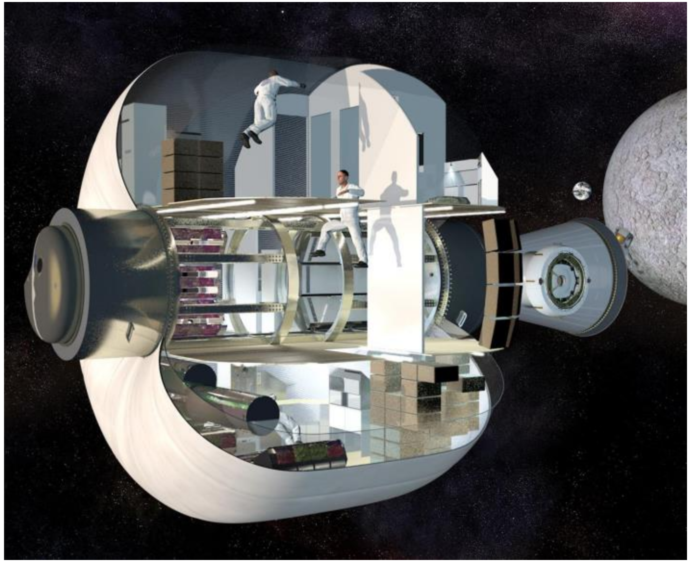
Problem Definition

Mission Context

SNC's inflatable LIFE™ Habitat is designed as a solution for deep space habitation. Cargo will arrive prior to the crew and will need to be unloaded from supply vehicles.

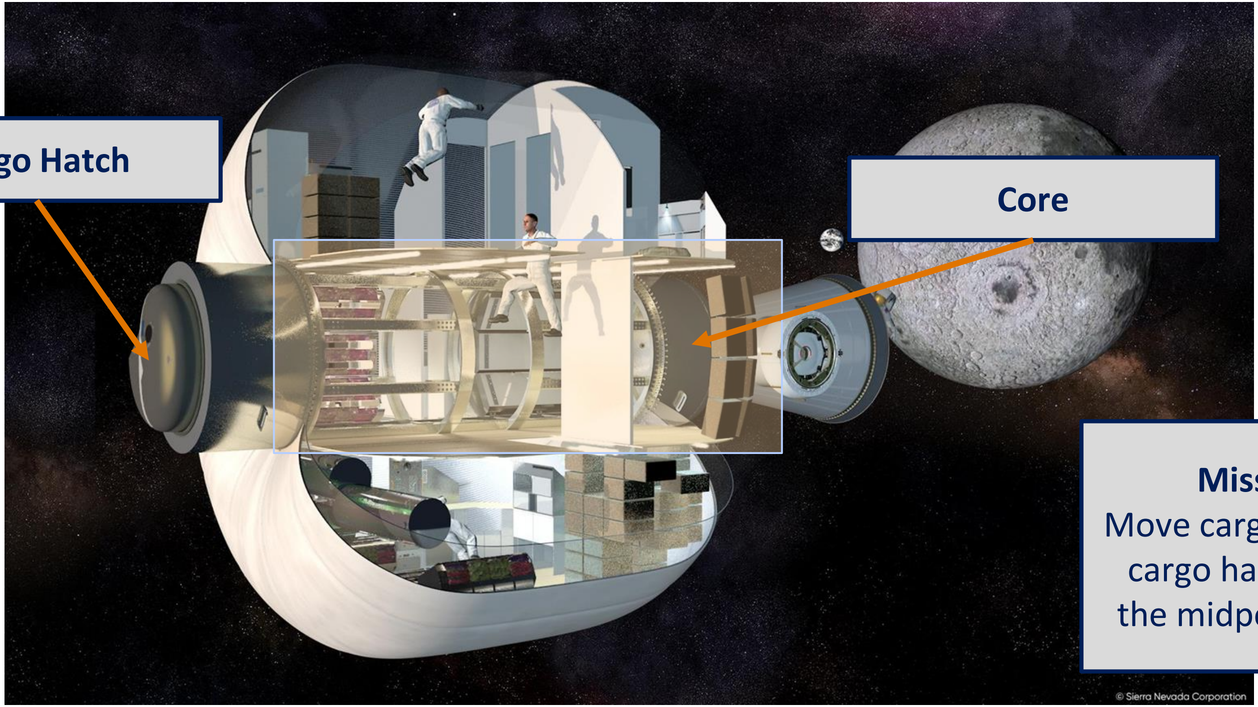
Mission Goal

Demonstrate the feasibility of using robotics to manage and store cargo throughout the LIFE module.



LIFE™ Habitat

LIFE™ Habitat Mission



Cargo Hatch

Core

Mission Goal:
Move cargo bags from the cargo hatch opening to the midpoint of the core

Mission Statement

RIVeR will demonstrate the feasibility of utilizing Intra-vehicular Robotics (IVR) to identify, sort, and distribute cargo bags within Sierra Nevada's LIFE™ Habitat. RIVeR will adapt a robotic arm translation system to pick up and move bags to a designated location.

ConOps

Stage 1: Capture

Phase D: Rotate with Bag

Arm lifts bag and rotates to pose required for translation

Stage 2: Translation

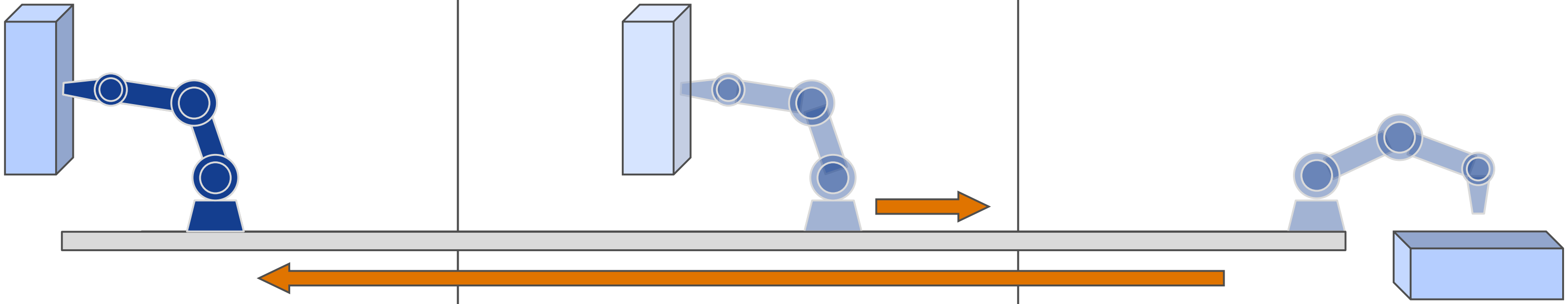
Phase B: Stop

Translation stops at the end of the track

Stage 3: Drop Off

Phase C: Reset

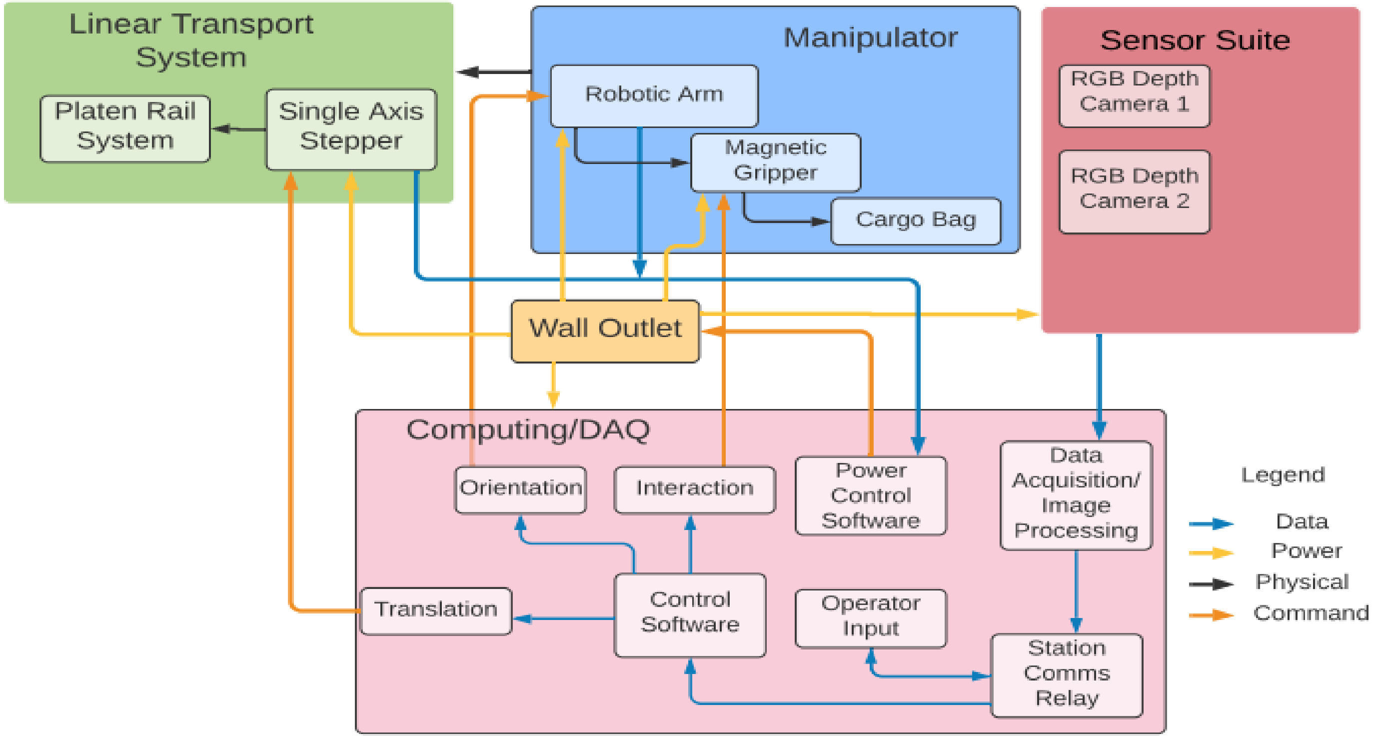
The arm returns to the start of the track to restart process



Location 1: Cargo hatch opening

Location 2: Drop Off Location

FBD



Linear Transport System
Platen Rail System
Single Axis Stepper
Manipulator
Robotic Arm
Magnetic Gripper
Cargo Bag
Sensor Suite
RGB Depth Camera 1
RGB Depth Camera 2
Wall Outlet
Computing/DAQ
Orientation
Interaction
Power Control Software
Data Acquisition/ Image Processing
Translation
Control Software
Operator Input
Station Comms Relay
Legend
Data
Power
Physical
Command

Section 2

Baseline Design

Presenters: Kyle Li, James Tiver, Marin Grgas,
Brandon Torczynski, Lindsay Cobb

Critical Project Elements

1. Sensor Suite

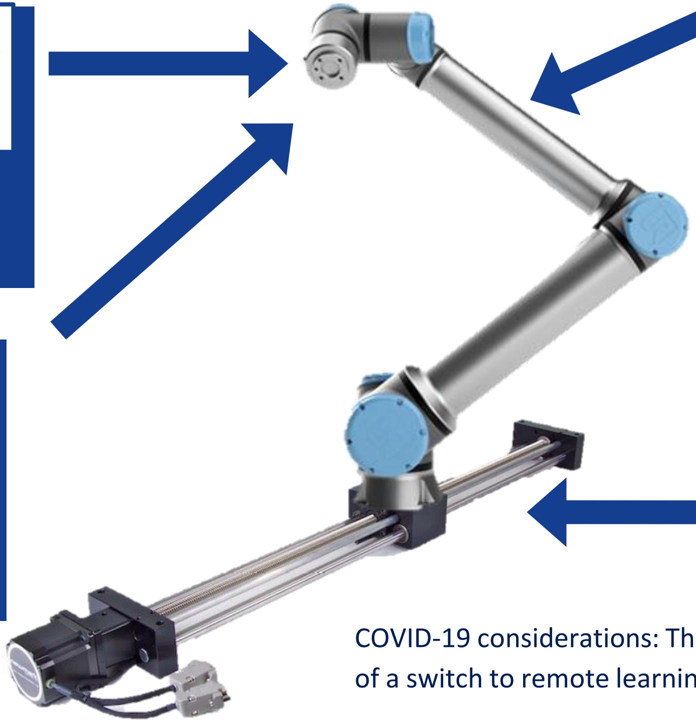
Pixy2 Camera

Purchased from Pixy

2. End Effector

SMC MHM-32
Magnetic Gripper

Purchased from SMC



3. Robotic Arm

UR10e

Acquired by SNC

4. Translator

Threaded Rail
and Motor

Designed/Manufactured by RIVeR

COVID-19 considerations: The project can be built and tested in parts in case of a switch to remote learning or limited team access to work spaces.

1. The Sensor Suite

RIVeR

1. Sensor Suite

Pixy2 Camera

Purchased from Pixy

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SMC MHM-32
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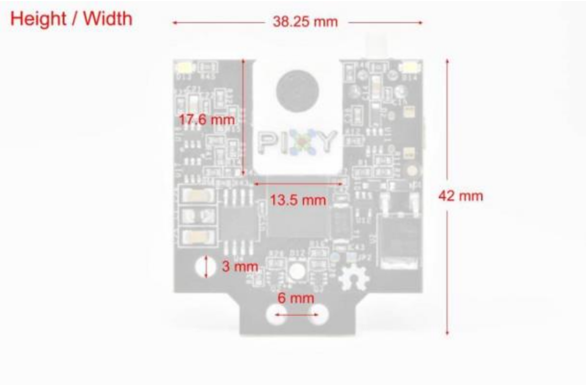
and Motor

Designed/Manufactured by RIVeR

Sensor Suite

- Determine the position and orientation of the cargo and key core locations
- Baseline sensor selection: Pixy2 (at least 2+ for triangulation)
    - RGB camera with a prepackaged processor and image recognition algorithms
- Camera can learn to recognize any object
- Returns 2D location of learned object as well as object bounds



2. The End Effector

1. Sensor Suite

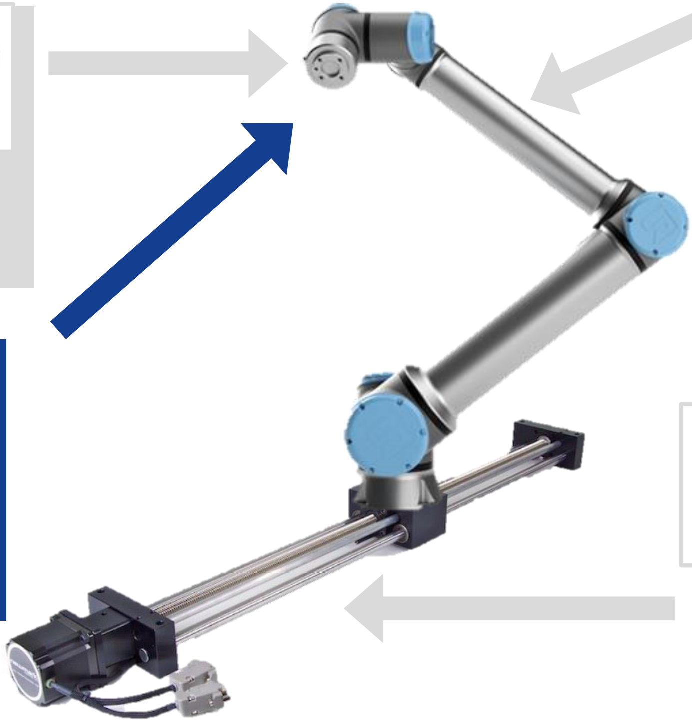
Pixy2 Camera

Purchased from Pixy

2. End Effector

SMC MHM-32
Magnetic Gripper

Purchased from SMC



3. Robotic Arm

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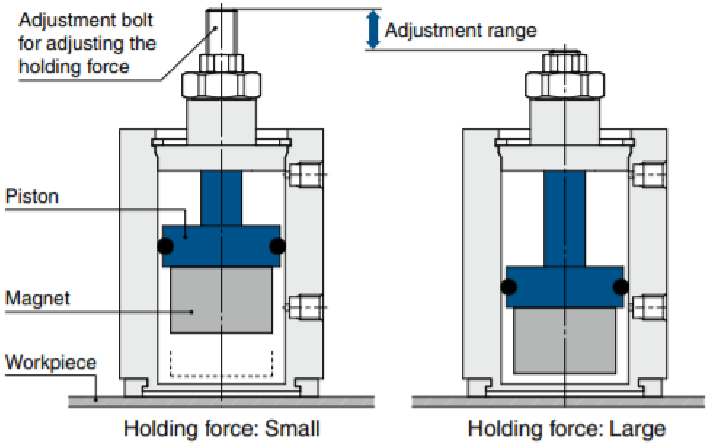
Threaded Rail
and Motor

Designed/Manufactured by
RIVeR

End Effector

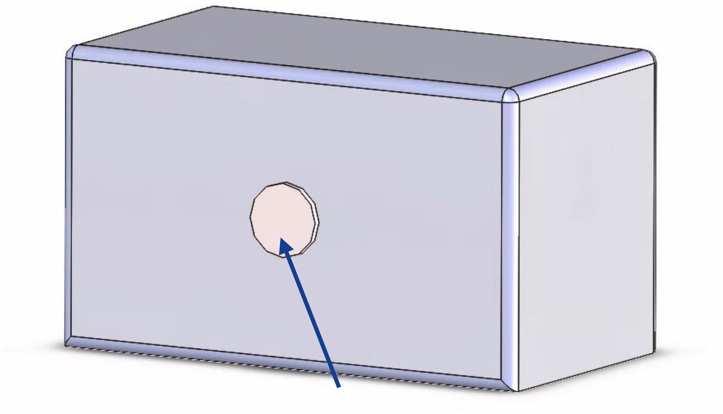
SMC MHM-32 Magnetic Gripper

- Magnet attached to a piston
- Uses compressed air to actuate



Bag Attachment

- Dummy cargo transport bag (CTB) to be used:
  - **Mass**: 5 kg
  - **Dimensions**: 41 cm x 23 cm x 24 cm
- Softshell case with steel plate attachment
  - **Dimensions:** 59 mm diameter x 6mm W
  - 5 mm margin



Steel Plate

NASA's CTB	Internal Dimensions [cm]	Mass of Bag [kg]	Max Cargo Mass [kg]
Full Size	41.27 x 24.13 x 49.66	1.68 kg	25.54 kg
Half Size	41.27 x 22.86 x 24.13	0.84 kg	12.63 kg

3. The Robotic Arm

1. Sensor Suite

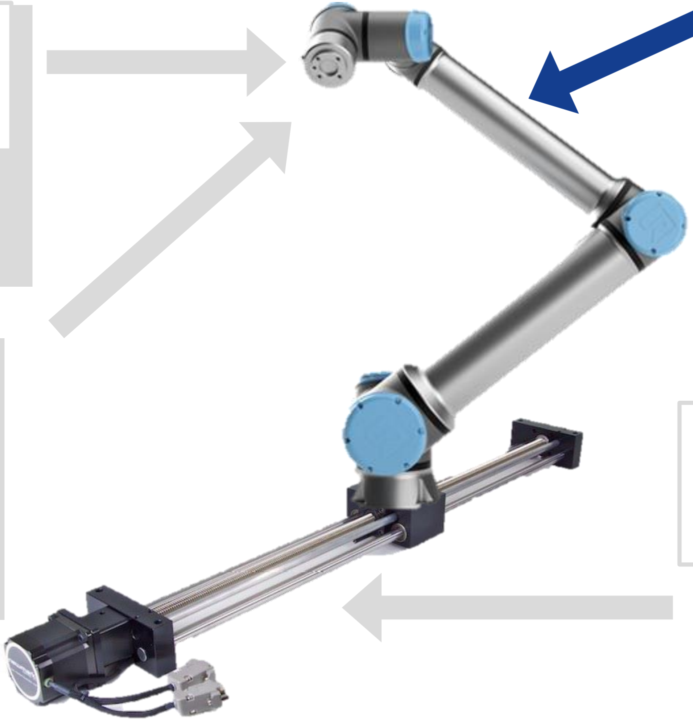
Pixy2 Camera

Purchased from Pixy

2. End Effector

SMC MHM-32
Magnetic Gripper

Purchased from SMC



3. Robotic Arm

UR10e

Acquired by SNC

4. Translator

Threaded Rail
and Motor

Designed/Manufactured by RIVeR

Robotic Arm

- UR10e
  - Maker: Universal Robots
- High payload (10 kg) lift and long reach (1.30m)
- Six degrees of freedom and ± .05 mm pose repeatability
- SNC is in process of acquiring
  - Not guaranteed yet
  - Back up options included in appendix

4. The Translator

1. Sensor Suite

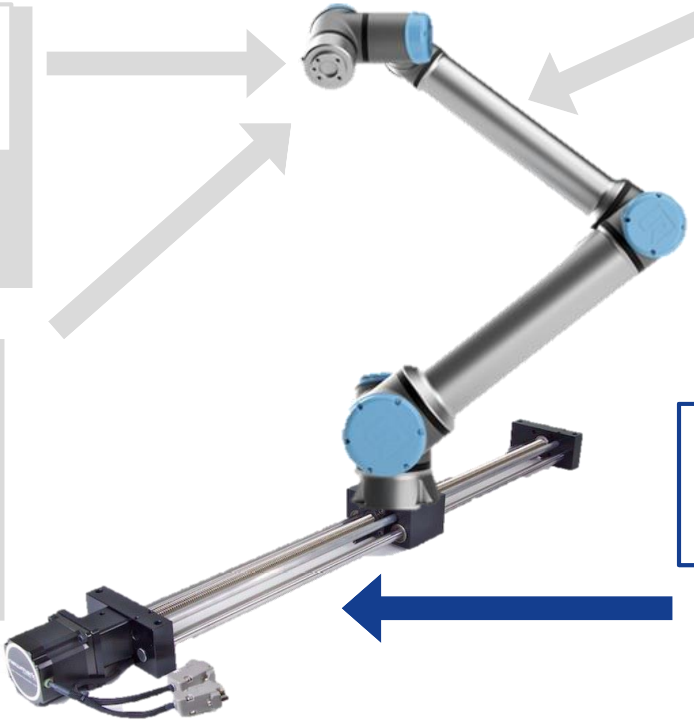
Pixy2 Camera

Purchased from Pixy

2. End Effector

SMC MHM-32
Magnetic Gripper

Purchased from SMC



3. Robotic Arm

UR10e

Acquired by SNC

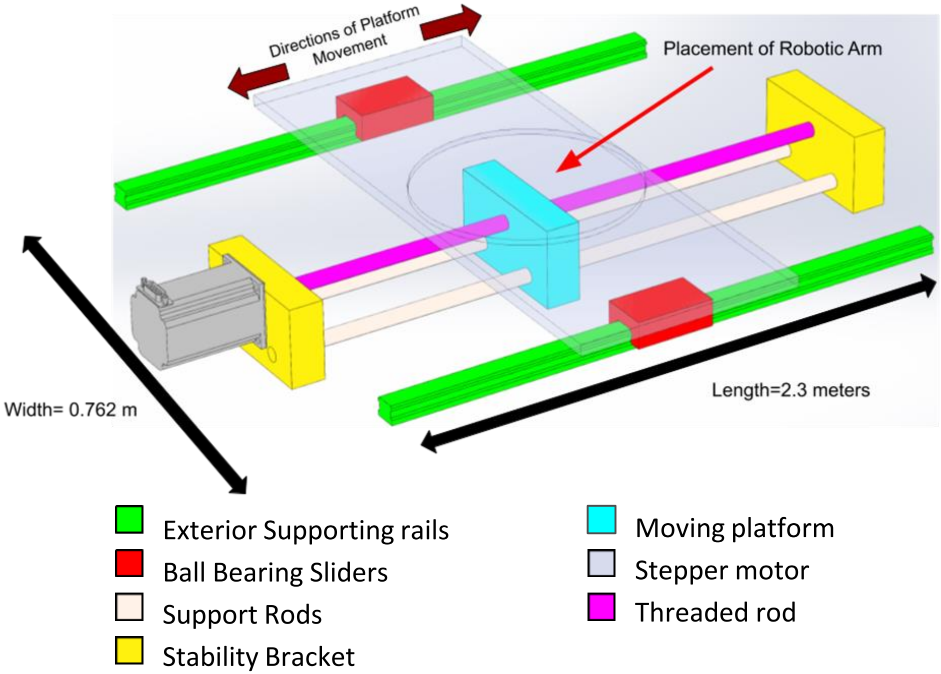
4. Translator

Threaded Rail
and Motor

Designed/Manufactured by RIVeR

Translator

- Purpose: access between cargo hatch and core midpoint
- Stepper motor is attached to a threaded rod
  - Moves the Blue platform back and forth
- Green rails add support/stability



Parts Purchased vs Manufactured

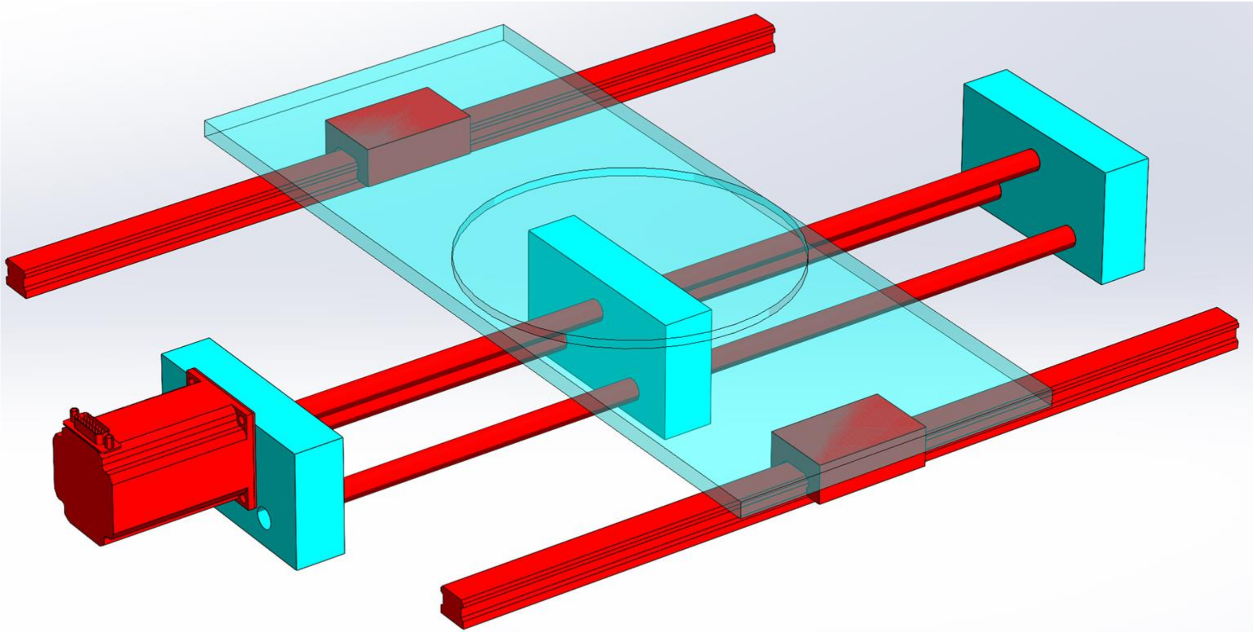
Key:

Red: Purchased

Blue: Manufactured

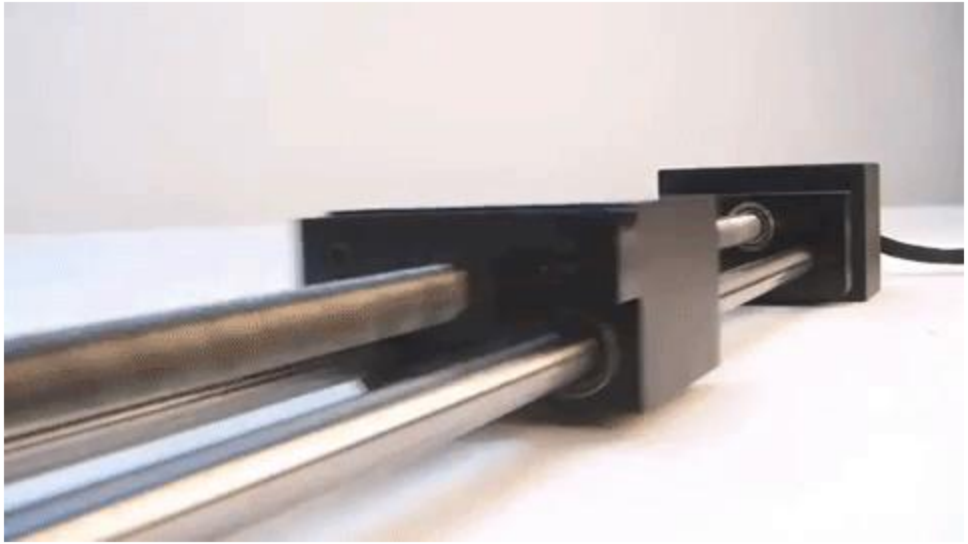
Challenges of assembly:

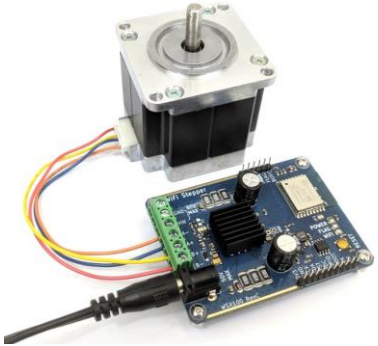
- In house manufacturing
- Alignment of parts
- Wire management
- Stability control
- Accuracy control



Translator Operation

- Stepper motor will be calibrated and controlled via arduino
- The Motor has a built in encoder so we can actively track where the arm is on the track



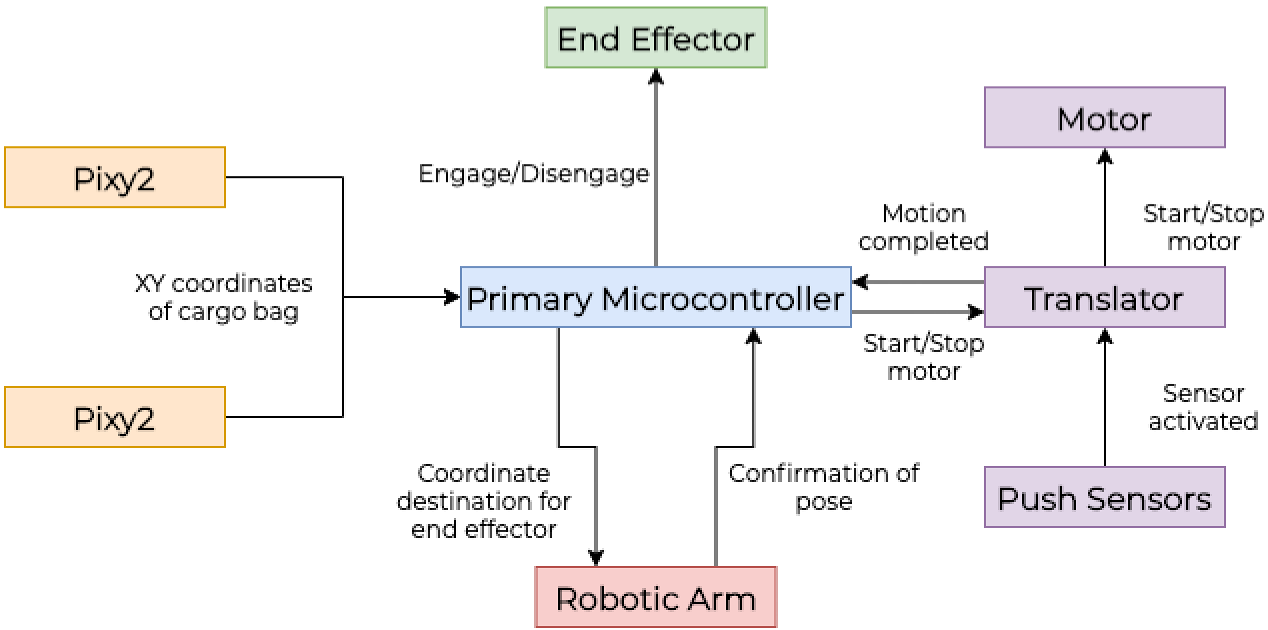


Translator Operation

- Push Sensors (located at track ends)
  - Prevent unwanted motion
  - Calibrate system

- Wire Management
  - Cable Track will hold power cables/pressure hose for the robotic arm and end effector
  - Prevents tangling and increases durability

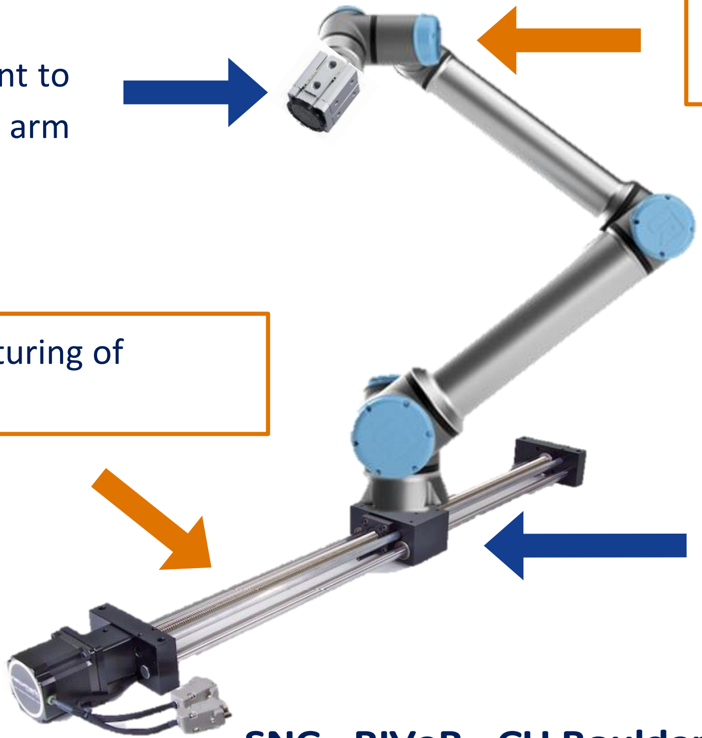
Software FBD



Integration Summary

Software development to transfer bag identification to robotic arm

End effector attachment to robotic arm



Design and manufacturing of translator

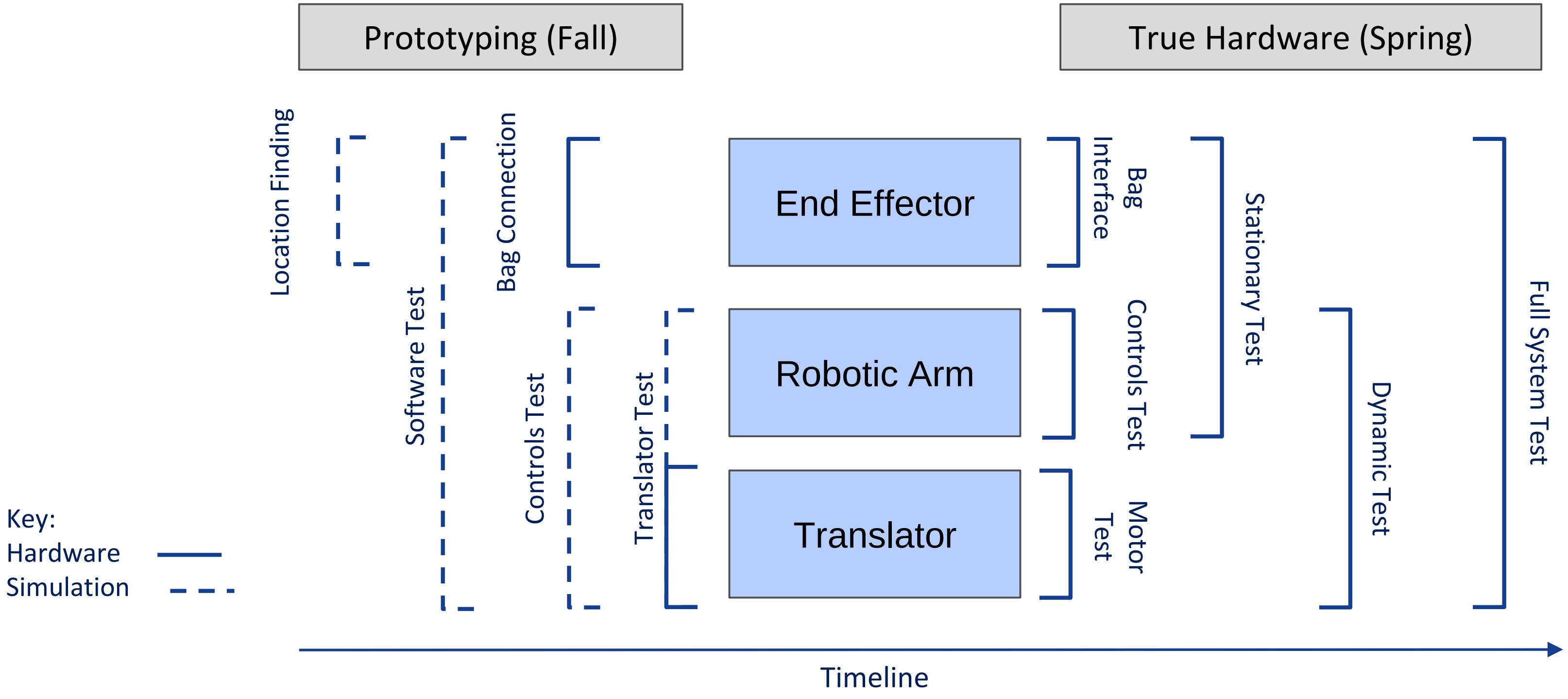
Robotic arm attachment to translator

Key design focus

Testing Plan

- Sensor Testing
  - Identify a cargo bag and relay the necessary information through the system.
- Stationary Test
  - Robotic Arm and end effector testing using developed controls and sensors to pick up and release a bag.
- Dynamic Test
  - Integrate the robotic arm and translator to test the power and communication to both systems.
- Full System Test
  - Entire system integrated and functioning together

Testing Roadmap



Section 3

Feasibility Analysis

Presenters: Jordan Abell, Nick Miller, Logan Vangyia, Brandon Torczynski, Marin Grgas

Robotic Arm Performance

The UR10e supports a max load of 10 kg

Expected operating load with margin is 80 N (~8 kg)

Material composition: Plastic (end caps), Aluminum (arm), Steel (joints, base plate)

Supports six degrees of freedom across the arm

Pose repeatability: ± .05 mm

Physical

Footprint	Ø 190 mm
Materials	Aluminium, Plastic, Steel
Tool (end-effector) connector type	M8 | M8 8-pin
Cable length robot arm	6 m (236 in)
Weight including cable	33.5 kg (73.9 lbs)

Axis movement	Working range	Maximum speed
Base	± 360°	± 120°/s
Shoulder	± 360°	± 120°/s
Elbow	± 360°	± 180°/s
Wrist 1	± 360°	± 180°/s
Wrist 2	± 360°	± 180°/s
Wrist 3	± 360°	± 180°/s

Joint Force Analysis

Joint torque analysis with fully extended arm and 80 N load

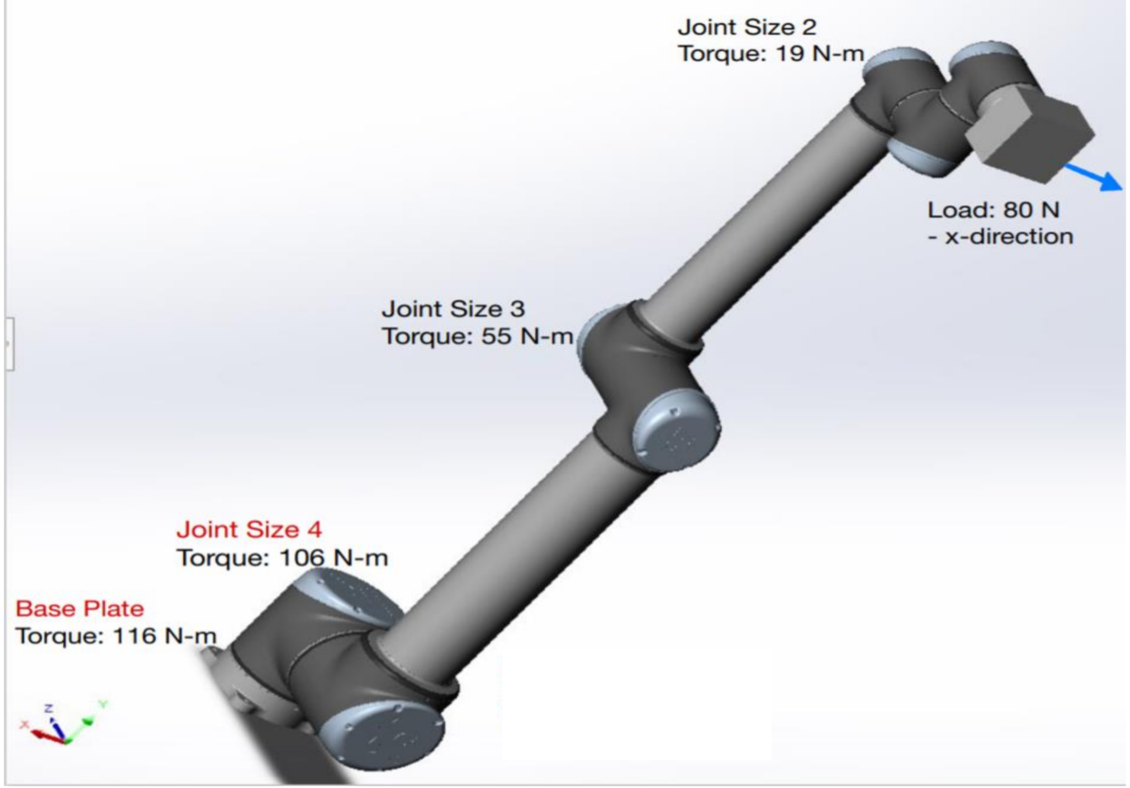
Yield strength: 41.7 MPa

Max stress across all components: 6.3 MPa

Manufacturer defined max torque per joint size

Size 2	56 Nm
Size 3	150 Nm
Size 4	330 Nm

FR.1	FR.2	FR.4	✓



Robotic Arm Software (UR-10e)

- UR10 configuration package within ROS MoveIt for simulation
- Universal Robots software suite
  - Two levels of control: Polyscope(GUI) or script (URScript language)
  - Built-in variables and functions that monitor and control I/O, robot trajectories, and joint position
  - Commands sent to on-board low-level controller (URControl) through TCP/IP socket
- Documentation on:
  - Environment clearance shapes
  - Pick training
  - Place training

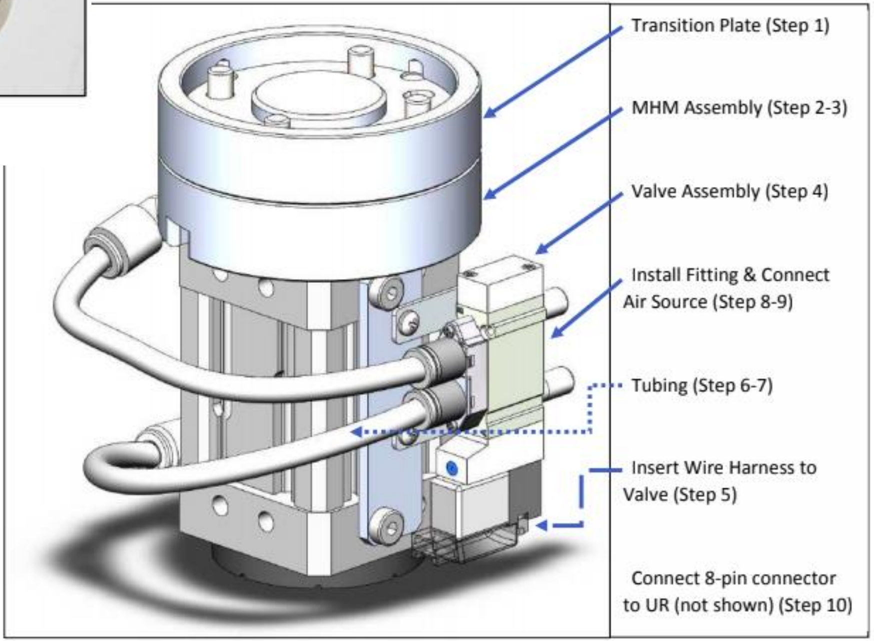
End Effector

UR-10e Interface

- Transition Plate
- Pressurized air
- Power connection
  - Solid State Sensors
    - M12 Connector
  - Directional Control Valve
    - D-Sub Connector

Figure 1:
(1) Transition Plate
(4) M6x10L SHCS

Overview



FR.5	The end-effector shall be interchangeable for modified use in future tasks.	✓

End Effector

F_M = Magnetic Force = 500 N
F_R = Reaction Force
F_F = Friction Force
m = mass of the bag = 5 kg
ℓ = max length of the bag = 0.42 m
d_M = Diameter of the magnetic gripper = 0.049 m

Force Analysis

$$\sum F_y = F_f - mg = 0$$

$$\mu F_M = mg$$

$$\mu = \frac{mg}{F_M}$$

$$\boxed{\mu = 0.10} \Rightarrow \text{Reasonable}$$

$$\sum F_x = F_{R,max} - F_M = 0$$

$$F_{R,max} = F_M$$

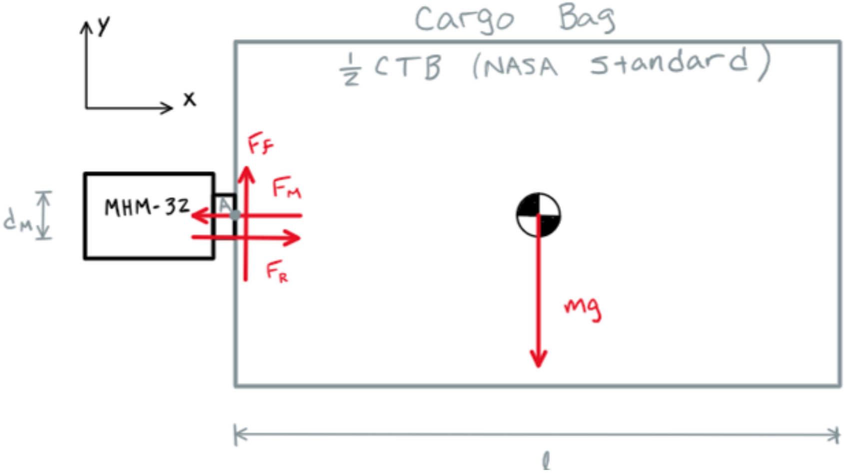
$$\sum M_A = F_R \cdot \tfrac{1}{2} d_M - mg \cdot \tfrac{1}{2}\ell = 0 = 0$$

$$\tfrac{1}{2} d_M F_R = \tfrac{1}{2} mg\,\ell$$

$$F_R = \frac{mg\ell}{d_M}$$

$$F_R = 420.0 \text{ N}$$

$$\boxed{\begin{array}{c} F_R < F_{R,max} \\ 420.0 \text{ N} < 500 \text{ N} \\ \Rightarrow \text{FBD is Feasible} \end{array}}$$



FR.1	All systems shall be operational in a 1G testing environment.	✓
FR.2	The system shall be capable of translating a 5kg cargo bag the length of the track.	✓
FR.6	The end-effector shall be able to control cargo during translation and rotation.	✓

End Effector

Magnetic Force Model

$$F = \frac{k}{r^2}$$

We know:

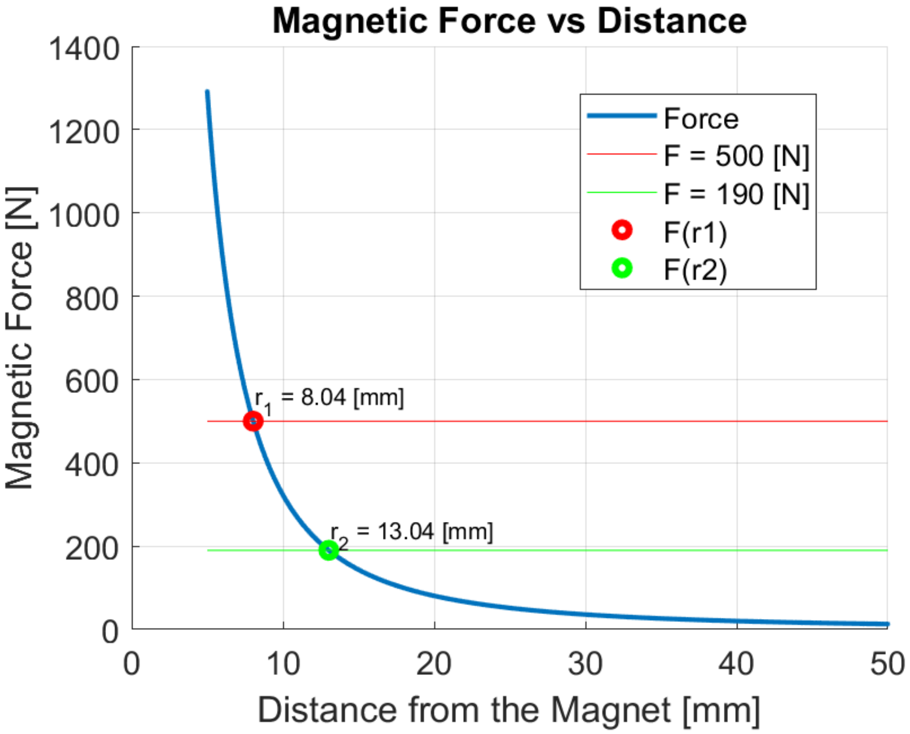
- $F_1 = 500$ N
- $F_2 = 190$ N
- $\Delta r = 5$ mm

$$\frac{F_1}{F_2} = \frac{r_2^2}{r_1^2} = \frac{(r_1 + \Delta r)^2}{r_1^2}$$

$$k = 32287.183[Nmm^2]$$

$$F(75[mm]) = 5.740[N]$$

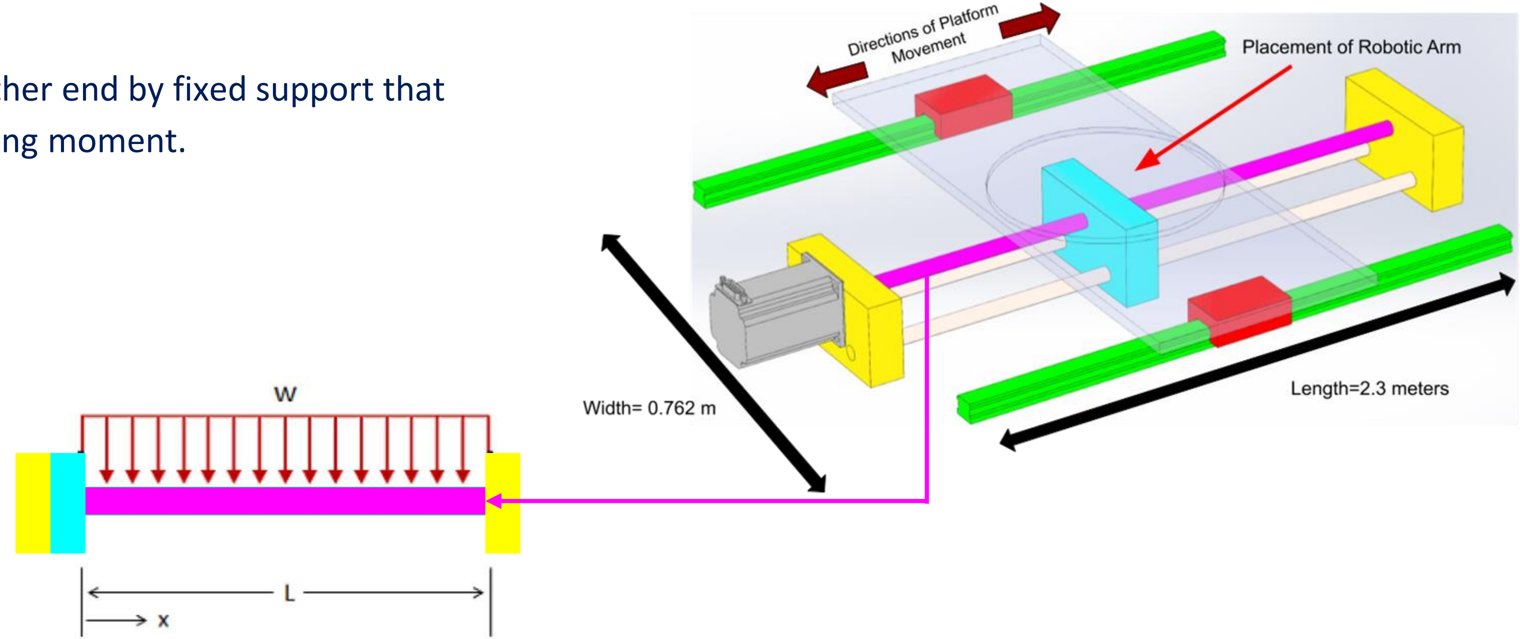
- SMC advertises a residual holding force of “0.3 [N] or less”



Translator-Deflection Analysis

- 2.272 m, Steel, Grade B7, 1-⅛”-7 Threaded Rod.
- Assuming uniform distributed load for rod weight.
- Secured on either end by fixed support that restricts bending moment.

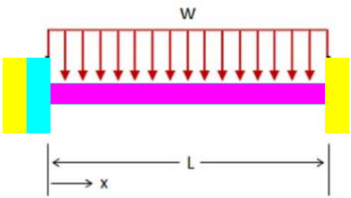
$L = 2.272$ m
$w = 115.8$N
$E = 210$ GPa
$I = .65\ \mu kgm^2$

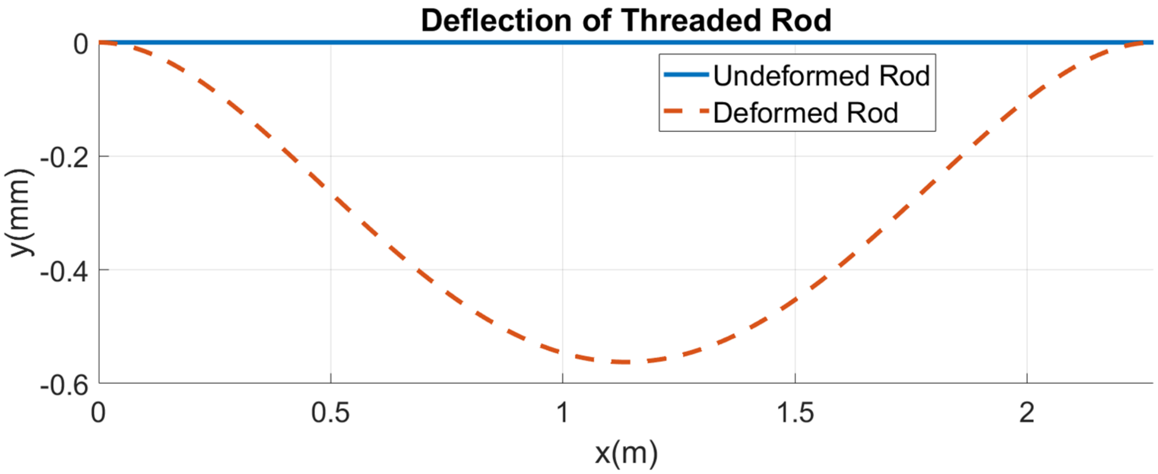


Translator-Deflection Analysis

- Maximum deflection of -.562 mm negligible.
- Deflection minimizes as arm reaches center.
- Fixed support on either end is feasible.

L = 2.272 m
w = 115.8N
E= 210 GPa
I = .65 μkgm²





$$\delta = -\frac{wx^2}{24EI}(L-x)^2$$

FR.1	All systems shall be operational in a 1G testing environment.	✓
FR.8	The linear translator shall be able to maintain structural integrity under the torques and forces applied to it when moving cargo.	✓

Translator - Motor Velocity Analysis

- **Platform Velocity:**
  - Assume constant angular velocity and full step size for the motor
  - Assume the motor and rod are synchronous and have the same rotation

$$v_{max} = \frac{1}{n * t_{rot}} = \frac{1}{n} * \frac{v_s * s}{360^\circ} = 0.131\ \frac{m}{s}$$

  - Where:
    - n = 7 threads/in = 275.6 threads/m
    - v_s = 7200 steps/s
    - s = full step size = 1.8°

- **Time to Traverse Entire Translator:**
  - L = v*t
    - L = 2.272m

Time (s)	Velocity (m/s)
17.3	0.131
34.8	0.065
87.0	0.026

FR.7	The translation system shall be able to navigate from one end of the track to the other.	✓

Translator - Motor Force Analysis

- **Force on Motor:**
  - Constraint: maximum radial load = F_{max} = 66.72 N

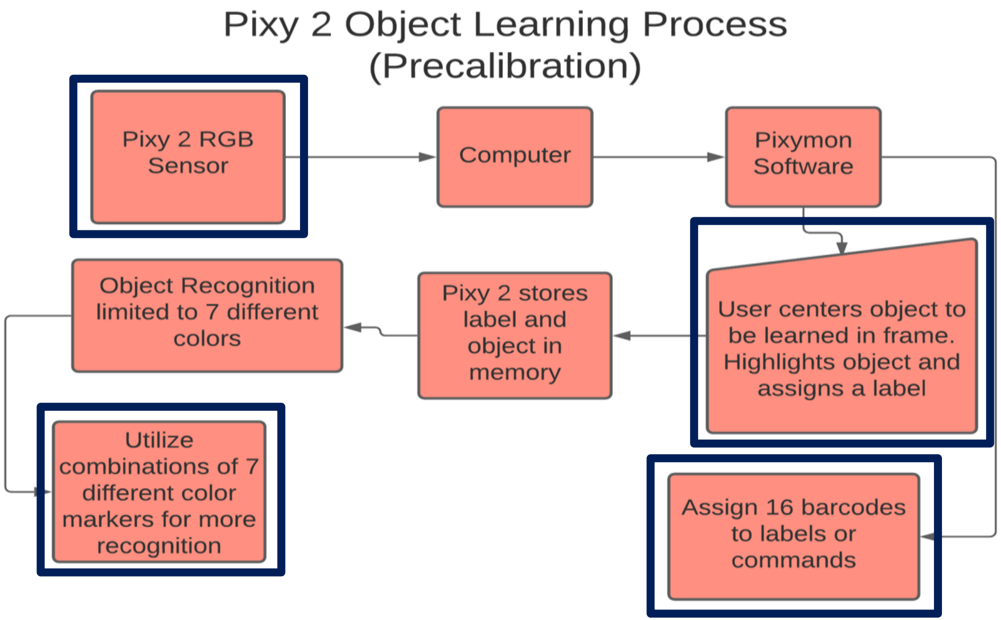
$$F_{move} = F_s + F_{screw} = \mu * N + \frac{N}{2\pi(\frac{R}{p})S_e} = 51.81\ N$$

- Where:
  - **N** = arm-bag load = 147.15N , $\mathbf{S_e}$ = screw efficiency = 20% (assumption)
  - **R** = radius of screw = 14.29 mm, $\boldsymbol{\mu_s}$ = static friction coefficient = 0.15
  - **p** = screw pitch = 3.628 mm
- $F_{move} < F_{max}$ ⟶ FR.8 satisfied ⟶ **Motor is Feasible**

FR.1	All systems shall be operational in a 1G testing environment.	✓
FR.8	The linear translator shall be able to maintain structural integrity under the torques and forces applied to it when moving cargo.	✓

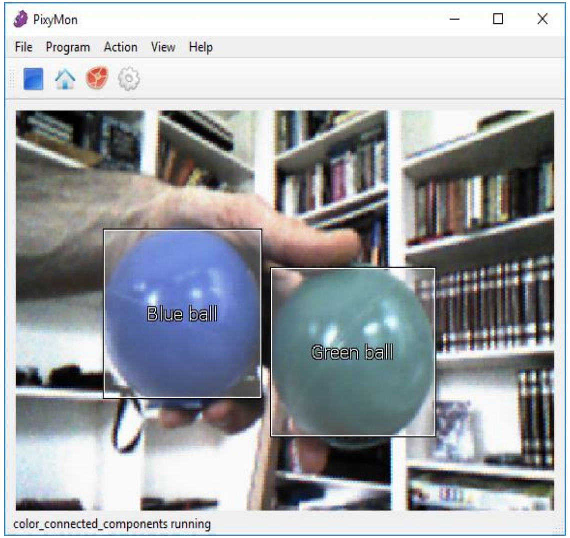
Sensor Suite: Object Recognition

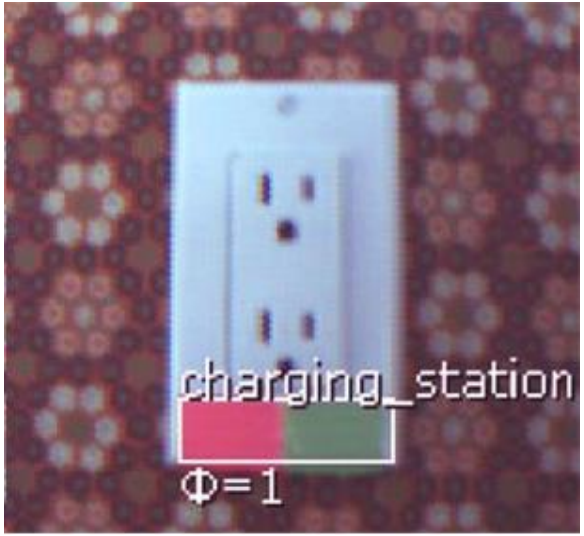
- Sensor can be calibrated to learn objects and barcodes
- Objects can be given a label
- Once the label is learned, the sensor will forever recognize it in varying orientations.

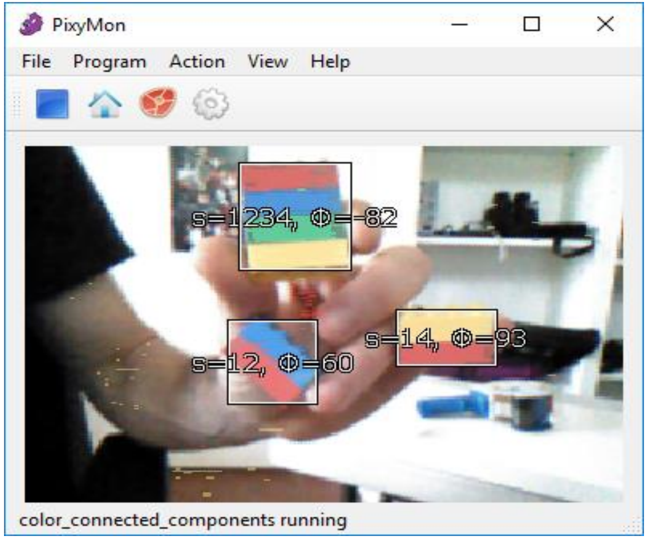


Sensor Suite: Object Recognition

- Pixy 2 can detect multiple objects
- Outputs: orientation, bounds, distance
- Restricted by FOV of 60° horizontal, 40° vertical, and resolution of 1296x796







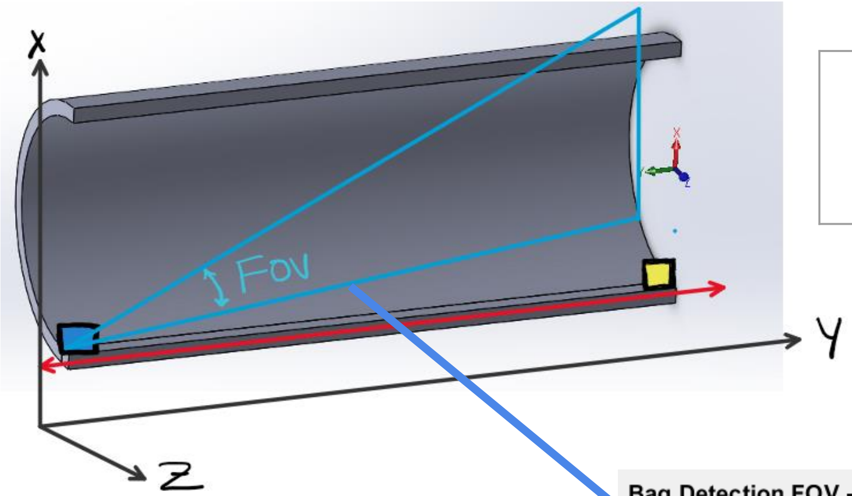
FOV Feasibility

Pixy 2 Lense FOV

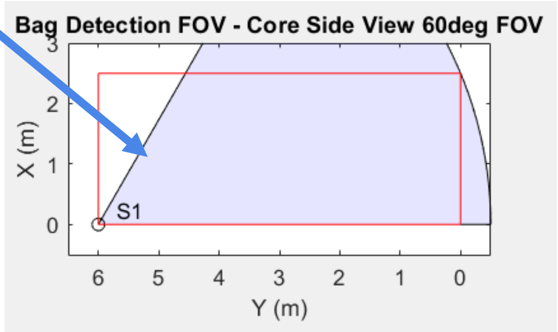
- 60 degrees horizontal
  - Top View (Y-Z)
- 40 degrees vertical
  - Side View(X-Y)

Simplifying Assumptions:

- Cylinder
  - L = 6 meters
  - D = 2.5 meter
- Sensors at each end



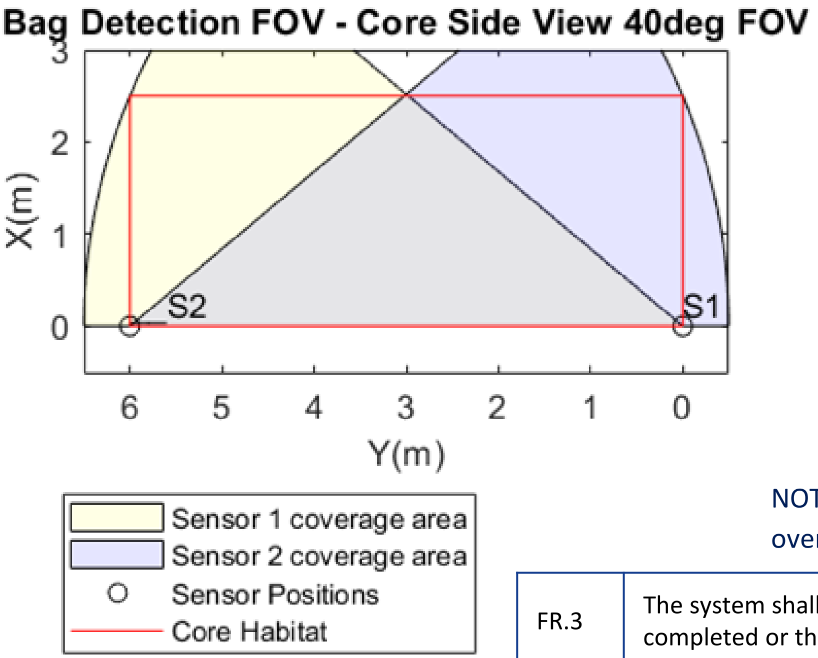
Sensor 1
Sensor 2
Rail



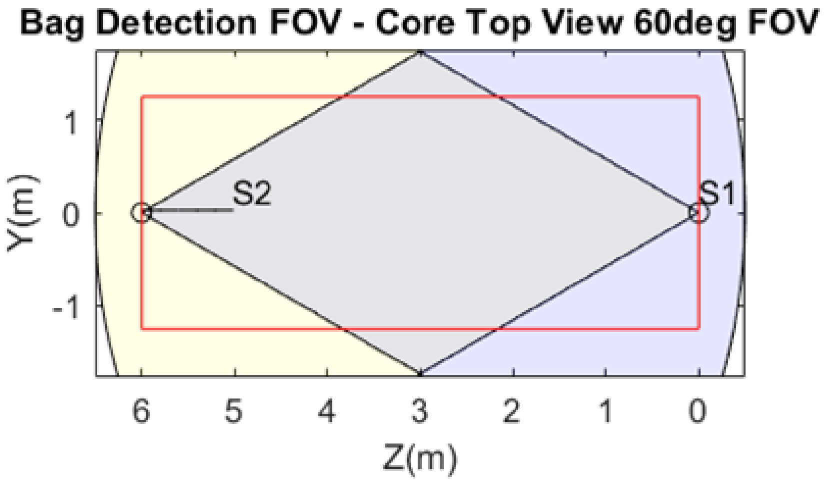
FR.1	All systems shall be operational in a 1G testing environment.	✓
FR.4	The system shall operate within the volume of the core.	✓

Top and Side Views Feasibility

Top view (Y-Z plane)



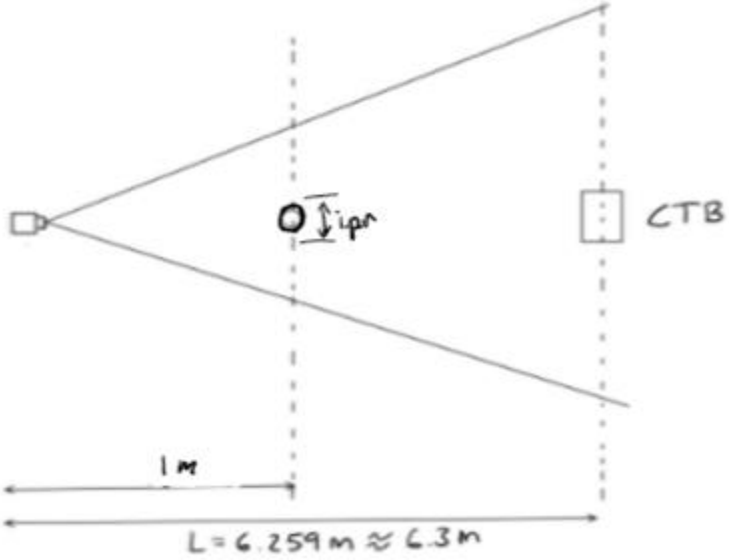
Side view (X-Y plane)



NOTE: Grey represents overlapping coverage area

FR.3	The system shall provide a method for verifying that a given cargo transportation task has been completed or the given task has failed beyond recovery.	✓

Resolution Feasibility



Core is 5.6m long cylinder with 2.5m diameter

Place camera as far as possible from hatch (6.3m)

Needs 4x1 pixel size of learned object

- 0.0133 image projection ratio

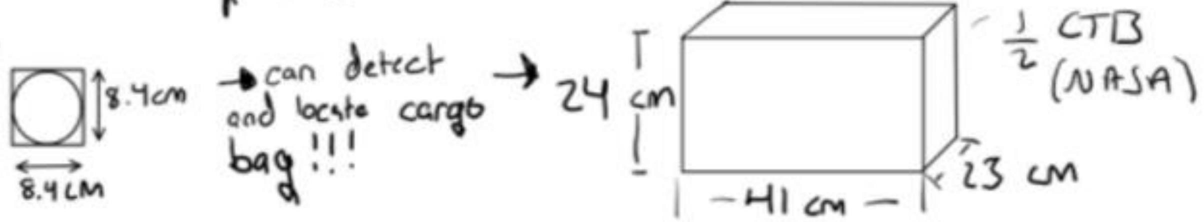
Minimum bag dimension for detection:

- 8.4 cm x 8.4 cm

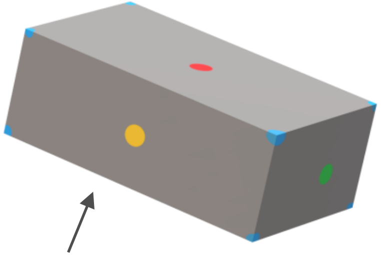
CTB Exceeds this dimension on all sides

image projection ratio (ipr) = 0.013$\overline{3}$ For L=6.3m

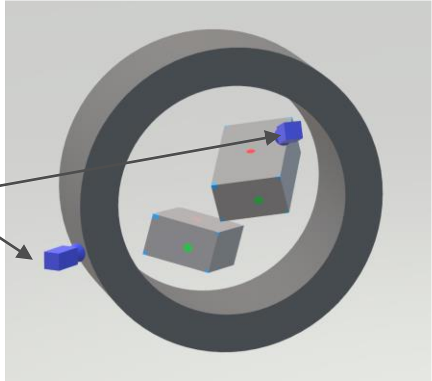
(6.3)(.0133) = 8.4 cm →



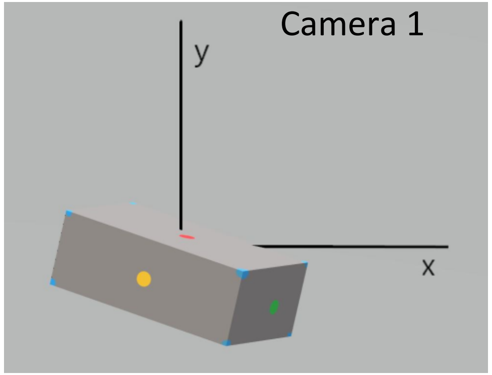
Determining Bag Position

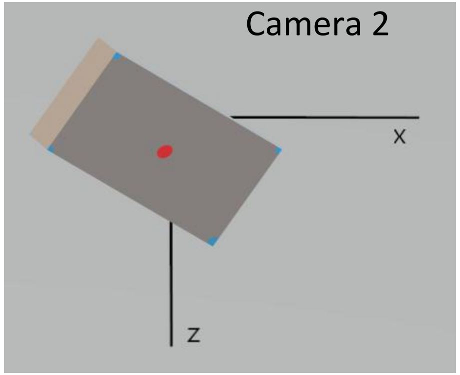


Create facet markers on bag



Use multiple non parallel view angles

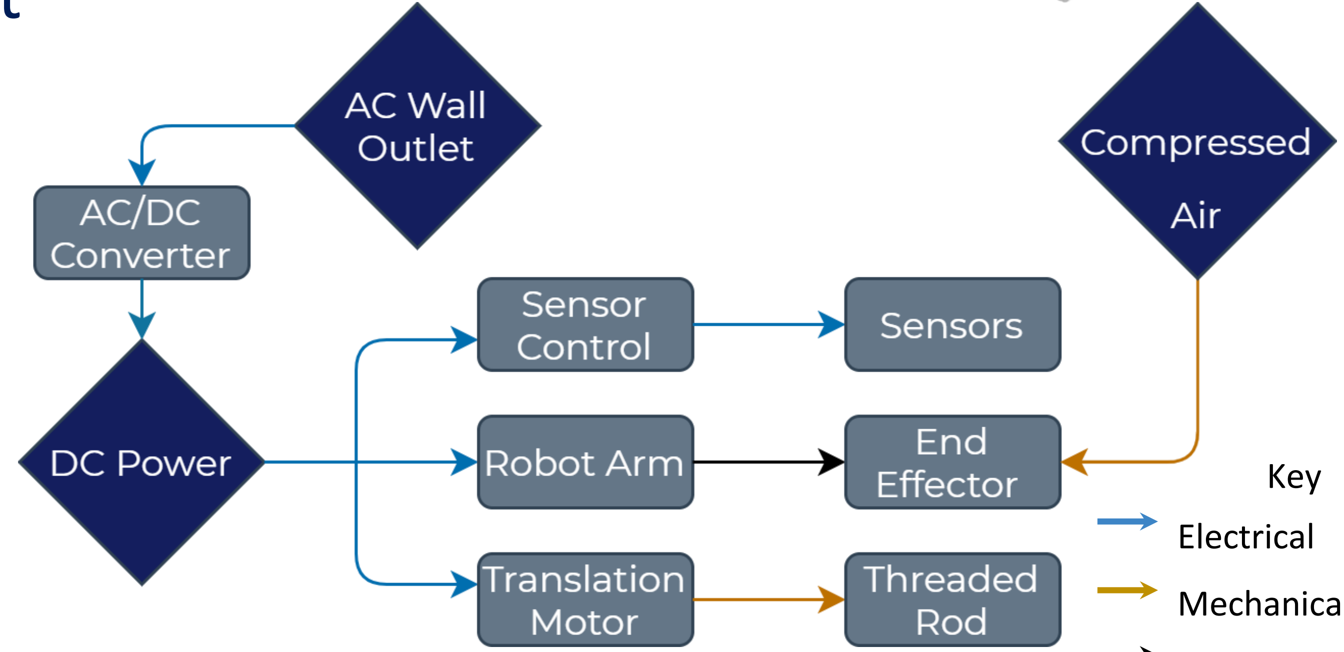


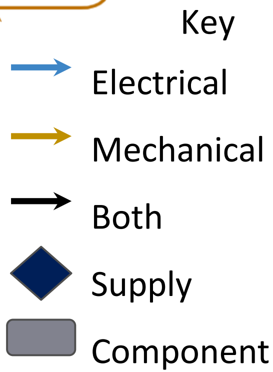


Using multiple planar views, determine x, y, and z position

Power Budget

- Robotic Arm
  - 350W, 24V
- End Effector
  - 1.66W, 24V
- Sensor Suite
  - 5W, 5V
- Translation
  - 168W, 40V
- Total Power
  - 524.66W





No official power constraint. Typical wall outlet can output 1800 watts.

Feasible ✓

Section 4

Summary

Presenters: Kyle Li

Preliminary Design

Objective: Demonstrate the feasibility of using robotics to manage and store cargo throughout the LIFE module.

1. Sensor Suite

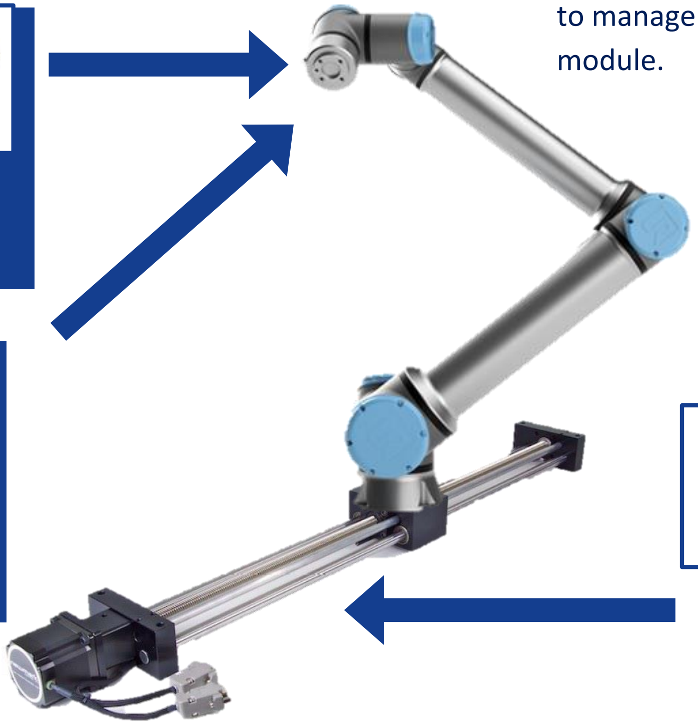
Pixy2 Camera

Bag identification and location finding

2. End Effector

SMC MHM-32
Magnetic Gripper

Bag interface and control



3. Robotic Arm

UR10e

Reach and rotation capabilities

4. Translator

Threaded Rail
and Motor

Allow access to full operation area

Conclusion

#	Requirement	Slide Ref.	Feasibility
FR.1	All systems shall be operational in a 1G testing environment.	29, 33, 36, 40	✓
FR.2	The system shall be capable of translating a 5kg cargo bag the length of the track.	29, 33	✓
FR.3	The system shall provide a method for verifying that a given cargo transportation task has been completed or the given task has failed beyond recovery.	38, 40	✓
FR.4	The system shall operate within the volume of the core.	19, 29, 40	✓
FR.5	The end-effector shall be interchangeable for modified use in future tasks.	32	✓
FR.6	The end-effector shall be able to control cargo during translation and rotation.	33	✓
FR.7	The translation system shall be able to navigate from one end of the track to the other.	21, 22	✓
FR.8	The linear translator shall be able to maintain structural integrity under the torques and forces applied to it when moving cargo.	36	✓

Acknowledgements

Loren McDaniel and Sierra Nevada Corporation

Dr. Neogi

Matt Rhode

Bobby Hodgkinson

Dr. Jackson

Josh Mellin

Any Questions?

Backup

Backup Arms

SNC IRAD Test Arm

SNC's in-house arm with proprietary SNC software

Franka Emika Panda

On-campus arm used by the HIRO Lab

MEGACLAW

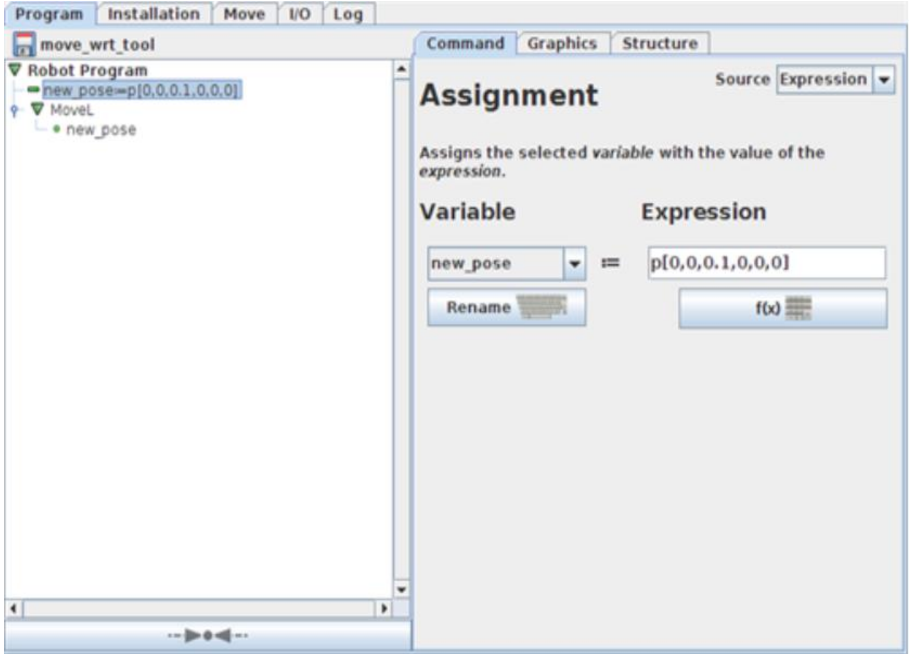
Previous senior project arm based on crustcrawler model.

WidowX 200

Purchasable robotic arm for small-scale demonstration

Robotic Arm Software (UR-10)

Polyscope Interface



URScript Function

stopj(*a*)

Stop (linear in joint space)

Decelerate joint speeds to zero

Parameters

`a`: joint acceleration (rad/s^2) (of leading axis)

Example command: `stopj(2)`

- Example Parameters:
  - a = 2 rad/s^2 → rate of deceleration of the leading axis.

Functional Requirements

Category	ID	Requirement
System Wide	FR.1	All systems shall be operational in a 1G testing environment.
	FR.2	The system shall be capable of translating a 5kg cargo bag the length of the track.
	FR.3	The system shall provide a method for verifying that a given cargo transportation task has been completed or the given task has failed beyond recovery.
	FR.4	The system shall operate within the volume of the core.
End Effector	FR.5	The end-effector shall be interchangeable for modified use in future tasks.
	FR.6	The end-effector shall be able to control cargo during translation and rotation.
Translator	FR.7	The translation system shall be able to navigate from one end of the track to the other.
	FR.8	The linear translator shall be able to maintain structural integrity under the torques and forces applied to it when moving cargo.

End Effector

Parts List for Operation:

- Manual Dump Valve
- Filter/Regulator Combo
- Electronic Dump Valve
- Coupler w/ wall mount bracket
- 0-160 psi gauge
- Single Solenoid Valve
- Solenoid Valve Silencers
- Speed Controller Valve
- ¼” Tubing

End Effector

Magnetic Field Model Calculations

$$\frac{F_1}{F_2} = \frac{\frac{k}{r_1^2}}{\frac{k}{r_2^2}}$$

$$\frac{F_1}{F_2} = \frac{r_2^2}{r_1^2} = \frac{(r_1 + \Delta r)^2}{r_1^2}$$

$$\frac{\Delta r^2}{r_1^2} + \frac{2\Delta r}{r_1} + 1 - \frac{F_1}{F_2} = 0$$

$$r_1 = 8.036[mm]$$

Root-Finding (Bisection) -->

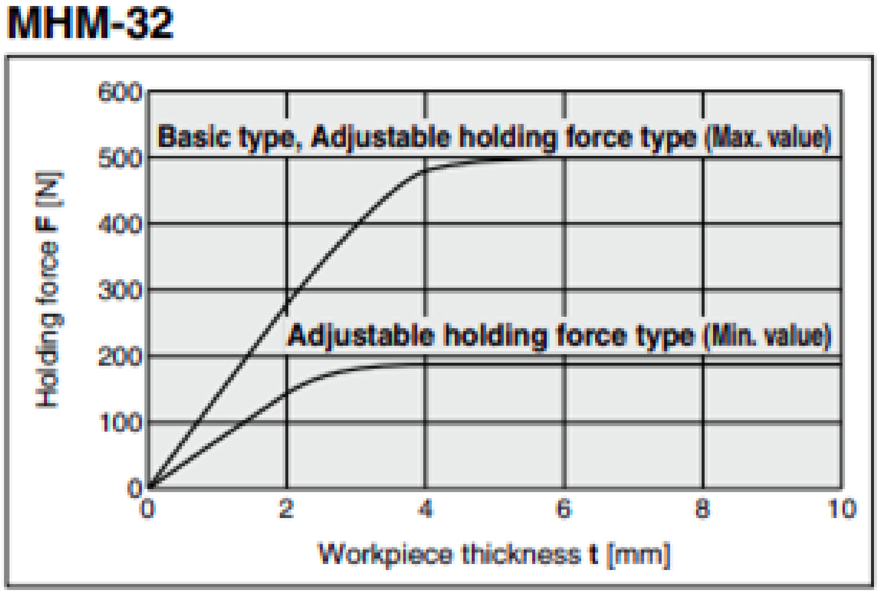
$$r_2 = 13.036[mm]$$

$$F = \frac{k}{r^2}$$

$$k = 32287.183[Nmm^2]$$

End Effector

Magnetic Force vs Workpiece Thickness (from Datasheet)

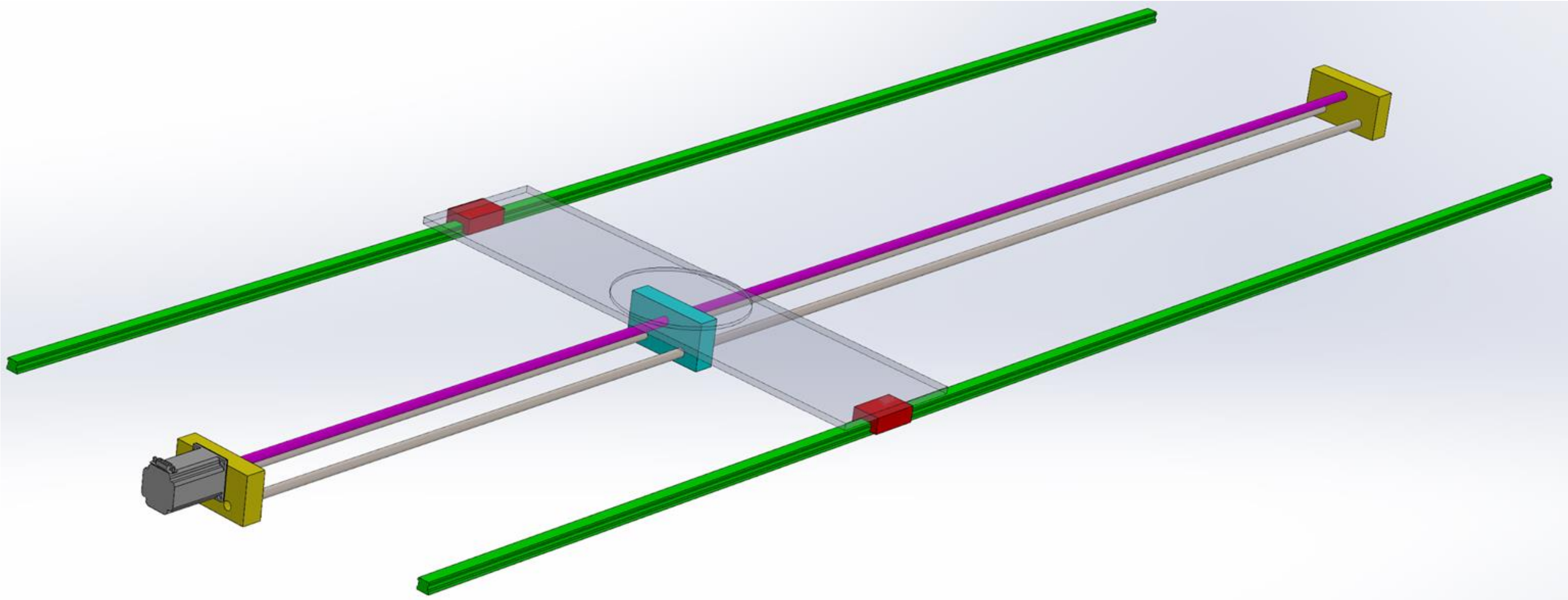


Translator-Deflection Calculations

- Assuming evenly distributed load.
- Only force on threaded rod will be its own weight
- Arm weight is supported by side rails.

$$\rho = 7.8\frac{kg}{m^3}$$
$$Radius = r = .0143m$$
$$I = \frac{1}{2}\pi r^4$$
$$E = 210GPa$$
$$L = 2.3622m$$
$$w = \rho \pi r^2 Lg = 115.8N$$
$$\delta = -\frac{wx^2}{24EI}(L - x)^2$$

Translator Full Size CAD



Sensor Suite: Pixy 2 Specs

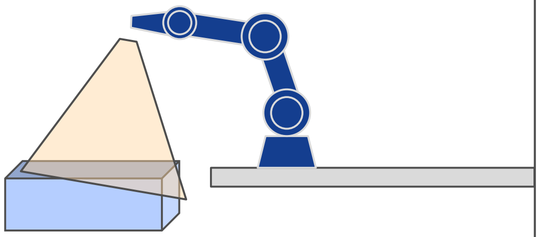
- Processor: NXP LPC4330, 204 MHz, dual core
- Image sensor: Aptina MT9M114, 1296×976 resolution with integrated image flow processor
- Lens field-of-view: 60 degrees horizontal, 40 degrees vertical
- Power consumption: 140 mA typical
- Power input: USB input (5V) or unregulated input (6V to 10V)
- RAM: 264K bytes
- Flash: 2M bytes
- Available data outputs: UART serial, SPI, I2C, USB, digital, analog
- Dimensions:1.5” x 1.65” x 0.6”
- Mass: 10 grams
- Integrated light source, approximately 20 lumens

ConOps

Stage 1: Capture

Phase A: Identify

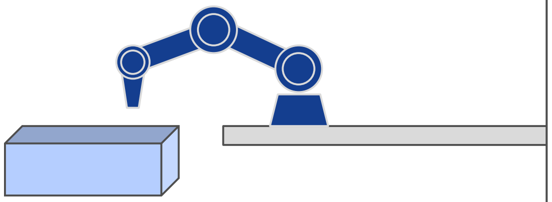
Sensor suite identifies cargo bag and returns location



Stage 1: Capture

Phase B: Orient

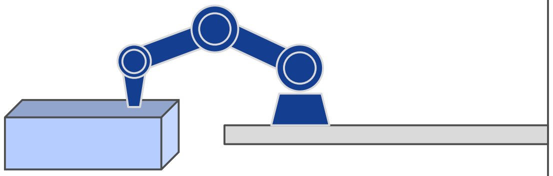
Arm rotates to necessary pose to make contact with bag attachment



Stage 1: Capture

Phase C: Attach to bag

End effector engages to capture bag



ConOps

Stage 1: Capture

Phase D: Rotate with Bag

Arm lifts bag and rotates to pose required for translation

Stage 2: Translation

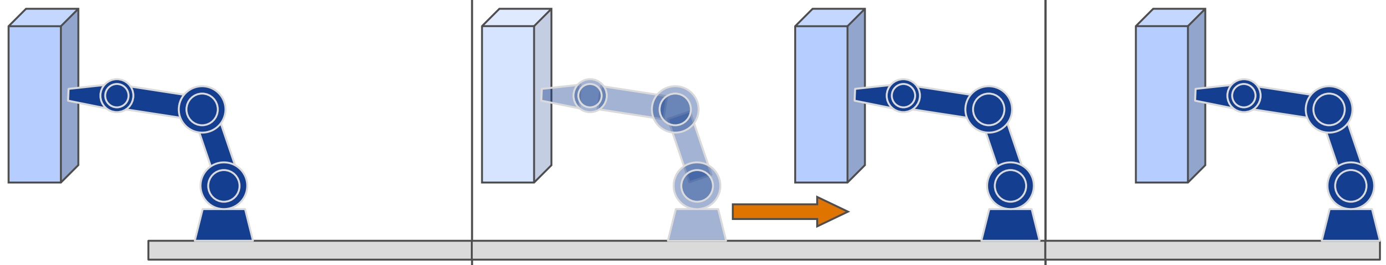
Phase A: Translate

Arm translates to end of track while controlling the bag

Stage 2: Translation

Phase B: Stop

Translation stops at the end of the track

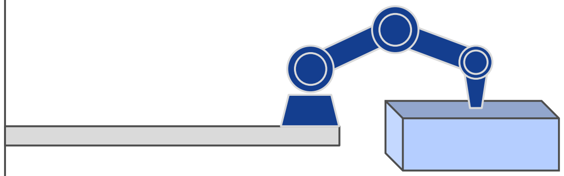


ConOps

Stage 3: Drop Off

Phase A: Rotate

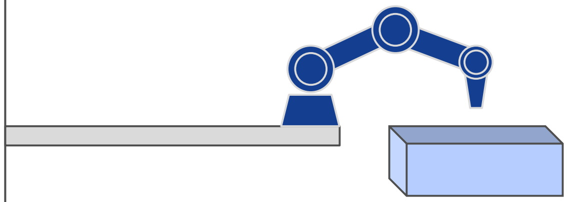
Arm rotates with bag to the drop off pose



Stage 3: Drop Off

Phase B: Release

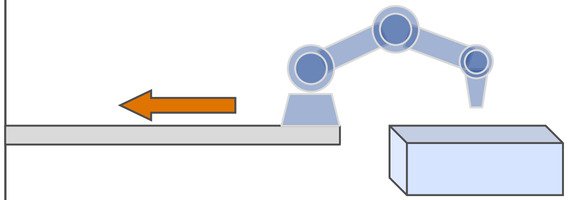
The end effector disengages to release control of the bag



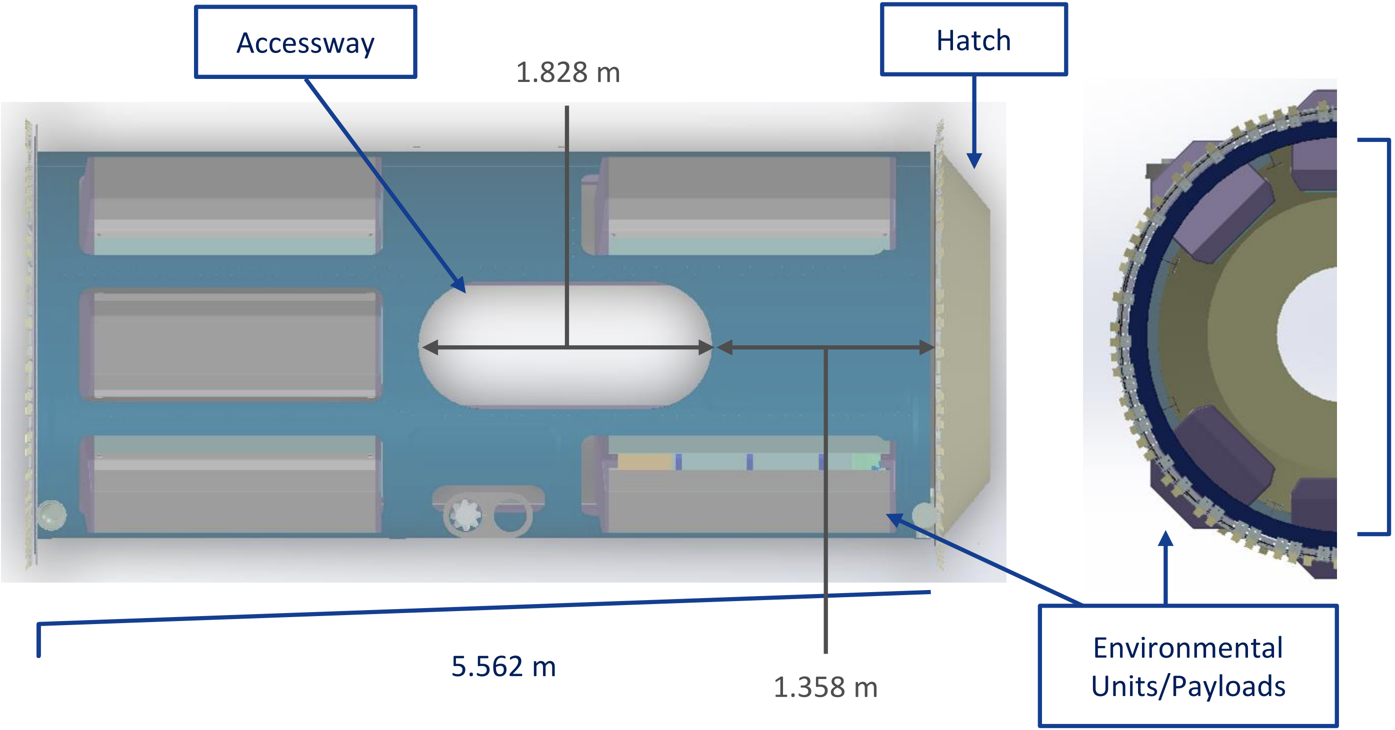
Stage 3: Drop Off

Phase C: Reset

The arm returns to the start of the track to restart process



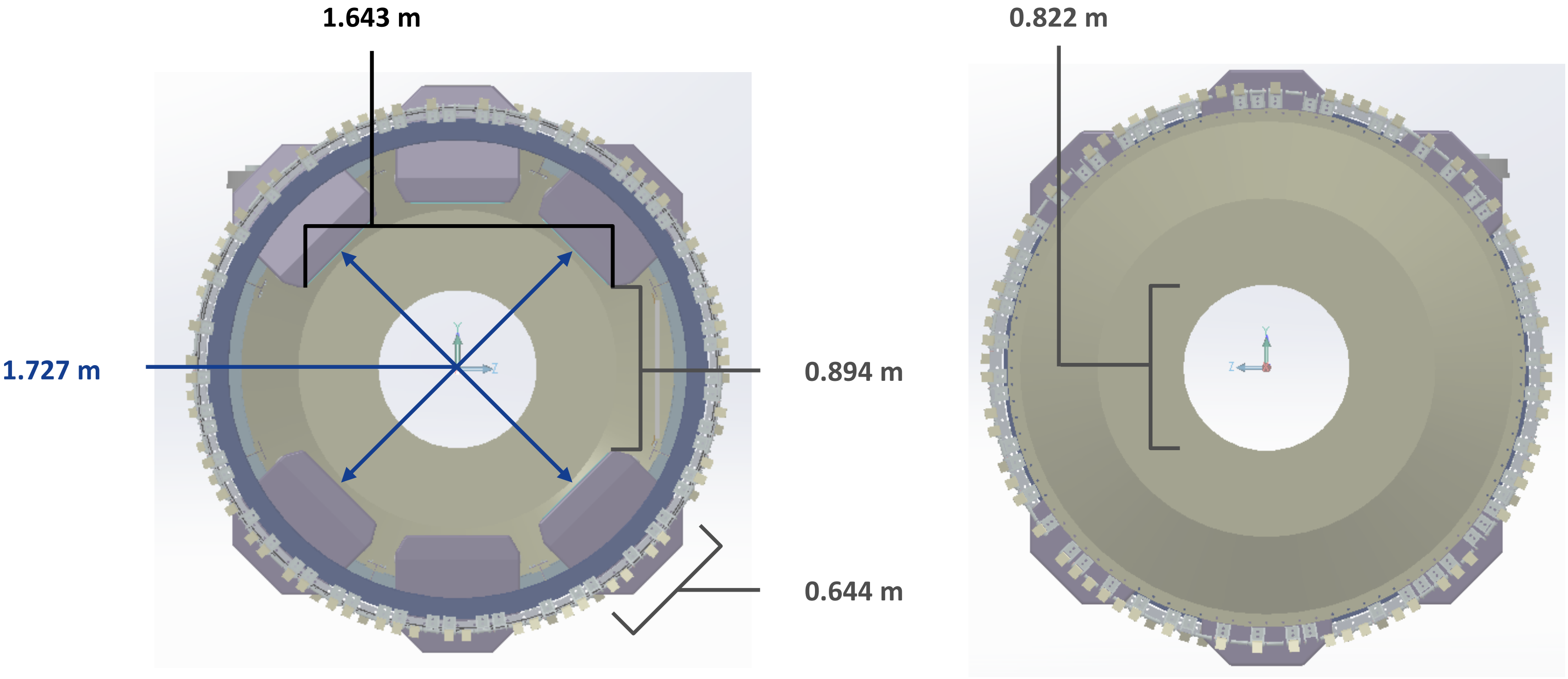
LIFE Module Dimensions I



Length of Core:
5.562 m
Core Internal Diameter:
2.391 m

Distance from hatch to center of accessway:
2.272 m

LIFE Module Dimensions II



UR10e Technical Specifications

Performance

Power consumption	Approx. 350 W using a typical program
Safety System	All 17 advanced adjustable safety functions incl. elbow monitoring certified to Cat.3, PL d. Remote Control according to ISO 10218
Certifications by TUV Nord	EN ISO 13849-1, Cat.3, PL d, and full EN ISO 10218-1
F/T Sensor - Force, x-y-z	
Range	100 N
Resolution	2.0 N
Accuracy	5.5 N
F/T Sensor - Torque, x-y-z	
Range	10 Nm
Resolution	0.02 Nm
Accuracy	0.60 Nm

Specification

Payload	10 kg / 22 lbs
Reach	1300 mm / 51.2 in
Degrees of freedom	6 rotating joints DOF
Programming	Polyscope graphical user interface on 12 inch touchscreen with mounting

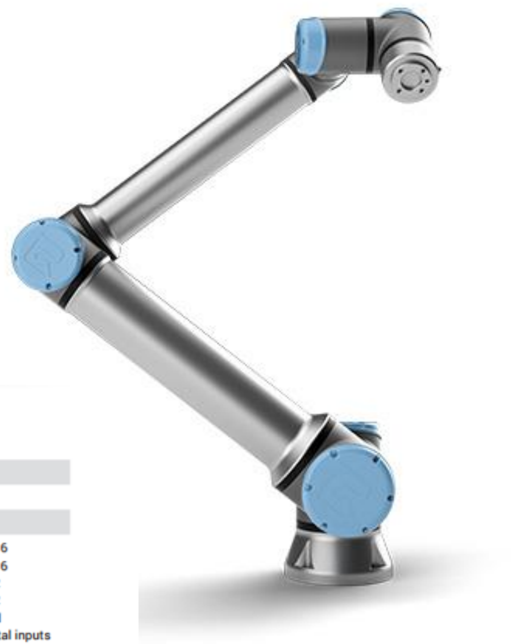
Movement

Pose Repeatability	+/- 0.05 mm, with payload, per ISO 9283	
Axis movement robot arm	Working range	Maximum speed
Base	± 360°	± 120°/s
Shoulder	± 360°	± 120°/s

Control box

Features

IP classification	IP44	
ISO Class Cleanroom	6	
Ambient temperature range	0-50°	
I/O ports	Digital in	16
	Digital out	16
	Analog in	2
	Analog out	2
	500 Hz control, 4 separated high speed quadrature digital inputs	
I/O power supply	24V 2A	



Sources

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- https://www.anaheimautomation.com/products/linearcomponents/linear-guides-item.php?sID=557&serID=40&pt=i&tID=1162&cID=543&dsID=569
- https://docs.pixycam.com/wiki/doku.php?id=wiki:v2:using_color_codes

Alternative Robotic Arms

- http://www.crustcrawler.com/ and https://www.trossenrobotics.com/widowx-200-robot-arm.aspx