Spring Final Review

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Advisor: Dr. Neogi

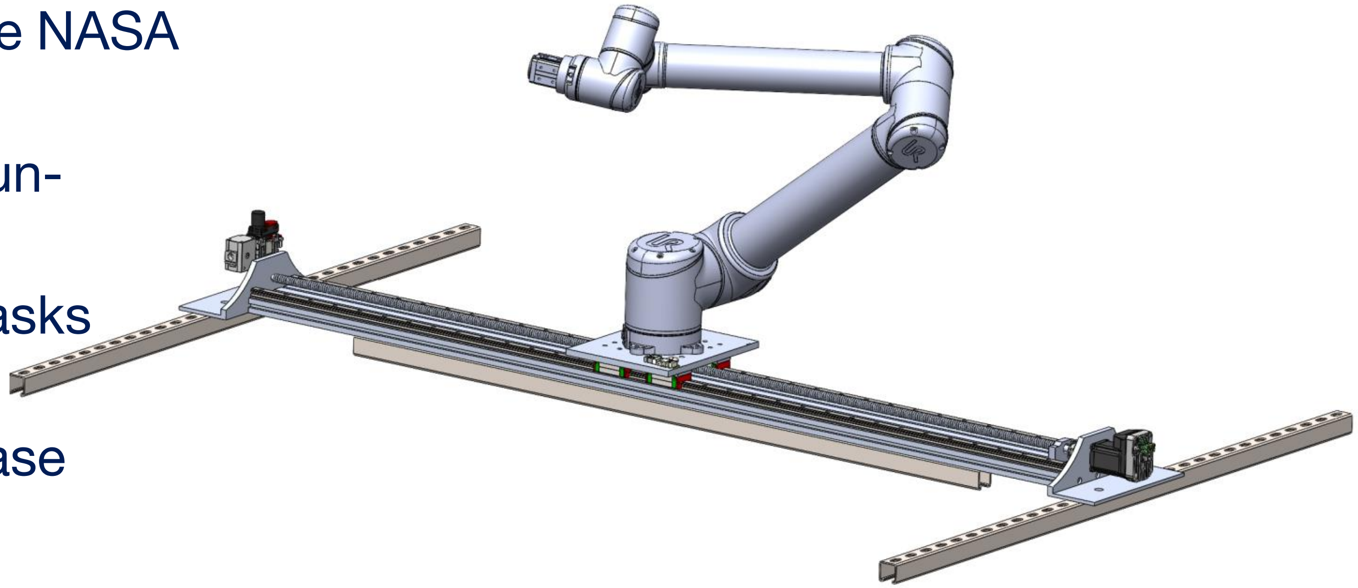
Section 1

Project Overview → Purpose → Objectives → CONOPS → FBD

Purpose

RIVeR

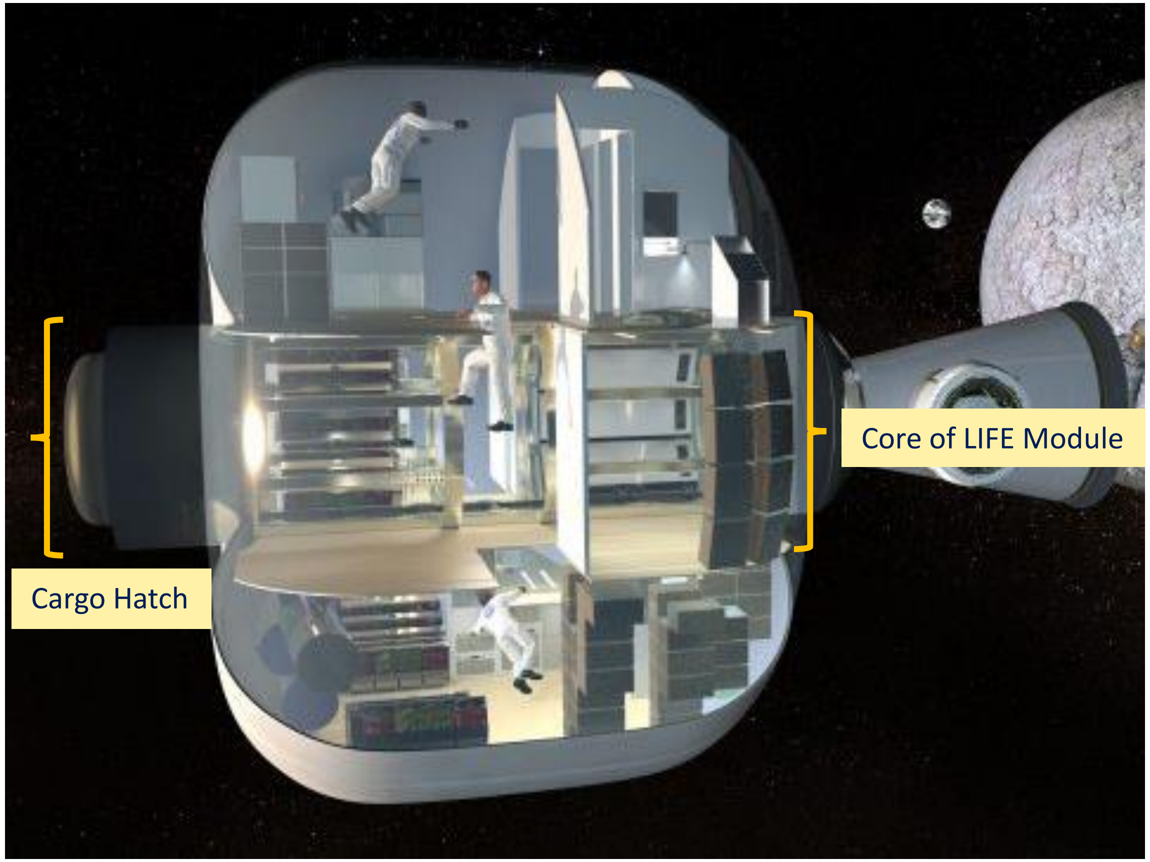
- Prove the feasibility of using Intra-Vehicular Robotics (IVR) to identify and distribute NASA cargo bags
- Demonstrate task management in an un-crewed spacecraft
- Use robotics for cargo management tasks anticipated on a space habitat
- Use a robotic arm to capture and release autonomously



Field of Operation

RIVeR

- Sierra Nevada Corporation's LIFE habitat is designed for astronauts living in orbit around the Moon
- Cargo will arrive prior to the crew that will require autonomous unpacking and distribution
- RIVeR is a proof of concept for adapting robotics to intra-vehicular tasks
- **Impact**
  - Allows for multiple resupply missions prior to crew arrival
  - Alleviates crew responsibilities for transporting cargo throughout the habitat
  - Demonstrate to SNC and NASA the application of robotics



Levels of Sucess

Complete

RIVeR

Level	**Translator**	Robotic Arm	End Effector
Level 1	Platform that is **capable of being mounted to the rail system** of size 2.15m x 0.3m.	Robotic arm can **move to a desired pose** under a given command without colliding with simulated LIFE module environment.	End effector is able to take a command to **operate the bag capture mechanism**.
Level 2	Translator is able to **integrate with the robotic arm** including power and communication systems.	Robotic arm can plan and **move to a specified pose while the base is being moved** by the translator.	**End effector can capture bag with operator input** and maintain hold while translating and rotating the arm.
Level 3	**Translate robotic arm up to 2 meters** in one direction given a control input with 1 cm of accuracy.	**Robotic system can capture a bag and release it at a specified location**, with a remote operator determining pick up and drop off location.	**End effector receives input from the robotic arm** to be aligned, capture, and control a bag instead of a remote operator.
Level 4	**Translation is automated** and repeatable; sensor suite returns position data to the system/user to refine position during operations.	The system will complete a cargo transportation task by **identifying, locating, capturing, and releasing a bag with no manual inputs** from an operator.	The end effector is **correctly aligned to capture a bag based on the coordinate location** returned by the imaging sensors.

CONOPS

Stage 1: Capture

A) Identify a cargo bag and return location coordinates

B) Position arm to attach to bag

C) Engage magnetic end effector

D) Rotate to required pose

Stage 2: Translation

A) Begin motorized translation

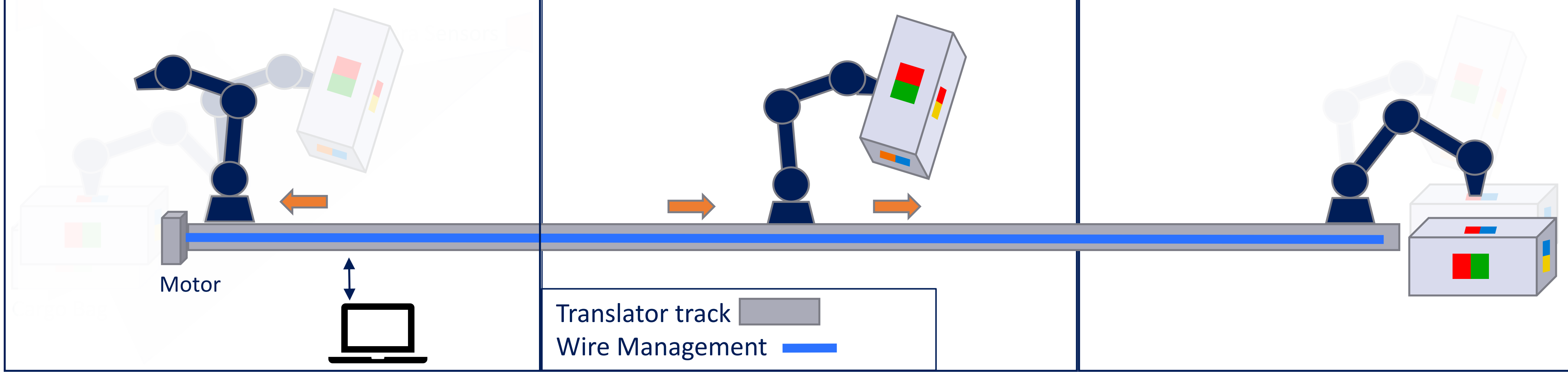
B) Stop translation at drop off location

Stage 3: Release

A) Rotate to drop off pose

B) Disengage end effector

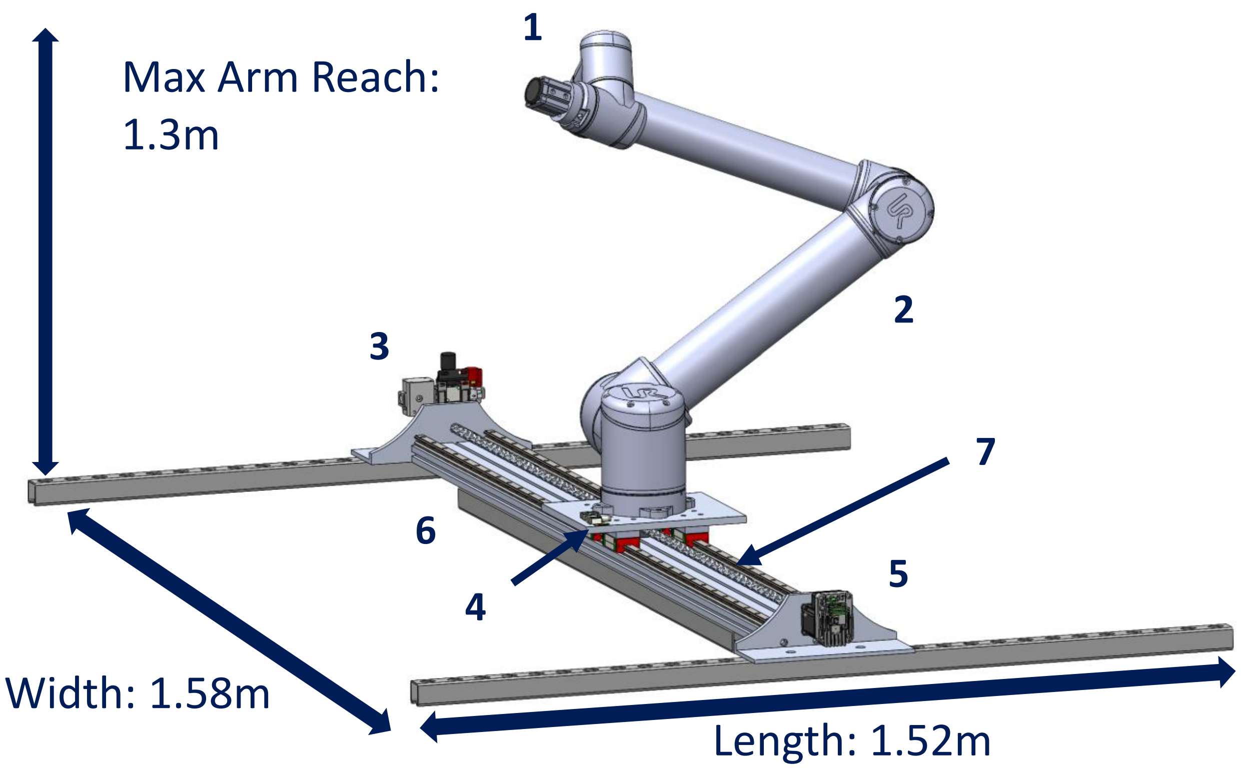
C) Return to origin and restart process



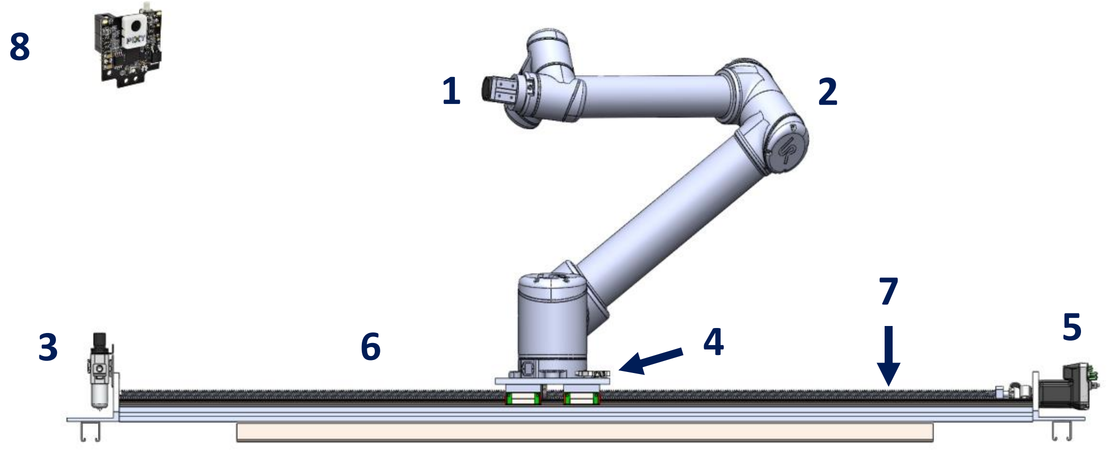
Section 2

- Design
- Design Overview
- FBD

Overall Design

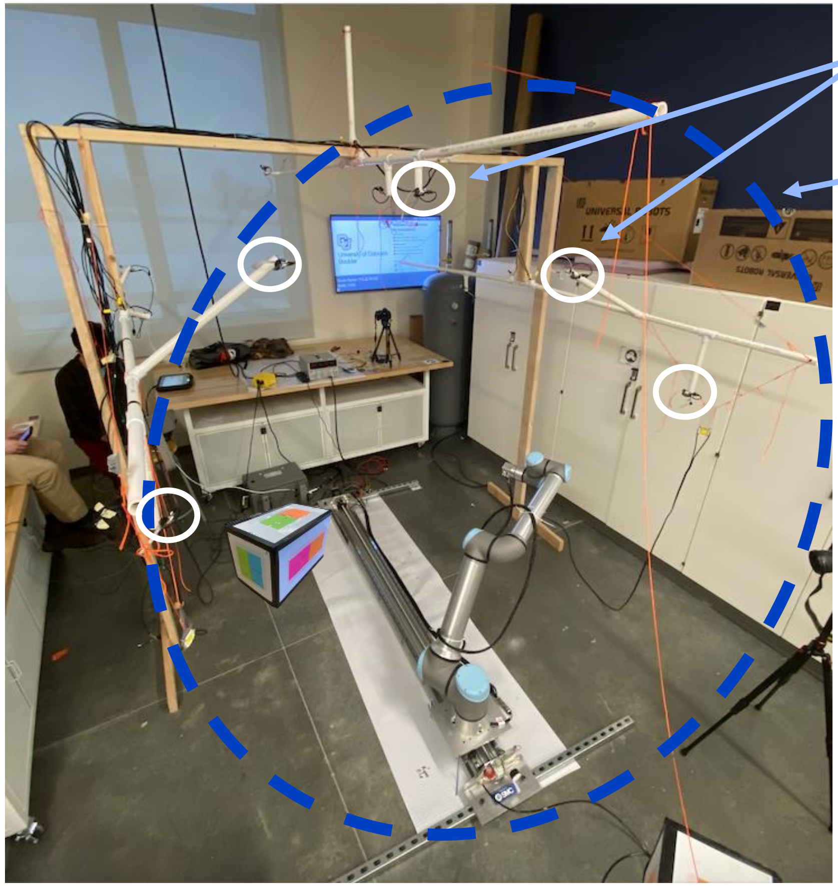


System Mass: 110kg

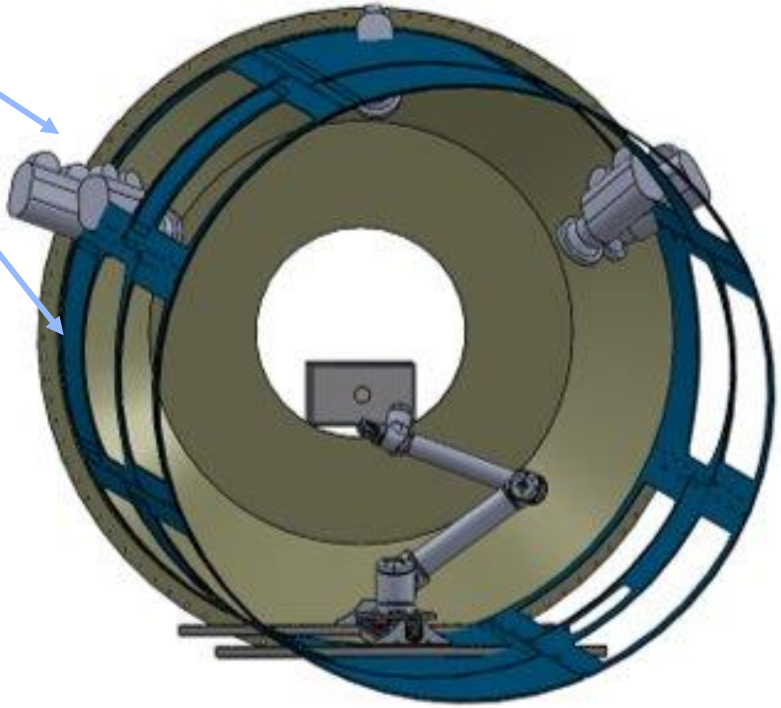


1. End-Effector
2. UR10e
3. Filter/Regulator Combo
4. Solenoid
5. Stepper Motor
6. Linear Stage
7. Lead Screw
8. Pixy2 Cameras (10x)

Design Overview

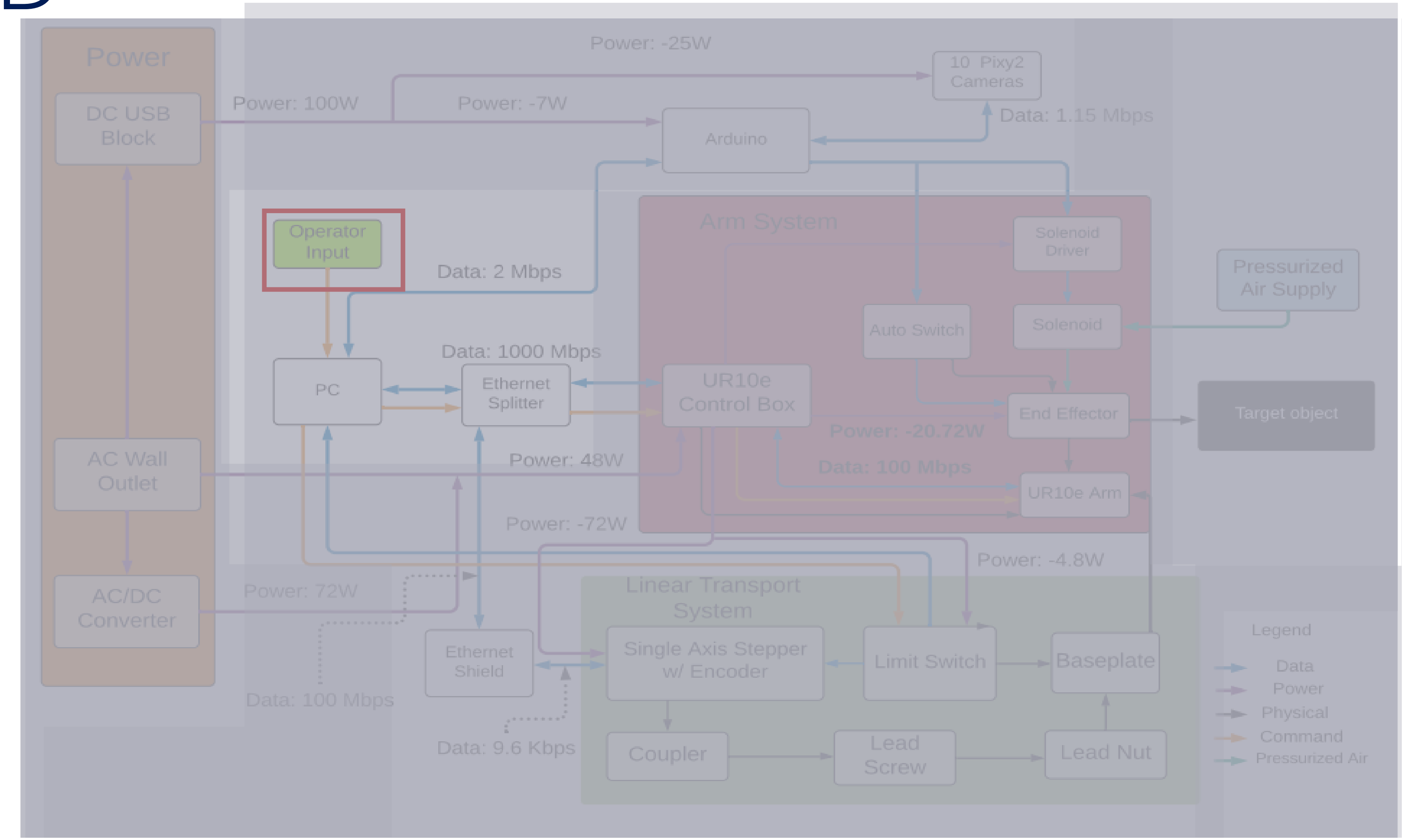


Core Mock-Up for Camera/Lighting Mounts



ow RIVeR Integrates into LIFE Habitat Enviornment

FBD


Power
DC USB Block
AC Wall Outlet
AC/DC Converter
Power: -25W
Power: 100W
Power: -7W
10 Pixy2 Cameras
Data: 1.15 Mbps
Arduino
Operator Input
Data: 2 Mbps
Arm System
Solenoid Driver
Pressurized Air Supply
Auto Switch
Solenoid
Data: 1000 Mbps
PC
Ethernet Splitter
UR10e Control Box
End Effector
Target object
Power: -20.72W
Data: 100 Mbps
Power: 48W
UR10e Arm
Power: -72W
Power: -4.8W
Power: 72W
Linear Transport System
Single Axis Stepper w/ Encoder
Limit Switch
Baseplate
Ethernet Shield
Data: 100 Mbps
Data: 9.6 Kbps
Coupler
Lead Screw
Lead Nut
Legend
Data
Power
Physical
Command
Pressurized Air

Section 3

- **Test Overview**
- Translator Accuracy
- End Effector Accuracy
- ROS Environment
- Full System

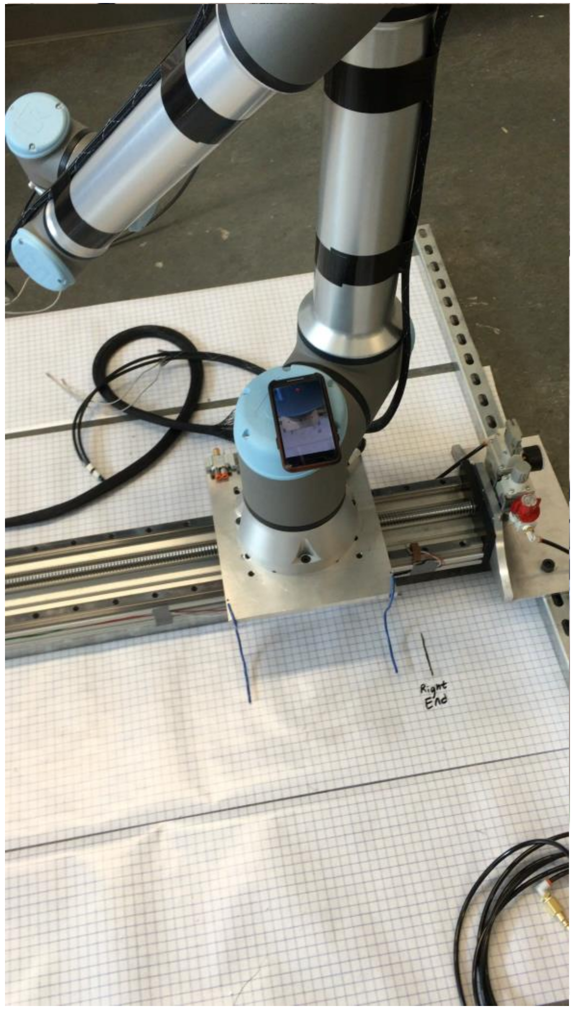
Testing Overview

Functional Test | Complete
Validation Test | In Progress
☆ In Presentation

RIVeR

Phase	Milestone	Hardware	Purpose	Status
Phase I	Component Testing	Various	Verify baseline parameters/operations	Complete
	Stationary Test	Robotic Arm, End Effector and Cargo Bag	Test end effector and robotic arm interface and verify end effector is strong enough	Complete
Phase II	Translator Test ☆	Translator Motor	Verify motor accuracy and strength	Complete
	Estimation Tests ☆	Pixy2, PC, End Effector	Test accuracy of cameras, end effector accuracy needs, and positional algorithms	Complete
	Dynamics Test	Translator and UR10e	Test translator and robotic arm function in tandem	Complete
Phase III	ROS Environment Test ☆	PC, UR10e, Pixy2, End Effector, Translator	Test read/communication/command systems between components	Complete
	Full System Test ☆	Translator, Robotic Arm, and Camera Suite	Test entire system functionality	Complete

Translator Tests



Purpose: Verify the capability of the translator to move the UR-10 and meet design requirements.

Equipment: UR-10, Translator, Baseplate, Motor, Motor Power Supply, PC

Variables: carrying weight, motor torque, distance traveled, acceleration, accuracy.

Motor characteristics tested: Acceleration, Accuracy, Load, and torque validation

Design Requirements Satisfied:

- DR 1.1- Ability to move cargo down the length of the core
- DR 3.2- Determine the position of cargo bag on the translator

Pass Conditions:

- Acceleration: 3 cm/s^2
- Minimum Load: 30 kg
- Accuracy: know the position of the translator within 5 cm

End Effector Tests

Purpose: Verify/Characterize the capability of the end effector to grab and secure bag during transport and meet design requirements.

Equipment: MHM-32D, Electronic & Manual Dump Valves, Solenoid & Driver Circuit, Compressed Air, Actuation & Grab sensors

Variables: Vertical, Horizontal Offset, Angle

End Effector characteristics tested: Offset Margin, Grab and Actuations sensor capability and accuracy, Max Angle of Attachment

Design Requirements Satisfied:

- FR.6 The end-effector shall be able to control and direct cargo.
- DR.6.1 The end-effector shall secure cargo for the duration of all translation and rotation required for a task.

Pass Conditions:

- N/A

Estimation Tests

Purpose: Verify that the cargo bag estimation process can estimate the position and orientation of the cargo bag within the uncertainty bounds required by the end effector

Equipment: Computer, Pixy Sensors, End Effector, Cargo Bag

Variables: magnetic linear displacement, angular displacement, number of cameras observing the test location, number of markers seen, cargo bag position and orientation

Components tested: End Effector, Pixy Sensors, Estimation Software

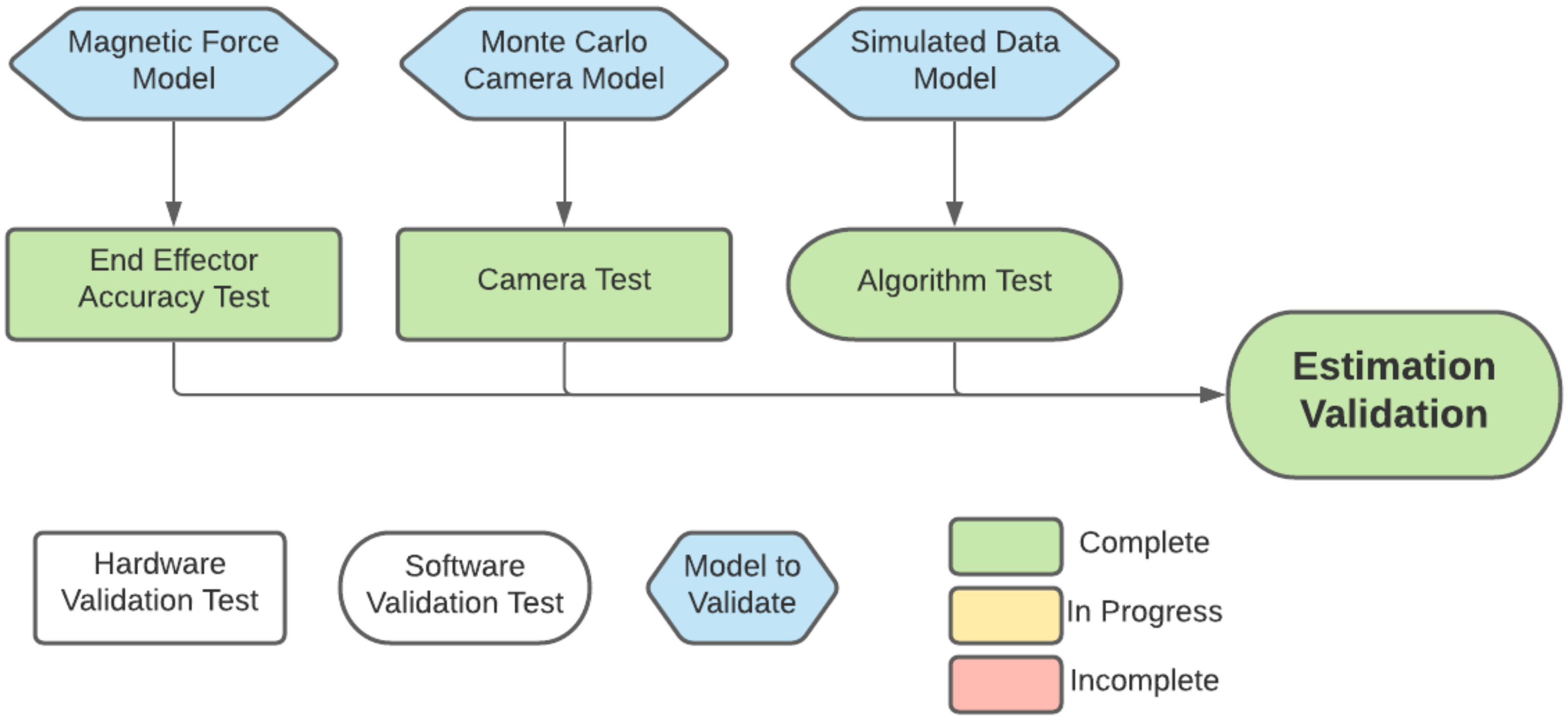
Design Requirements Satisfied:

- DR – 3.1, 3.2, 3.3
- DR – 6.1

Pass Conditions:

- Estimation errors for all markers remain within the accuracy bounds determined through end effector testing
- The sensor network can obtain the necessary data for estimation in at least 90% of bag configuration scenarios

Estimation Tests



ROS Environment Tests

Purpose: Verify all software & hardware components can correctly communicate through ROS

Equipment: Computer, UR10, Arduino, Sensors, Stepper Motor

Variables: Sensor data, connection and operational statuses, tasks, commands

Components tested: ROS Software, EEF, UR10, Translator, Pixy Sensors, Limit Switches

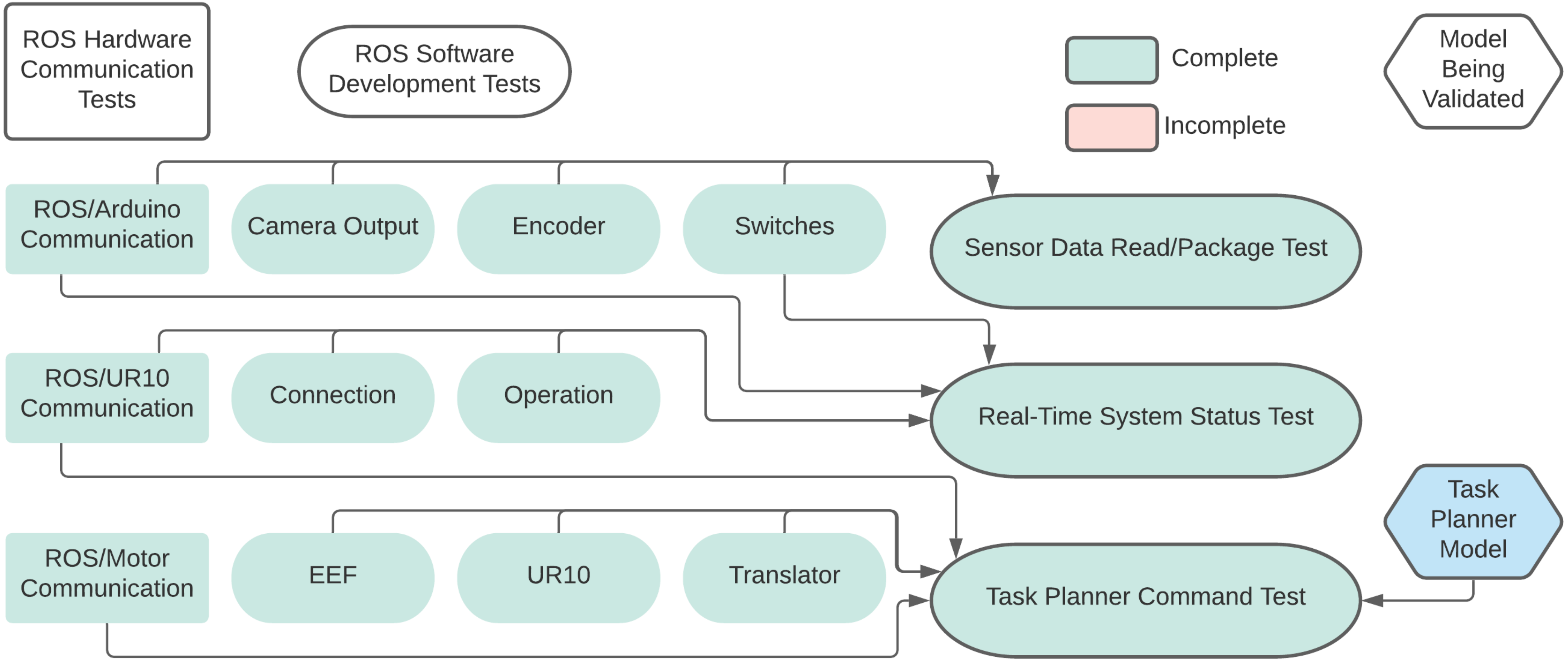
Design Requirements Satisfied:

- DR – 2.2
- DR – 3.2, 3.3, 3.4
- DR – 7.1

Pass Conditions:

- Intended data is packaged in correct *rosmsg* and published to unique *rostopic*
- Desired *rosmsg* is received and correct data is unpacked
- Sensory data lines read off unique *rostopics w*hen Arduino is activated with hardware connected
- Camera/motor connection, translator/arm operation, limit switch statuses update in real time
- EEF actuates upon receiving engagement command, UR10 trajectory is executed correctly, translator moved to commanded position within 5cm

ROS Environment Tests



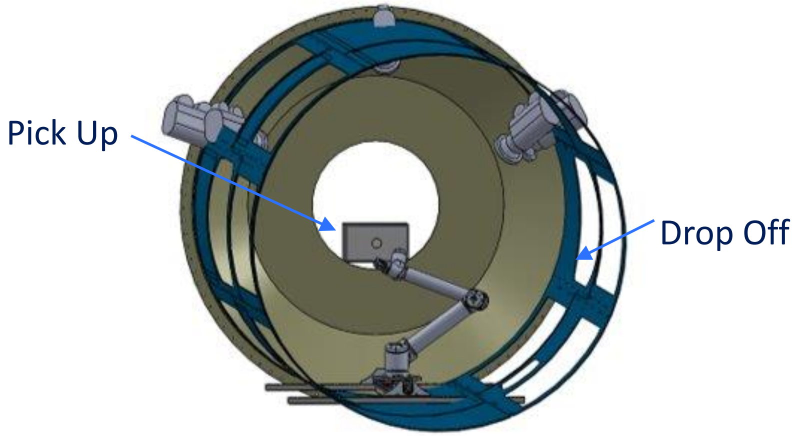
Full Systems Test

Overview: Use camera suite to identify a cargo bag and have the robotic arm/translator system capture and release a bag in the proper locations. No operator input.

Rationale: Verify complete operation of the system as an integrated process.

Location: Senior projects room

Equipment: Wall outlet, compressed air



Procedure:

1. Power on all components
2. Initiate program
3. Calibrate the sensor system
4. Cameras identify bag and send location to arm
5. Arm captures cargo bag, translator moves arm to drop-off side
6. Arm releases bag in drop off location
7. System resets for next bag

Section 4

Test Results

Translator Accuracy

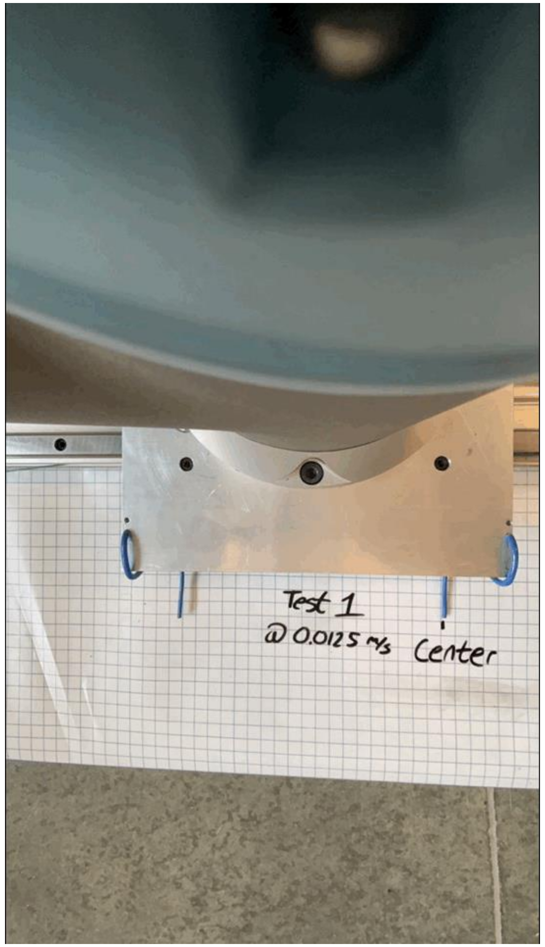
End Effector Accuracy

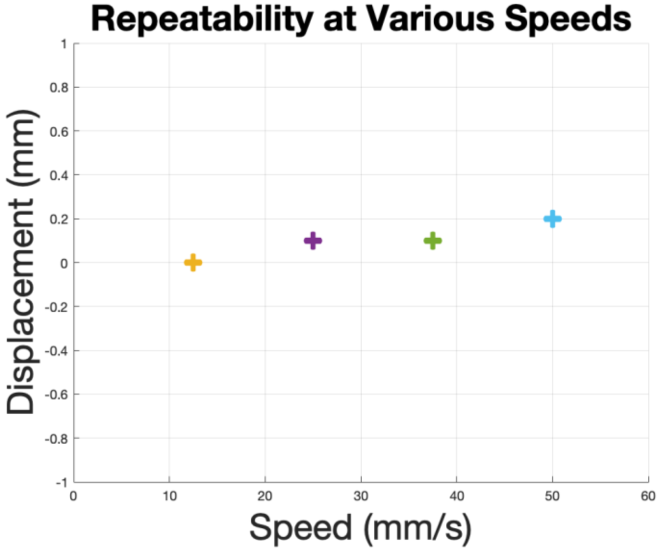
Ca

Full System

Translator Results

RIVeR

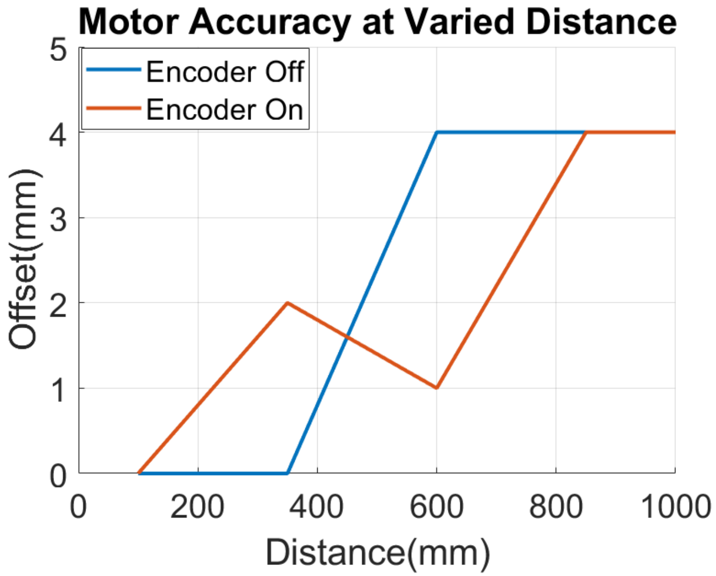




DR 1.1	The translation system shall be able to accelerate the cargo bag and combined arm/end effector 3cm/s2
DR 3.2	The translation system shall be capable of translating the robotic arm, end effector, and cargo bag's combined mass
DR 5.2	The translator shall be able to move to a prescribed location within a margin of 5 cm.

Variable	Required Value	Expected Value	Tested Value	Design Requirements Satisfied
Accuracy	5 cm	1.13 mm	4 mm	DR 5.2
Acceleration	3 cm/s^2	N/A	30 cm/s^2	DR 1.1
Carrying Mass	35 kg	N/A	39 kg	DR 3.2,DR 5.2
Holding Torque	N/A	.652 Nm	.376 Nm	Torque Validation

Translator Results



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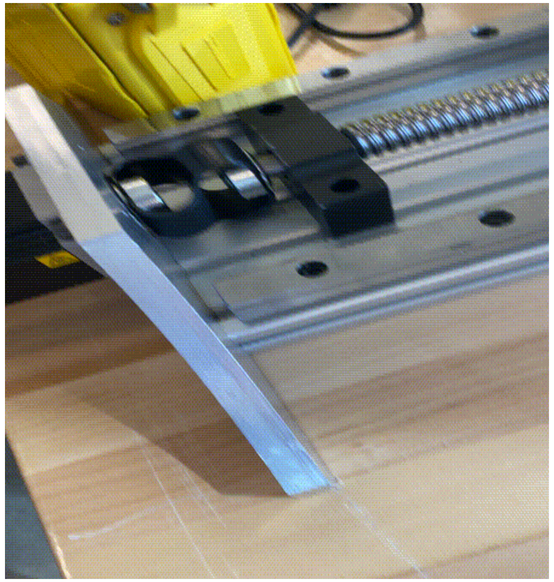

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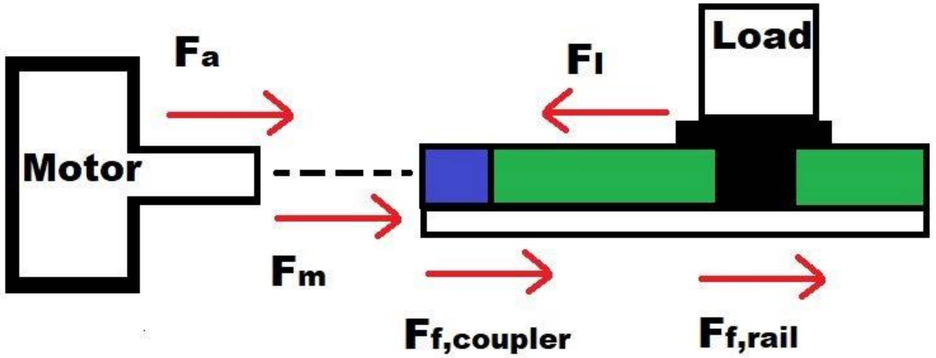
Translator Results

$$F_{static} = F_m + F_{f,static} = 729.7N \Rightarrow T = \frac{F_a * l}{2\pi\eta} \Rightarrow T_{static} = \frac{F_{static} * l}{2\pi\eta} = 0.6452\,Nm$$

F_m = Machining Force
F_f = Frictional Force
F_I = Inertial Force



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Holding Torque	N/A	.652 Nm	.376 Nm	Torque Validation

End Effector Margin

RIVeR

Complete: 12 April

Levels of Success

End Effector Level 3

Design Requirements

FR.6 The end-effector shall be able to control and direct cargo.

DR.6.1 The end-effector shall secure cargo for the duration of all translation and rotation required for a task.

Expected Results

Ability for the end effector to still grasp the bag with a relatively large offset between the magnet and metal disk centers

Pass/Fail Condition

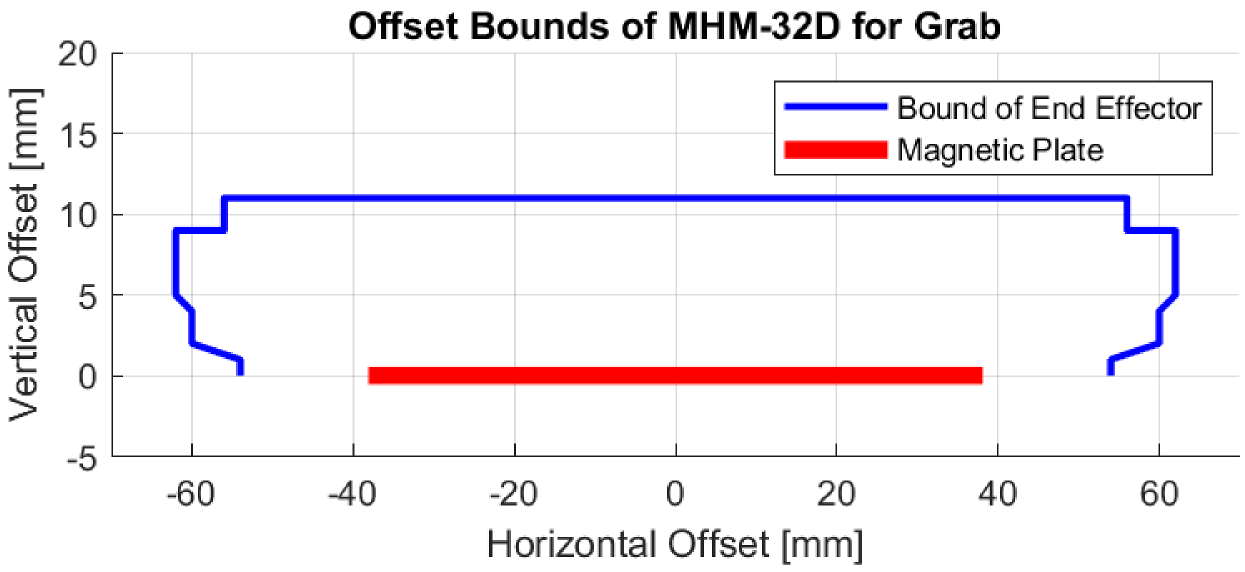
Minimum distance required to capture a cargo bag is within the accuracy of the combined sensor suite and robotic arm system

Results

End Effector successfully grabs bag within determined offset bounds

End Effector Bounds for Grab

Results:



- Max Vert. Offset: 11 mm
- Max Horz. Offset: 62 mm
- Max Offset: 62 mm

- To characterize the bounds of the MHM-32 magnet by manually actuating the magnet at various distances b/t the centers
- The max effective horizontal offset was measured for each vertical offset from 1mm to 11mm (increments of 1mm)
- Tests were conducted on 50mm and 76mm diameter metal plates, similar trends were observed with both

Camera Suite Accuracy I

Levels of Success
Translator Level 4
End Effector Level 4

Design Requirements

DR.3.1 The system shall identify a cargo bag with its orientation and position.

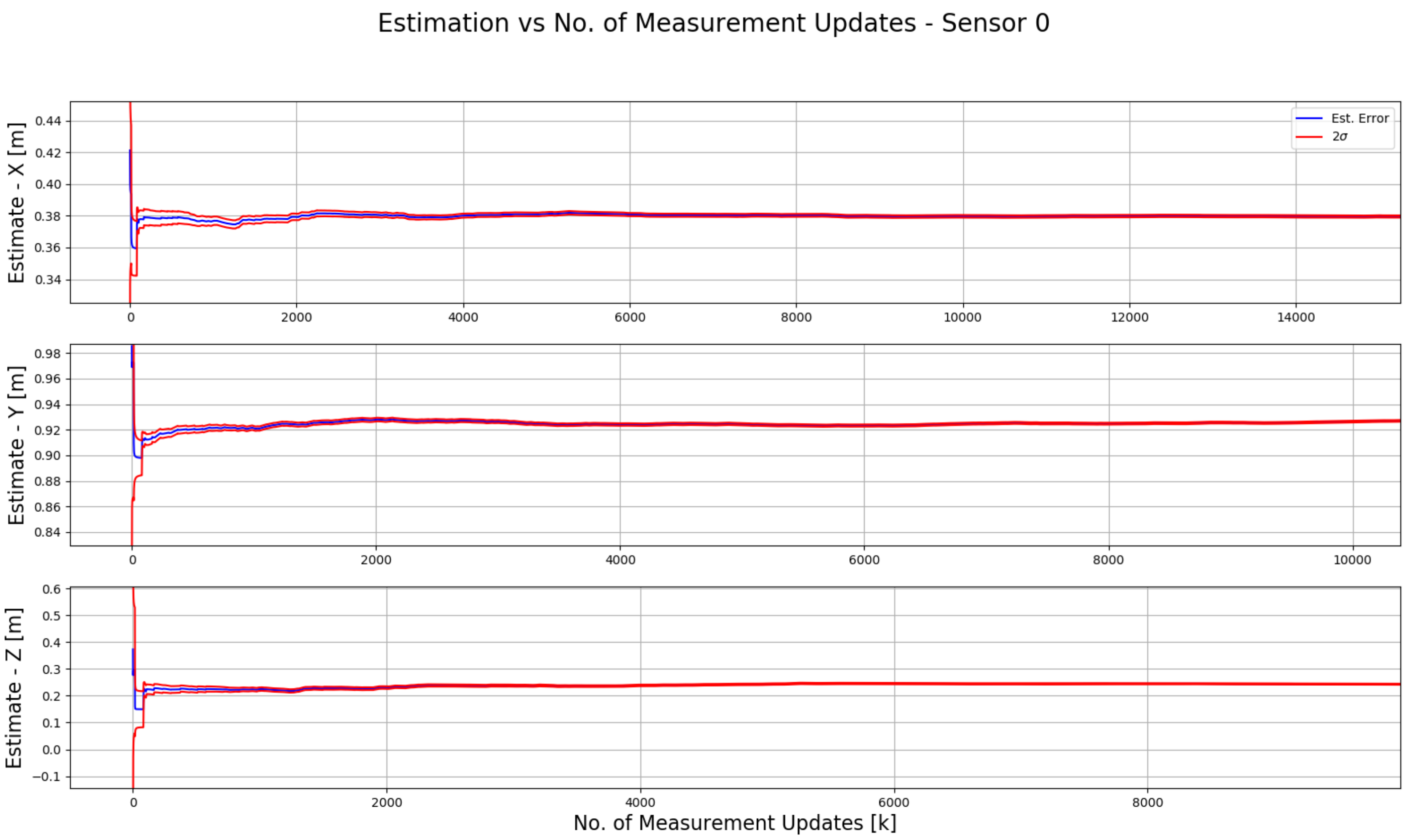
DR.3.4 The operating system shall be able to determine if the cargo is irretrievable.

Camera Suite Setup

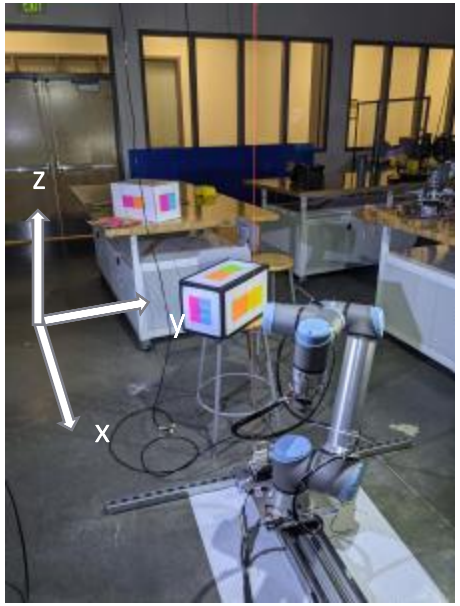
Camera Suite Accuracy II

Model Results:

Test Results:



Variable Orientations



Orientation 1

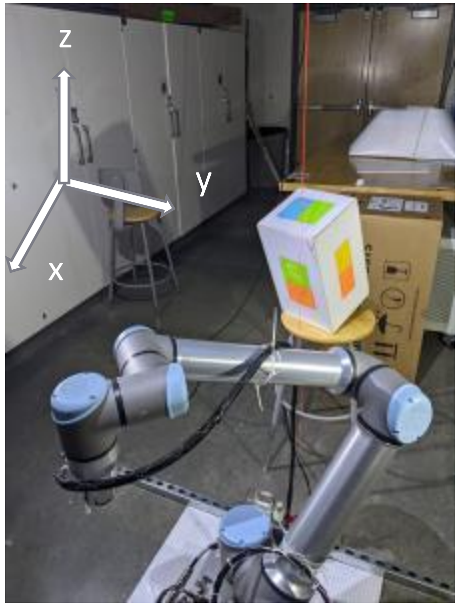
- Flat on stool
- (+) Rotation about *z*-axis
- Magnetic plate on top face

Orientation 2

- Flat on stool
- (-) Rotation about *z*-axis
- Magnetic plate on top face

Orientation 3

- Compressible material used to lift front edge more significantly
- Rotation about *(x, y, z)* axes
- Magnetic plate on front face



Orientation 4

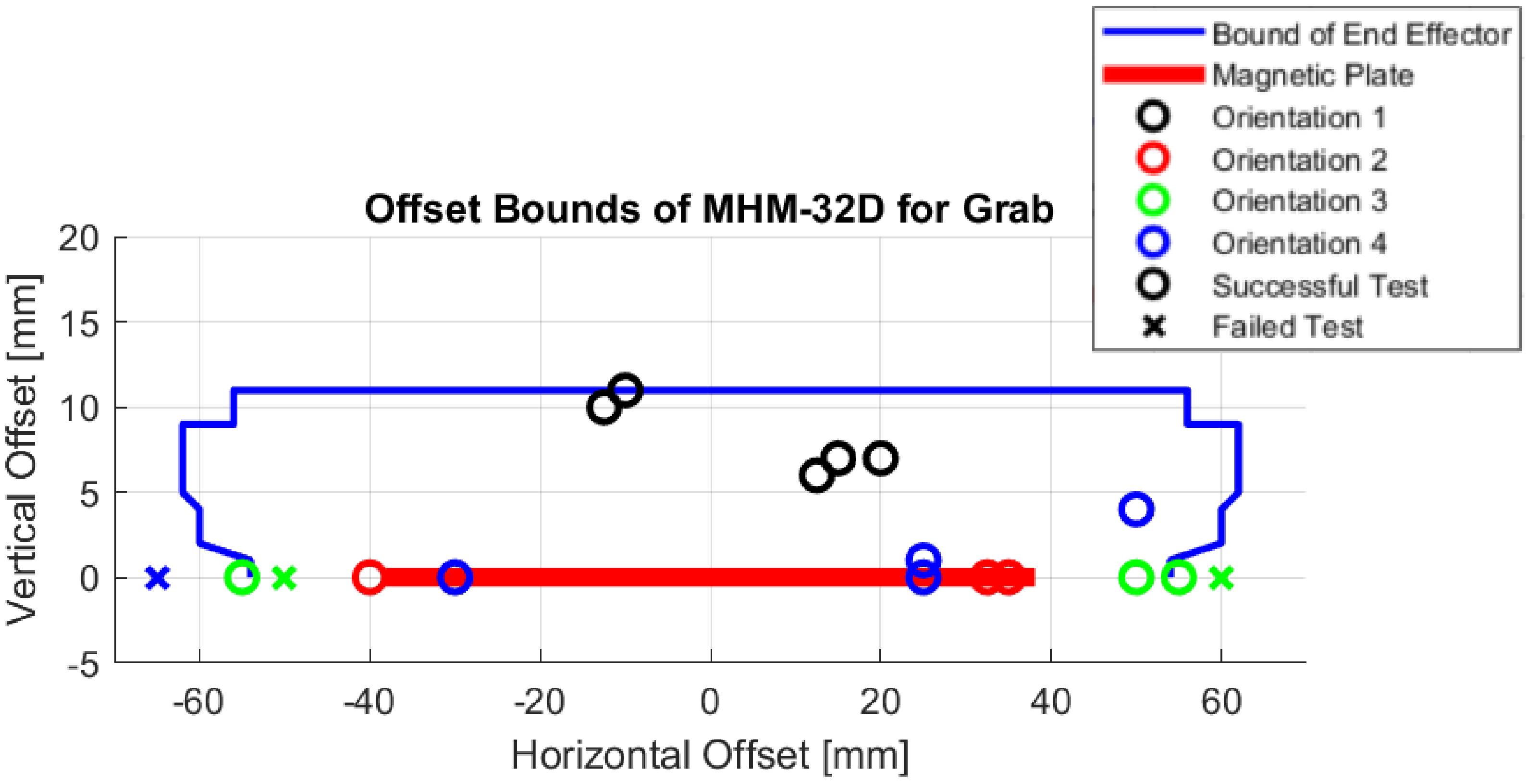
- Box stood up with back edge lifted
- Rotation about *(x, y, z)* axes
- Magnetic plate on front face

Camera Suite Accuracy III

Results:

Horizontal and Normal Offset Between EE and Magnet

True Box Center vs Estimated Box Center



Full System Test

Complete: 12 April

Levels of Success

Translator Level 4

Robotic Arm Level 4

End Effector Level 4

Design Requirements

DR.3.1 The system shall identify a cargo bag with its orientation and position.

DR.3.2 The system shall be able to determine if the cargo has reached the target location

DR.6.1 The end-effector shall secure cargo for the duration of all translation and rotation required for a task.

Expected Results/Model

The ability for the arm to autonomously locate and transfer cargo boxes from one side of the core to another.

Pass/Fail Condition

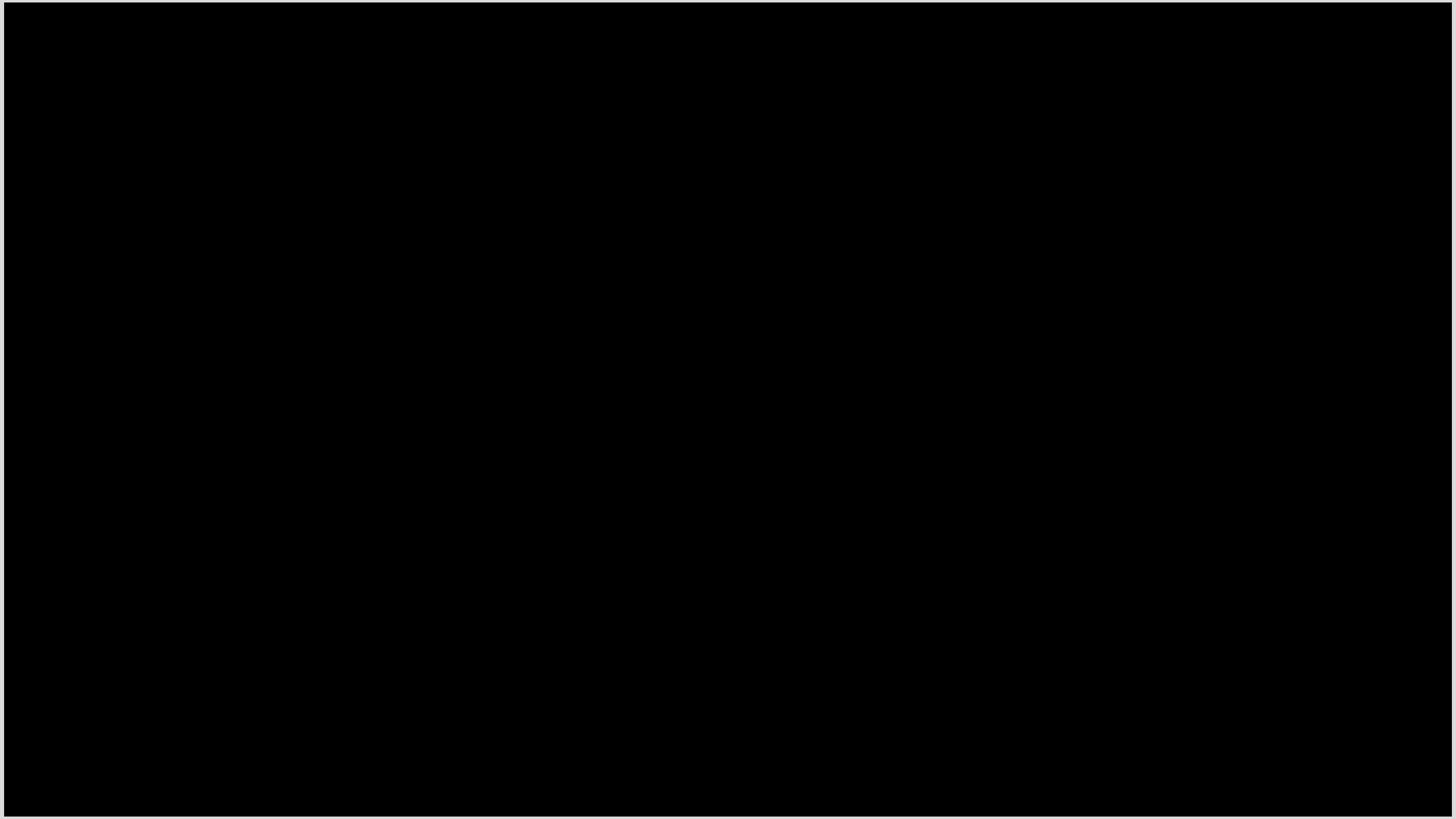
Complete cycle using cameras to identify a bag, robotic arm captures the bag and deposits it at the drop off location. System confirms drop off is complete.

Results

Repeatability: 17/22 trials; 77.27% success

Average Operation Time: 6 minutes 25.33 seconds

RViz Comparison



Full System Test Video

Operations:

1. Observe cargo location, setup planning environment, plan task sequence
2. Orient EE to capture position
3. Activate EE
4. Move to translation pose
5. Translate across
6. Move to drop off pose
7. Drop off cargo bag at designated location

Step 1: Observe & Plan

1. Observe the Environment
2. Construct the Environment in the Task Planner
   1. Add locations to the "Pickup Domain"
   2. Add locations to the "Dropoff Domain"
3. Construct a graph that represents state transitions that satisfy physical conditions and the task specification
4. Find the shortest path on the graph to determine the action sequence

```
Plan sequence:
 -> move
 -> grasp
 -> move
 -> translate
 -> move
 -> release
 -> move
 -> translate
```

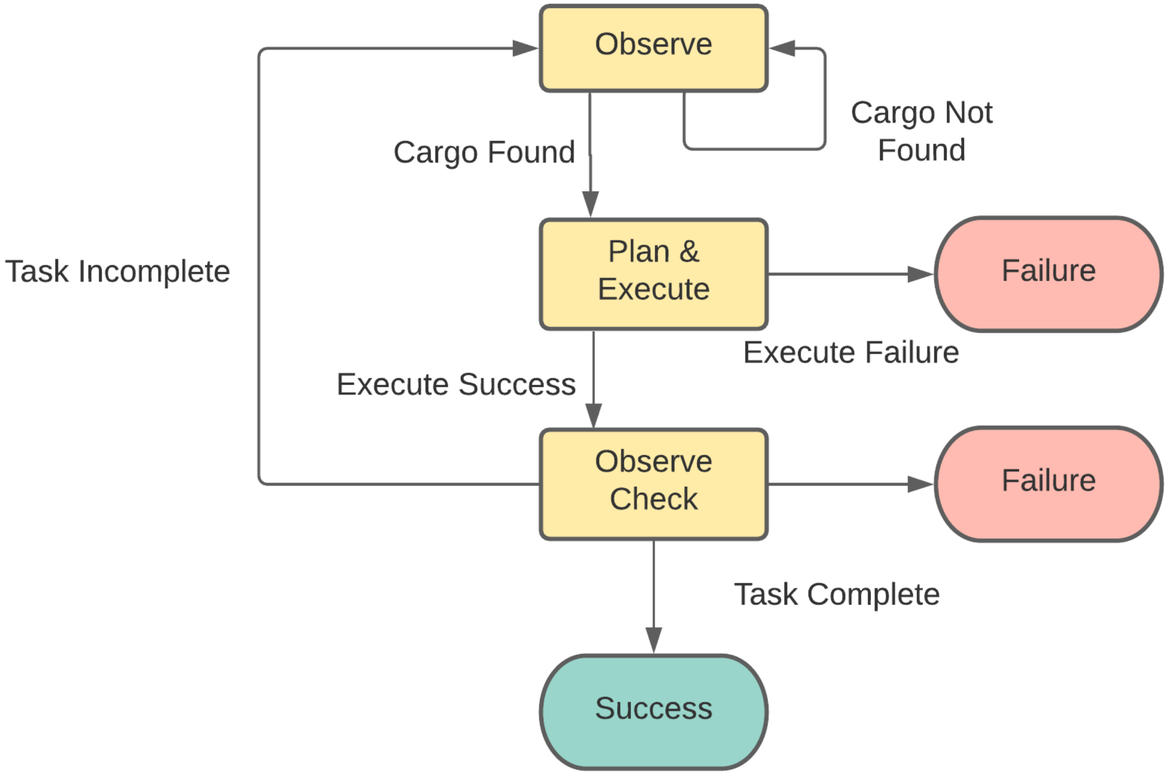
Step 2: Plan Execution

RIVeR

```
Currently on action: move
 MOVING TO:L0
Currently on action: grasp
recieved msg BagConfigPoseArray
 --bags were not found or TP not initiated
Waiting on EEF to grasp. Trial: 0
Waiting on EEF to grasp. Trial: 1
Waiting on EEF to grasp. Trial: 2
Waiting on EEF to grasp. Trial: 3
Waiting on EEF to grasp. Trial: 4
[ERROR] [1618866822.111399613]: End effector time out
 PICKING UP: obj0Loc
Currently on action: move
 MOVING TO:safep
Currently on action: translate
recieved msg BagConfigPoseArray
 --bags were not found or TP not initiated
Waiting on translator. Commanded Position: 2
Currently on action: move
 MOVING TO:goalL1
Currently on action: release
Currently on action: move
 MOVING TO:safed
Currently on action: translate
Waiting on translator. Commanded Position: 1
```

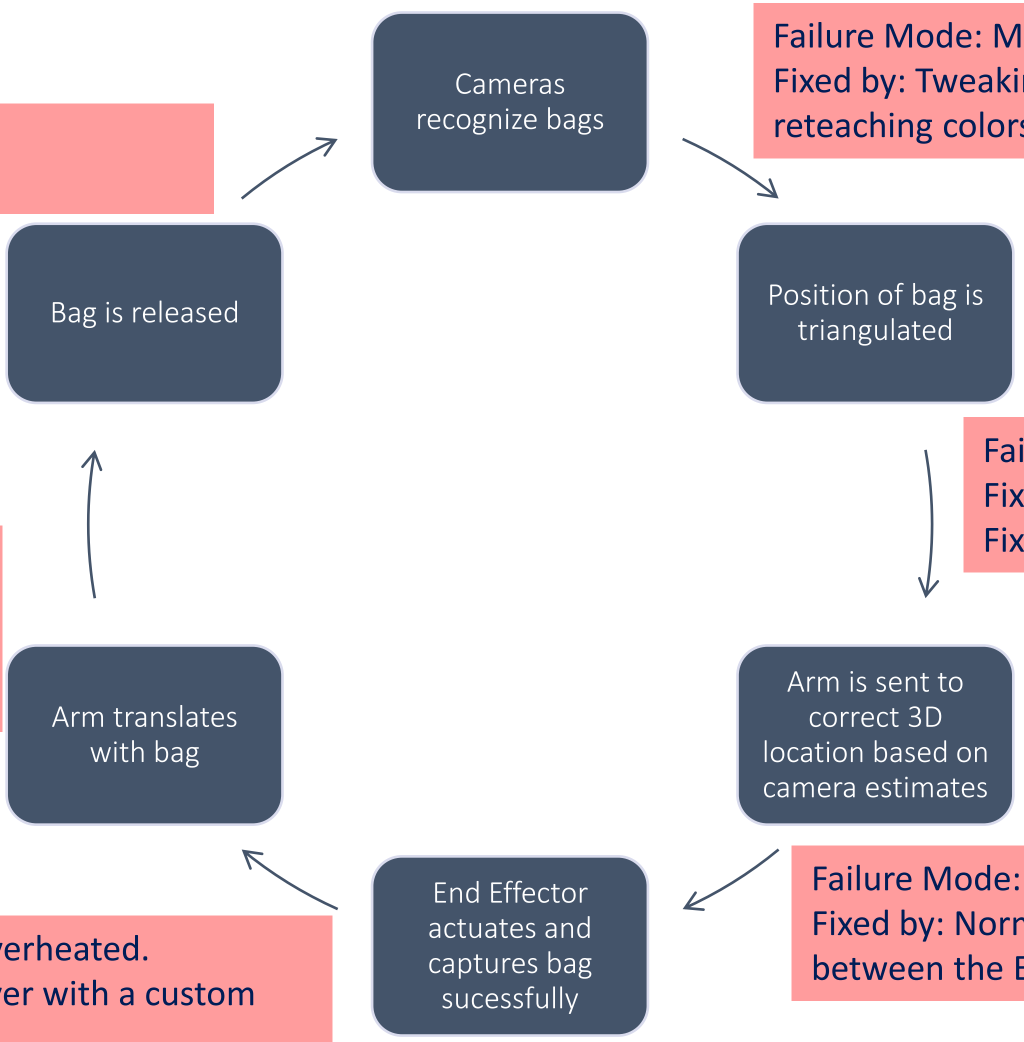
1. Move to the cargo location
2. Grasp the cargo by engaging the EEF
   1. Send out EEF command
   2. Wait on response from grasp switch (timeout)
3. Move to the translation pose ("safep")
4. Translate to the drop off location
   1. Wait on the translator limit switch (disabled)
5. Move to goal location
6. Release the bag
7. Move to the translation pose ("safed")
8. Reset by translating back to the beginning

Status: Success/Failure



Common Failure Modes

RIVeR



Failure Mode: Marker ID failure or marker mismatch.
Fixed by: Tweaking Pixy sensitivity settings or reteaching colors.

Failure Mode: Not enough visible color markers.
Fixed by: Optimizing camera positions.
Fixed by: Using a better bag position/orientation

Failure Mode: Arm couldn't plan trajectory to capture the bag.
Fixed by: Normalizing the quaternion that rotates the vector between the EE and magnetic plate.

Failure Mode: Solenoid driver overheated.
Fixed by: Replacing solenoid driver with a custom circuit.

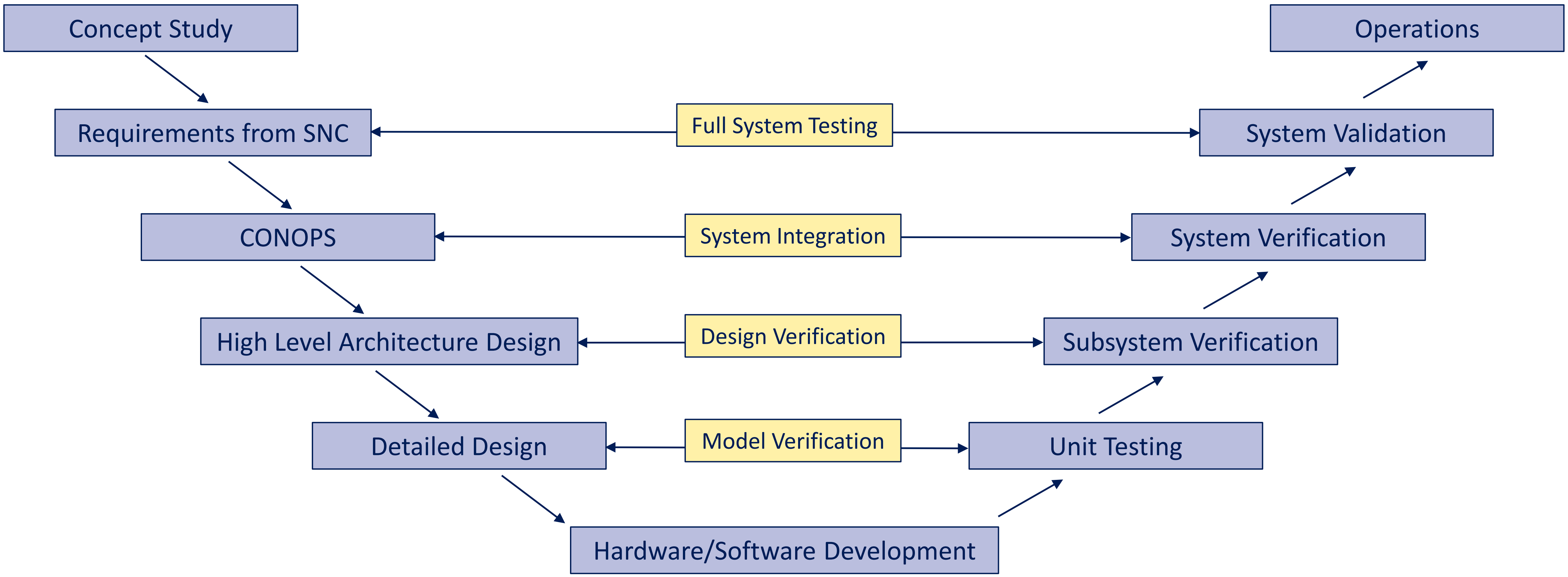
Failure Mode: Motor stalls due to minor flexing in the threaded rod.
Fixed by: Restarting motor and running at slower speeds.

Failure Mode: None
Fixed by: N/A

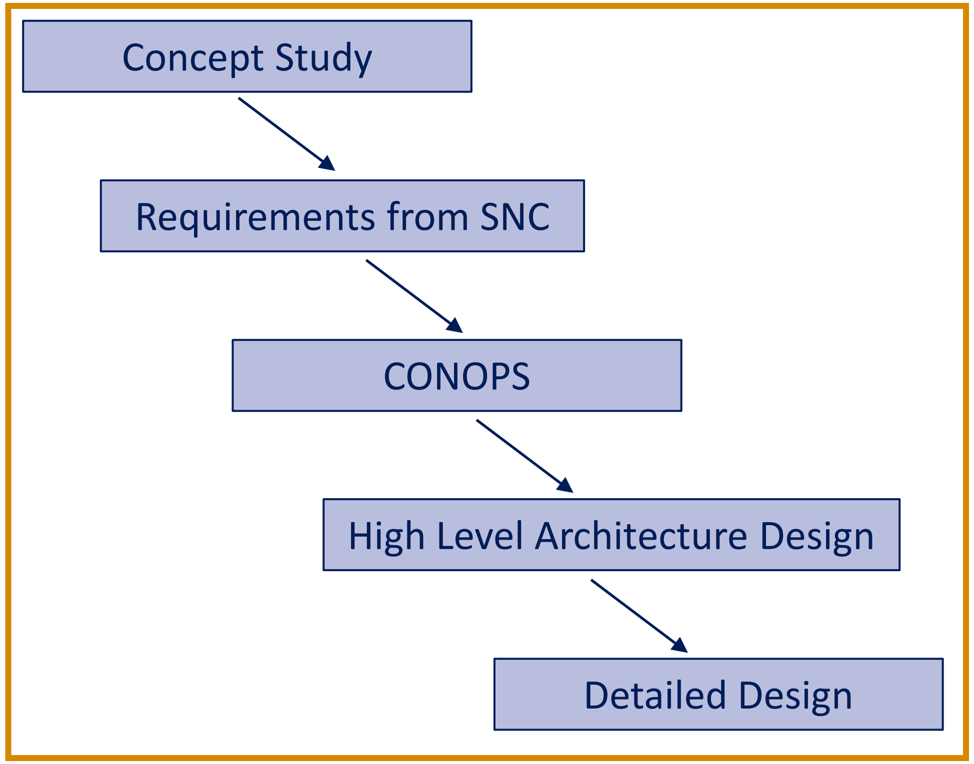
Section 5

Systems Engineering → Approach → Fall Semester → Hardware → Spring Semester

Systems Engineering Approach



Fall Semester



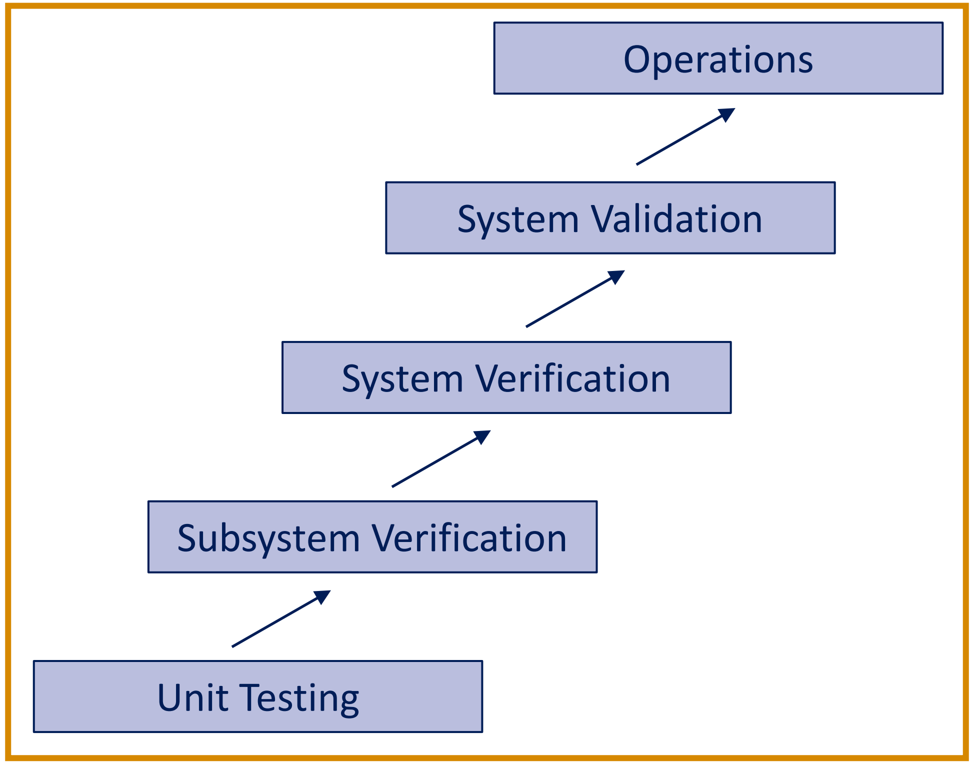
- Major Tasks
  - Requirements development from functional objectives
  - Trade Studies
    - End Effector, Linear Stage, Sensor Suite
    - Sensor Suite was the only hardware that was insufficient but higher quality would increase price
- Major Risks
  - Managing complexity of project
- Challenges
  - Determining an appropriate scope
  - Researching solutions
- Lessons Learned
  - Writing the *right* requirements for the project
  - Understanding the scale of a project
  - Balancing requirements and expectations from customer and PAB

Hardware Development

Hardware/Software Development

- Major Tasks
  - Minor component selection and manufacturing
  - Developing ROS architecture
- Major Risks
  - Complexity of software outgrowing project scope
  - Camera accuracy and reliability
- Challenges
  - Wiring and powering all components
  - Accounting for variability in bag orientation
  - Communication among team when things change or update
- Lessons Learned
  - Creating appropriate models
  - Developing a quantitative testing plan
  - Keeping detailed records of components and overall progress

Spring Semester

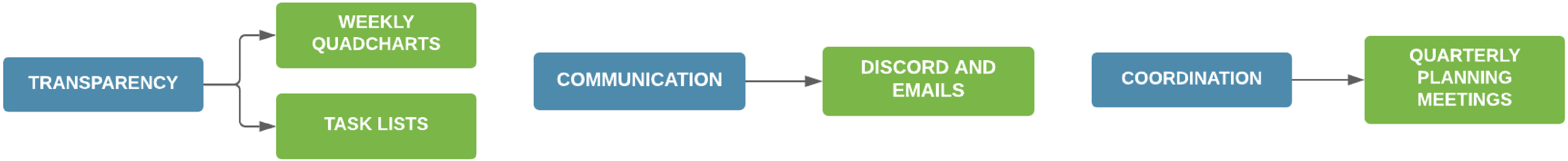


- Major Tasks
  - Testing components
  - Integrating subsystems for entire project
  - Quantifying Accuracy
- Major Risks
  - Camera accuracy being insufficient
  - Integrating all components through ROS
  - Hardware integrity and components breaking
- Challenges
  - Staying under budget
  - Keeping team up to date on changes and challenges
- Lessons Learned
  - Tracking progress and major project changes
  - Keeping on schedule
  - Hindsight – how I would have improved requirements and levels of success despite open ended problem

Section 6

- Project Management
- Approach
- Lessons Learned
- Budget

Project Management Approach



TRANSPARENCY

- All sub-teams **present weekly quadcharts** on this week's tasks, deliverables, risks, and plans
- For all deliverables there are **specific tasks** assigned to at least one team member with a clear due date.

COMMUNICATION

- Administrative emails are CC'd to all subteam leads.
- **All team chats, announcements, files** are readily available/linked on Discord.

COORDINATION

- All subteam leads meet quarterly to **plan out expectations, resource allocations, and discuss major risks**.

Lessons Learned – Program Management

SUCCESSES

- Very little confusion for deliverables/expectations
- Coordinated all sub-teams well, very few bottlenecking incidents
- Ensured a consistent weekly workload, few crunch/inactive periods

DIFFICULTIES

- Keeping track of internal deadlines
- Addressing unexpected pitfalls
- Oversight of inter-subteam coordination on deliverables

LESSONS LEARNED

- Make expectations clear and have regular updates
- An extra set of eyes on a topic can always be enlightening
- Delegate responsibilities to pairs of people whenever possible
- Enforce task list utilization

Lessons Learned – Pixy2 Sensors

RIVeR

SUCCESSES

- Correctly estimating position and orientation of cargo boxes
- Calibrating camera positions

DIFFICULTIES

- Pixy 2 color identification
- Pixy mounting solution
- ROS serial Arduino
- Bag identification for certain orientations

LESSONS LEARNED

- Cheap optical cameras need bright, even lighting
- Developing our own color detection algorithm with higher quality cameras would significantly improve performance
- Test set-up would be made much easier with a higher quality mounting solution (one that is easier to adjust sensors precisely, one at a time).
- With more cameras and better placement we could avoid unidentifiable positions/orientations

Lessons Learned - Software

SUCCESSES

- Internal communication framework (ROS)
- Software autonomy
- Successful integration of many complex SW and HW pieces (eventually)

DIFFICULTIES

- Complex SW integration
- Vague SW interfaces needed to be cleaned up and specified during integration

LESSONS LEARNED

- Software integration should begin as early and as often as possible in the project timeline
- Clearly define interfaces early

Lessons Learned - Translator

SUCCESSES

- High motor accuracy
- Linear stage was able to handle moments of the system
- Limit switches effectively tracked position of the baseplate

DIFFICULTIES

- Ethernet communication with the motor
  - Receiving UDP packets
- Limit switch broke after 1 month use
- Tolerancing manufactured parts
  - Misplaced interface holes

LESSONS LEARNED

- Arduino prefers UDP over TCP
- Use a different protocol for more control
- Slotting holes allows for easy integration
- Procure parts with good datasheets
  - Important for interfacing components
- Use higher grade limit switches if using for homing

Lessons Learned - End Effector

SUCCESSES

- High offset margin
- Consistent successful engagement/disengagement with bag at a max vertical offset of 11 mm
- Consistent successful engagement/disengagement with bag at 38-41 mm offset (depending on height)

DIFFICULTIES

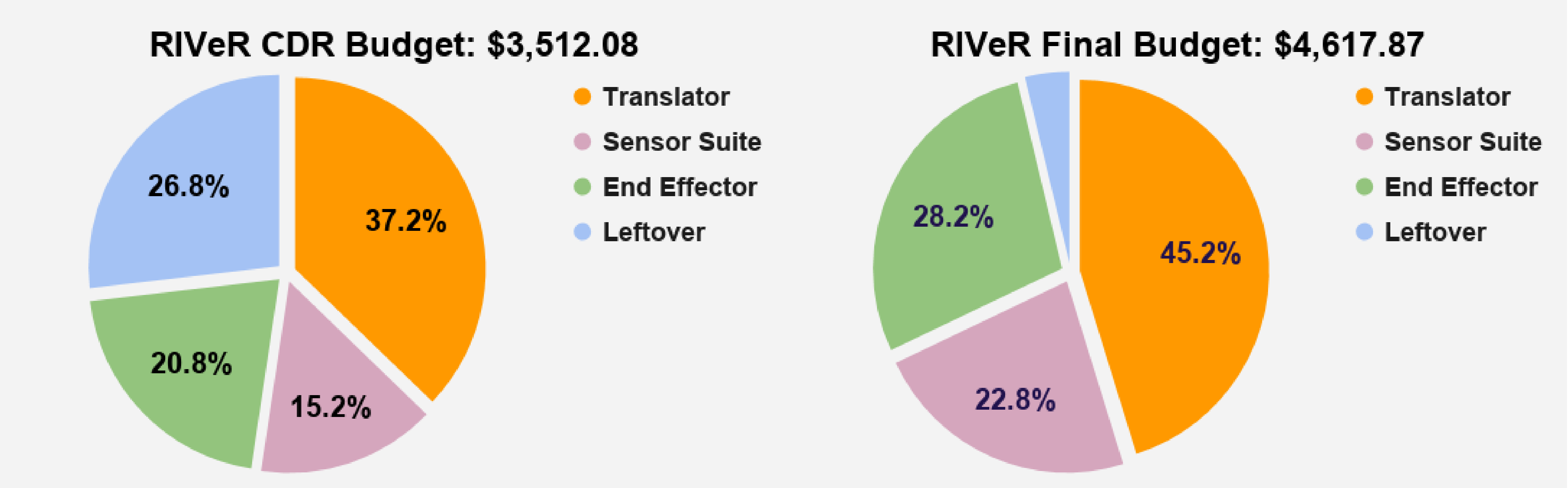
- First solenoid driver burnt out
- Remote actuation of solenoid
- Effective and clean wire management

LESSONS LEARNED

- Ensure that when end effector is not in use that the driver is powered off
- Prepare better heat dissipation solutions for electronic components with high clock speeds
- Have an initial wiring plan

Planned vs Actual Budget

Budgetary Changes: $1,105.59 extra added to budget post-CDR



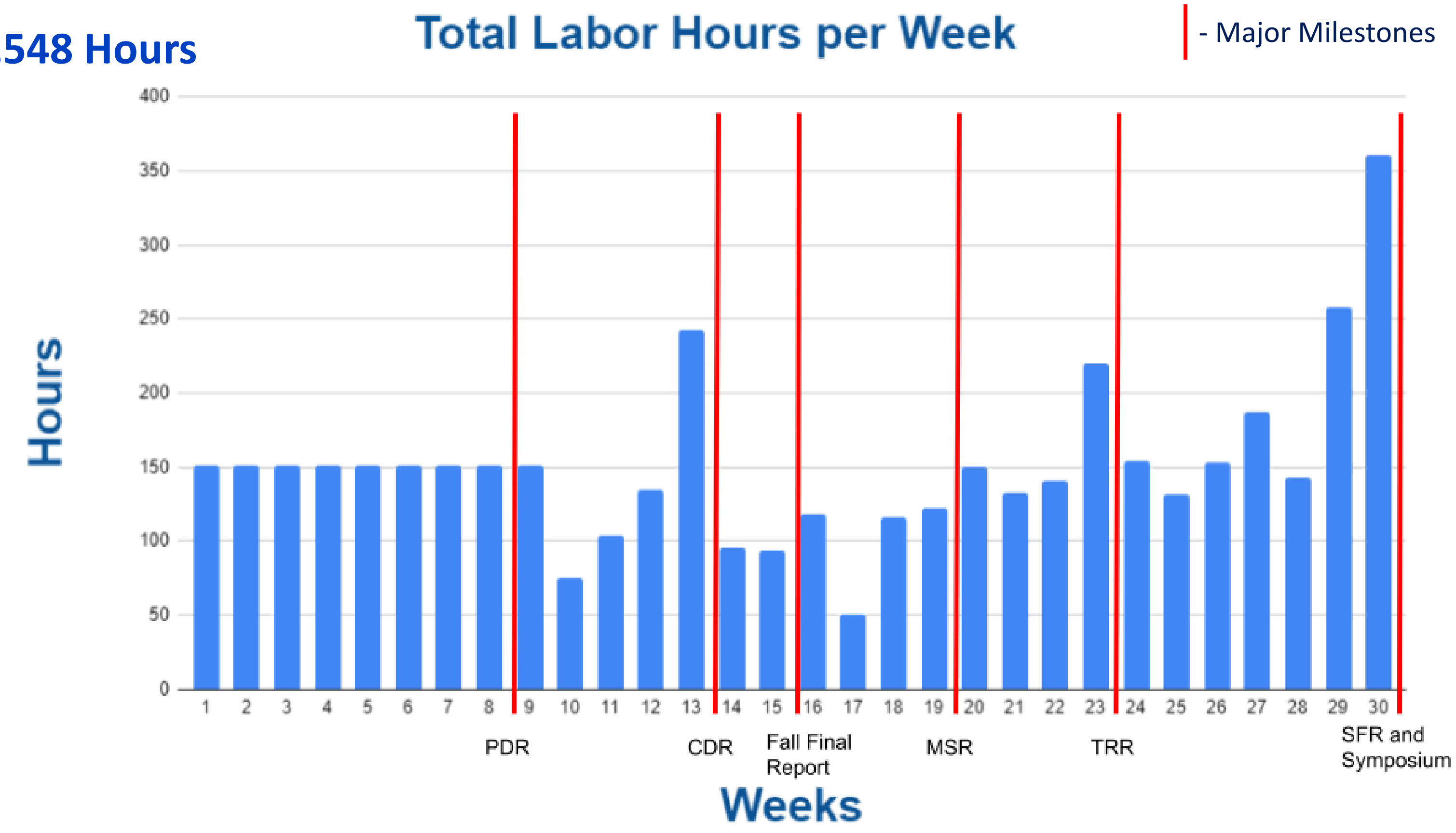
Post-CDR Purchases

Translator Items	Cost	End Effector Items	Cost	Sensor Items	Cost
Shaft Coupling	$26.62	Stepper Driver	$22.94	High-Pressure Pipe	$13.41
Cable Carrier	$108.84	Manual Dump Valve Coupler	$5.49	PVC Pipe	$37.98
Cable Mounting Brackets	$8.44	UR10 Baseplate	$177.15	PVC Pipe Fitting	$14.85
Strut Channel - Zinc Plate Steel	$160.93	Micro Switch for Bag Detection	$17.63	RAM Swivel Socket	$74.91
Hex Head Screw (x5)	$10.20	Micro Switch Connection Wires	$4.95	1-1/4" Phillip Screw Pack	$7.86
Hex Nut (x5)	$4.73	Zinc Head Screw- 10 mm (x50)	$15.53	Arduino Motor Shield	$13.49
Grid Paper Roll	$16.99	Steel Head Screw- 14mm (x25)	$5.73	PLTC Cable	$14.64
Steel Head Hex - 1.75" (x5)	$33.02	Brass Industrial Quick Disconnect Hose Coupling for Air	$3.24	Belkin Ethernet Cable	$7.42
NEMA 23 Mount Bracket	$12.99	M8 3-Pin Connector	$9.99	2x4 x 8ft	$18.45
		Telemecanique M8 Sensors	$25.74	2x4 x 10ft	$9.62
		Limit Switch	$6.12	Corner Braces	$7.72
		Solid Inline PNP Direct	$61.64	Nylon Mason Line	$5.47
				15 ft Micro USB Cable	$45.12
				LED 100W Chip (x4)	$39.86
				Protoboard	$9.94
				Voltage Booster (x2)	$8.99
				White Foam Board (x10)	$31.98
				Matte Spray Black	$4.97
$382.76		$356.15		$366.68	
$1,105.59					

"Industry" Cost of Project

- **Given:** $65,000 for 2,080 hours ---> **$31.25/hour**
- Hours Worked (Fall and Spring): **4,548 Hours**
  - Average: 151 hours/ week
  - **Labor Cost: $142,142.86**
- 200% Overhead Rate **$284,285.71**
- Total Cost Including Overhead:

$426,428.57



Special Thanks

Sierra Nevada Corportation and Loren McDaniel

Dr. Neogi

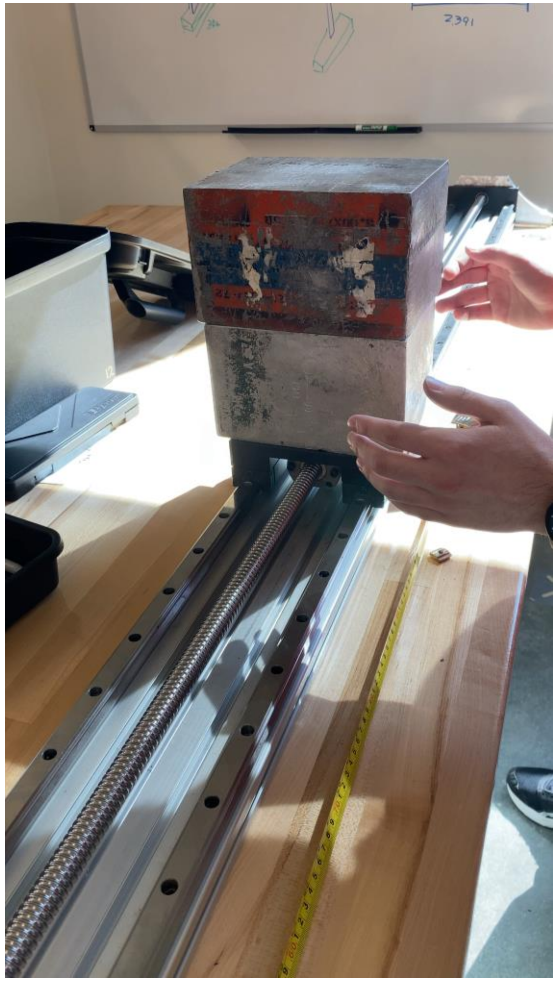
CU Boulder Aerospace Department

PAB

Back Up

System Test Video

Testing Videos



Translator Accuracy

Levels of Success Accomplished

Translator Level 3

Design Requirements

DR.5.2 The translator shall be able to move to a prescribed location within a margin of 5 cm.

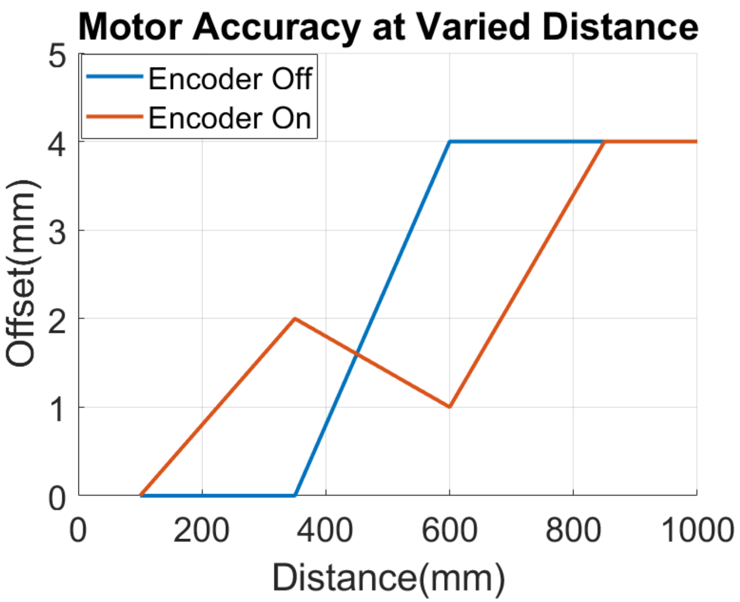
Expected Results/Model

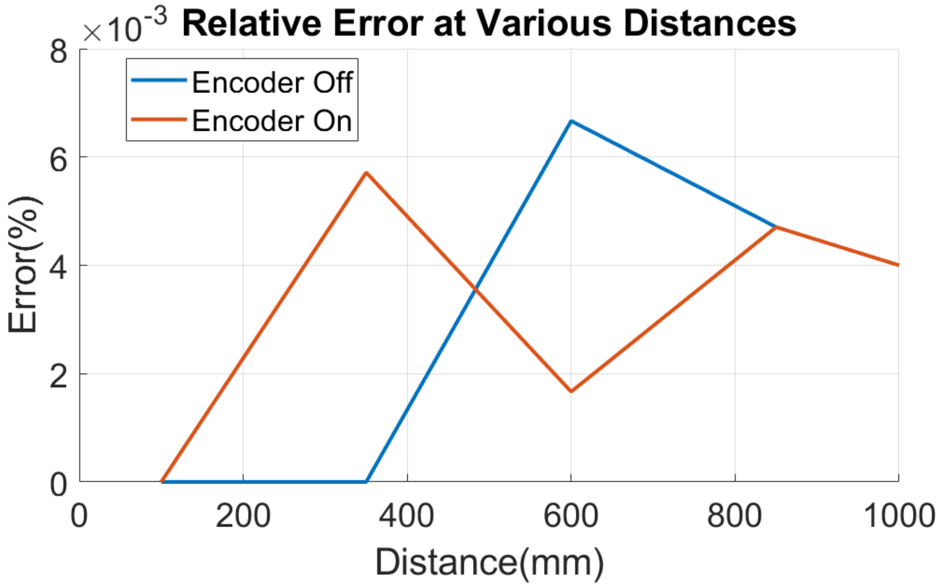
- .13 mm accuracy from motor/linear stage

Pass/Fail Condition

- Translator is accurate up to 5 cm precision

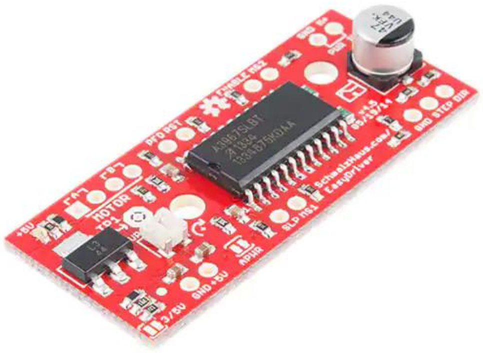
Results

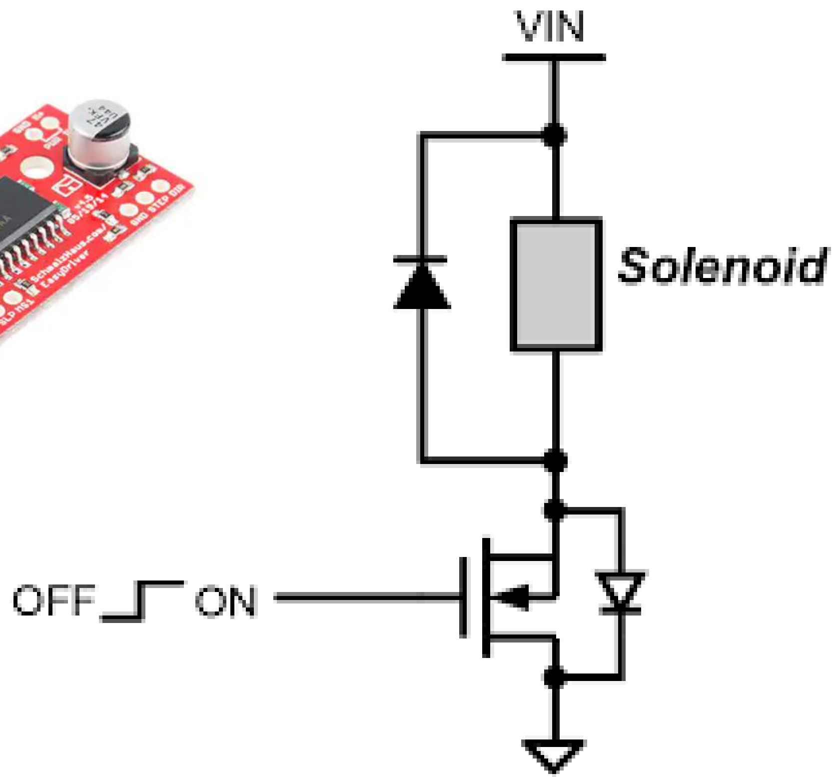




Solenoid Driver Failure

- Likely causes
  - Overheating
  - Extended current draw from constant solenoid activation





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		$1,105.59			

Motor	$76.04
Camera Mounting	$190.27
Temporary Arm Mounting	$208.88
Cable Carrier	$117.28
Wires, Connectors	$345.95
Camera Lights	$58.79
Swtiches, Sensors	$54.44
Misc	$53.94
$1,105.59	

Safety (1/2)

Safety Hazards	Safety Procedures
Hanging camera mounts	All operators must enter mounting cage from sides or middle where cameras are not hanging
High temperature lighting	All operators must enter mounting cage from sides or middle where lights are not hanging
Pressurized solenoid	Follow proper (un)installation procedures for using solenoid
Arm Translation	All operators must not cross translator track at any time during operation. All operators must stand at least a foot away from center of translator when arm is being translated.
Arm Movement	All operators stand beyond arm envelope (1.3 meters)

Safety (2/2)

Safety Hazards	Additional Operational Safeguards
Hanging camera mounts	Orange string cables are clearly visible at ends of mounts to ensure hanging fixtures can are not hard to miss.
High temperature lighting	Lighting will be powered off when not in operation to avoid overheating.
Pressurized solenoid	Solenoid will be depressurized when not in operation.
Arm Translation	Arm does not perform maneuvers during translation along track. Protective stops are put in place using limit switches.
Arm Movement	Arm motion is constrained within a defined set of planes. Arm utilizes emergency braking software. Arm moves at slow speeds to meet industry minimum requirements for collaborative operations: "Robot/hazard speed is reduced the closer an operator is to the hazard. Protective stop is issued before contact." - (ANSI/RIA R15.06) Arm will be shut down during maintenance tasks.