HEIST

Critical Design Review

ASEN 4018 - Team 5

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ENGINEERING SCIENCES

HEIST

HYBRID ENVIRONMENTAL IMMERSIVE
SIMULATION TRAINING

INTAKE NUMBER:
4018/4028

DATE:
2022/2023

Agenda

- Project Purpose and Objectives (2 min)
- Design Solution (3 min)
- Critical Project Elements and Risks (3 min)
- Design Requirements and their Satisfaction (9 min)
- Verification and Validation (9 min)
- Project Planning (4 min)

Main Acronyms and Definitions

VR - *Virtual Reality*	• Computer-generated environment
PR - *Physical Reality*	• The world we live in
HR - *Hybrid Reality*	• VR and PR combined. Interaction with PR has consequences in VR
PCs - *Physical Constraints*	• Real world body constraints to limit motion
EVA - *Extravehicular Activity*	• Astronaut activity outside of a spacecraft/habitat
ORU - *Orbital Replacement Unit*	• Block of electrical components for easy replacement/fixes

Motivation

- Expensive to train astronauts for space operations
  - Current system requires training in a very specific facility (inaccessible elsewhere - expensive to build)
- Current VR training is not immersive
- Want to build an immersive and cheap procedural training system

Mission Statement

The HEIST system will develop the capability to train humans for lunar extravehicular habitat maintenance and repair operations using hybrid reality.

Project's Goals

Develop a hybrid reality training system (VR + PR)

- Track the user's interaction with PR hardware
- Track the user's motion (head and hands) in PR
- Display the outcomes of the user's actions in VR

Increase training immersion

- Constrain user's arm and shoulder motion
- Display environmental constraints (in VR)

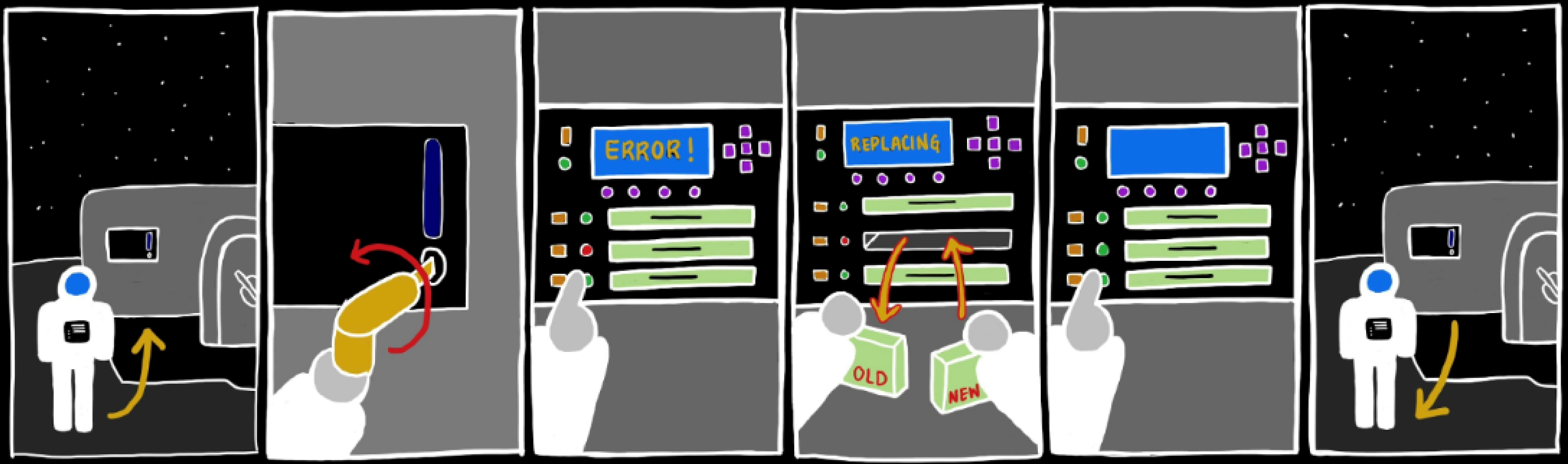
Create a safe and versatile training environment

Objectives & Levels of Mission Success

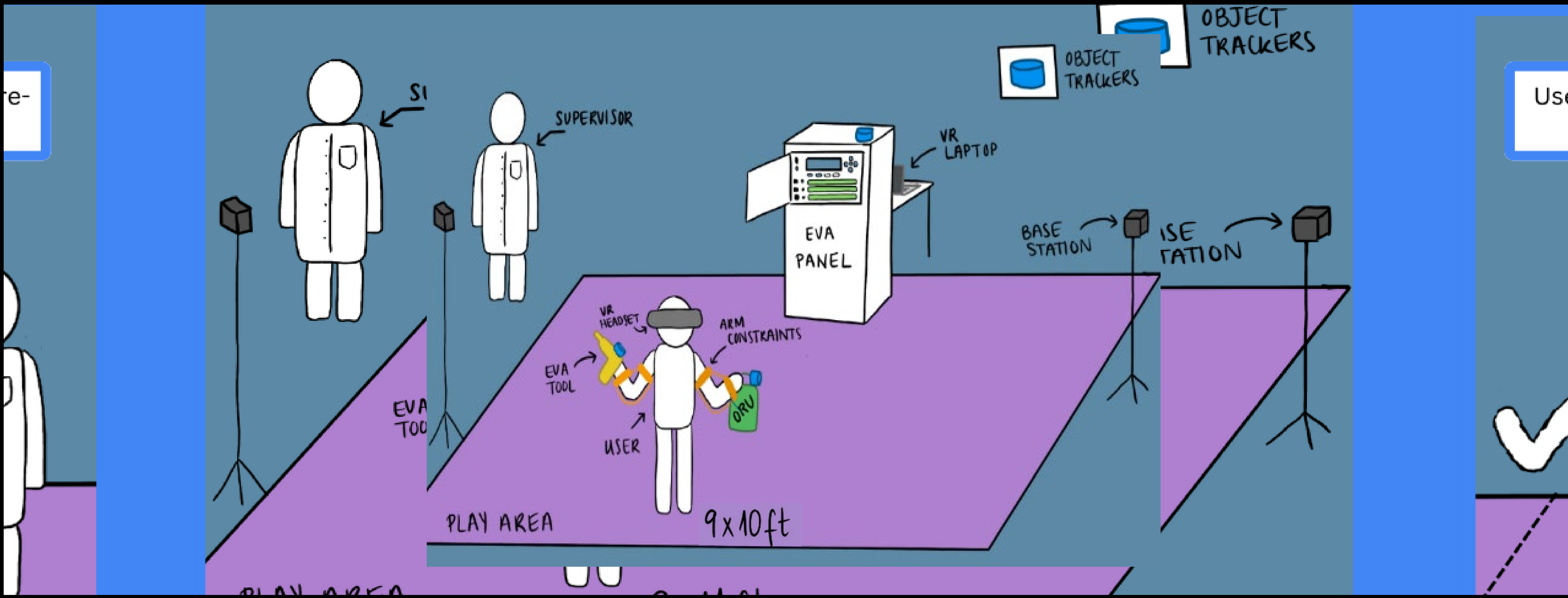
Objectives	Level 1 Success	Level 2 Success
VR Environment	The project must include a VR environment that allows for some user interaction and resembles a lunar environment	The project must include a fully interactive and visually accurate VR lunar environment that includes shadows, lighting, and lunar textures
Integrate with Real-World Elements	The project must allow for **one** tool and/or panel to integrate from PR to the VR environment, resulting in an HR environment	The project must allow for the integration of **multiple** tools and/or panels in the HR environment
Lunar Environment Conditions	The project will represent lunar lighting, temperature, **or** auditory inputs	The project will simulate lunar lighting, temperature, **and** auditory inputs
Movement Constraints	The project will incorporate range-of-motion constraints that limit arm and shoulder mobility more than regular clothes	The project will incorporate range-of-motion constraints that limit arm, upper-body, and hand mobility

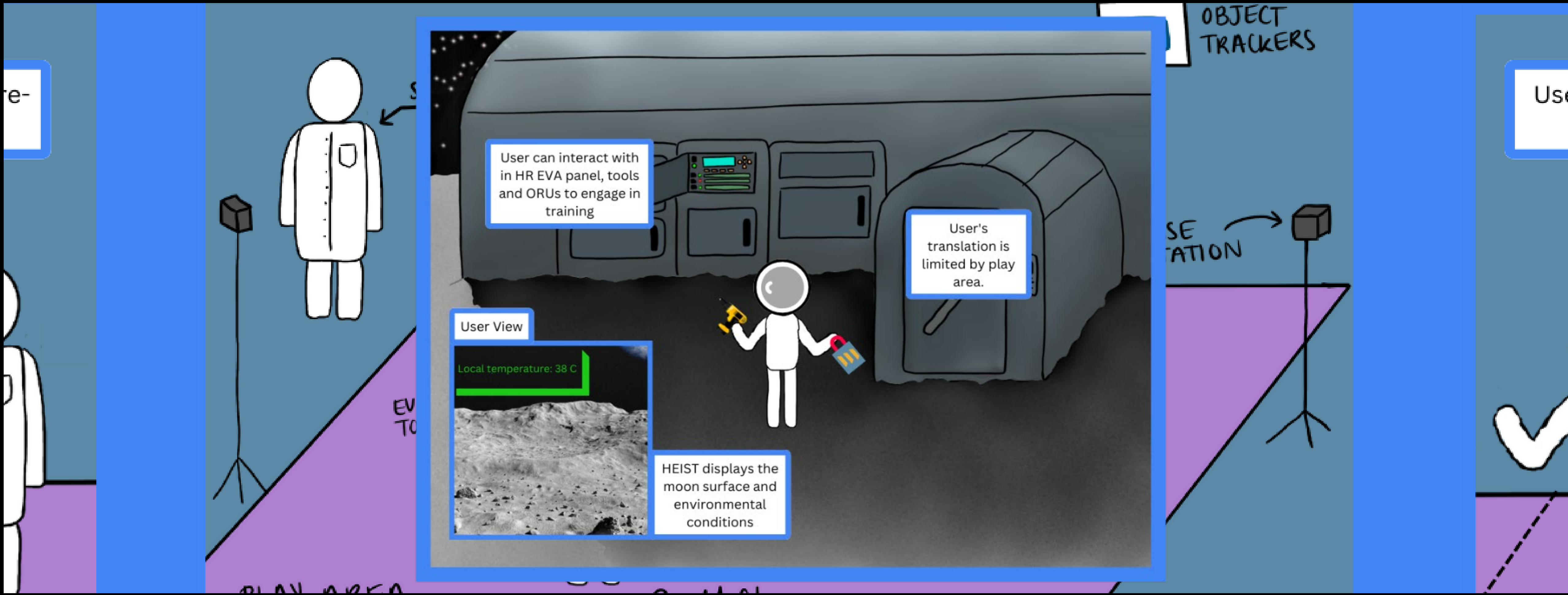
Scenario: Solar Panel Repair

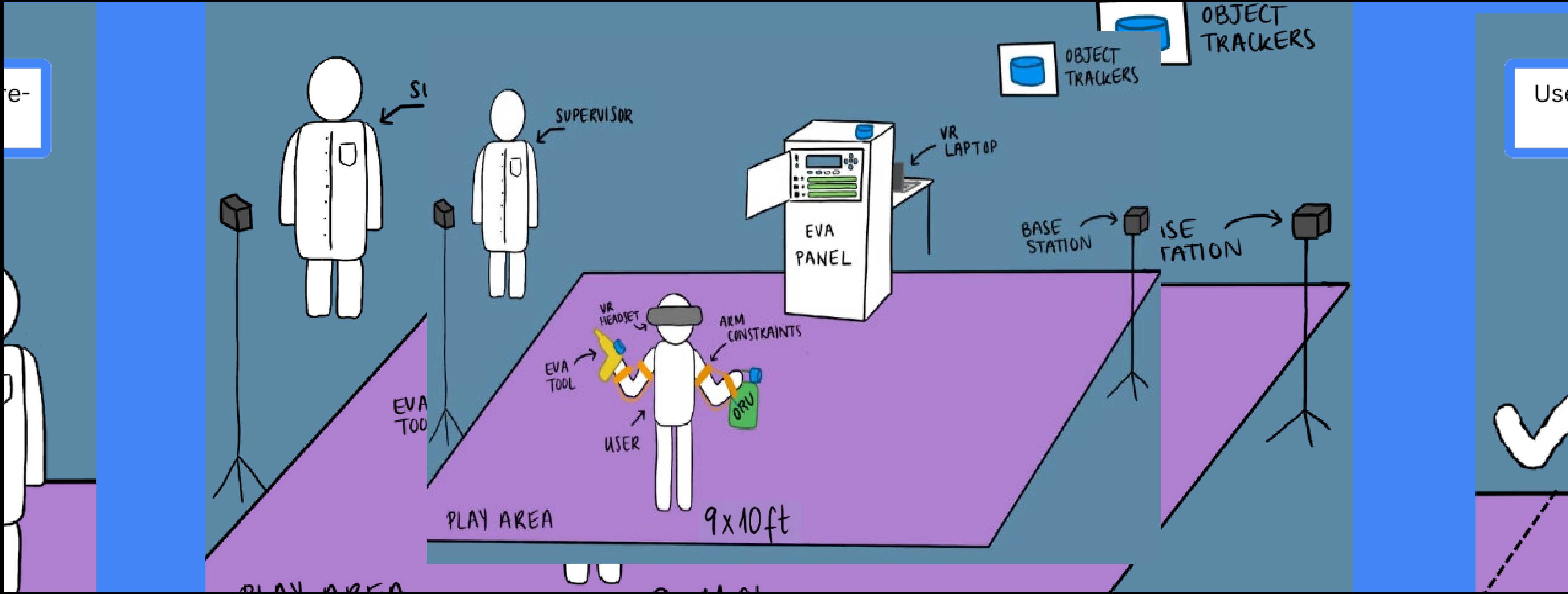
The heaters have failed at a moon sensor station, and thermally sensitive equipment is at risk. The user's task is to identify a damaged solar panel control unit (ORU) and address the issue immediately.



Approach panel | Open panel with tool | Find failure | Replace ORU | Ensure new ORU is working | Close panel and leave


OBJECT TRACKERS
SUPERVISOR
VR LAPTOP
EVA PANEL
BASE STATION
VR HEADSET
ARM CONSTRAINTS
EVA TOOL
ORU
USER
PLAY AREA
9x10ft


OBJECT TRACKERS
User can interact with in HR EVA panel, tools and ORUs to engage in training
User's translation is limited by play area.
User View
Local temperature: 38 C
HEIST displays the moon surface and environmental conditions


OBJECT TRACKERS
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SUPERVISOR
VR LAPTOP
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BASE STATION
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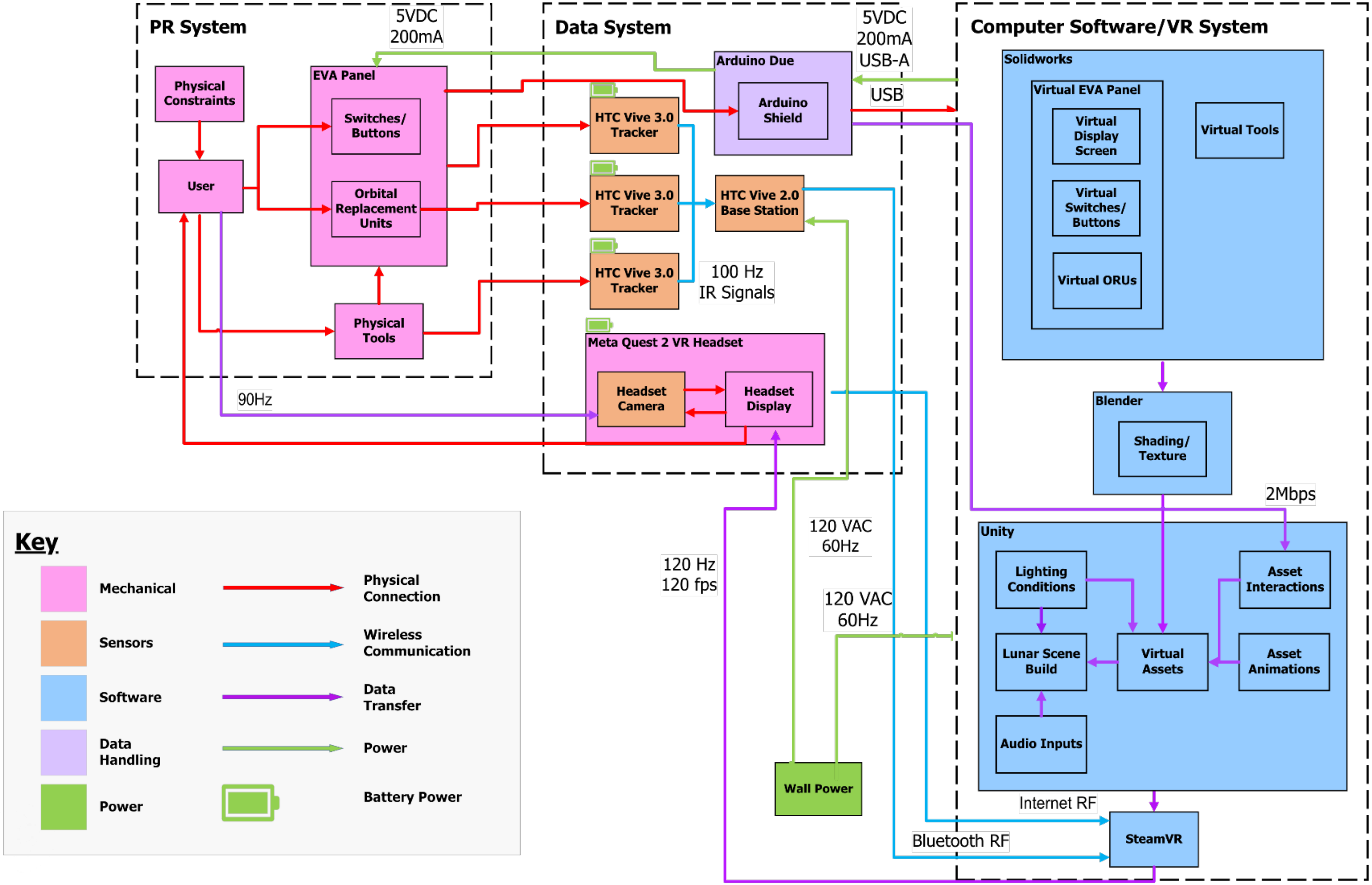
ARM CONSTRAINTS
EVA TOOL
ORU
USER
PLAY AREA
9x10ft

Design Solution


PR System
5VDC
200mA
Physical Constraints
EVA Panel
Switches/ Buttons
User
Orbital Replacement Units
Physical Tools
90Hz
Data System
5VDC
200mA
USB-A
Arduino Due
Arduino Shield
USB
HTC Vive 3.0 Tracker
HTC Vive 3.0 Tracker
HTC Vive 3.0 Tracker
HTC Vive 2.0 Base Station
100 Hz
IR Signals
Meta Quest 2 VR Headset
Headset Camera
Headset Display
Computer Software/VR System
Solidworks
Virtual EVA Panel
Virtual Display Screen
Virtual Switches/ Buttons
Virtual ORUs
Virtual Tools
Blender
Shading/ Texture
2Mbps
Unity
Lighting Conditions
Asset Interactions
Lunar Scene Build
Virtual Assets
Asset Animations
Audio Inputs
120 Hz
120 fps
120 VAC
60Hz
120 VAC
60Hz
Wall Power
Internet RF
Bluetooth RF
SteamVR
Key
Mechanical
Physical Connection
Sensors
Wireless Communication
Software
Data Transfer
Data Handling
Power
Power
Battery Power

PR Hardware

VR Visualization

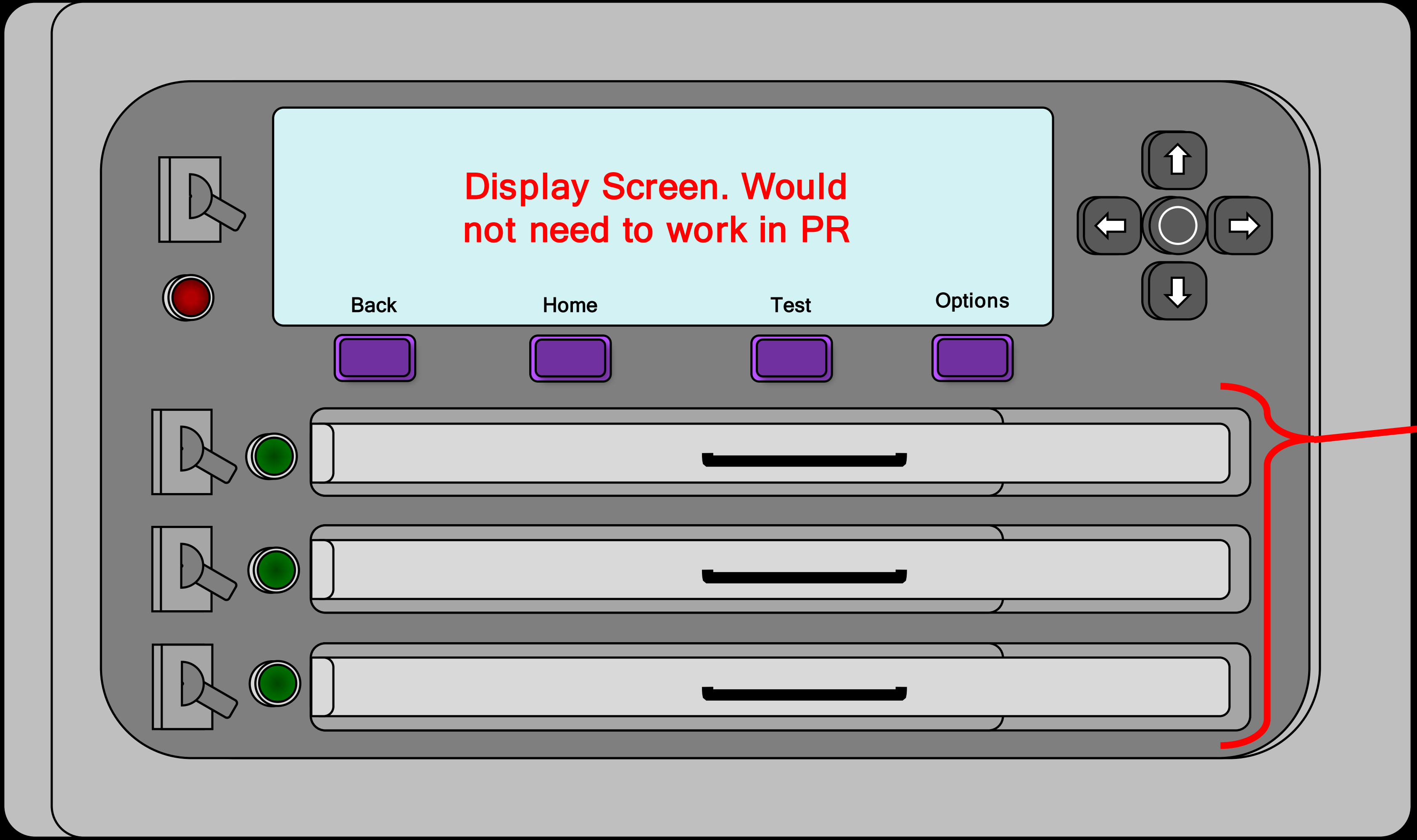
EVA Tool Design

Appendix

3D-printed tool will open the panel's locking mechanism

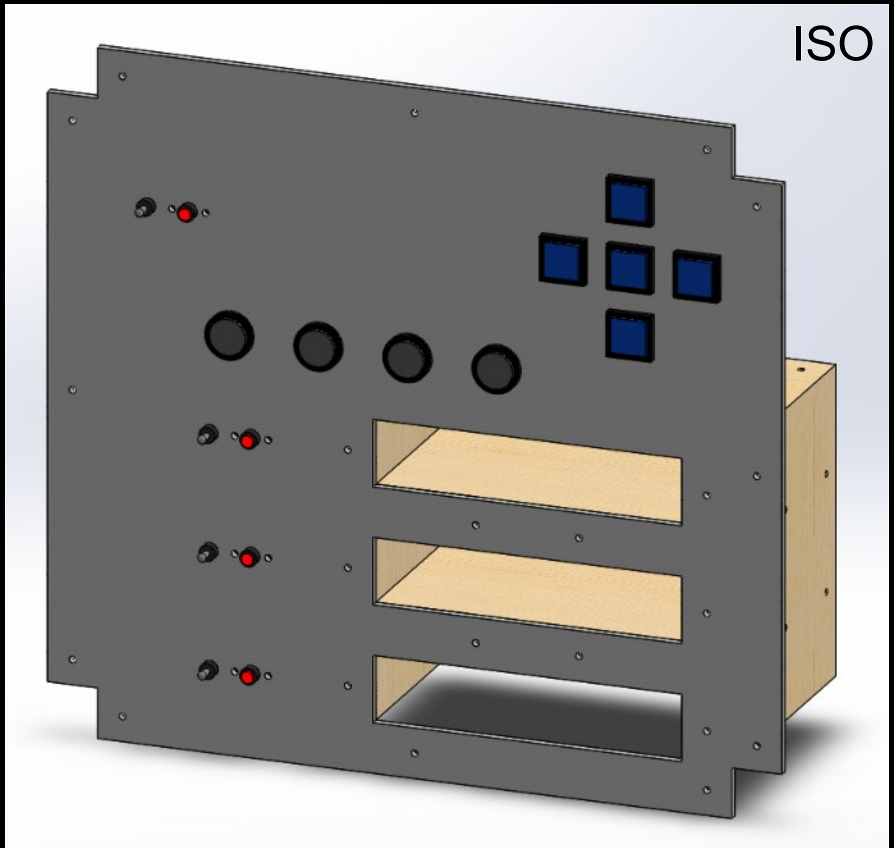
VR Visualization

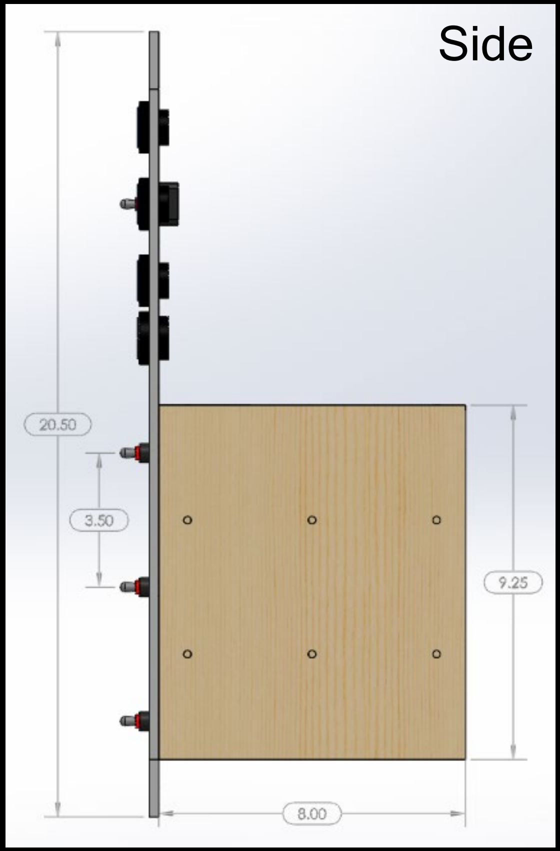
ORU = Orbital Replacement Unit

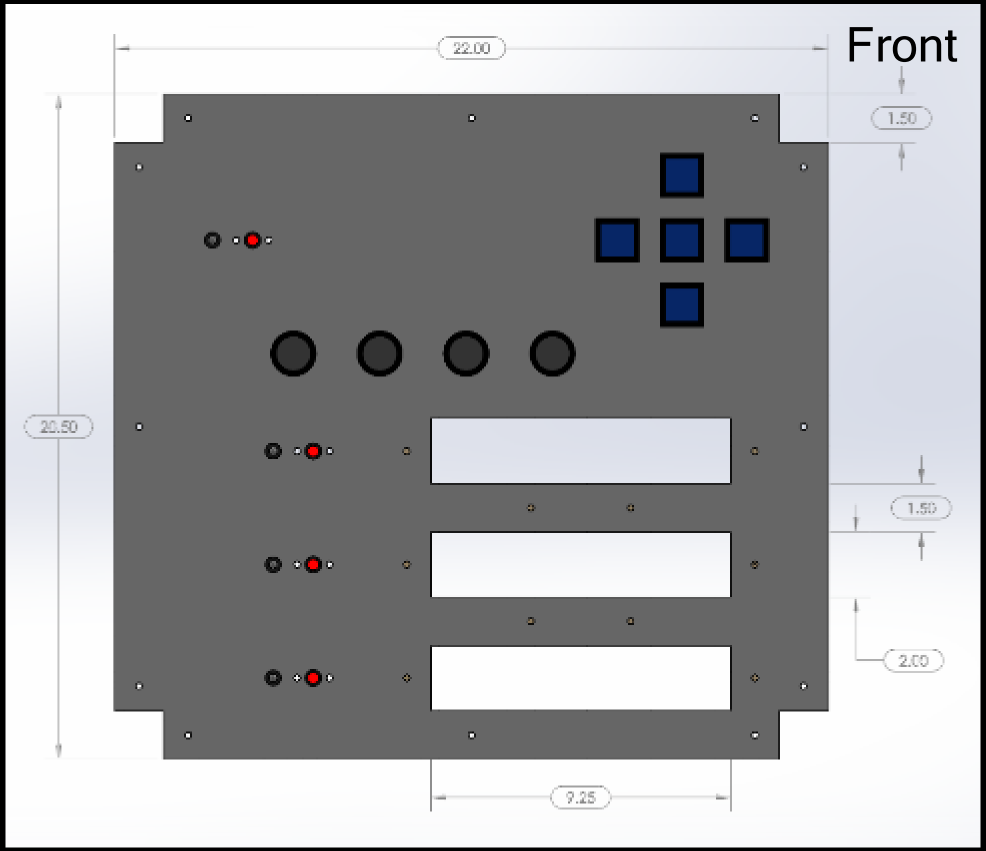


ORUs
Only one needs to be removed and tracked but 2nd level of success would be to track all and allow all to be removed

PR EVA Panel



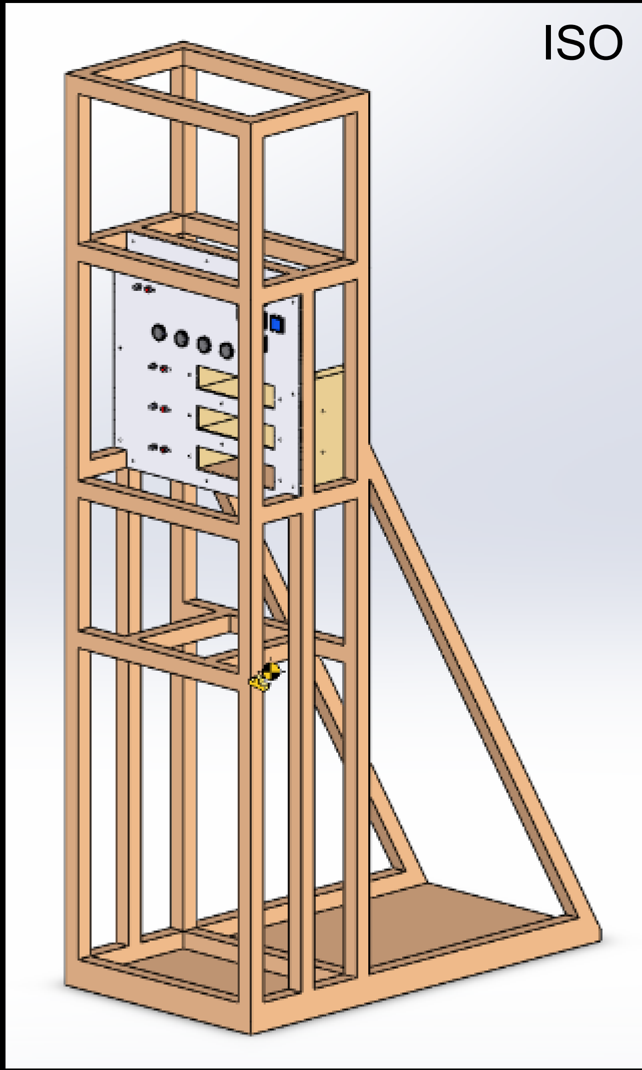


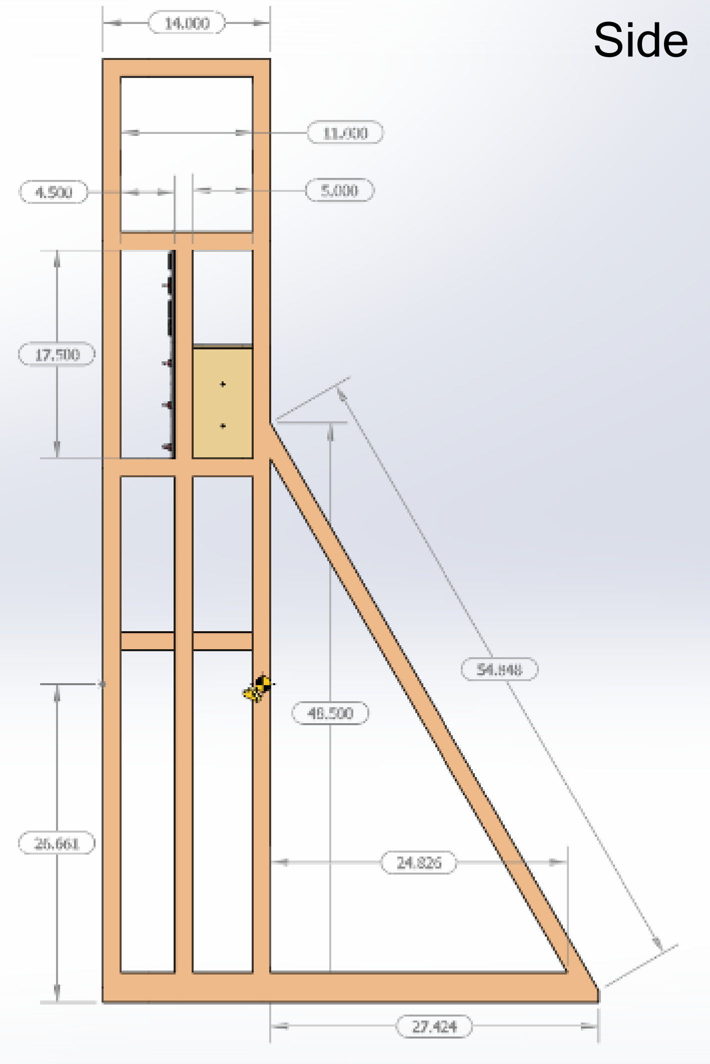


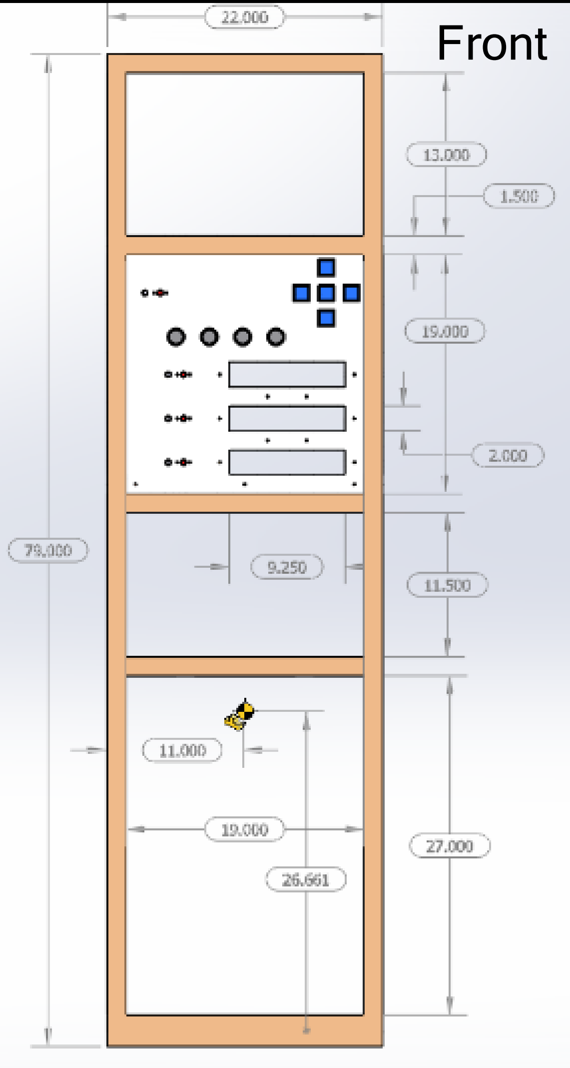
Units = inches

Appendix | ORU Design | EVA Tool Design | Panel Door

EVA Panel Structure





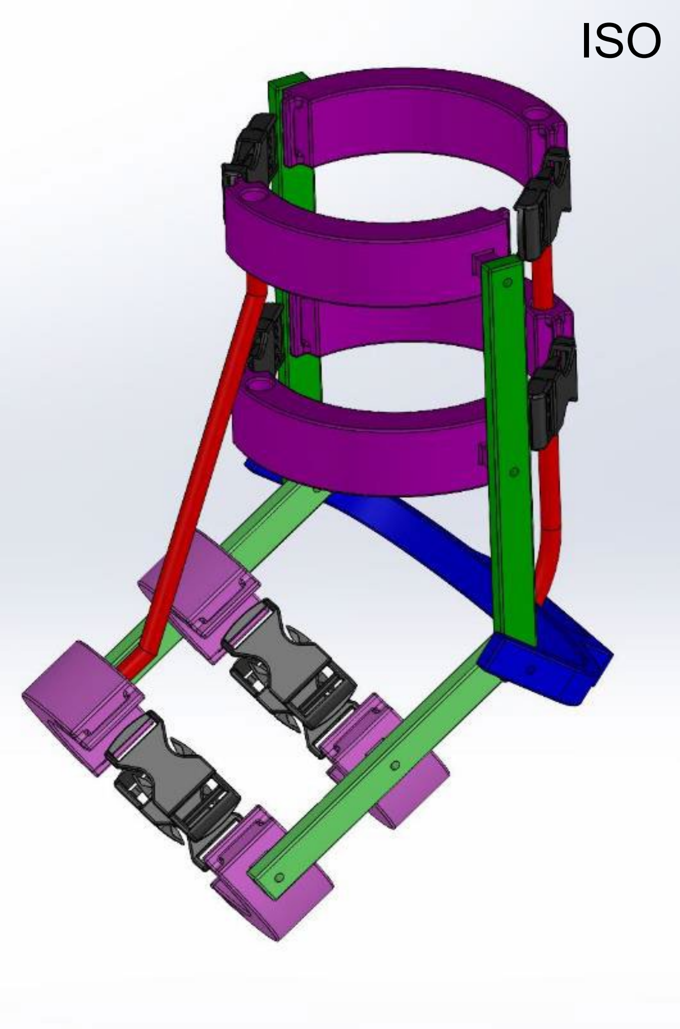


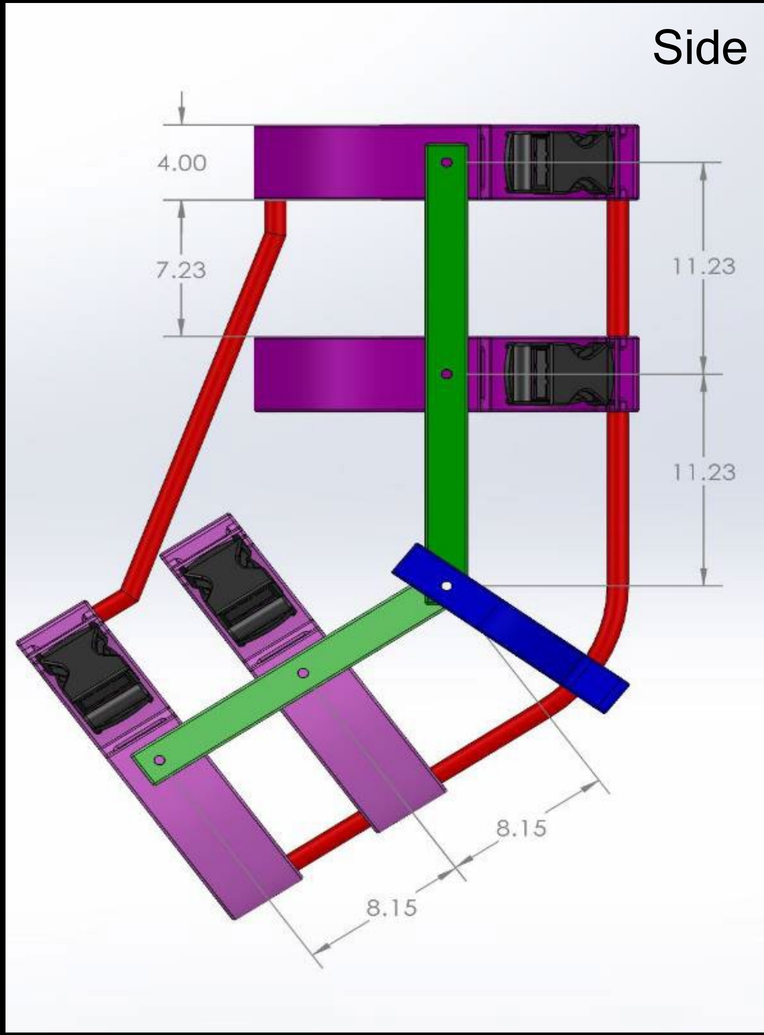
Units = inches

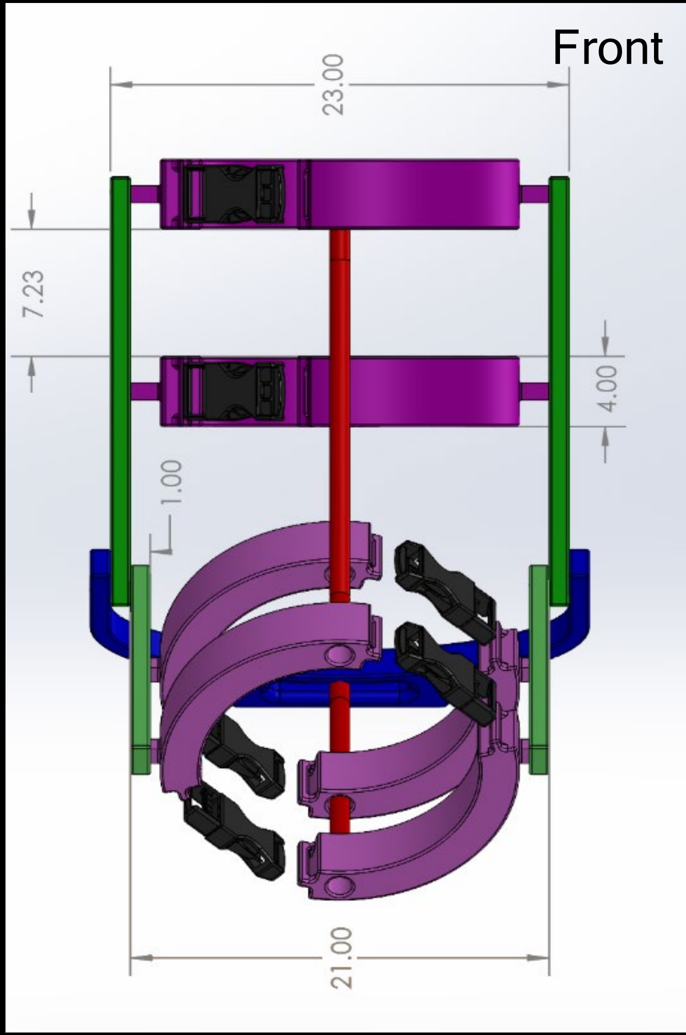
EVA Panel Tipping Model

Appendix

Arm Harness Constraint



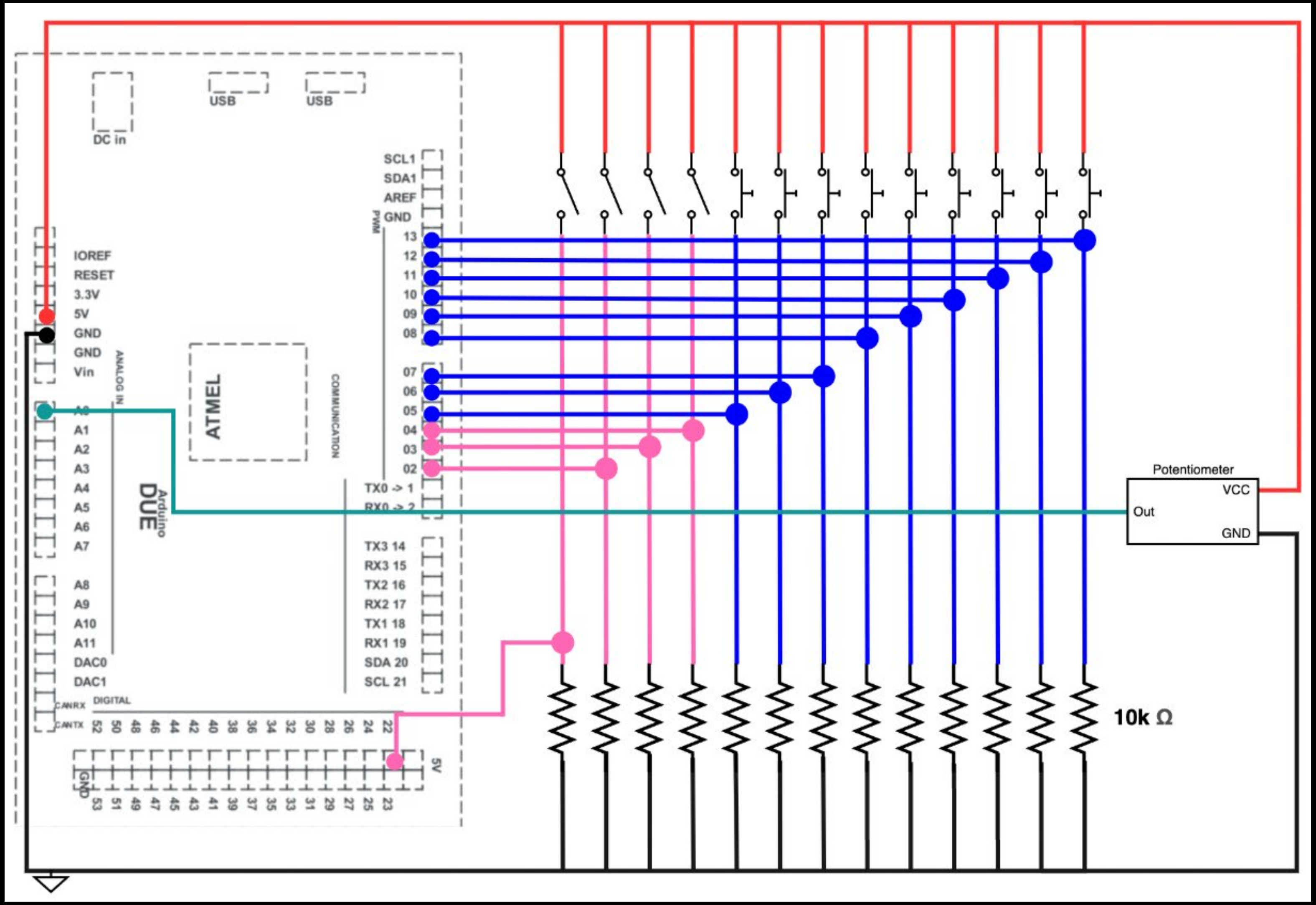




Units = centimeters

Data Acquisition, Handling & Display

EVA Panel Schematic



Schematic includes:

- Switches (x4)
- Buttons (x9)
- 10k Ω resistors (x13)
- Potentiometer (1x)
- Arduino Due (1x)
- Wire

Blue wires are for switches, pink for buttons, and teal for the potentiometer

All signals from switches/buttons will be **digital**.

Signal from potentiometer will be **analog**.

HR Data Transfer - Feasibility Demo

Goals

- ~ Demonstrate capability to accurately determine the state of multiple RW assets per DR 1.2.2.1
- ✓ Update state of RW assets at a rate of 90 Hz or greater per DR 1.2.2
- ✓ Communicate state of RW assets to Unity per DR 1.2.6

PR - VR Data Transfer DEMO

Arduino UNO + Button + Switch + Rotary Encoder + Multiplexed Keypad

Results

- Arduino communicates input devices' state to laptop at 2600 Hz - 2900 Hz
- The laptop can read and store state bitstrings in Unity
- Accurately reads the state of 19 inputs with two limitations:
  - Keypad 'Ghost' Presses
    - Mitigate: Don't require simultaneous inputs
  - Rotary Encoder Skips
    - Mitigate: Use a potentiometer

HTC Vive 3.0 Trackers

- Battery Life: 7.5 hours
- Mass: 75 g
- Dimensions: 70.9 × 79.0 × 44.1 mm
- Field of View (FOV): 240˚
- Cost: $ 130 / unit
- Functionality: Support for SteamVR, require HTC Vive Base Station 1.0 or 2.0

HTC Vive Base Stations (BS1.0 / BS2.0)

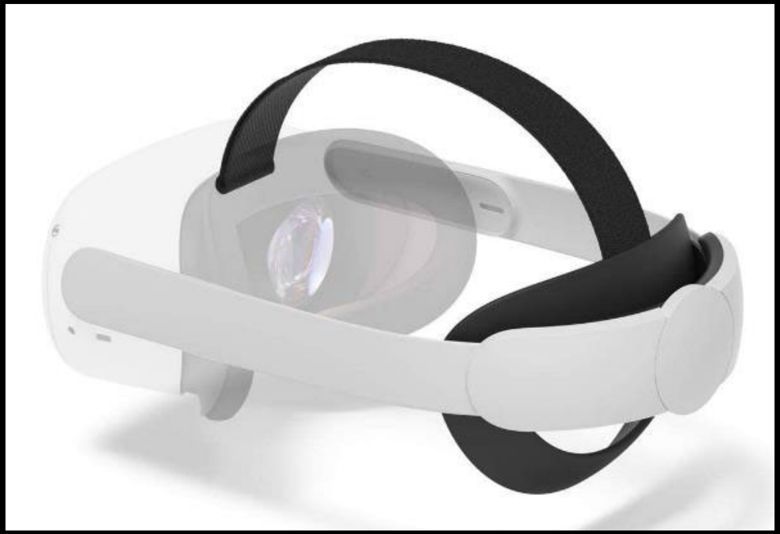
- Battery Life: Plugged in → 120 V
- Tracking Frequency: 60Hz → 100Hz (out of stock)
- Tracking range: 3.5 m (~11’5”) → 7 m (~ 23’)
- Field of View (FOV): 160˚ horizontal
- Require Line of Sight (LOS) w/ other Base Stations
- Require 2 BS to avoid blocking FOV of trackers
- Cost: $ 150 / unit → ~ $250 / unit

BS = Base Station

META Quest 2

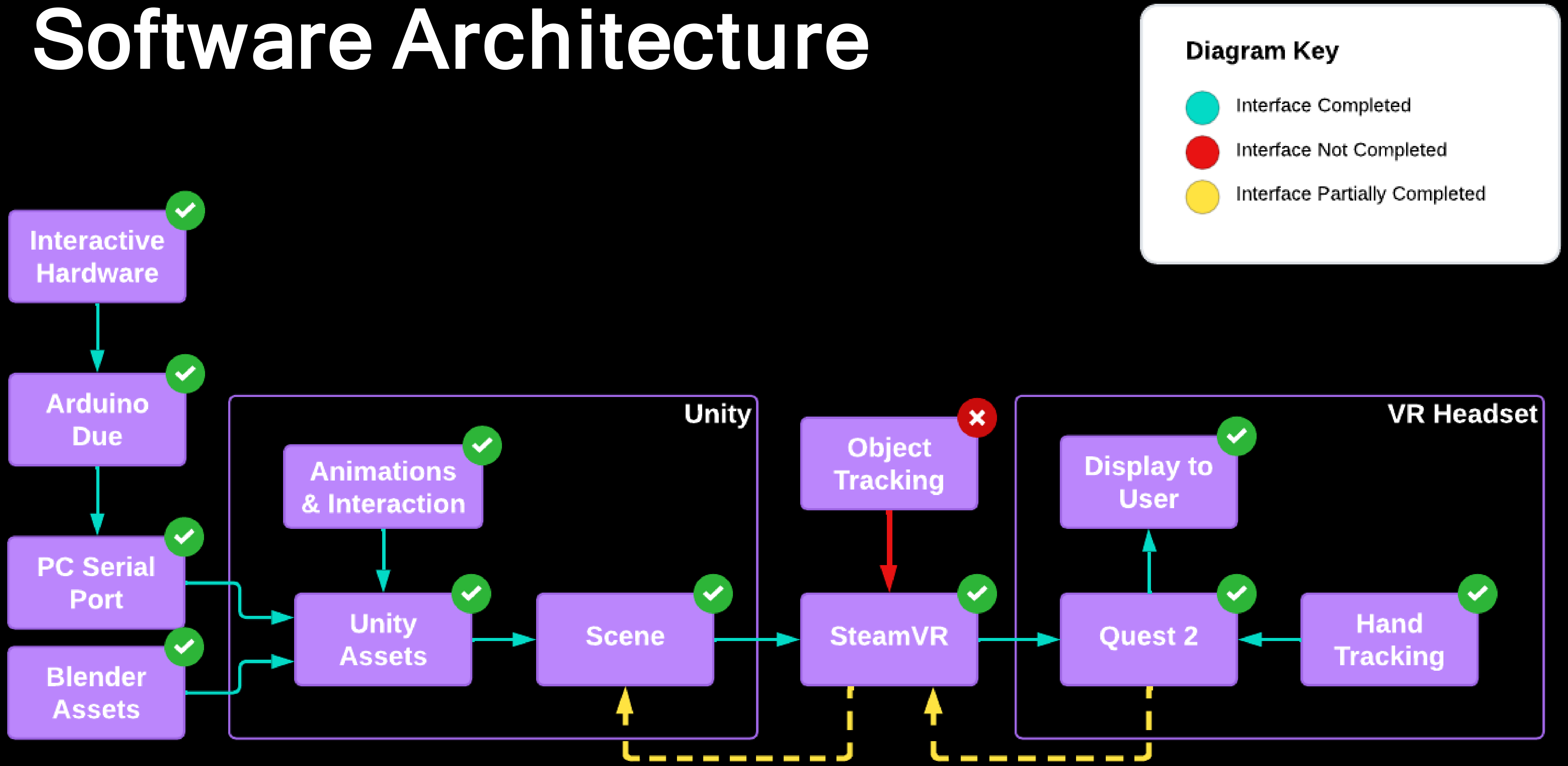
- Battery Life: 2-3 hours
- Display Speed: 60, 72, 90, 120 FPS
- Tracking range: Arm length
- Tracking Type: Optical
- Field of View (FOV): Test pending
- Require Line of Sight (LOS) for tracking
- Cost: $400 / unit → Check out from Department

Front cameras handle optical hand tracking

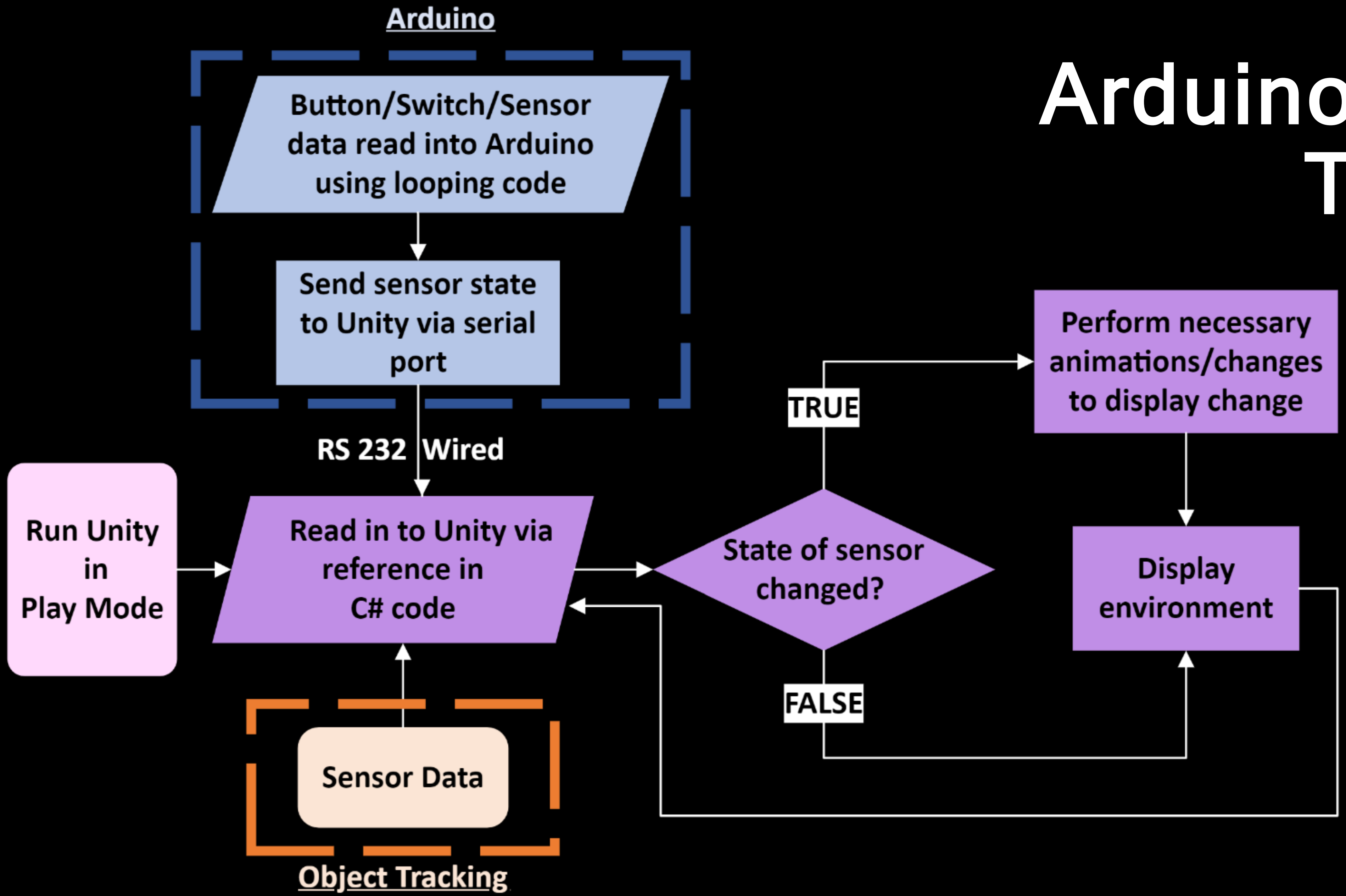


Software

Software Architecture



Arduino/Object Tracking



CPEs and Risks

Critical Project Elements (CPEs)

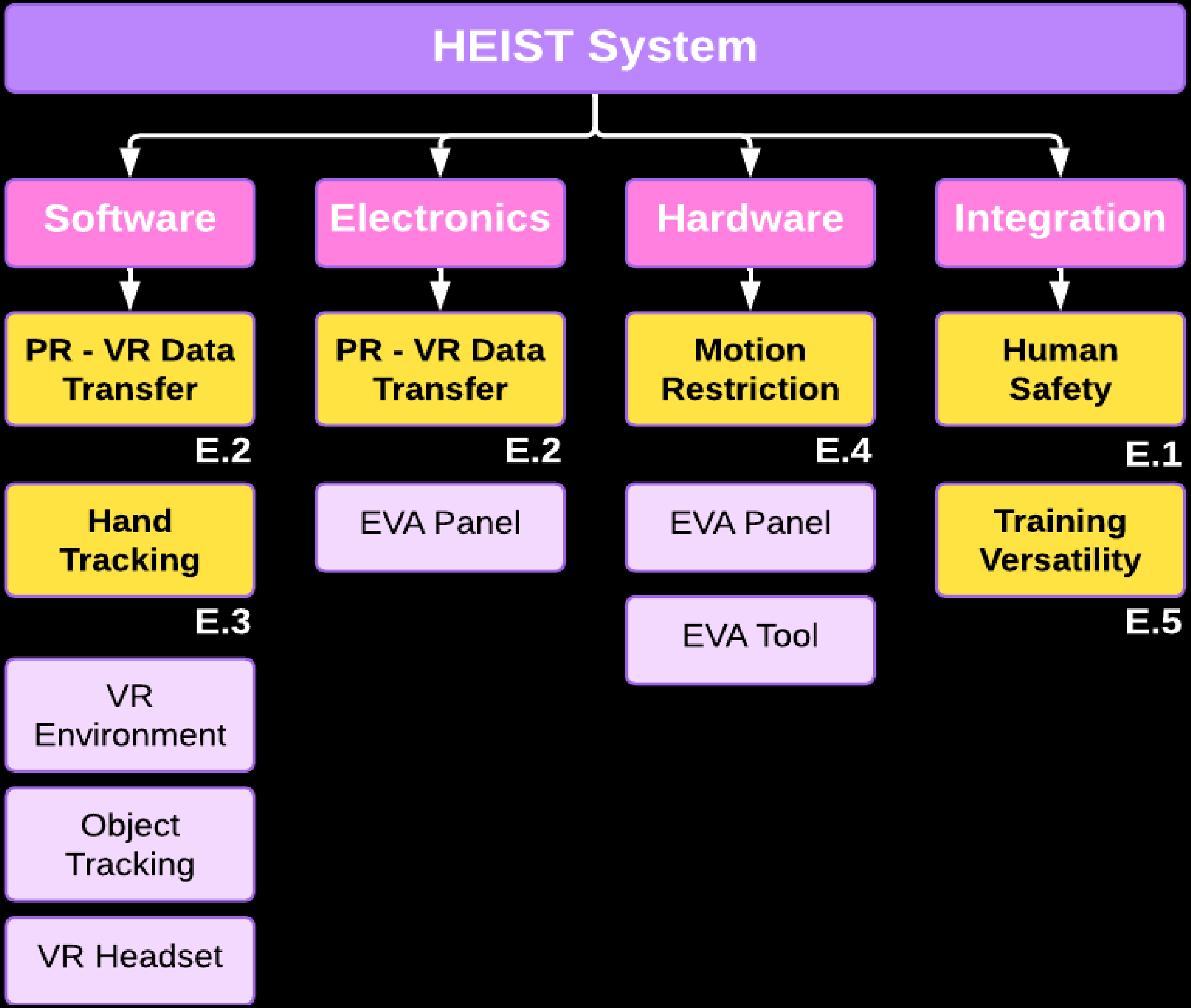


Diagram Key

- Project Elements
- Critical Project Elements (CPEs)

E.1 Human Safety associated Risks

Motion sickness due to high sensitivity

- *Cause:* User is prone to motion sickness
- *Consequence*: Difficulty participating in the simulation
- *Mitigation*: Screen users to prevent participation of high-risk users

Motion sickness due to latency / refresh rate

- *Cause*: High latency. Low refresh rate. Low resolution
- *Consequence*: Difficulty participating in the simulation
- *Mitigation*: Decrease resolution to acceptable range and complexity of the environment

E.2 PR-VR Data Transfer associated Risks

Lag in PR – VR data transfer (high latency)

- *Cause*: Simulation can't handle required data rates
- *Consequence*: Increased latency → Increased risk of motion sickness
- *Mitigation*: Reduce complexity. Prototype and test.

E.3 Hand Tracking associated Risks

Inaccurate hand tracking

- *Cause*: Hands are outside of FOV of headset's cameras
- *Consequence*: Inability to operate hardware. Increased risk of motion sickness.
- *Mitigation*: Teach user proper location of hands and limitations of hand tracking

E.4 Motion Restriction associated Risks

Arm constraints harm the user

- *Cause*: Hard surfaces pressing against the skin
- *Consequence*: Loss of immersion. Inability to continue training
- *Mitigation*: Incorporate soft surfaces (cushioning). Human testing.

Arm constraints provide too much restriction

- *Cause*: Restriction applied to joint movements that don't need restriction
- *Consequence*: Inability to engage in simulation. Loss of immersion.
- *Mitigation*: Modelling and human testing.

Risk Assessment

PROBABILITY	DESCRIPTION OF LEVEL
1	Almost certain it will NOT happen
2	Almost certain it will happen AT LEAST ONCE
3	Almost certain it will happen MULTIPLE TIMES
4	Certain it will happen AT LEAST ONCE
5	Certain it will happen MULTIPLE TIMES

	but able to conintue. 2 week delay. Loss of immersion
4	Inabilty to use a subsystem. Temporary state of mild discomfort (< 1h). May be able to continue. 3 week delay
5	Inability to use the entire system. Intense discomfort (nausea, dizziness, etc.). Forces to stop training. 1 month delay

Risk Matrix

MS = Motion Sickness

PRE - MITIGATION

IMPACT					
5			- Arm Constraints harm user -MS (latency/resolution)	MS (high sensitivity)	
4		Inaccurate hand tracking			
3		Too much arm constraint	Lag in PR - VR connection		
2					
1					
	1	2	3	4	5
	PROBABILITY				

Risk Matrix

MS = Motion Sickness

POST - MITIGATION

IMPACT		PROBABILITY 1	2	3	4	5
	5		MS (high sensitivity)			
	4	Inaccurate hand tracking	MS (latency/resolution)			
	3	Too much arm constraint	- Arm Constraints harm user - Lag in PR - VR connection			
	2					
	1					

Design Requirements & Satisfaction

Building off CPEs…

CPEs	Requirements	Summary
E.1 Human Safety	FR 3	HR Latency
E.4 Motion Restriction	DR 2.1	Arm Constraints

HR Latency – Unity Processing Time

DR 1.2.10 - The VR system shall reflect user's interaction with PR input devices (buttons, switches, etc.) in real time

PR – VR Interaction Demonstration and Latency Testing

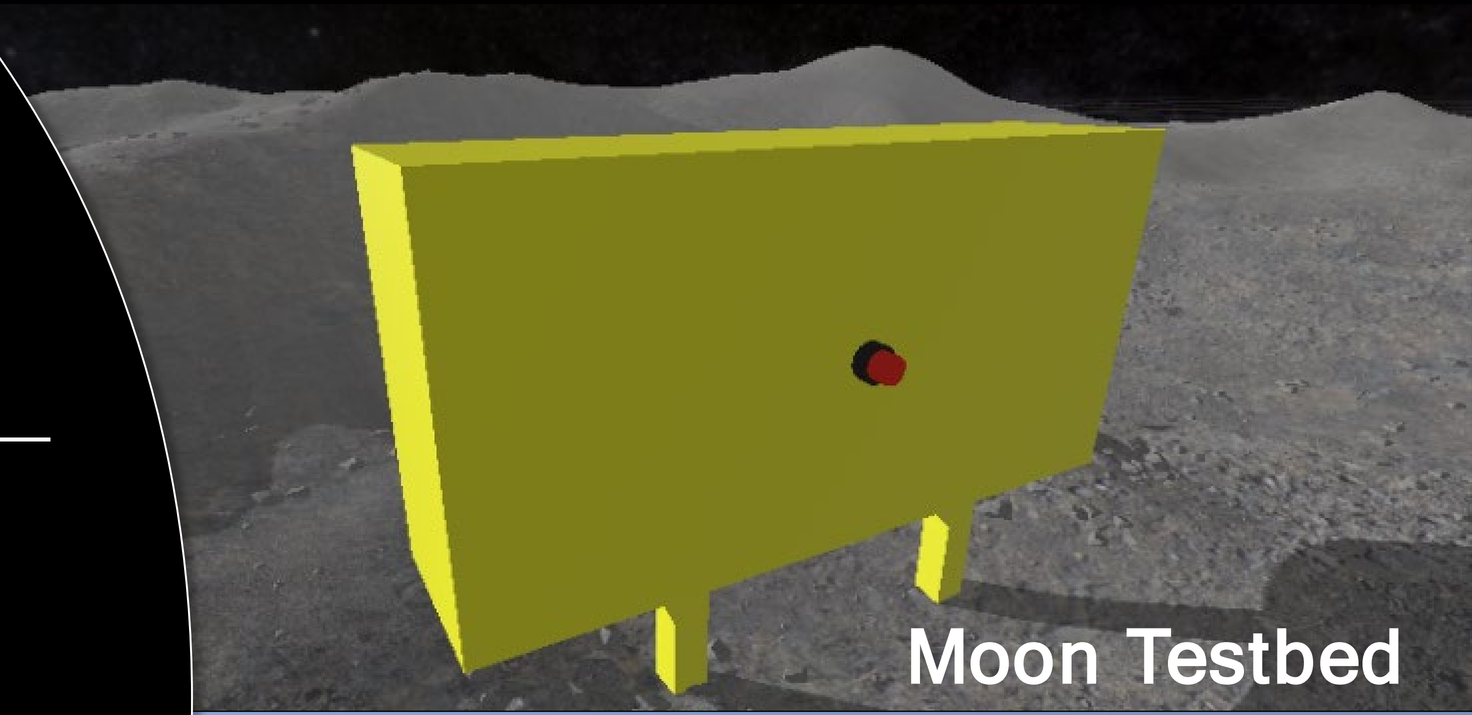
Arduino + Button + USB/USB A Serial Port connection (5 VDC, 9600 bps) + Unity Scene with scripted interactable and timing function

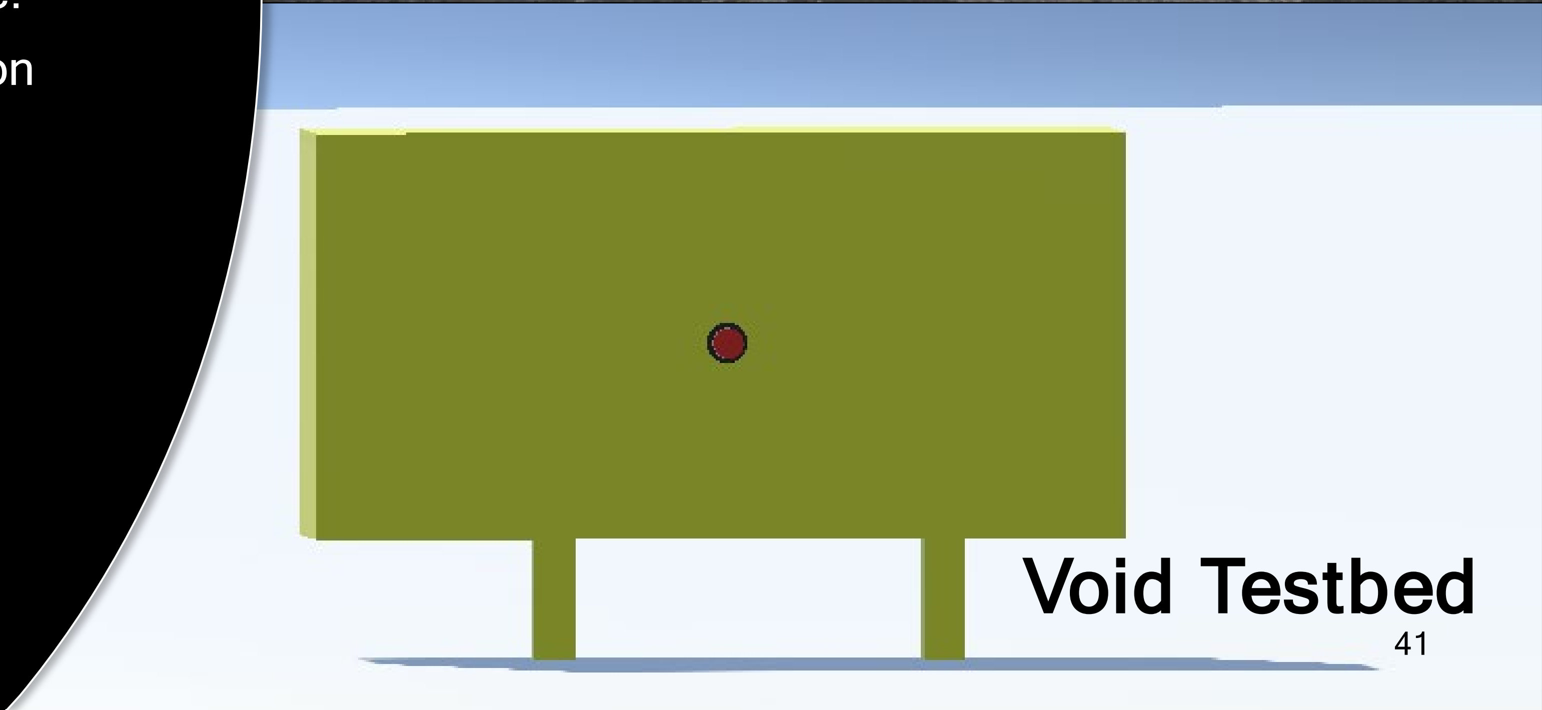
Goals

- Increase general understanding of serial read latency between Arduino and Unity
- Find correlation between the number of interactable elements in a scene and latency
- Determine if there is noticeable latency or delay due to environment size

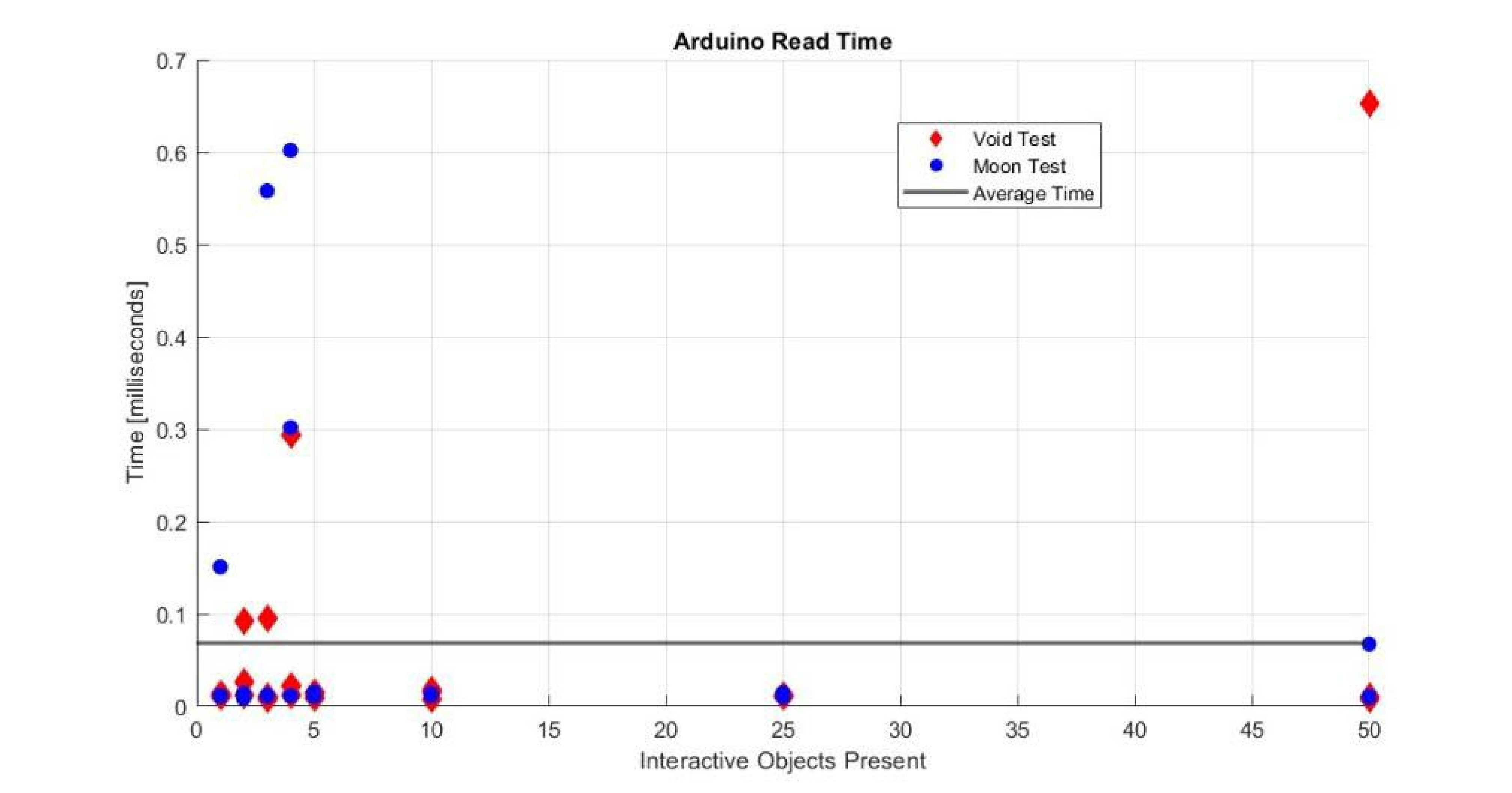
Unity Processing Time - Model Setup

- Measurable: Press the button on the Arduino to trigger button press in Unity
- Stopwatch function within C# to measure:
  - Time for Unity script to register button press from serial port
  - Time for Unity script to complete
- Variables:
  - Environment Size
  - Number of Interactable Elements

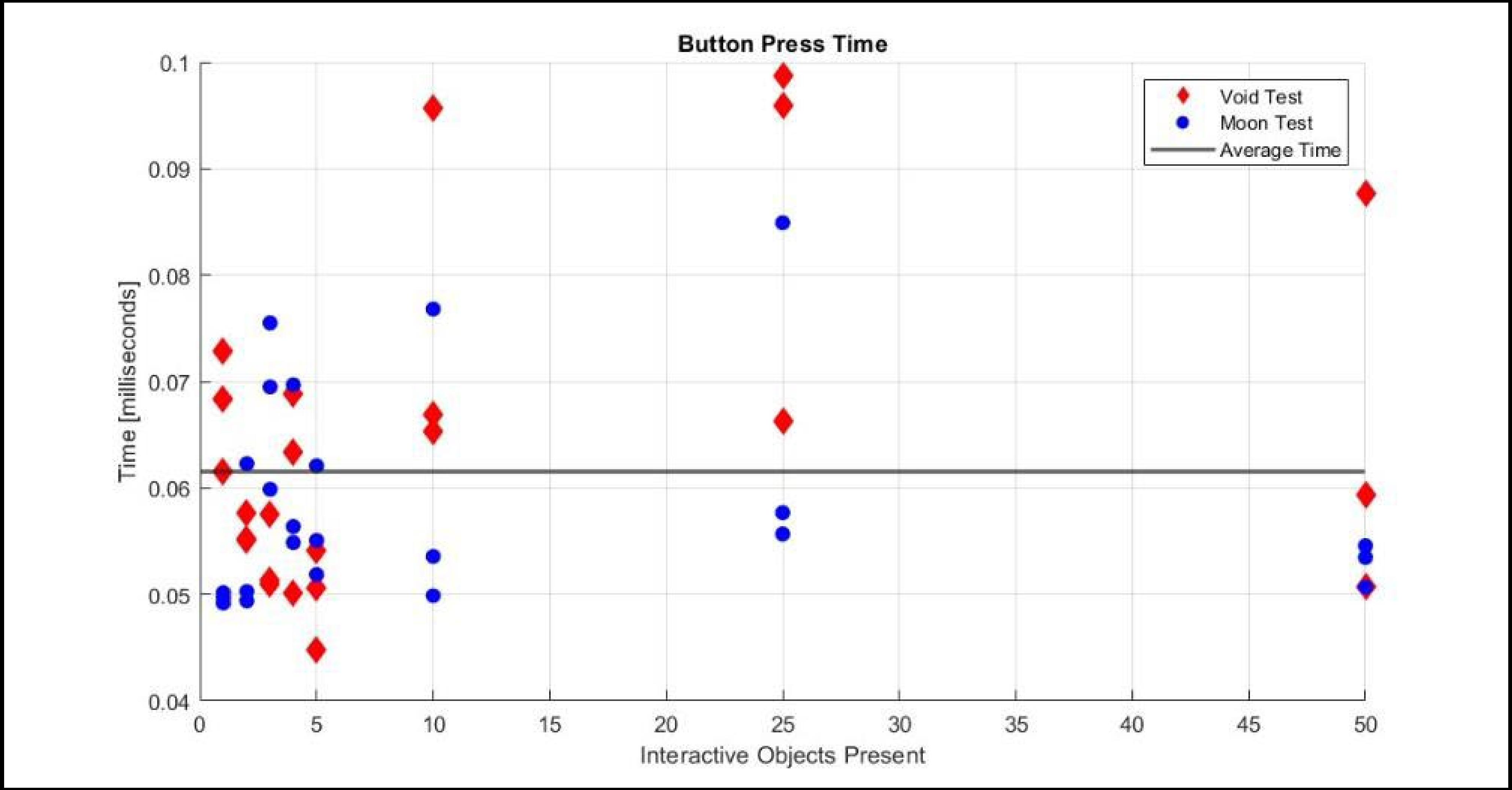




Arduino Button Read Time

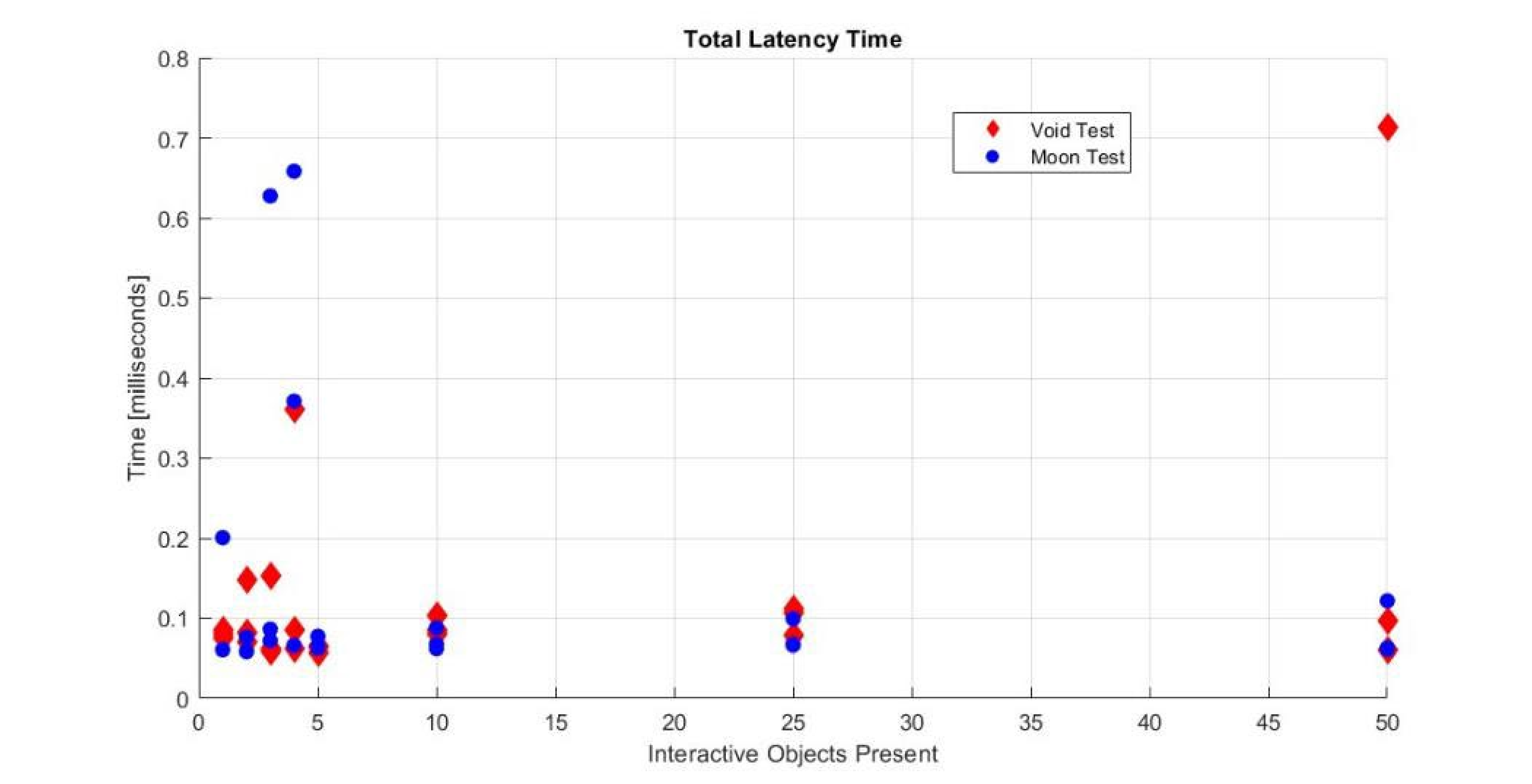


Unity Processing Time



Intro | Purpose Objectives | Design | CPEs Risks | Reqs. | V & V | Planning

Total Processing Time



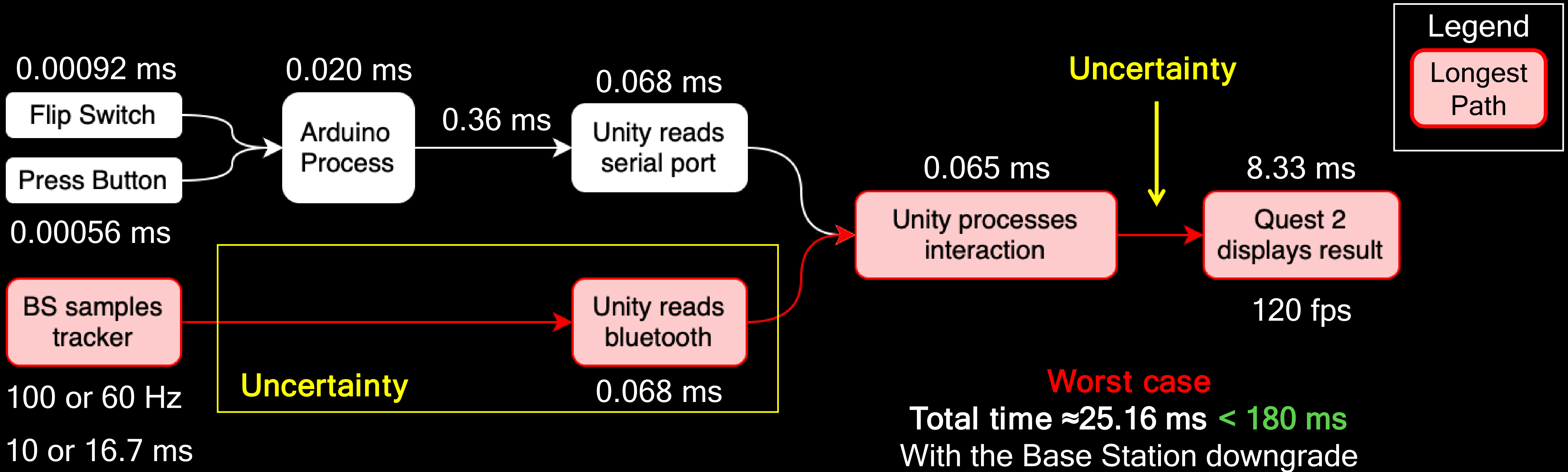
HR Latency - Timing Diagram

BS = Base Station

DR 1.2.7 - The dynamic PR elements' tracking data shall be communicated to the VR at a rate of **90 Hz**

DR 3.1.4 - The VR headset shall display the VR simulation with a minimum frame rate of **90 fps (90 Hz)**

DR 3.1.6 - The PR-VR data transfer shall have a latency smaller than **180 ms**



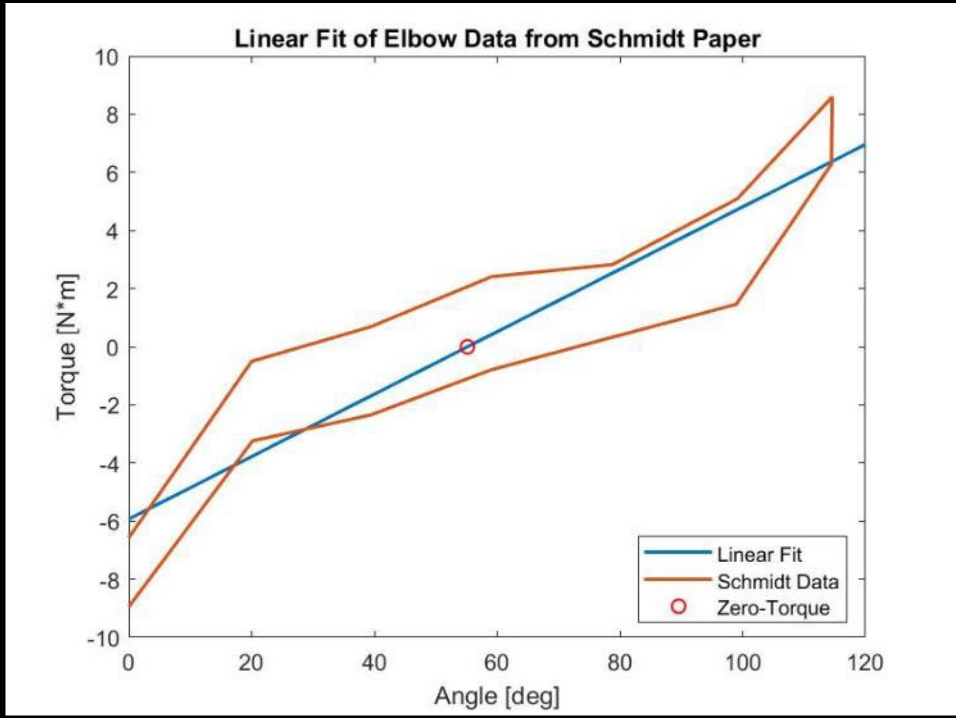
Worst case
Total time ≈25.16 ms < 180 ms
With the Base Station downgrade

Arm Constraints

DR 2.1.2 - The PCs shall constrain the user's elbow extension movement within a range of **0 - 115** deg.

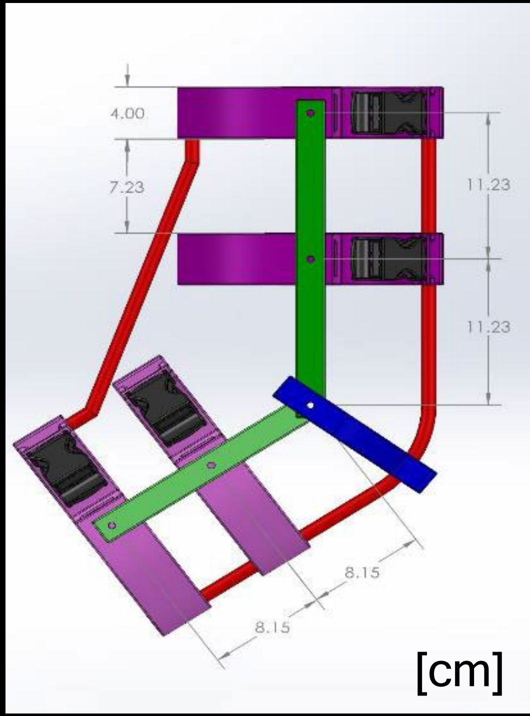
DR 2.1.2.1 - The PCs shall provide counter-torque to the elbow within a range of **-9 to 9 ± 10%** Nm.

GOAL

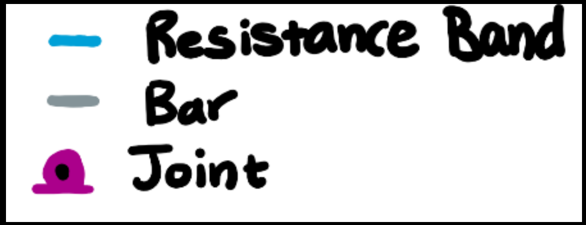


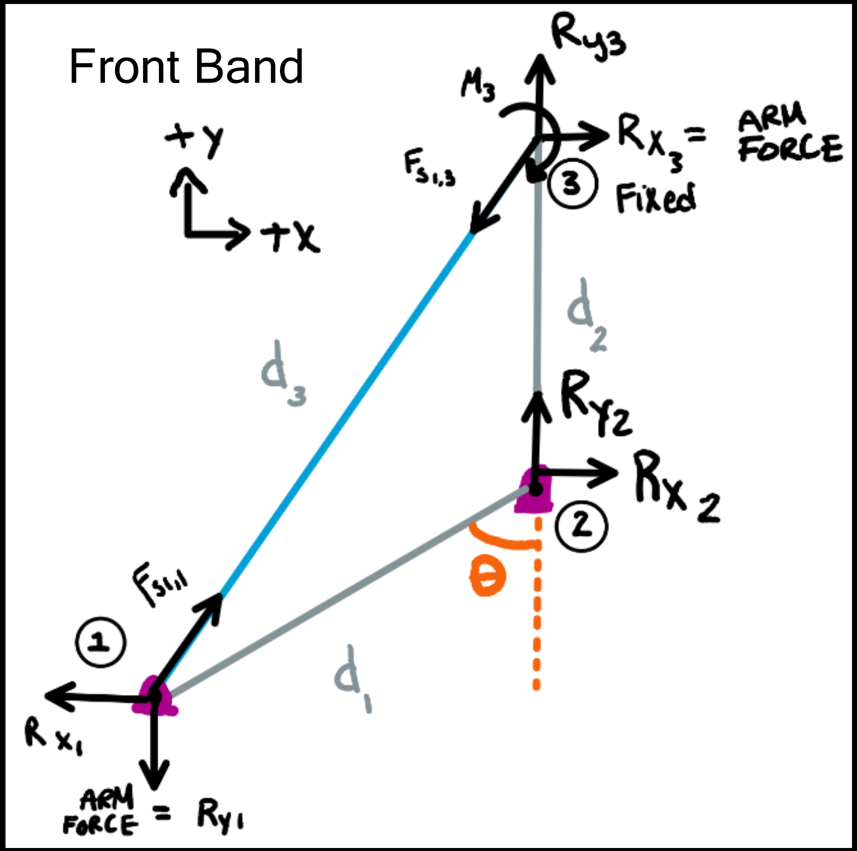
- Data was taken with an empty, pressurized suit
- Angle of elbow at zero-torque: **55.2°**
- Linear fit is done as it is hard to model hysteresis

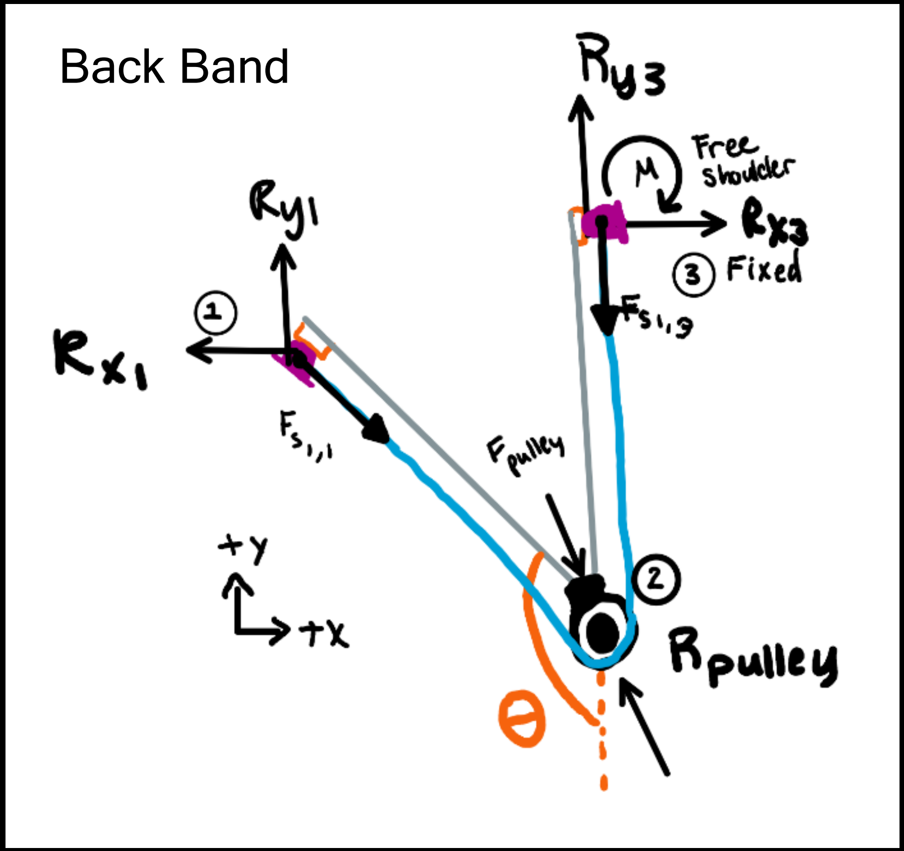
SOLUTION

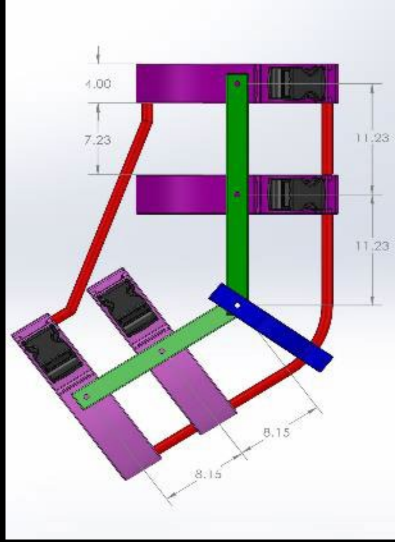


Free Body Diagram

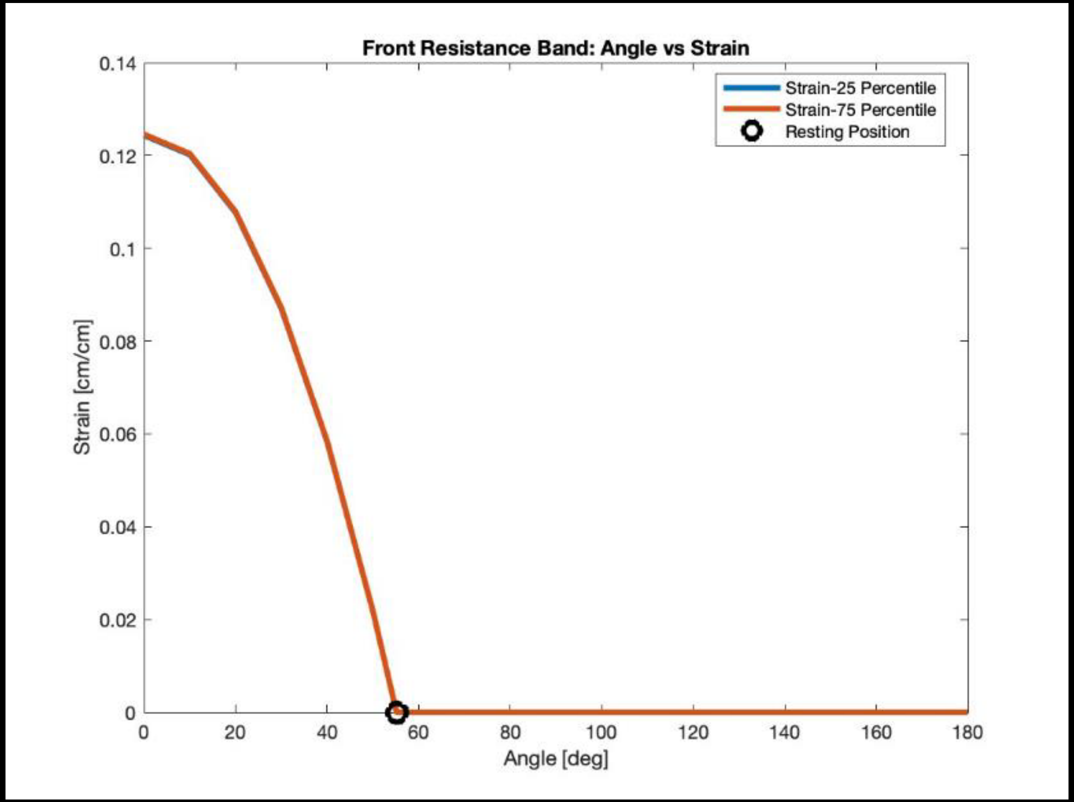


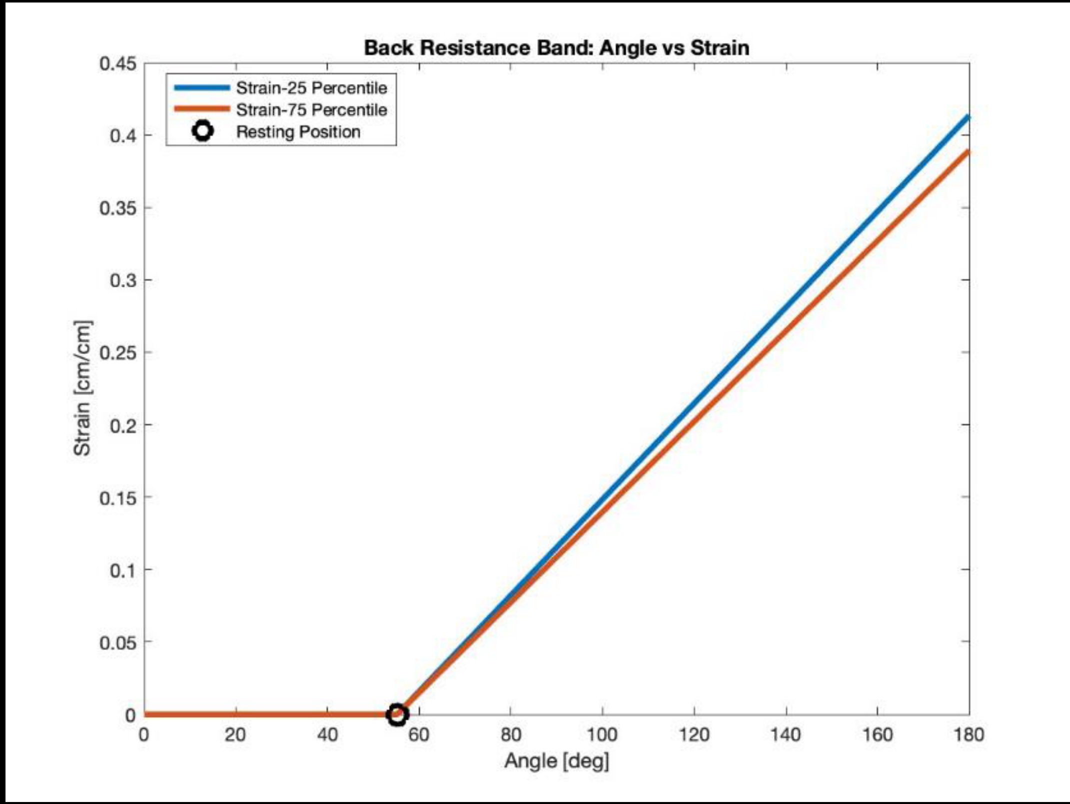






Strain Range Based on Angle





Front Resistance Band

Find new length using Law of Cosines equation

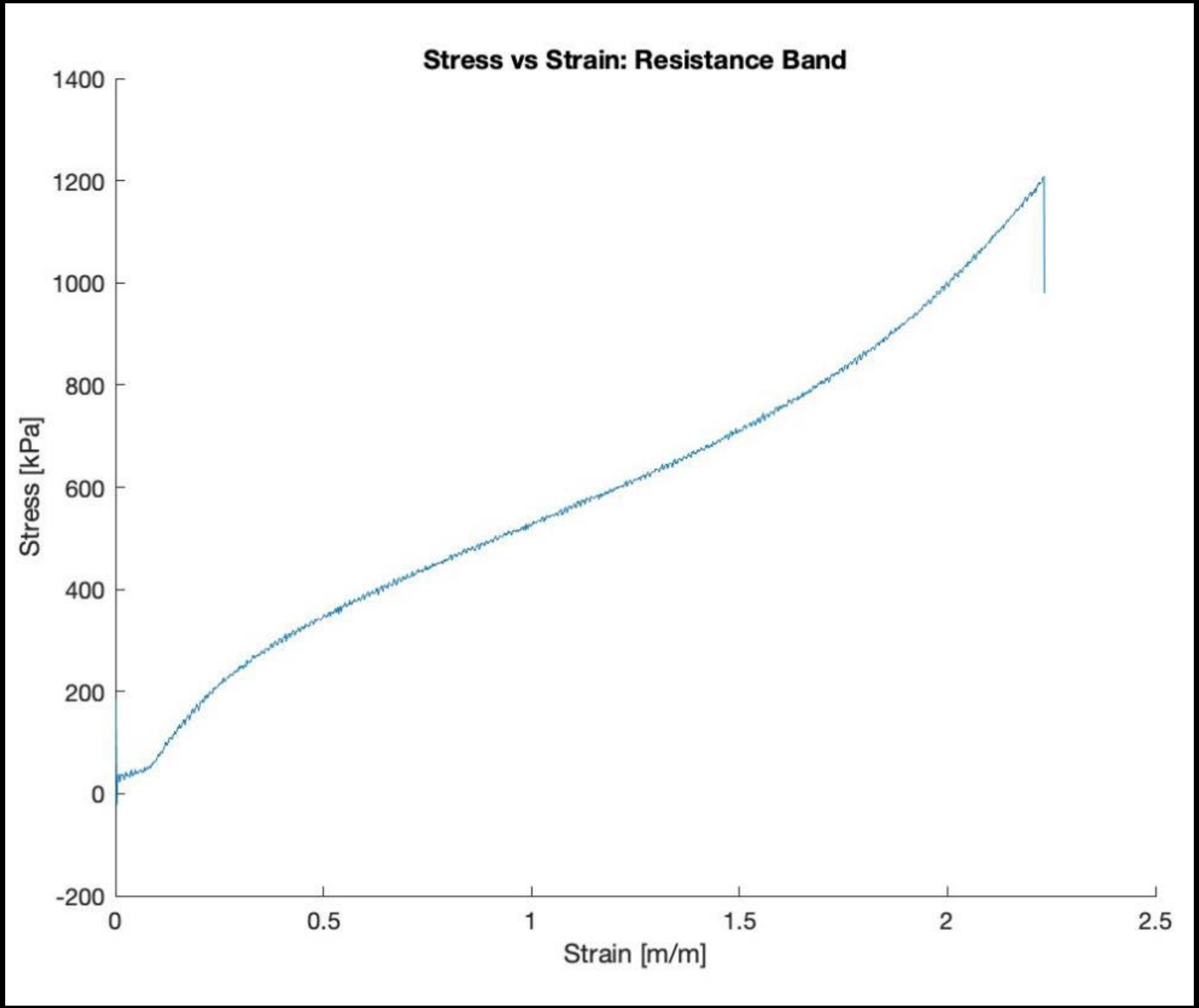
$$L = \sqrt{d_1^2 + d_2^2 - 2d_1 d_2 \cos(\theta_2)}$$

Back Resistance Band

Find new length using change in arc length

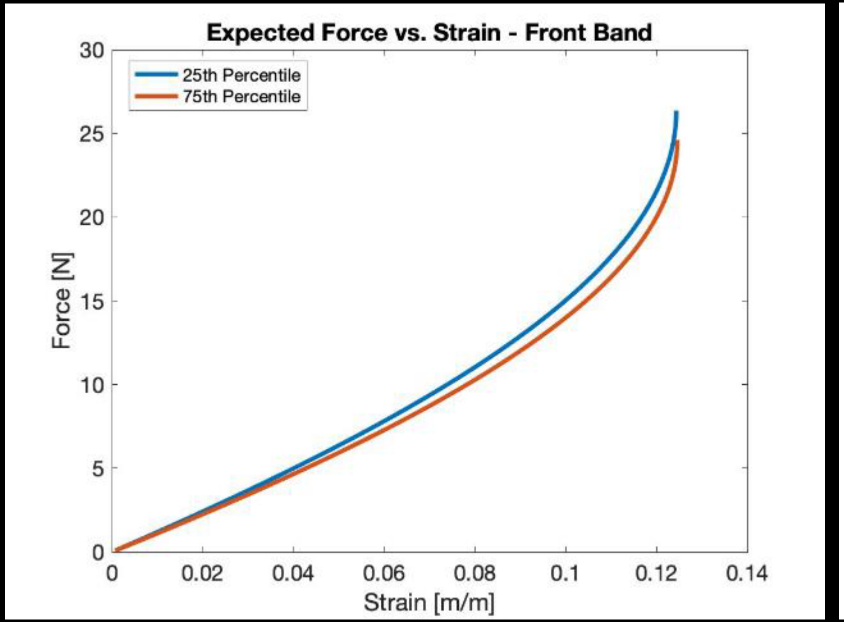
$$\mathrm{L} = d_1 + d_2 + r(180 - \theta)$$

Wire Arm Harness – Material Testing Results

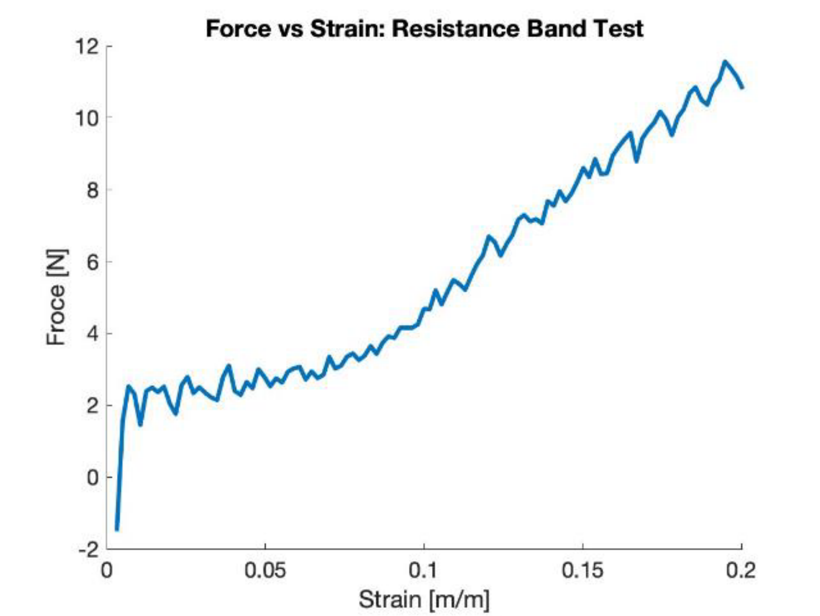


Wire Arm Harness – Performance Feasibility Results

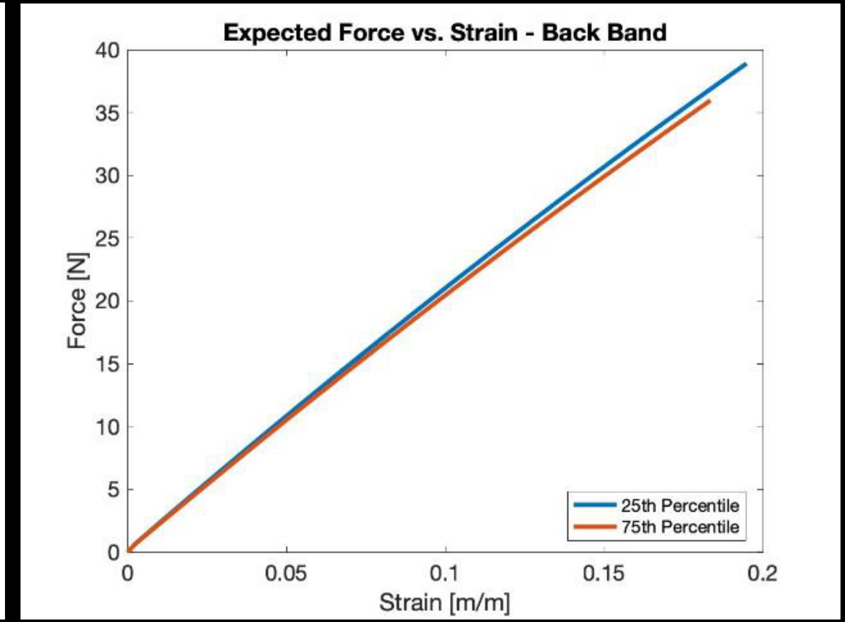
Front Band Needed



Resistance Band Tensile Results



Back Band Needed



The resistance band tested fails to provide the force vs strain required to provide the proper torque on the elbow to mimic the EVA spacesuit

Verification & Validation

Verification

Final HR Latency Test

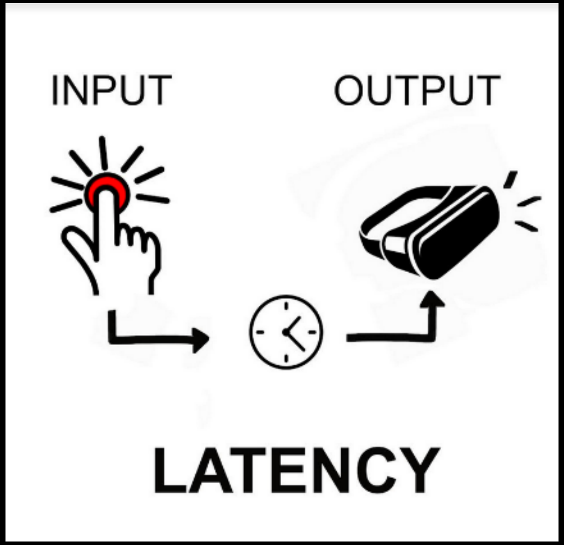
HR Latency Test

Safety Concern

Motion Sickness

DR 1.2.2 - The state of PR input devices shall be sampled at a rate of at least 90 Hz.

DR 3.1.6 - The PR-VR data transfer shall have a latency smaller than 180 ms.



The system will be set up in its final configuration (including Arduino & EVA panel)

Test Objective: confirm latency of HR Arduino interface is less than 180 ms

Method: press button on EVA Panel (start timer) and stop timer when user sees the button trigger in VR.

Facilities / Equipment

Additional Arduino DUE

Additional Button

Additional Laptop

Data Acquisition

Time between input to Arduino and action displayed to the user

Goal Latency & Issues

~ 200 ms Latency

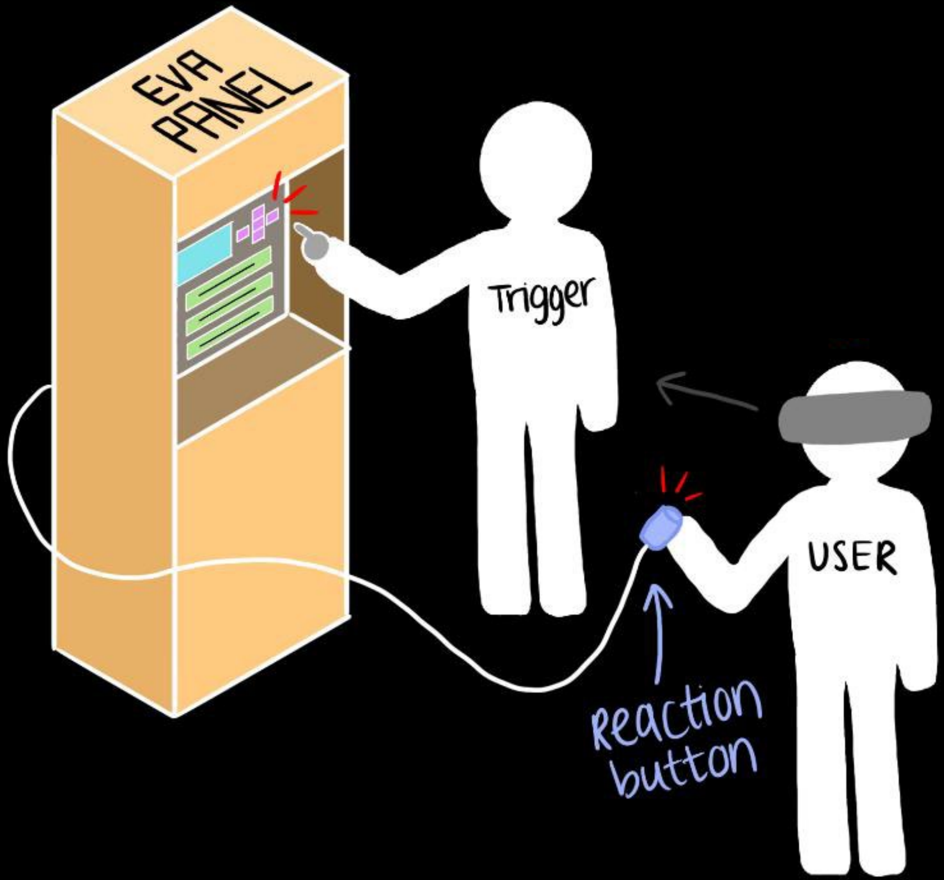
Issue

If the same user clicks the button AND reacts to latency, they develop a predictive reaction (anticipate the latency and react earlier).

Solution

One person must provide the input (press the button in the panel) and another must react in VR. Randomize trigger time.

Test Setup



TEST PLAN

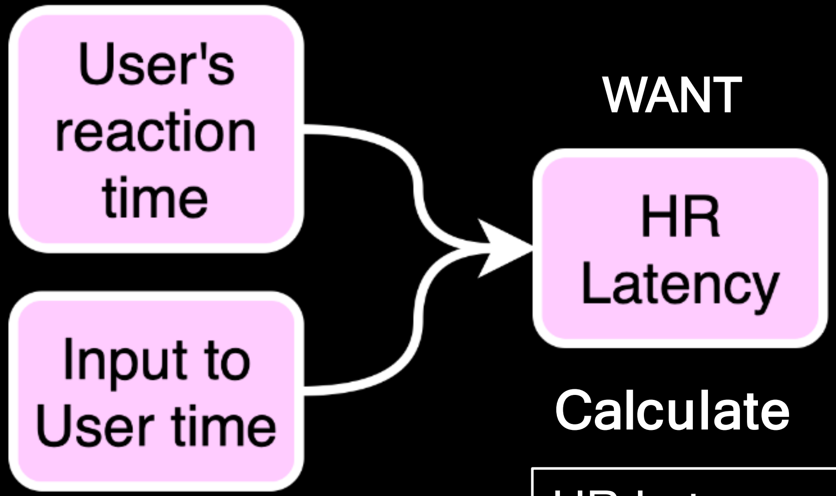
1. Measure user's average reactions time to visual queues with www.humanbenchmark.com
   - Make sure to have large enough N
2. Put user in VR environment
3. Have another person click a button on the EVA Panel (*INPUT*)
4. Have the user click a "reaction button" when they see the button trigger in VR (*OUTPUT*)
5. Repeat 3-4 until sample pool (N) is large enough

Time between *INPUT* and *OUTPUT* is measured with another Arduino DUE that's connected to the trigger button and the reaction button to avoid interference with nominal operation of simulation.

Measurements & Passing Criteria

Measure

WANT



Calculate

HR Latency ≈ [Input to User time] – [User’s average reaction time]

How to pass the test?

- Find the latency of the system
- Ensure that the latency is less than 180 ms
- Quantify possible sources of errors with various test subjects

Measurement Limitations

- Reaction times are highly variable (depending on emotional, physical, mental state)
- Accuracy of reaction time test is only as good as ms (most computer applications in µs)
- Hardware dependent test

Verification

Arm Constraints Counter-torque

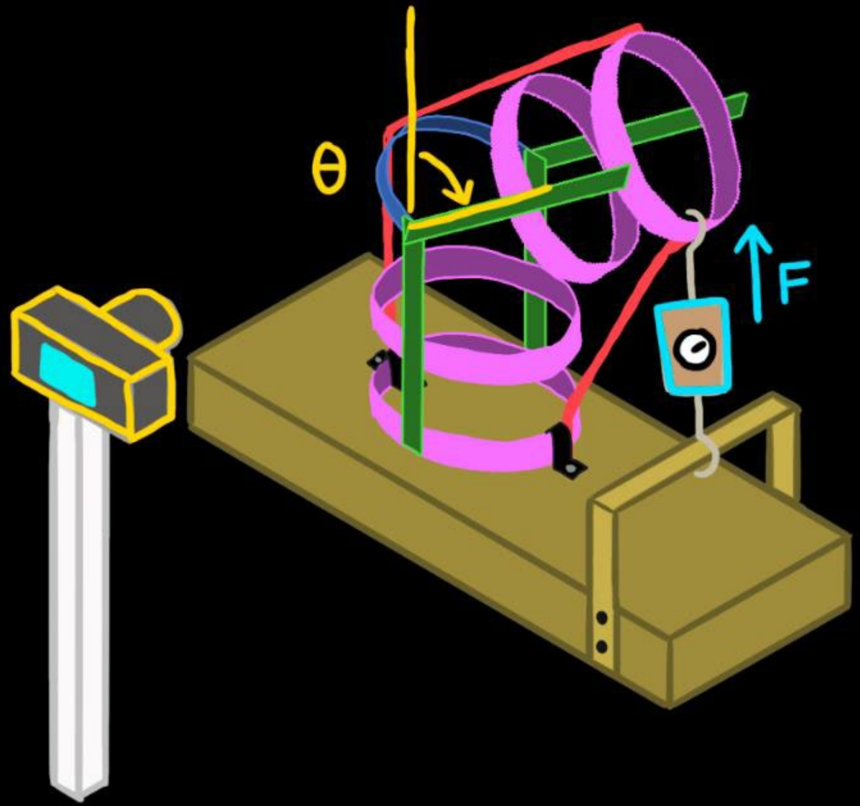
Test Setup & Dependency

DR 2.1.2 - The PCs shall constrain the user's elbow extension movement within a range of **0 - 115** deg.

DR 2.1.2.1 - The PCs shall provide counter-torque to the elbow within a range of **-9 to 9 ± 10%** Nm.

Band Slip Test → Arm Constraint Counter-torque Test → Safety Demo

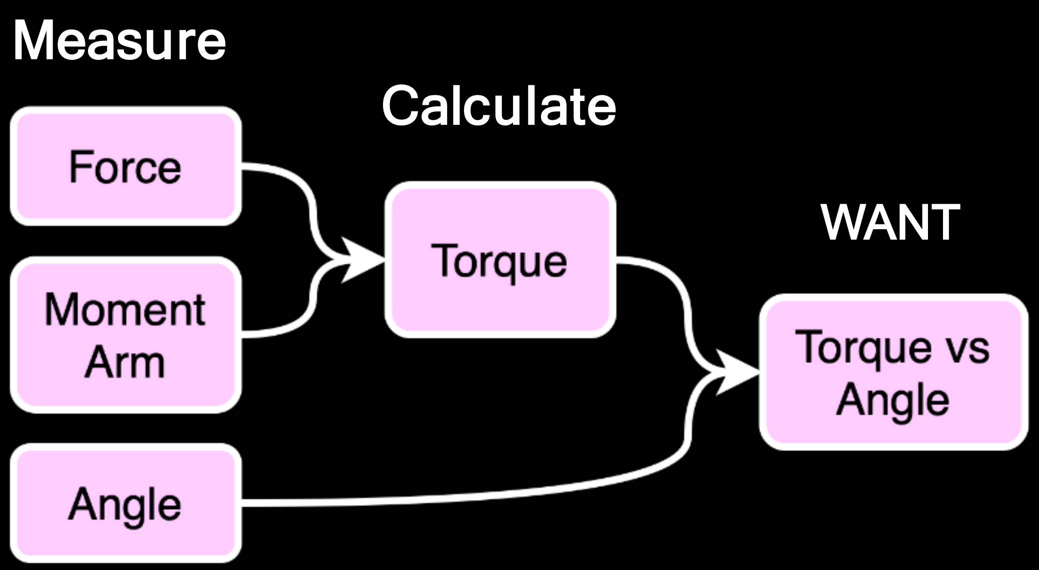
"Empty suit" test



Facilities/Equipment

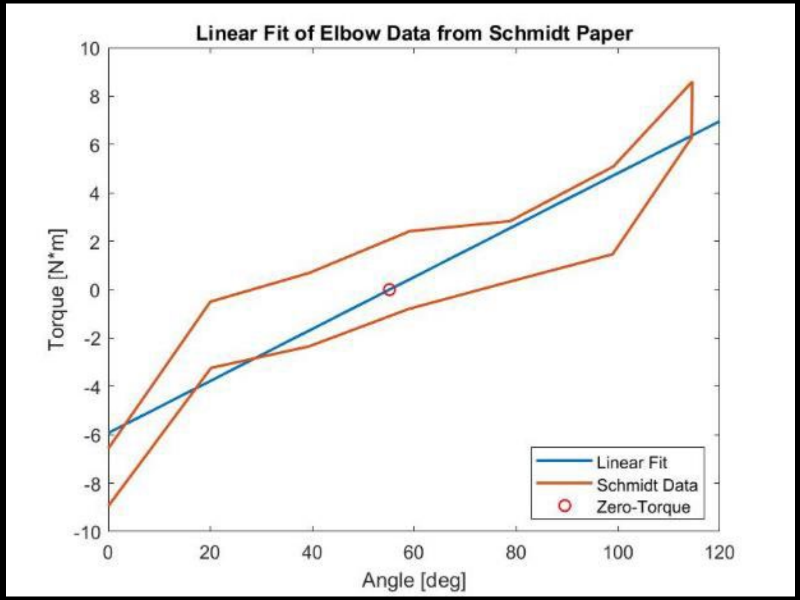
- ✓ Fish Scale ➔ **Force**
- ▸ Testing structure (build)
- ✓ Fixed surface: floor or table + weights
- ▸ Camera + tripod
- ✓ LoggerPro App ➔ **Angle**

Measurements & Passing Criteria



How to pass the test?

- Find max force applied by constraints
- Ensure bands have **FS = 2** with respect to their material properties
- Torque produced is reasonably close to Schmidt's data



Measurement Limitations

Resolution of fish scale currently available = ±1 oz
Limit of fish scale currently available = **33 lb**. ✓
Convert from "mass units" to "force units" → Multiply by g
Parallax errors in optical measurement of angle

Validation

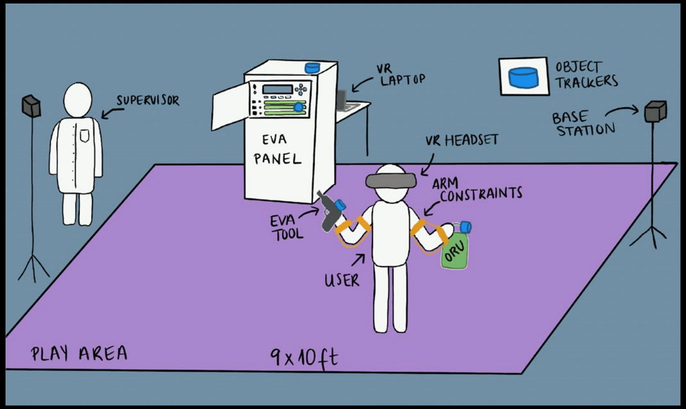
Day-in-the-life Test

FR 1 - HEIST shall be an immersive HR system where the user can enter a VR environment and interact with it though PR elements.

FR 2 - The PCs shall inhibit movement of at least one part of the body.

FR 3 - The user shall be in no danger while operating in the HR environment.

- System will be set up in its final configuration.
- User will enter the hybrid simulation and undergo the full training procedure.
- **SUPERVISOR** will check in with the user every 10 minutes to ensure they are not:
  - Motion Sick
  - Harmed by the Arm Constraints



Customer will test the finalized HEIST system

Facilities / Equipment
9x10 ft area

Data Acquisition
Feedback form is given to the user to quantify satisfaction of FRs

Potential Safety Concern

Motion Sickness

Project Planning

Tests to be conducted…

Safety Concerns:
- VR-Related Tests → Motion Sickness
- EVA Panel Tipping Test → Physical Injury

	Phase	Subsystem	Test	Goal of Test	Reqs. Verified	Special Equipment / Facilities	Access	Resources
Prototyping	T0	Hardware	Force vs Displacement	Determine non-linear behavior of resistance band	Prototype	MTS Machine, MTS Room	Request	KatieRae
Prototyping	T0	Hardware	Band Slip Test	Determine if resistance band would slip from attachment point under expected loads	Prototype			
Prototyping	T0	Electrical	PR-VR Interface	Ensure data can be transmitted from Arduino into Unity	1.2.2 / 1.2.6 / 1.2.10.1			
Prototyping	T0	Electrical	Arduino Sampling Rate	Ensure that the Arduino DUE is sampling at the speed we have assumed in our analysis	1.2.6 / 1.2.7			Trudy
Prototyping	T0	Software	Button Press	Ensure data from Arduino can trigger VR interaction in Unity	1.2.10			
Component	T1	Electrical	Switch Bouncing Time	Determine bouncing time of switch. Confirm it is below 1/90	1.2.2	Oscilloscope, AERO 150	Yes	Trudy
Component	T1	Electrical	Button Bouncing Time	Determine bouncing time of button. Confirm it is below 1/90	1.2.2	Oscilloscope, AERO 150	Yes	Trudy
Component	T1	Electrical	Battery Discharge	Determine if the VR headset can run the simulation on a single charge for at least 2 h	3.1.2	Snapdragon Profiler	Yes	
Component	T1	Software	Hand Tracking Accuracy	Determine accuracy of VR headset hand tracking and relate it to FOV of headset cameras	1.2.3 / 1.2.4	2 Safety Supervisors	Yes	3 HEIST members
Subsystem	T2	Software	Processing Workload	Check workload of system during simulation to ensure there's enough processing margin in the VR computer	1.1			
Subsystem	T2	Software	Latency Test	Verify latency model. Ensure Unity processing time is below threshold for motion sickness	3.1.6			
Subsystem	T2	Electrical	Object Accuracy Test	Verify object tracking accuracy requirements.	1.2.1.1 / 1.2.1.2			
Subsystem	T2	Hardware	EVA Panel Tipping	Verify tipping model. Ensure EVA Panel will not tip over under critical operating conditions	3.2	Empty room. 3 Safety Supervisors	Request	4 HEIST members
Subsystem	T2	Hardware	Counter-torque	Determine counter-torque of arm constraint subsystem	2.1.1.1 / 2.1.2.1	Pull Scale	Yes	KatieRae, Trudy, Wingate
System Integration	T3	Electrical	Day-in-the-life	Ensure electrical components function correctly and read outputs at required rates	1.2.2 / 1.2.6 / 1.2.10			
System Integration	T3	Software	Day-in-the-life	Ensure latency, resolution, and refresh rate requirements are met	3.1.4 / 3.1.5 / 3.1.6	OVR Metrics Tool Snapdragon Profiler	Yes	
System Integration	T3	All	Day-in-the-life	Validate design	Functional Reqs.	9x10 ft space	Request	Anderson (Customer)

Equipment
MTS Machine
Oscilloscope
Pull Scale

Facilities
MTS Room
Empty Room
9x10 ft Space

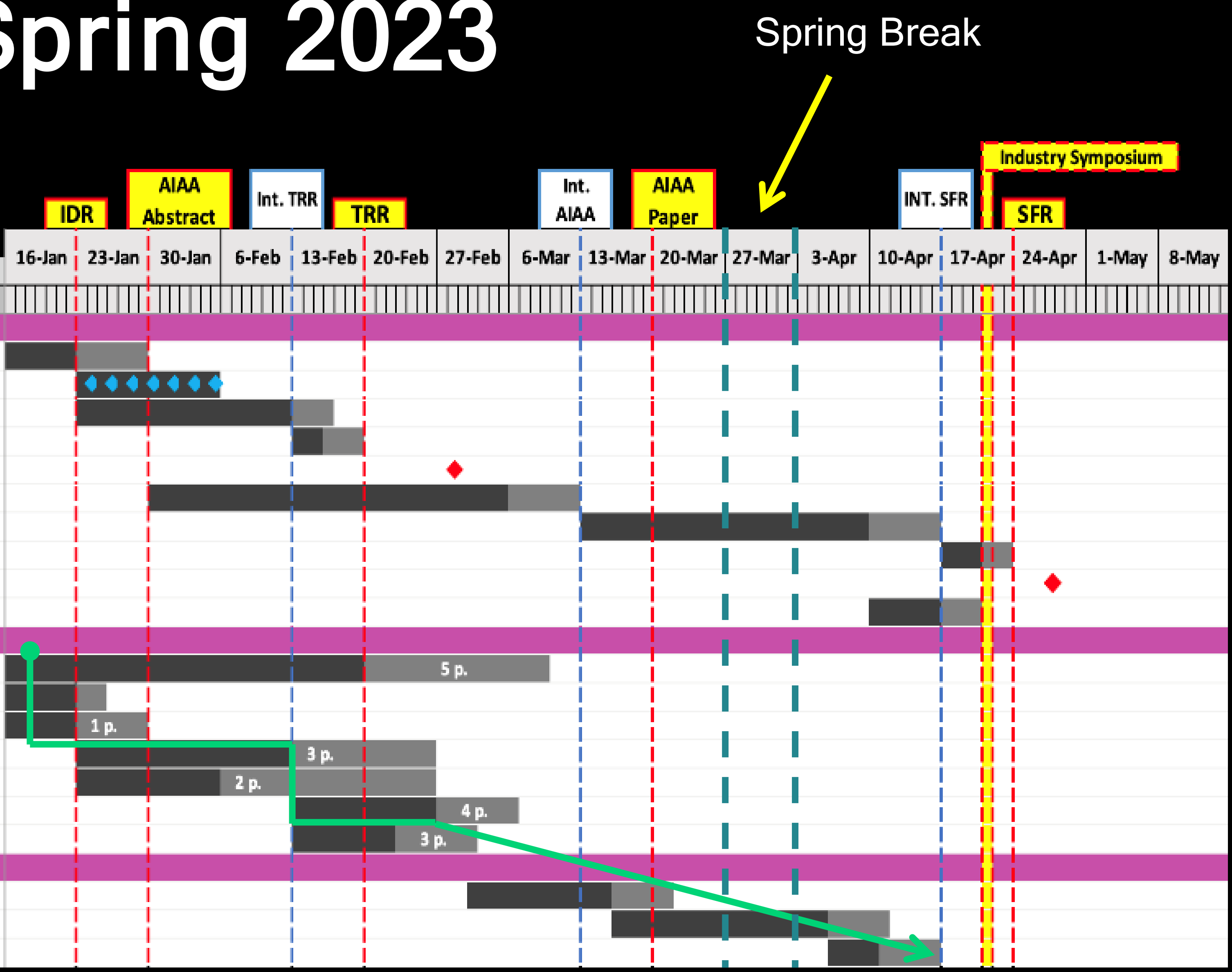
Spring 2023

WBS & GANTT CHART

SEMESTER START DATE	16-Jan-23
SEMESTER END DATE	10-May-23

LEGEND	
ES	EARLY START
EF	EARLY FINISH
LS	LATE START
LF	LATE FINISH

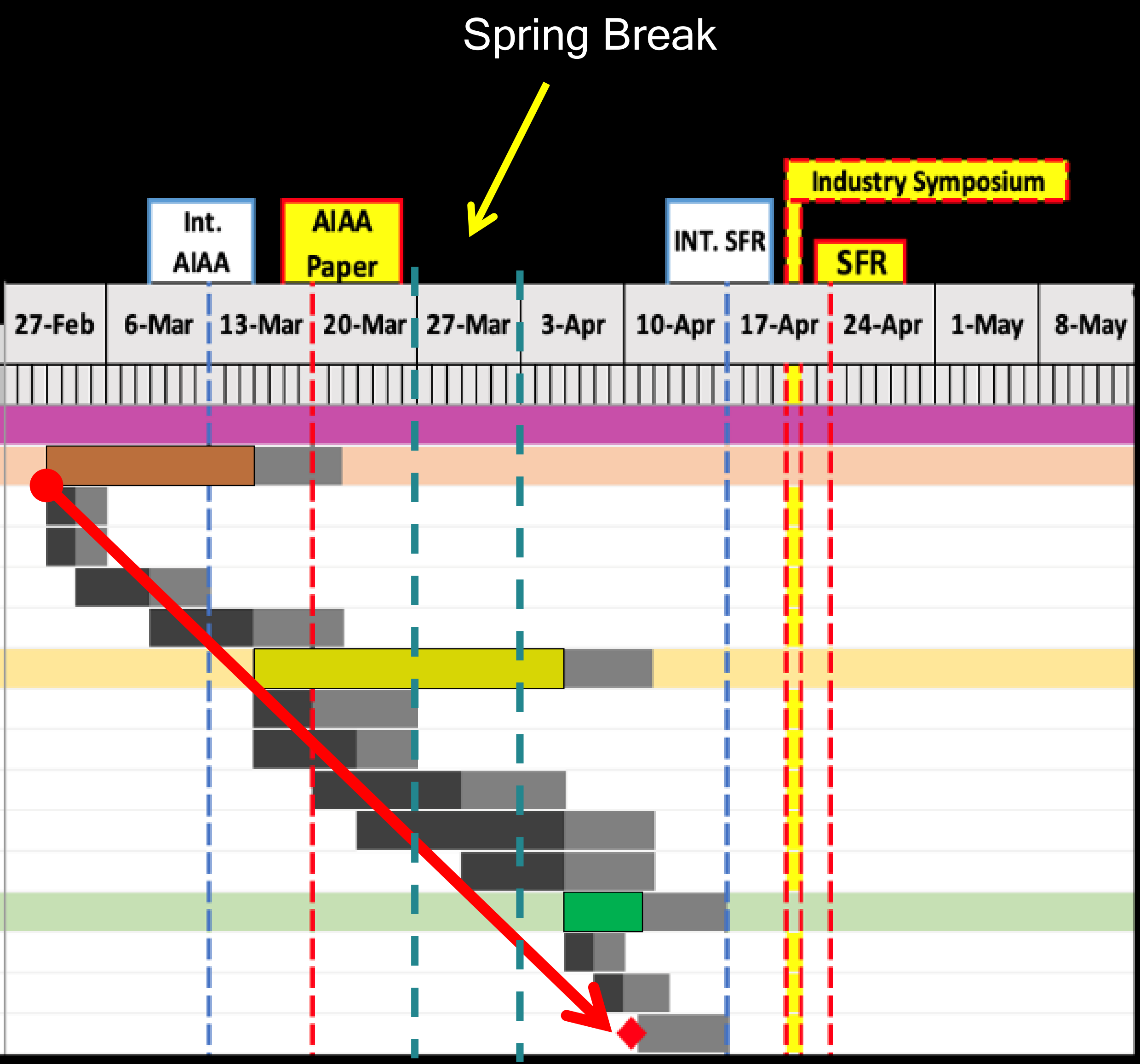
	DAYS	DATE				DAYS
TASK	DURATION	ES	EF	LS	LF	FLOAT
DELIVERABLES						
AIAA Abstract	7	16-Jan	22-Jan	23-Jan	29-Jan	7
Internal Design Review	14	23-Jan	5-Feb	23-Jan	5-Feb	0
Test Readiness Review - SLIDES	21	23-Jan	12-Feb	27-Jan	16-Feb	4
Test Readiness Review - SLIDE REVIEW	3	13-Feb	15-Feb	17-Feb	19-Feb	4
Test Readiness Review - PRESENTATION	1	27-Feb	27-Feb	27-Feb	27-Feb	0
AIAA Paper	35	30-Jan	5-Mar	6-Feb	12-Mar	7
Spring Final Review - SLIDES	28	13-Mar	9-Apr	20-Mar	16-Apr	7
Spring Final Review - SLIDES REVIEW	4	17-Apr	20-Apr	20-Apr	23-Apr	3
Spring Final Review - PRESENTAION	1	26-Apr	26-Apr	26-Apr	26-Apr	0
Prepare Symposium	7	10-Apr	16-Apr	14-Apr	20-Apr	4
BUILD & DEVELOPMENT						
Develop VR Environment	35	16-Jan	19-Feb	3-Feb	9-Mar	18
Order Components	7	16-Jan	22-Jan	19-Jan	25-Jan	3
Build EVA Tool	7	16-Jan	22-Jan	23-Jan	29-Jan	7
Build Arm Constraints	21	23-Jan	12-Feb	6-Feb	26-Feb	14
Build EVA Panel + Electronics	14	23-Jan	5-Feb	13-Feb	26-Feb	21
Integration	14	13-Feb	26-Feb	21-Feb	6-Mar	8
Testing Setup: Hardware & Software	10	13-Feb	22-Feb	21-Feb	2-Mar	8
VERIFICATION & VALIDATION						
Phase T1: Component Testing	14	2-Mar	15-Mar	8-Mar	21-Mar	6
Phase T2: Subsystem Testing	21	16-Mar	5-Apr	22-Mar	11-Apr	6
Phase T3: Day-in-the-life testing	5	6-Apr	10-Apr	12-Apr	16-Apr	6



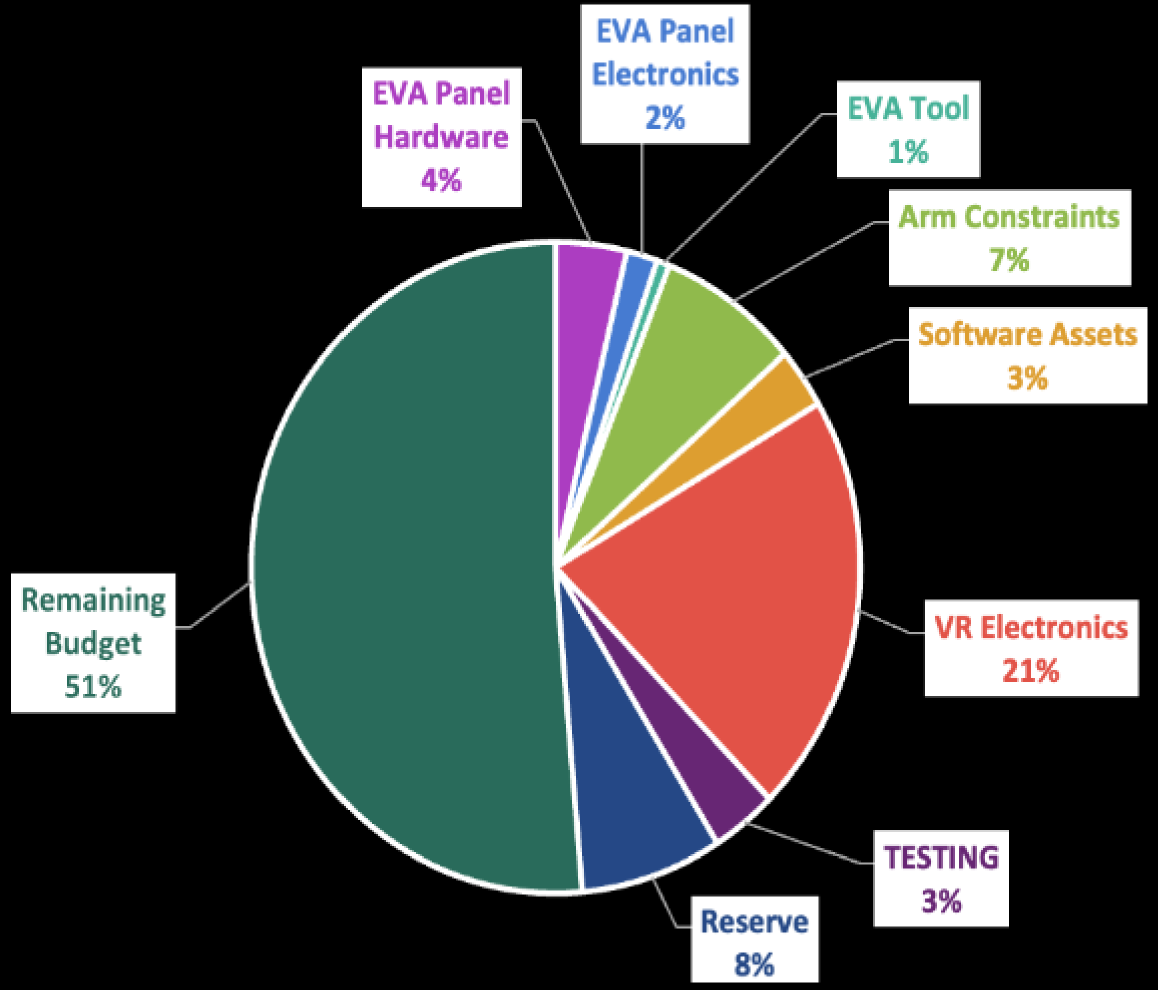
Testing Phases

LEGEND	
ES	EARLY START
EF	EARLY FINISH
LS	LATE START
LF	LATE FINISH

TASK	DAYS DURATION	DATE ES	DATE EF	DATE LS	DATE LF	DAYS FLOAT
VERIFICATION & VALIDATION						
PHASE T1: Component Testing	**14**	**2-Mar**	**15-Mar**	**8-Mar**	**21-Mar**	**6**
Switch Bouncing Time	2	2-Mar	3-Mar	4-Mar	5-Mar	2
Button Bouncing Time	2	2-Mar	3-Mar	4-Mar	5-Mar	2
Battery Discharge	5	4-Mar	8-Mar	8-Mar	12-Mar	4
Hand Tracking Accuracy	7	9-Mar	15-Mar	15-Mar	21-Mar	6
PHASE T2: Subsystem Testing	**21**	**16-Mar**	**5-Apr**	**22-Mar**	**11-Apr**	**6**
Processing Workload	4	16-Mar	19-Mar	23-Mar	26-Mar	7
EVA Panel Tipping	7	16-Mar	22-Mar	20-Mar	26-Mar	4
Latency Test	10	20-Mar	29-Mar	27-Mar	5-Apr	7
Counter-Torque	14	23-Mar	5-Apr	29-Mar	11-Apr	6
Object Tracking Accuracy	7	30-Mar	5-Apr	5-Apr	11-Apr	6
PHASE T3: System Integration Testing	**5**	**6-Apr**	**10-Apr**	**12-Apr**	**16-Apr**	**6**
Electrical Day-In-The-Life	2	6-Apr	7-Apr	8-Apr	9-Apr	2
Software Day-In-The-Life	2	8-Apr	9-Apr	11-Apr	12-Apr	3
Final Day-In-The-Life	1	10-Apr	10-Apr	16-Apr	16-Apr	6



Cost Plan



SUBSYSTEM	COST	MARGIN	TOTAL COST
EVA Panel Hardware	$ 100.00	50%	$ 150.00
EVA Panel Electronics	$ 60.00	10%	$ 66.00
EVA Tool	$ 25.00	10%	$ 27.50
Arm Constraints	$ 200.00	50%	$ 300.00
Software Assets	$ 100.00	20%	$ 120.00
VR Electronics	$ 700.00	20%	$ 840.00
TESTING	$ 100.00	40%	$ 140.00
Reserve	$ 300.00	0%	$ 300.00

Total	$ 1,943.50
Remaining Budget	$ 2,056.50

Appendix Detailed Budget

Credits

Presenters

Esther Revenga Villagra

Matthew Grewe

Akanksha Nelacanti

Sebastian Boysen

Sruthi Bandla

Lucy Davis

Hattie Rice

Additional Team Members

Trayana Athannassova

Rachael Carreras

Julia Claxton

Steven Young

Alicia Wu

Faculty Advisor

Dr. Allison Anderson

Mentor Company

Blue Origin

CDR Reviewers

Team CTHREEPIO

Team LunaSim

Jasmin Chadha

Thank you!

Q&A Time (20 min)

Appendix

Backup Slides

Table of Contents

Full List of Acronyms (1/2)

A	=	Analysis (V&V)
AR	=	Augmented Reality
BS	=	Base Station
CDR	=	Critical Design Review
CFO	=	Chief Financial Officer
COTS	=	Commercial Off The Shelf
CPE	=	Critical Project Element
D	=	Demonstration (V&V)
DH	=	Data Handling
DoF	=	Degree of Freedom
DR	=	Design Requirement
Elect	=	Electrical
EVA	=	Extravehicular Activity
FBD	=	Functional Block Diagram
FFBD	=	Functional Flow Block Diagram
FOV	=	Field Of View
FR	=	Functional Requirement
HEIST	=	Hybrid Environmental Immersive Simulation Training
HT	=	Hand Tracking
HR	=	Hybrid Reality
I	=	Inspection (V&V)
LOS	=	Line Of Sight
Mech	=	Mechanical
Mgmt	=	Management
MS	=	Motion Sickness
ORU	=	Orbital Replacement Unit
PC	=	Physical Constraint
PDD	=	Preliminary Design Document
PDR	=	Preliminary Design Review
PM	=	Project Manager
PR	=	Physical Reality
SE	=	Systems Engineer
SME	=	Subject Matter Expert
SW	=	Software
T	=	Test (V&V)
TBD	=	To Be Determined
TBR	=	To Be Refined
TPM	=	Technical Performance Measure
UI	=	User Interface
UX	=	User Experience
VR	=	Virtual Reality

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Training Scenario Details (1/2)

1. Exit the habitat and move to the remote sensor station
2. Inspect the sensor station for visible damage (should see broken solar panel)
3. Use the screwdriver to open the panel on side of the station
4. Use the display and keypad to check the system status tab
5. Read the system status tab to confirm solar panel error and recognize a failure of a resistor assembly (one of the three ORUs)
6. Use the keypad to navigate to the safe shutdown screen on the display and shut down safely
7. Use the switch on the panel to turn off the power to the panel
8. Use the button to unlock the ORUs
9. Uninstall the correct ORU for the resistor module

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Training Scenario Details (2/2)

10. Reinstall the new module
11. Verify connection (did the right ORU end up in the right slot) using button and watching the button light up
12. Use button to re-engage locking of the ORUs
13. Navigate to the solar panel, recognize the damaged cell and release its latches
14. Remove solar panel, install new solar panel, and engage the latches
15. Navigate to the panel once again
16. Use the switch to turn on the panel power
17. Use the keypad and display to ensure proper installment of the ORU and solar panel replacement
18. Ensure the functionality of the heater and the rise of local temperature
19. Close the panel, lock it, and return to habitat

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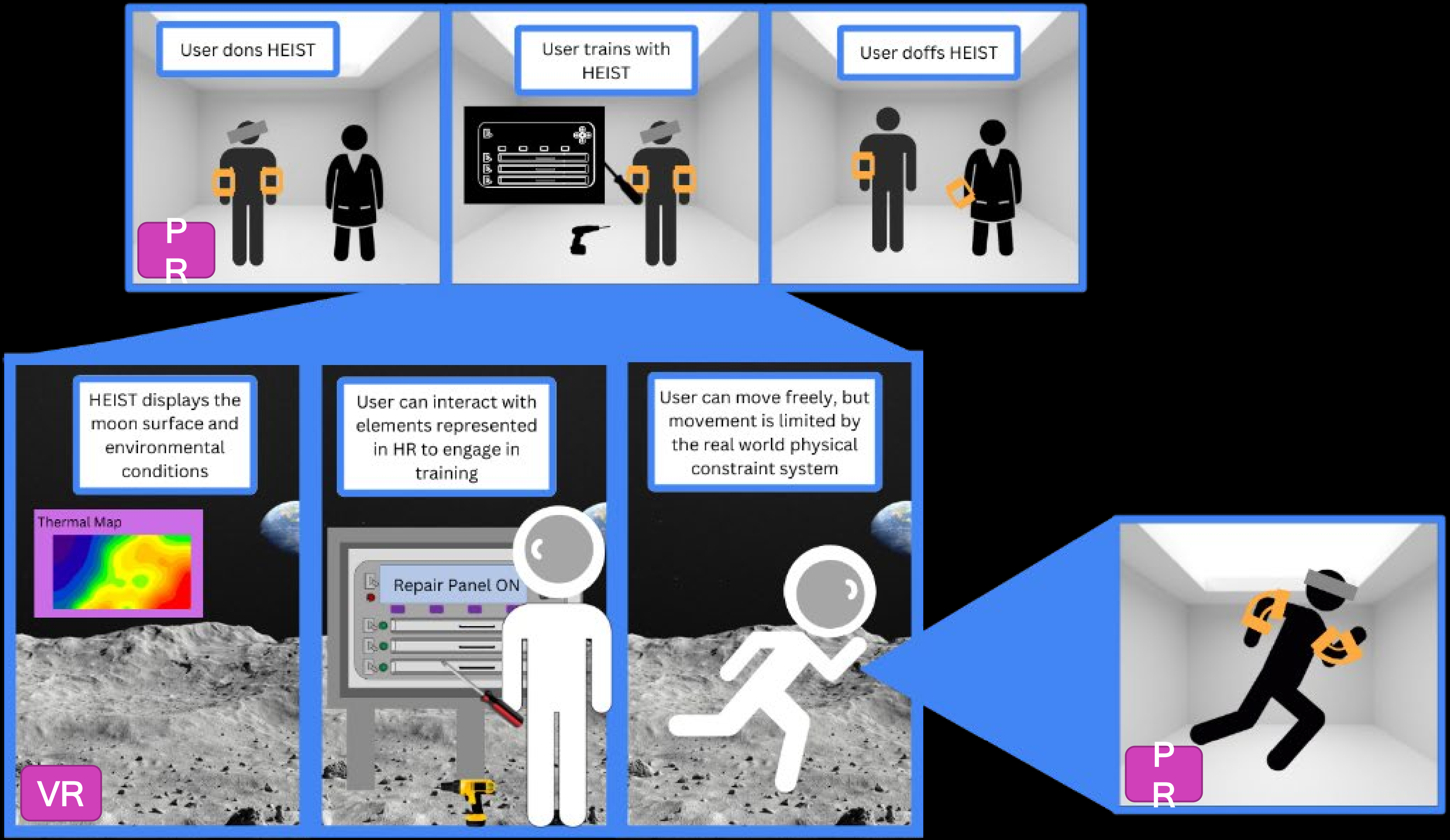

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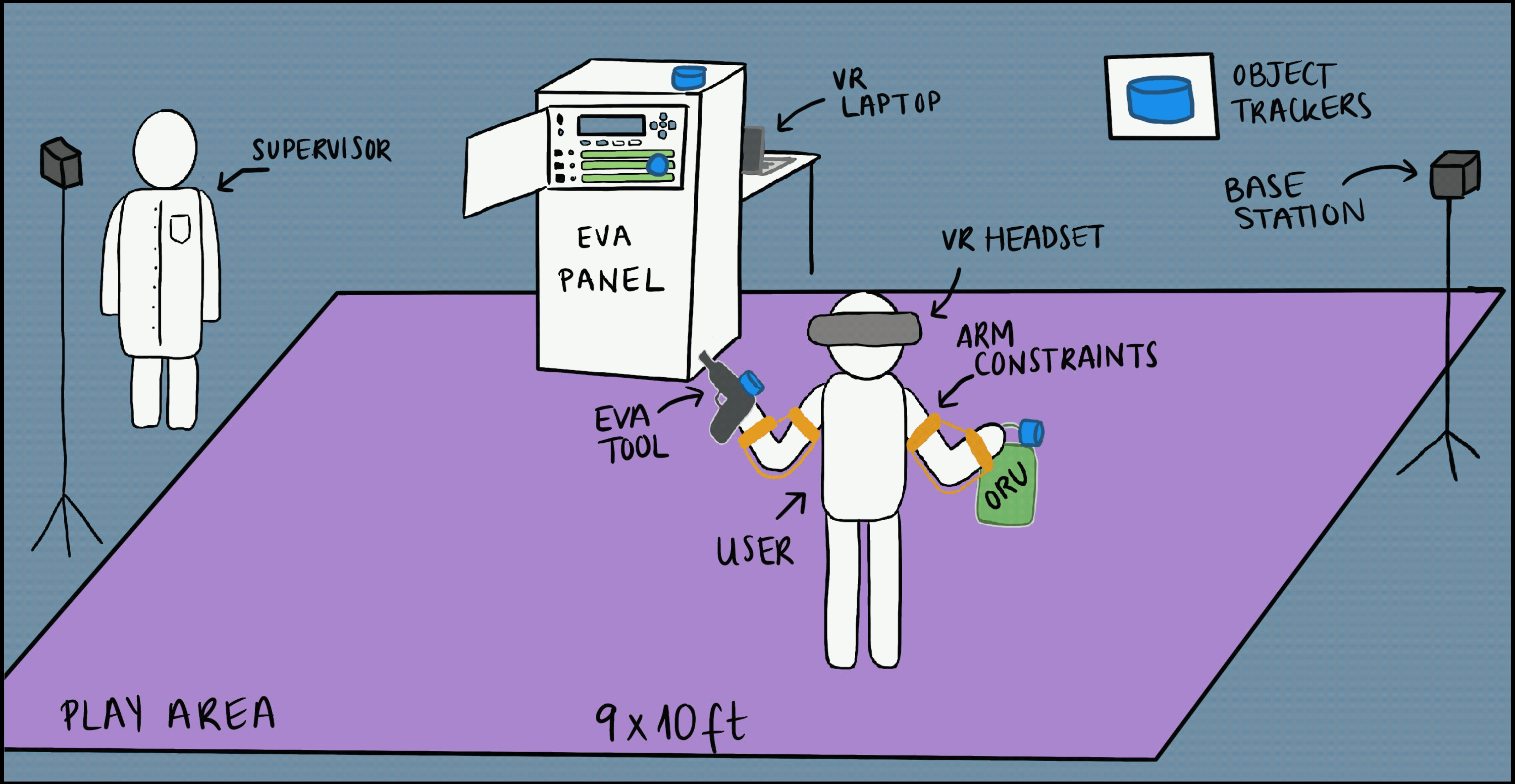

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Requirements

Acronym	Verification	Description
I	Inspection	Use of human senses to verify requirement
A	Analysis	Modelling
T	Test	Requires data aquisition and use of special equipment
D	Demonstration	Run test w/o special equipment to collect data

Requirements - FR1

Level 0	Level 1	Level 2	Level 3	Requirement	Predicted Compliance	SW	DH	Elect.	Mech.	Test
CONSTRAINTS										
C1				The cost of the project shall not exceed 4000 USD.						
C2				The system shall have a life span of no less than 3 years						
C3				Unity shall be used as the VR development engine.						
REQUIREMENTS FLOWDOWN										
FR 1	Immersiveness			**HEIST shall be an immersive HR system where the user can enter a VR environment and interact with it though PR elements.**						
				Physical Reality Environment (or PR) *is a tangible environment with real objects.*						
				Immersion *: deep mental involvment.*						
				Hybrid Reality (HR) *is an environment with combined real time interaction between Virtual Reality (VR) and Physical Reality (PR). It consists of a VR environment that receives ques from the PR when the user interacts with set PR elements.*						
				Virtual Reality Environment (or VR) *is a computer-generated environment.*						
	DR 1.1			**The user shall view a functional VR simulation of a lunar EVA.**						
	EVA CONDITIONS									
		1.1.1		The VR simulation shall display environmental conditions of the Moon.	Compliant	X				I
			1.1.1.1	The VR simulation shall visually display temperatures within the range of -200 ºC to 120 ºC.	Compliant	X				I
			1.1.1.2	The VR simulation shall visually display the high-contrast lighting properties of the Moon.	Compliant	X				I
		1.1.2		The VR simulation shall simulate the reduced field of vision (FoV) that the user would have wearing an EVA spacesuit helmet.	Compliant	X				I
			1.1.2.1	The VR simulation shall simulate a FoV of at least 90º horizontal by 90º vertical.	Compliant	X				I
	TRAINING FEEDBACK									
		1.1.3		The VR simulation shall provide mission-relevant task guidance to user.	Compliant	X				I
			1.1.3.1	The VR simulation shall provide training task sequence to the user, accessible at any time, in document form.	Compliant	X				I
		1.1.4		The VR simulation shall provide audio feedback to the user.	Compliant	X	X	X		I
			1.1.4.1	The VR simulation shall include ambient audio associated with an EVA.	Compliant	X		X		I
			1.1.4.2	The VR simulation shall include audio feedback in response to the user's input in PR.	Compliant	X	X	X		I

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Requirements - FR1

Acronym	Verification	Description
I	Inspection	Use of human senses to verify requirement
A	Analysis	Modelling
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Level 0	Level 1	Level 2	Level 3	Requirement	Predicted Compliance	SW	DH	Elect.	Mech.	Test
	PR-VR INTERACTIONS									
	DR 1.2			**The user's actions in PR shall correlate to effects in VR.**						
				NOTE: finger tracking is a Lvl. 2 success criteria, so it is not essential but nice to have.						
	TRACKING									
	PR Elem.	1.2.1		The position and orientation of PR elements that the user can interact with shall be tracked.	Compliant			X	X	T/D
			1.2.1.1	The PR elements' user-relative orientation shall be tracked with an accuracy 10º about three orthogonal axes.	Compliant			X		T
			1.2.1.2	The PR elements' user-relative position shall be tracked with an accuracy of 0.025 m on three orthogonal axes.	Compliant			X		T
			1.2.1.3	PR elements' tracked positional and orientation data shall be collected at a rate of 90 Hz.	Compliant		X	X		A
	PR Input	1.2.2		The state of PR input devices shall be sampled at a rate of at least 90 Hz.	Compliant		X	X		D
			1.2.2.1	At least 4 input devices shall be sampled during the simulation	Compliant		X	X		I
	Hands	1.2.3		The motion of the user's hands shall be tracked.	Compliant			X		T/D
			1.2.3.1	The user's hand orientation shall be tracked with an accuracy 7º about three orthogonal axes.	Partially Compliant			X		T
			1.2.3.2	The user's hand position shall be tracked with an accuracy of 2.5 cm on three orthogonal axes.	Partially Compliant			X		T
	Fingers	1.2.4		The the motion of the user's fingers shall be tracked.	Partially Compliant			X		D
			1.2.4.1	The position of the user's fingers shall be tracked with an accuracy of 1.25 cm on three orthogonal axes.	Partially Compliant			X		T
			1.2.4.2	User's finger orientation shall be tracked with an accuracy of 7º about three orthogonal axes.	Partially Compliant			X		T
	Power	1.2.5		All electronic components, including tracking devices, shall be powered to their rated values.	Compliant			X		I
	COMMUNICATION TO VR									
	PR Input	1.2.6		The state of PR input devices shall be communicated to the VR simulation at a rate of at least 90 Hz.	Compliant		X			D
	PR Elem.	1.2.7		The dynamic PR elements' tracking data shall be communicated to the VR at a rate of 90 Hz	Compliant		X			D
			1.2.7.1	The data handling system shall send PR object positional data to the VR at a rate of 90 Hz.	Non Compliant		X			D
			1.2.7.2	The data handling system shall send PR object orientation data to the VR at a rate of 90 Hz.	Non Compliant		X			D
	Hands	1.2.8		The user's hands tracking data shall be communicated to the VR in real time.	Compliant		X			D
	Fingers	1.2.9		The user's finger tracking data shall be communicated to the VR in real time.	Compliant		X			D

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Requirements - FR1

Acronym	Verification	Description
I	Inspection	Use of human senses to verify requirement
A	Analysis	Modelling
T	Test	Requires data aquisition and use of special equipment
D	Demonstration	Run test w/o special equipment to collect data

Level 0	Level 1	Level 2	Level 3	Requirement	Predicted Compliance	SW	DH	Elect.	Mech.	Test
	DISPLAY IN VR									
	PR Input	1.2.10		The VR simulation shall reflect user's interaction with PR input devices (e.g. switches, buttons, etc.) in real time.	Compliant	X				D
			1.2.10.1	The system shall display the state of PR input devices in the VR simulation in real time.	Compliant	X				D
			1.2.10.2	The VR simulation shall have indicators to show the current state of input PR devices.	Compliant	X				D
	PR Elem.	1.2.11		The VR simulation shall display the PR elements' motion to the user in real time.	Compliant	X				D
			1.2.11.1	The VR simulation shall display the orientation of PR elements relative to the user in real time.	Compliant	X				D
			1.2.11.2	The VR simulation shall display the location of PR elements relative to the user in real time.	Compliant	X				D
	Hands	1.2.12		The VR simulation shall display the user's hands motion in real time.	Compliant	X				D
			1.2.8.1	The VR simulation shall display the user's hands orientation in real time.	Compliant	X				D
			1.2.8.2	The VR simulation shall display the user's hands location in real time.	Compliant	X				D
	Fingers	1.2.13		The VR simulation shall display the user's finger motion in real time	Partially Compliant	X				D
			1.2.13.1	The VR simulation shall display the user's finger position in real time.	Partially Compliant	X				D
			1.2.13.2	The VR simulation shall display the user's finger orientation in real time.	Partially Compliant	X				D
	USER IMMERSION									
	DR 1.3			**The user shall only NEED TO interact with PR elements, not with the VR.**	Compliant	X			X	I
		1.3.1		The VR simulation shall only serve as an immersivity tool to provide visual and auditory ques to the user.	Compliant	X				I
		1.3.2		The user shall only interact with PR elements with their hands.	Compliant				X	I
		1.3.3		The user shall receive primary visual and auditory cues only from the VR simulation.	Compliant	X		X	X	I
	DR 1.4			**The user shall be spatially immersed in the VR simulation.**	Compliant	X			X	I
		1.4.1		The user shall be capable to turn 360º to view their surroundings in the VR simulation.	Compliant	X				I
		1.4.2		The user shall have the option to translate (walk) in the VR simulation.	Compliant	X			X	I
	PR-USER INTERACTIONS									
	DR 1.5			**The system shall have physical interactions with the PR that mimic Lunar habitat maintenance.**	Compliant				X	D
		1.5.1		The system shall have at least one (1) panel with a door that can be opened and closed.	Compliant				X	D
		1.5.2		The system shall have at least two (2) switches that can be flipped.	Compliant			X	X	D
		1.5.3		The system shall have at least two (2) buttons that can be pressed.	Compliant			X	X	D
		1.5.4		The system shall allow for the replacement of at least one (1) object in PR as part of the training scenario.	Compliant				X	D
		1.5.5		The system shall allow for the use of at least one (1) tool in PR as part of the training scenario.	Compliant				X	D
	DR 1.6			**The PR elements shall resemble the objects/tools that would be used during a lunar EVA mission.**	Compliant				X	I
		1.6.1		The PR elements shall have a similar volume as the objects/tools that would be used during a lunar EVA mission.	Partially Compliant				X	I
		1.6.2		The PR elements shall have a smilar weight as the objects/tools that would be used during a lunar EVA mission.	Compliant				X	I
			1.6.2.1	The PR elements shall weigh of 1/6 of the object's weight on Earth with an accuracy of 10%.	Compliant				X	T
		1.6.3		The PR elements shall have a similar shape as tools that would be used during a lunar EVA mission.	Partially Compliant				X	I

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Requirements - FR2

Acronym	Verification	Description
I	Inspection	Use of human senses to verify requirement
A	Analysis	Modelling
T	Test	Requires data aquisition and use of special equipment
D	Demonstration	Run test w/o special equipment to collect data

Level 0	Level 1	Level 2	Level 3	Requirement	Predicted Compliance	SW	DH	Elect.	Mech.	Test
FR 2	Physical Constraints			**The PCs shall inhibit movement of at least one part of the body.**						
				Physical Constraint (or PC) *is a real body movement restriction used to simulate wearing an EVA spacesuit; therefore, it is part of the PR.*	-					
	ARM CONSTRAINTS			**LVL 1 SUCCESS CRITERIA: ESSENTIAL**						
	DR 2.1			**The PCs shall simulate the impacts of physical constraints of a lunar EVA spacesuit on shoulder and elbow movement.**	Compliant				X	T/D
		2.1.1		The PCs shall constrain the user's shoulder abduction and adduction within a range of 0 - 150 degrees.	Compliant				X	T
			2.1.1.1	The PC shall provide a range of counter-torque to the shoulder between -31 and 29 ± 10% Nm.	Partially Compliant				X	T
		2.1.2		The PCs shall constrain the user's elbow extension movement within a range of 0 - 115 degrees.	Compliant				X	T
			2.1.2.1	The PCs shall provide counter-torque to the elbow within a range between -9 and 9 ± 10% Nm.	Partially Compliant				X	T
		2.1.3		The user shall perform the motor motions of pulling, picking up, and setting down PR elements.	Compliant				X	D
	HAND / FINGER CONSTRAINTS			**LVL 2 SUCCESS CRITERIA: NOT ESSENTIAL**						
	DR 2.2			**The PCs shall simulate the impacts of physical constraints of a lunar EVA spacesuit on hand and finger motion.**	Partially Compliant				X	T/D
		2.2.1		The PCs shall constrain movement of the user's fingers flexion.	Partially Compliant				X	T
		2.2.2		The PCs shall constrain the user's hand flexion within a range of -14 to 50 degrees.	Non Compliant				X	T
		2.2.3		The PC shall constrain the user's hand extension withing a range of -20 to 55 degrees.	Non Compliant				X	T
		2.2.4		The user shall be able to perform fine motor skills to push, flip, and grasp PR elements.	Compliant				X	D

Requirements – FR3, FR4

Acronym	Verification	Description
I	Inspection	Use of human senses to verify requirement
A	Analysis	Modelling
T	Test	Requires data aquisition and use of special equipment
D	Demonstration	Run test w/o special equipment to collect data

Level 0	Level 1	Level 2	Level 3	Requirement	Predicted Compliance	SW	DH	Elect.	Mech.	Test
FR 3	Safety			**The user shall be in no danger while operating in the HR environment.**						
	DR 3.1			**The system shall be safe for humans to use.**	Compliant	X		X	X	T/D
		3.1.1		The user shall not receive audio input or feedback at a volume higher than 70 dB.	Compliant	X				T/D
		3.1.2		The user shall be capable of spending at least one (1) hour in the simulation.	Compliant	X				T/D
		3.1.3		The user shall be supervised during the entire training simulation.	Compliant					I
			3.1.3.1	The supervisor shall check in with the user every 10 minutes about their comfort and any motion sickness issues.	Compliant					I
		3.1.4		The VR headset shall display the VR simulation with a minimum frame rate of 90 fps (90 Hz).	Compliant	X		X		I
		3.1.5		The VR headset shall display the VR simulation with a minimum resolution of 3840 x 2160 pixels (4K).	Compliant	X		X		I
		3.1.6		The PR-VR data transfer shall have a latency smaller than 180 ms.	Compliant					T
	DR 3.2			**The system shall cause no physical harm to the user.**	Compliant	X	X	X	X	I
		3.2.1		The PR system shall have no sharp edges that the user could harm themselves with.	Compliant				X	I
		3.2.2		The PR system shall have no obstacles that the user can't see though VR.	Compliant	X	X	X	X	I
		3.2.3		There shall be no objects other than those required for training in the PR training area.	Compliant		X	X	X	I
	DR 3.3			**The VR simulation shall display a boundary such that the user will be warned if they approach the edge of the designated training area.**	Compliant	X			X	I
		3.3.1		The VR simulation shall have a bounded training area of 8.5' x 9.5'.	Compliant	X				D
		3.3.2		The PR shall encompass a training area no larger than 9' x 10'.	Compliant				X	T
FR 4	Adaptability			**The customer shall be able to implement their own training scenarios within the HR environment.y**						
	DR 4.1			**The system shall provide mission augmentation and customization for custom uses and scenarios.**	Partially Compliant	X	X	X	X	T/D
	DR 4.2			**The VR simulation shall run a specified mission scenario upon user selection in launch menu.**	Compliant	X				T/D

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MS = Motion Sickness
LOS = Line Of Sight

Risk Identification

PROJECT ELEMENT	CAUSE	RISK	CONSEQUENCE	MITIGATION STRATEGY	Assessment P	Assessment I
SAFETY	User is prone to motion sickness	MS due to high sensitivity	Impeding further participation in the simulation	Screen users to decrease likelihood of motion sickness	4	5
EVA PANEL	Buttons/switches are too close together. Trackers are in the way	Hard to operate panel	Loss of immersion	Spacing buttons/switches (hand tracking accuracy). Place trackers where they don't impede operation	2	3
HARDWARE	Arm constraints don't allow needed arm rotations	Arm constraints harm the user	Loss of immersion Inability to continue the simulation	Human testing	3	5
SAFETY PR-VR INTERACTION	High latency. Low fps of display. Low resolution of display	MS due to latency/resolution	Impeding further participation in the simulation	Decrease resolution to aceptable range and complexity of environment	3	5
TRAINING VERSATILITY	Schedule delays	No time to design several scenarios	Decrease training versatility. Can't meet versatility 2nd level success criteria	Work in parallell. Have baseline for several scenarios ready to implement at any time	4	4
TRACKING	Loss of LOS between base station and tracker. Reflective surfaces	Delay/disconnect in tracking	The system would be hard or impossible to use	Redundant base stations. Reduce reflective surfaces by covering them with opaque materials	4	3
HAND TRACKING	Hands are outside the FOV of the headset's cameras	Inaccurate hand tracking	Increased chance of MS. Inability to operate hardware. Subsystem failure	Brief user in proper location of hands to ensure accurate tracking.	2	4
HARDWARE	Arm constraints provide too much counter-torque	Too much arm constraint	Inability to engage in the simulation Loss of immersion	Model and test	2	3
PR-VR DATA LINK	Arduino can't handle data rates due to amount of components	Lag in PR - VR connection	Increased latency in the simulation. Increased risk of motion sickness.	Prototyping and testing	3	3
VR SIMULATION	Not enough processing power	Simulation glitch / freeze	Loss of immersion Increased chance of motion sickness	Test more complex simulations than expected with available hardware to ensure it can handle it	3	3
MANUFACTURING	Too many teams using AES facilities for manufacturing	Manufacturing delay	Delay in schedule. Lack of access to the necessary components	Schedule access to required equipment ahead of time. Turn in part models as soon as possible	2	3

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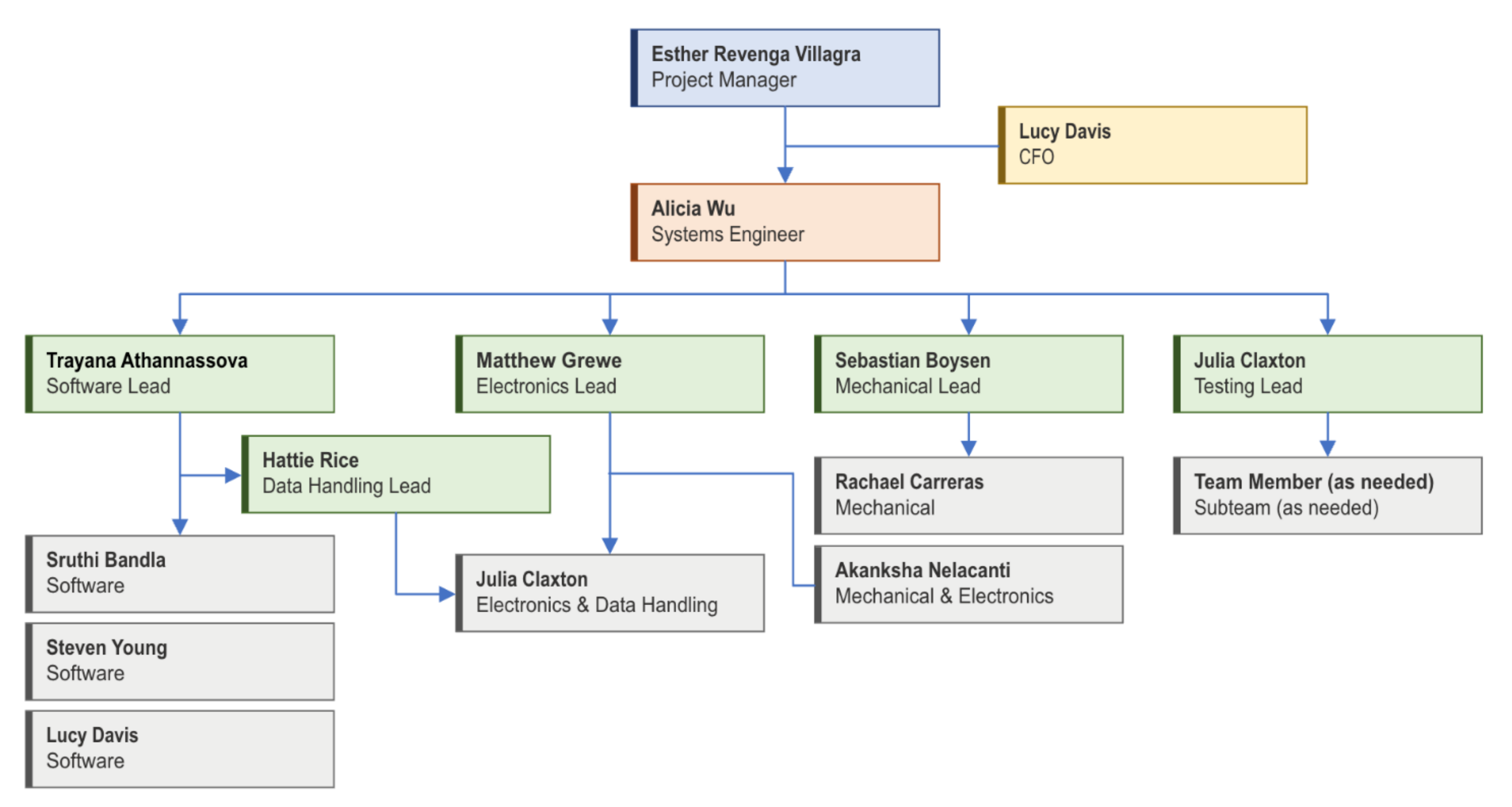
Organizational Chart



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Detailed Cost Plan

ITEM	QTY	COST/UNIT	COST	% MARGIN	SHIPPING	OVERALL COST	COMMENTS	SUPPLIER
SOFTWARE / VR ELECTRONICS								
Meta Quest 2	0	$ 399.99	$ -	0%	$ -	$ -	ELECTRONICS SHOP FOR NOW	META
Meta Quest 2 Elite Strap	1	$ 59.99	$ 59.99	0%	$ -	$ 59.99	ELECTRONICS SHOP FOR NOW	META
D-Link VR Air Bridge	1	$ 100.00	$ 100.00	0%	$ -	$ 100.00	Private "Hotspot" for laptop and headset	META
Virtual Desktop App	1	$ 20.00	$ 20.00	0%	$ -	$ 20.00	Display SteamVR in Oculus	META
VR Computer	0	$ 1,000.00	$ -	0%	$ -	$ -	UPPER ESTIMATE	-
HTC Vive 3.0 Tracker	2	$ 129.00	$ 258.00	100%	$ -	$ 516.00	NEED: 4 trackers	Amazon
HTC Base Station 1.0 + HTC Vive Tracker 3.0	2	$ 264.98	$ 529.96	5%	$ -	$ 556.46	NEED: 2 Base Stations	Amazon
Base Station Tripod	1	$ 39.21	$ 39.21	10%	$ -	$ 43.13	2 Tripods in package	Amazon
Software Assets	1	$ 100.00	$ 100.00	50%	$ -	$ 150.00	UPPER ESTIMATE	Unity Asset Shop
HARDWARE / PR ELECTRONICS								
3 Resistance Bands	2	$ 11.99	$ 23.98	100%	$ -	$ 47.96	Size [6 in x 4.5 ft.]	Amazon
30 Slide Buckles	1	$ 10.99	$ 10.99	5%	$ -	$ 11.54	Size 1 in	Amazon
Straps	1	$ 11.92	$ 11.92	5%	$ -	$ 12.52	Size 1 in wide	Amazon
Shoulder Compression Sleeve	2	$ 19.99	$ 39.98	30%	$ -	$ 51.97	Size 1 in wide	Amazon
3D Printing Filament	2	$ 25.00	$ 50.00	40%	$ -	$ 70.00	Worst case scenario	AES Department / PILOT
Aluminum for Arm Constraints						$ -		
Vinyl Glue	1	$ 13.99	$ 13.99	10%	$ -	$ 15.39	Prototyping	Amazon
2 in x 2 in x 8 ft Lumber	10	$ 2.98	$ 29.80	100%	$ -	$ 59.60	UPPER ESTIMATE	Home Depot
5/8 in x 5-1/2 in x 6 ft Fence Picket	2	$ 2.48	$ 4.96	10%	$ -	$ 5.46	For EVA Panel Door	Home Depot
Screws	1					$ -		
Nails	1	$ 2.56	$ 2.56	10%	$ -	$ 2.82	Count = 35	Home Depot
Cardboard (plastic)	1	$ 29.78	$ 29.78	30%	$ -	$ 38.71	48 in x 96 in	Home Depot
Hinges	1	$ 2.42	$ 2.42	10%	$ -	$ 2.66	2 pack	Home Depot
Wires	0	$ -	$ -	0%	$ -	$ -		AES Electronics Shop
Resistor Kit	1	$ 8.95	$ 15.38	0%	$ 6.43	$ 21.80	500 Resistors	SparkFun
Round Momentary Buttons (35 mm)	4	$ 2.75	$ 17.43	20%	$ 6.43	$ 27.34		SparkFun
Square Momentary Buttons (34x34mm)	1	$ 12.49	$ 12.49	0%	$ -	$ 12.49	5 Pack	Amazon
Microprocessor: Arduino DUE	1	$ -	$ -	0%	$ -	$ -	Potentilly broken DAC port (not needed)	AES Electronics Shop
Arduino MEGA Shield	1	$ 17.90	$ 17.90	10%	$ -	$ 19.69	Compatible with DUE. Screw connectors	Amazon
Toggle Switches	4	$ -	$ -	0%	$ -	$ -		AES Electronics Shop
Rotary Potentiometer - 10k Ohm, Linear	1	$ 1.05	$ 1.05	100%	$ -	$ 2.10		SparkFun
Foam PVC Black Sheet	2	$ 32.37	$ 64.74	50%		$ 97.11	24 in. x 24 in. x 0.236 in.	Home Depot
1/4" Inch Stainless Steel Bearing Balls	1	$ 4.95	$ 4.95	20%	$ -	$ 5.94	25 count. Use: modifying weight of tool	Amazon
TESTING	1	$ 100.00	$ 100.00	0%	$ -	$ 100.00	UPPER ESTIMATE	
Emergency	1	$ 300.00	$ 300.00	0%	$ -	$ 300.00		
Total	**52**		**$ 1,861.47**			**$ 2,350.67**	**Remaining Budget**	**$ 2,138.53**

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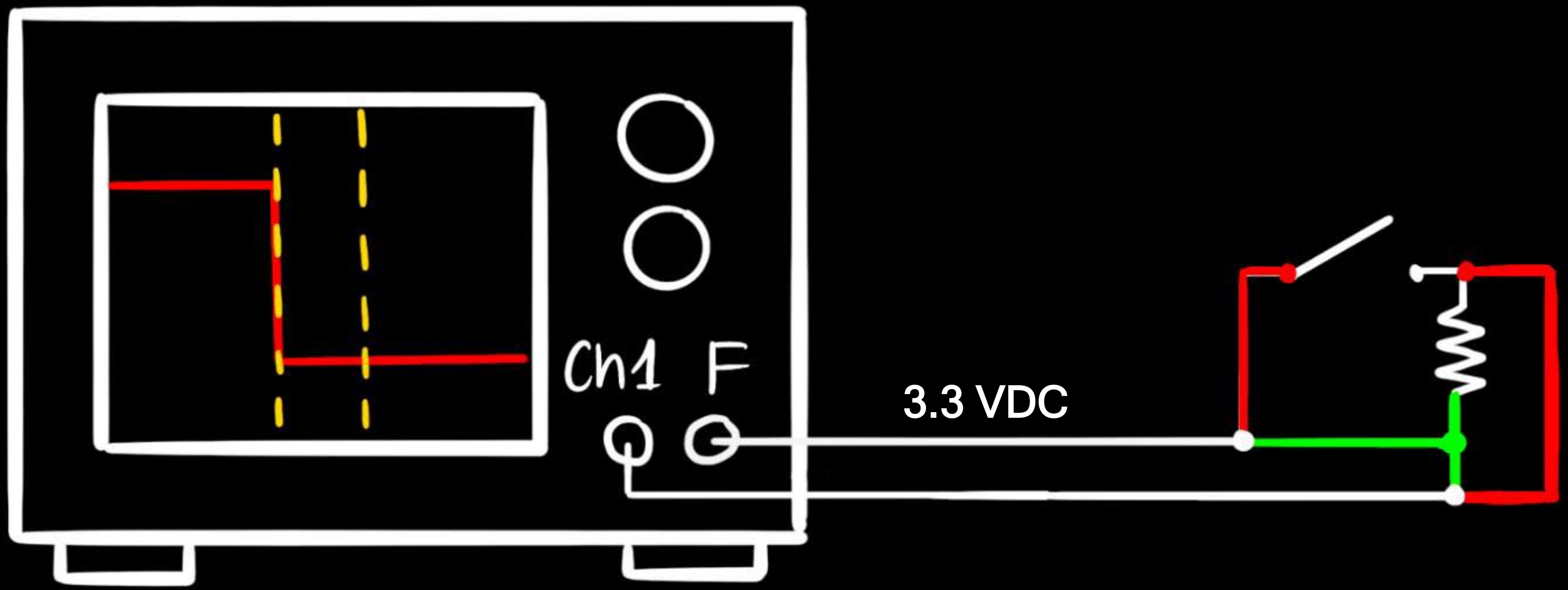
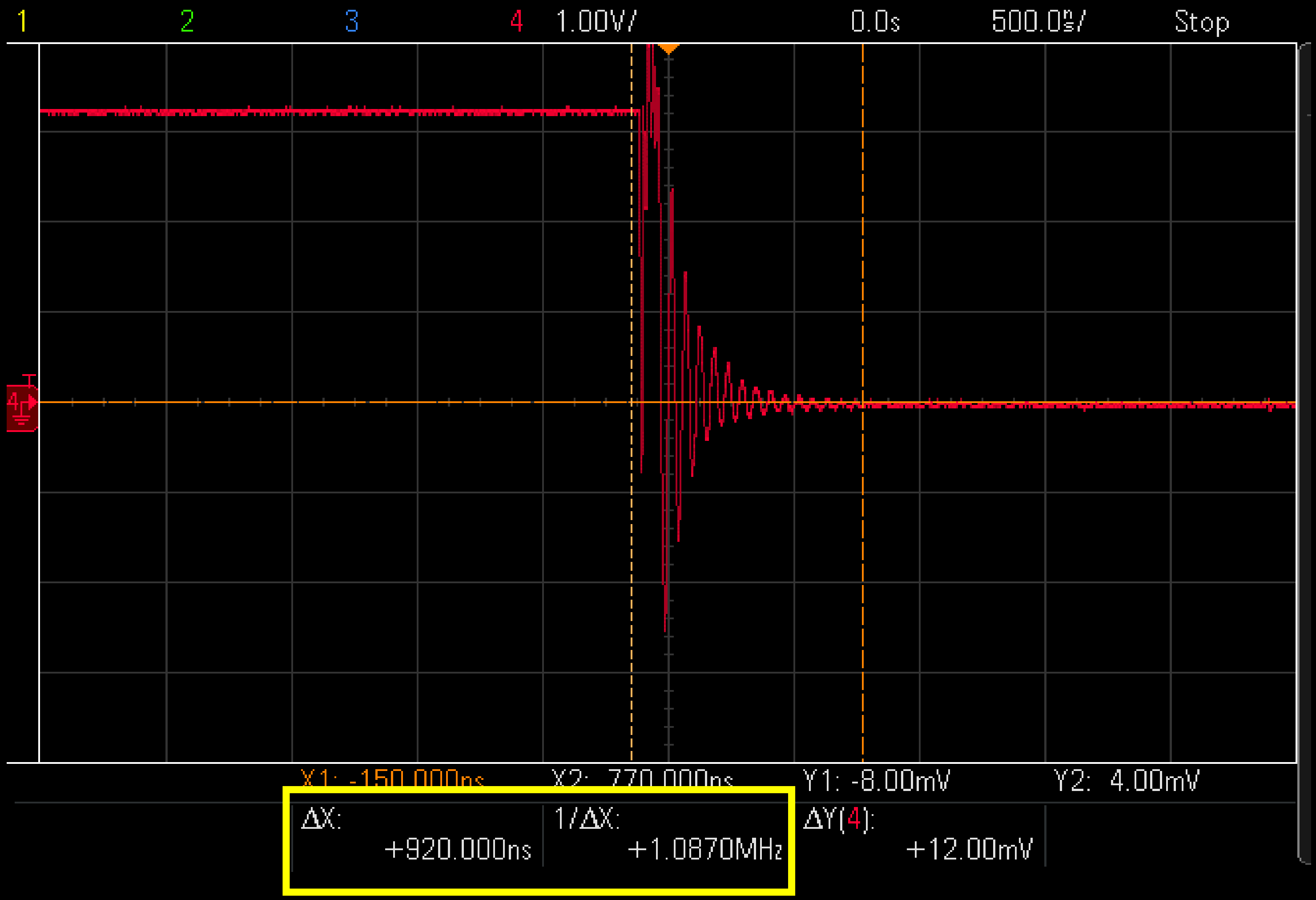
Switch/Button Bouncing Time Preliminary Tests

Switch/Button Bouncing Time Test



Switch Bouncing Time TEST RESULTS



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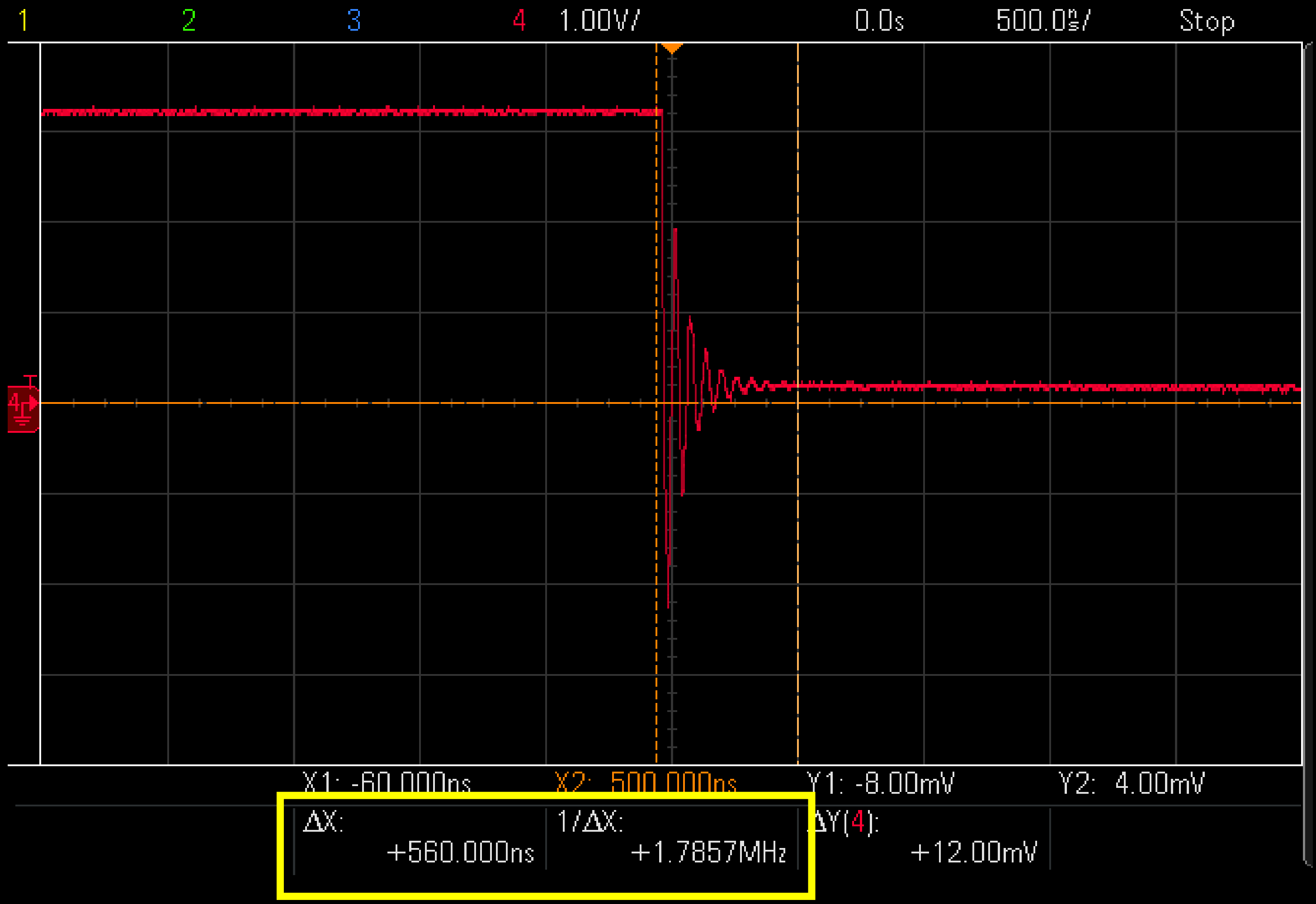
Button Bouncing Time TEST RESULTS



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HR Data Transfer DEMO

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HR Data Transfer Demo Goals

~ 1. Demonstrate capability to accurately determine the state of multiple RW assets per DR 5.1

✓ 2. Update state of RW assets at a rate of 90 Hz or greater per DR 6)

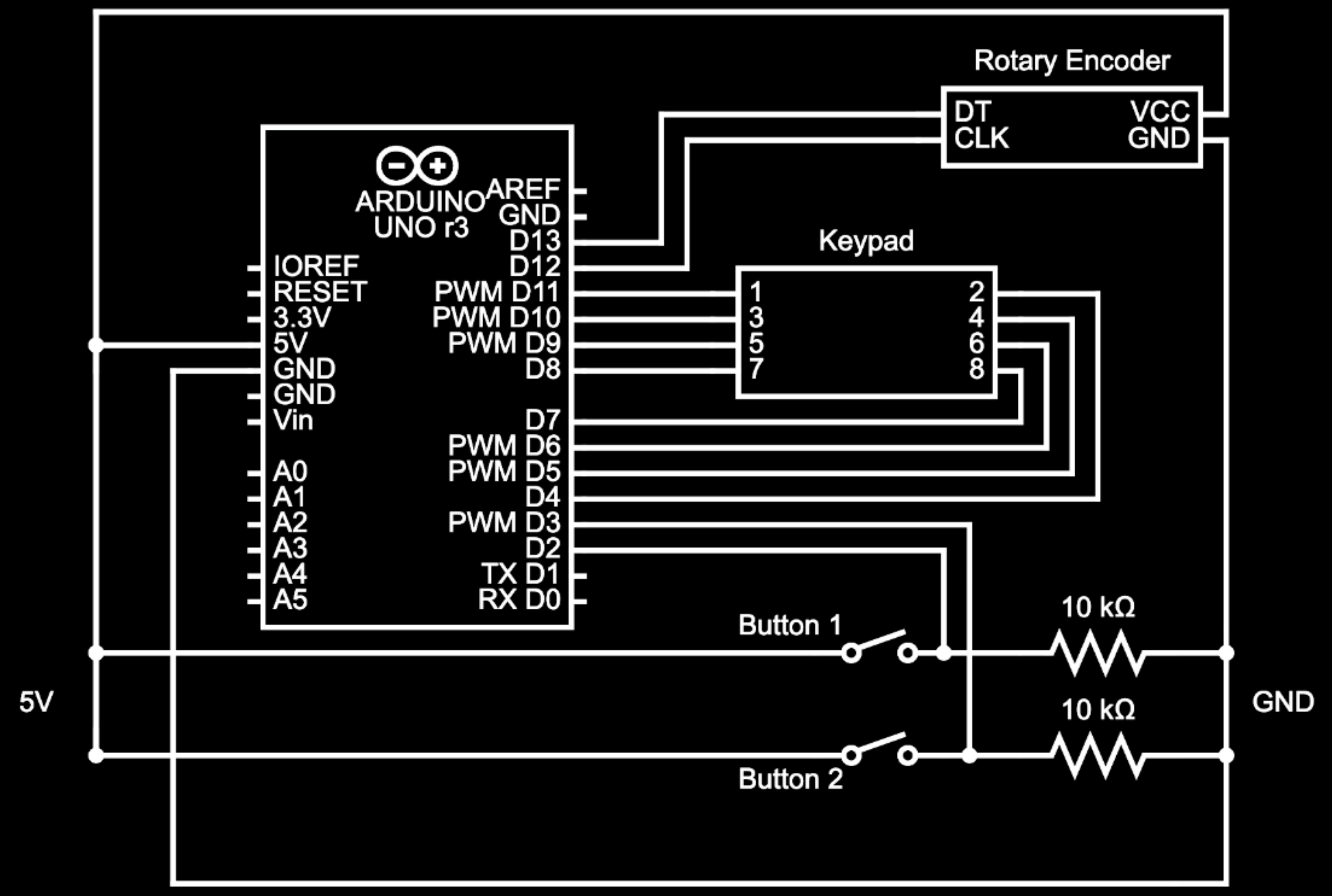
✓ 3. Communicate state of RW assets to Unity per DR ??

Demo Design

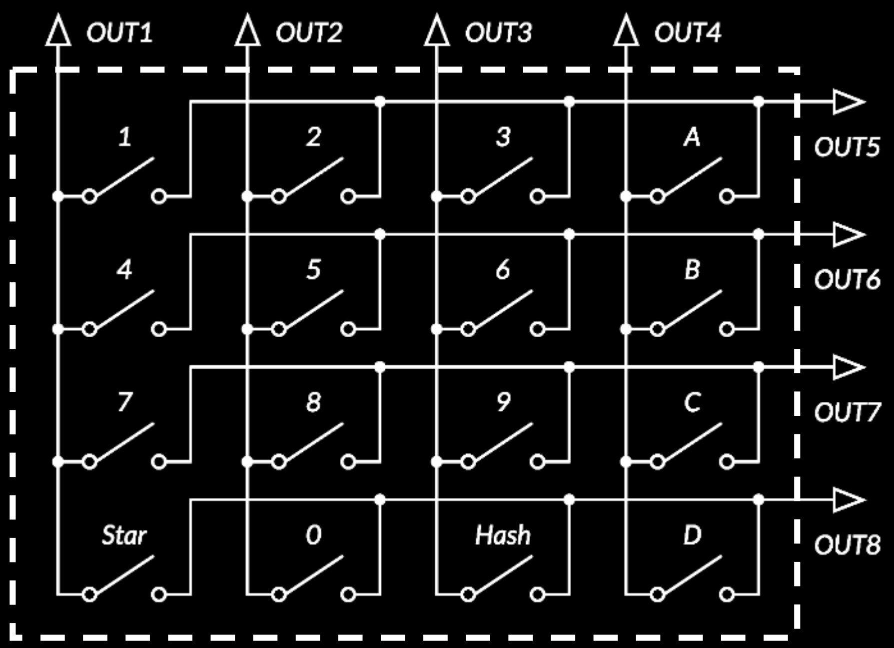
- 19 Input Devices:
  1. 4x4 multiplexed keypad
  2. 2 switches
  3. Rotary encoder

- States detected by Arduino Uno
- Wired RS-232 communication to laptop

^ picture of demo here (julia c) ^



Full Demo Schematic



Keypad Internal Schematic

Demo Performance

- Demo accurately reads state of 19 inputs with two limitations
- Arduino communicates input devices' state to laptop at 2600 Hz - 2900 Hz
- Laptop can read and store state bitstring in Unity

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Demo Limitations

1. Keypad 'Ghost' Presses
    - Due to the nature of the keypad's multiplexing array, certain key combinations being depressed simultaneously can create erroneous sensed presses on non-depressed keys
    - Only occurs when more than 3 keys are pressed simultaneously in certain combinations
2. Rotary Encoder Skips
    - Rotary encoder does not read high speed rotations accurately
    - Arduino loop speed is not fast enough to register each angle change pulse

Demo Limitations - Mitigation

1. Keypad 'Ghost' Presses
   - Do not require user to press more than 3 keys simultaneously
   - Reasonable limitation, as nearly all practical keypad use cases only require serial input and do not accept multiple simultaneous presses
2. Rotary Encoder Skips
   - Option 1: Do not employ a rotary encoder in situations with rapid rotations (screwdrivers, drills, etc.)
   - Option 2: Replace rotary encoder with potentiometer, which does not skip

HR Data Transfer - Feasibility Demo

DR 1.2.2.1 - At least 4 input devices shall be sampled during the simulation.

DR 1.2.6 - The state of PR input devices shall be communicated to the VR simulation at a rate of **90 Hz**.

PR - VR Data Transfer DEMO

Arduino UNO + Button + Switch + Rotary Encoder + Multiplexed Keypad

Results:

- Arduino communicates input devices' state to laptop at 2600 Hz - 2900 Hz
- The laptop can read and store state bitstrings in Unity
- Accurately reads the state of 19 inputs with two limitations:
  - Keypad 'Ghost' Presses
    - Mitigate: Don't require simultaneous inputs
  - Rotary Encoder Skips
    - Mitigate: Use a potentiometer

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HR Latency Model & Test

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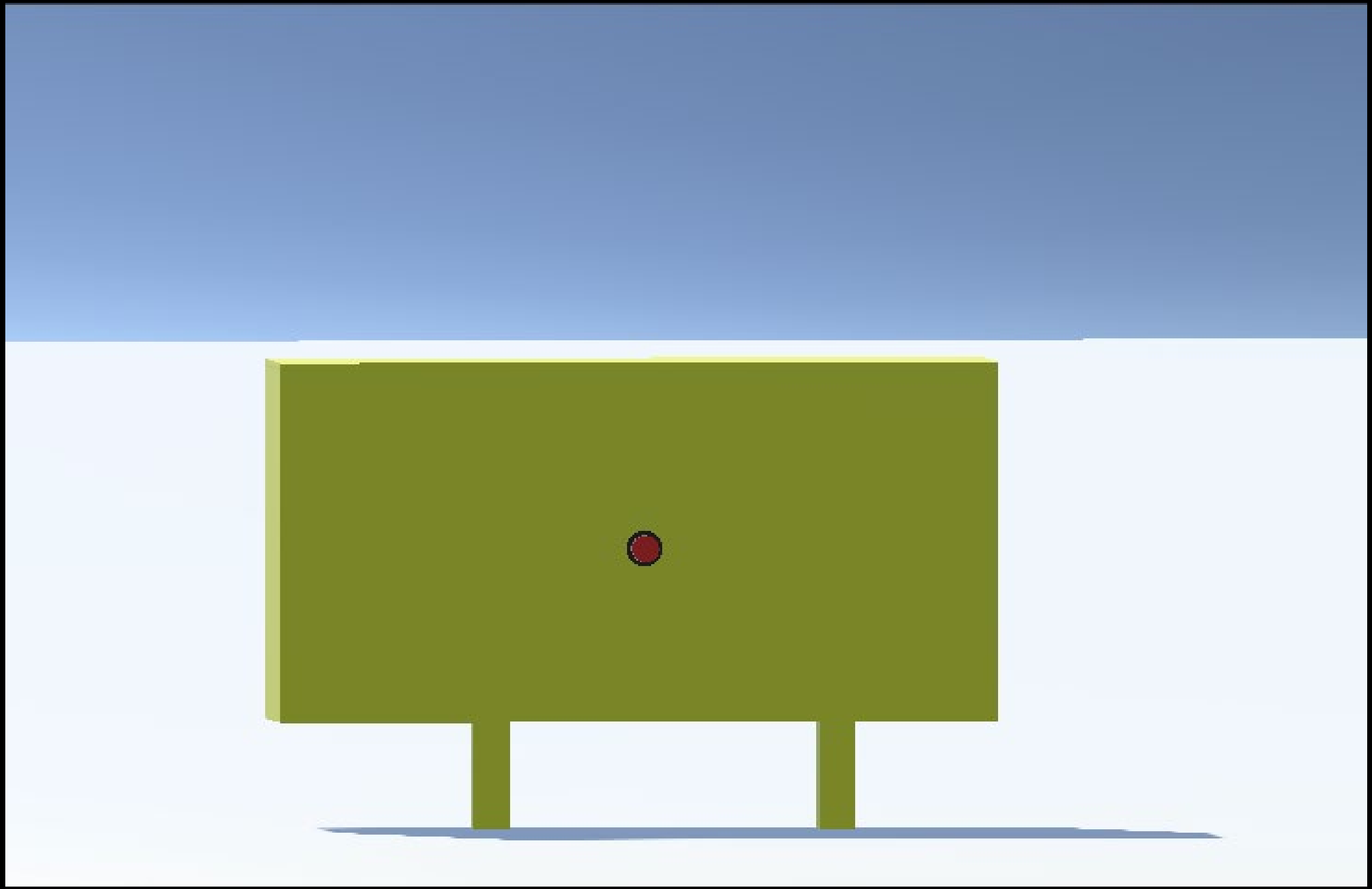
HR Latency Void Test Environment



- Team built static panel
- Simple 1D plane
- Default Unity scene basic lighting
- Interactable button element developed by team
  - Includes collision box with pop up text to display interactability range
  - On button click, displays text, turns on several point lights and shows animation of button pressing and depressing

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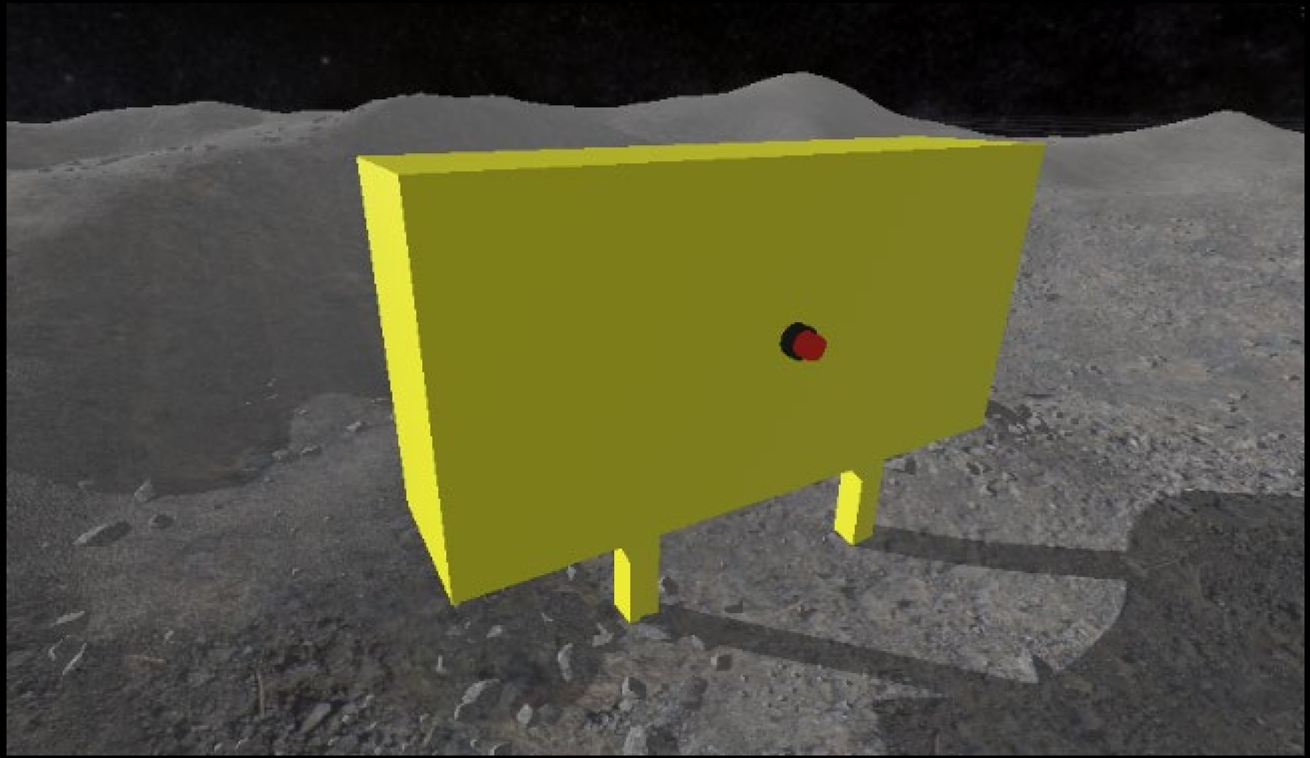
HR Latency Moon Test Environment



- Pre-built Unity moon environment available for free from Unity Asset store from developer Arcsine Technologies
  - Includes terrain, lighting and particle textures
- Team built static panel
- Default Unity scene basic lighting
- Interactable button element developed by team
  - Includes collision box with pop up text to display interactability range
  - On button click, displays text, turns on several point lights and shows animation of button pressing and depressing

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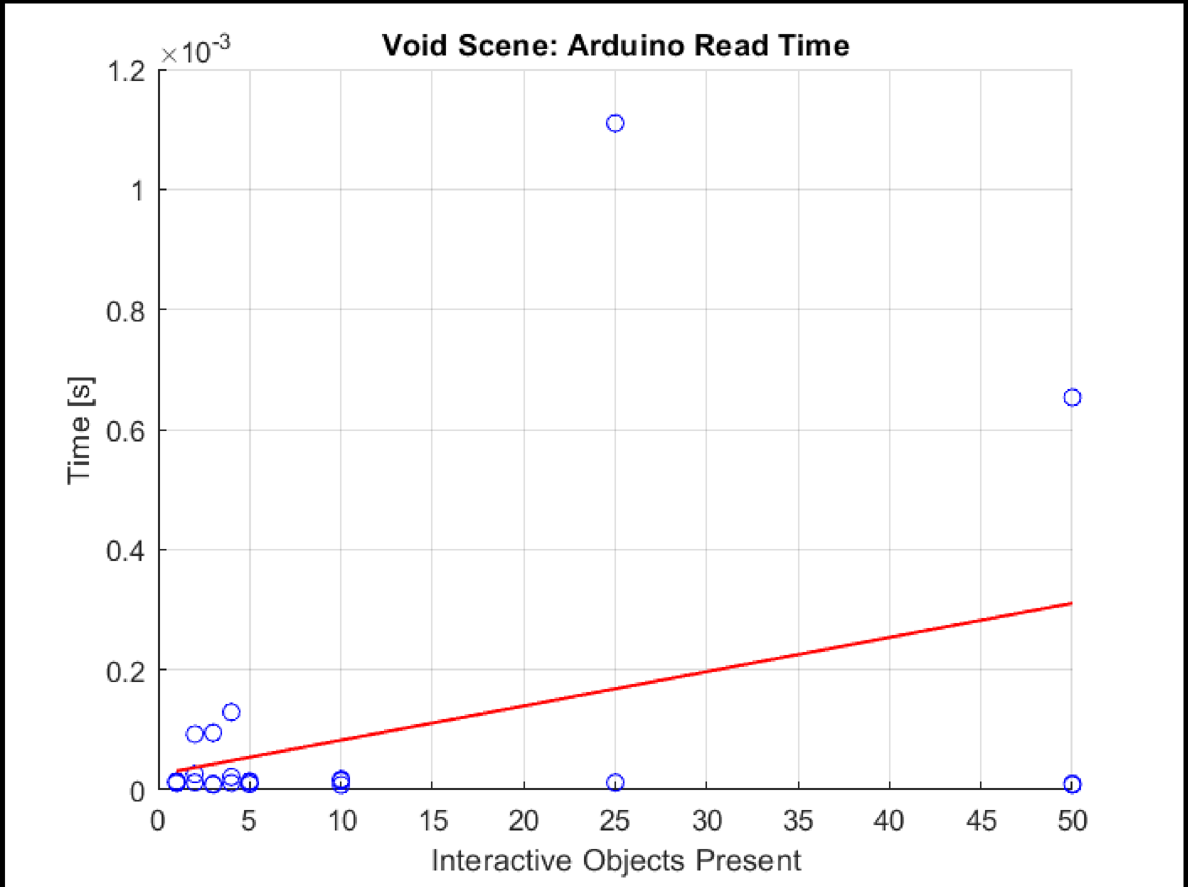
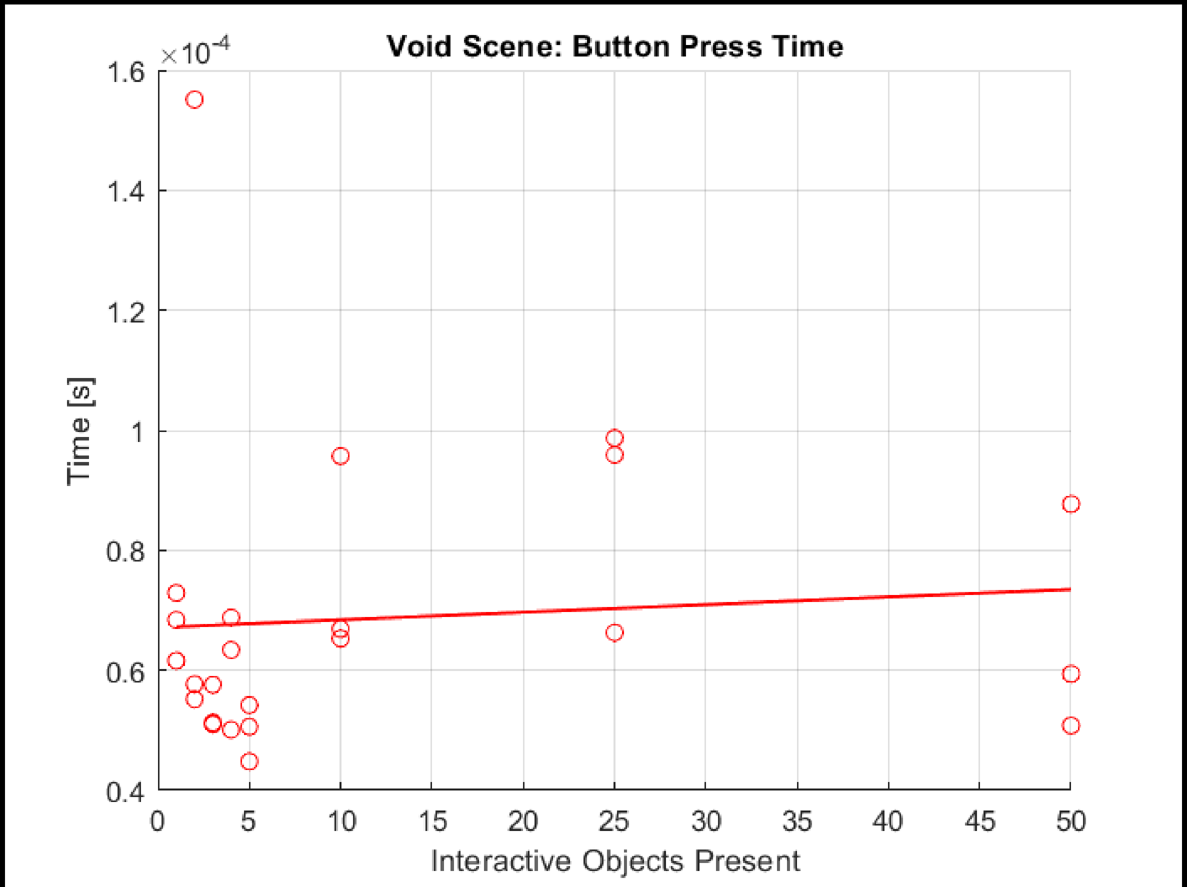
Unity Processing Result Trends (Void)





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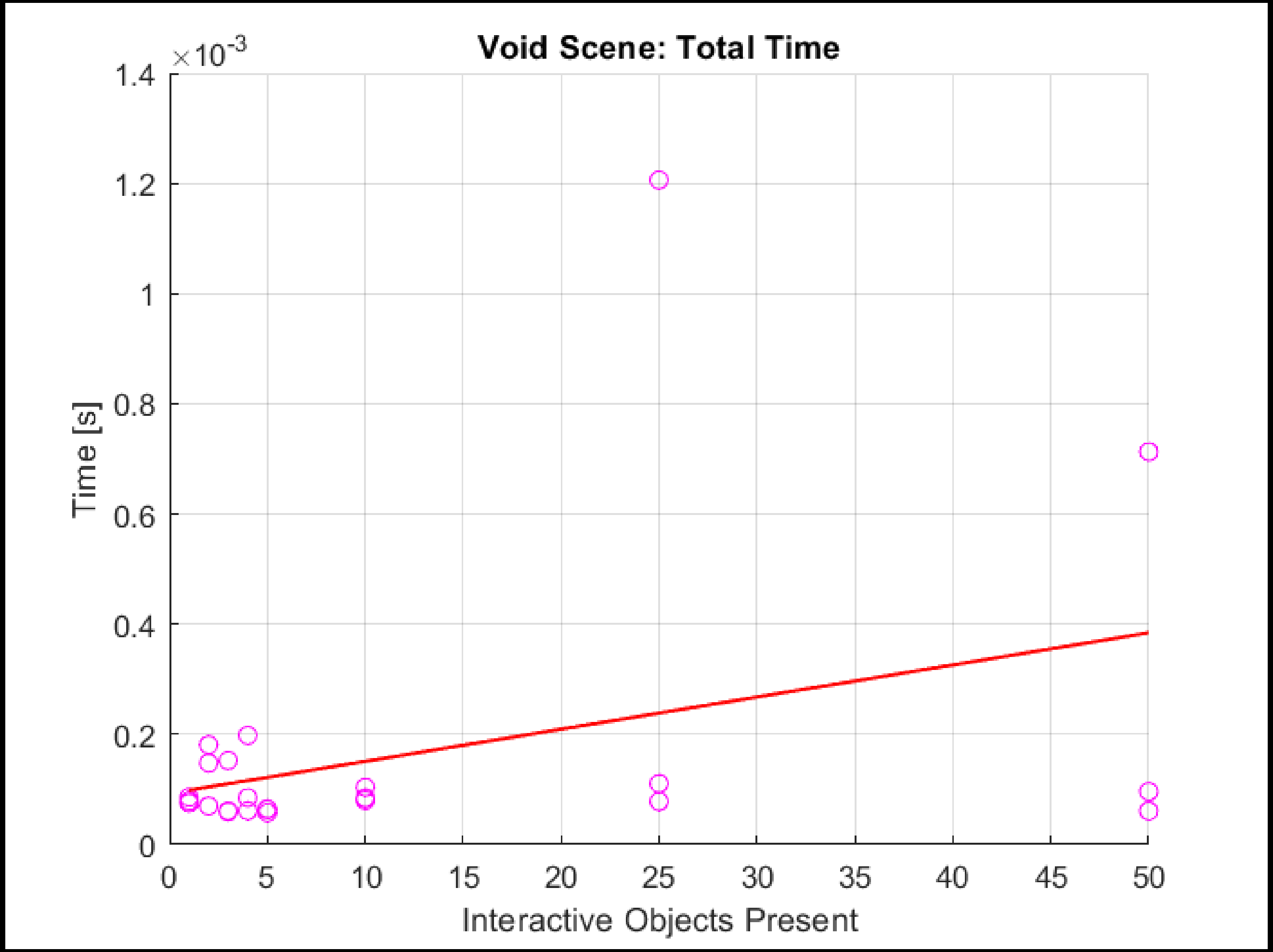
Unity Processing Result Trends (Void)



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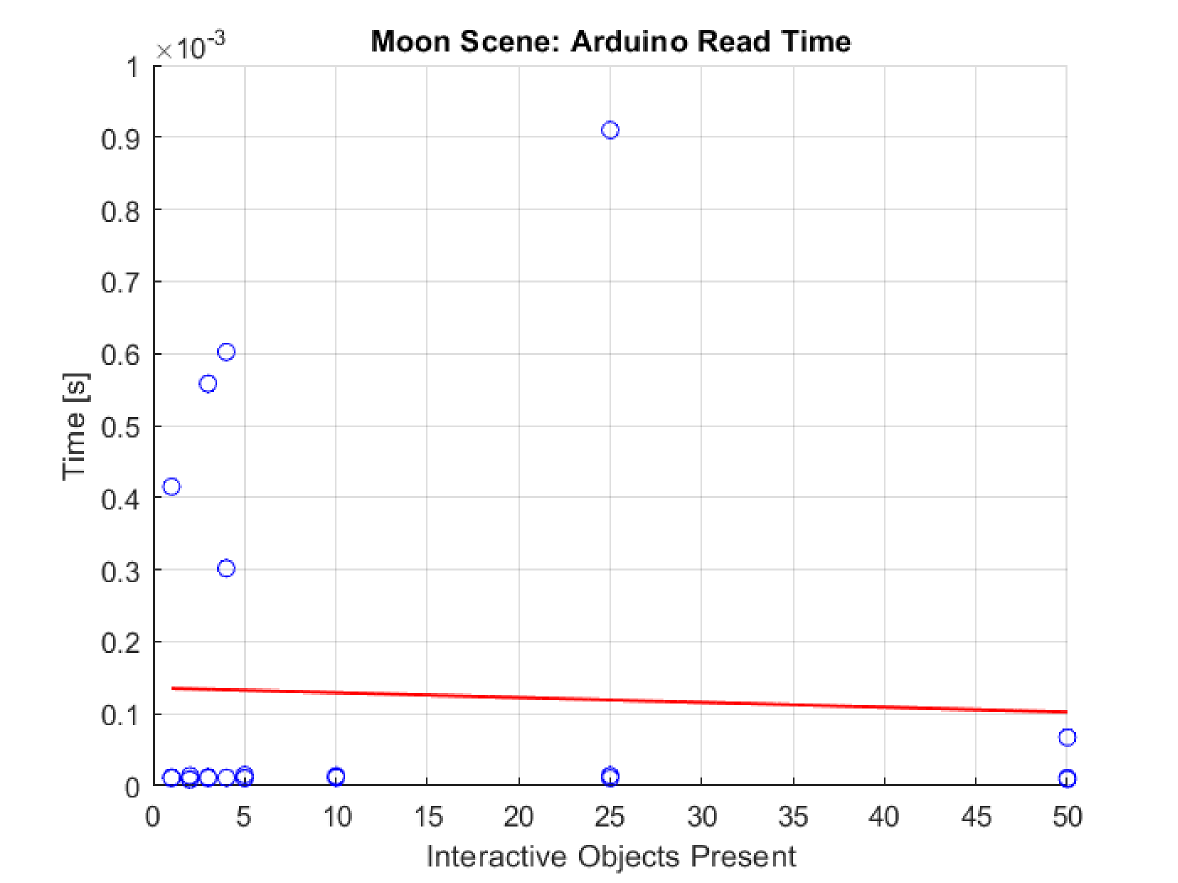
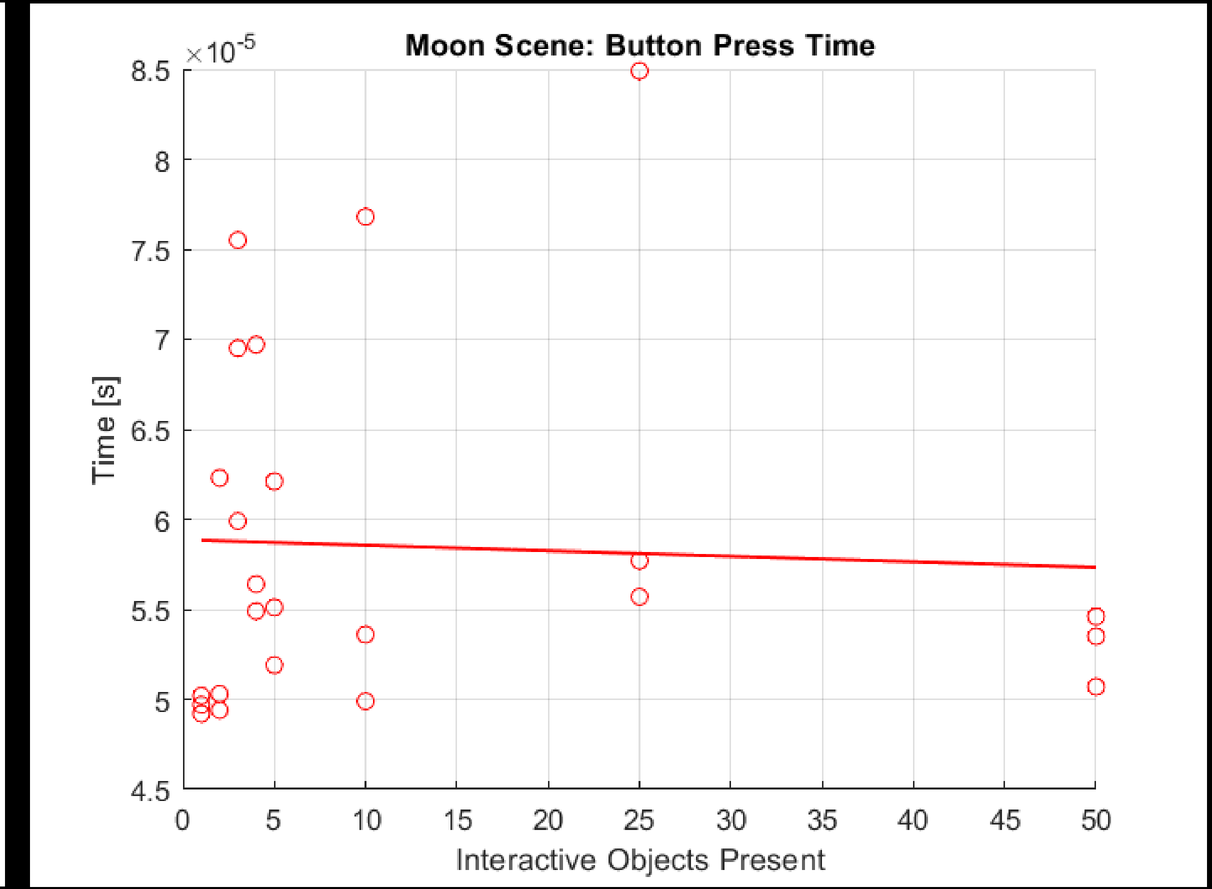
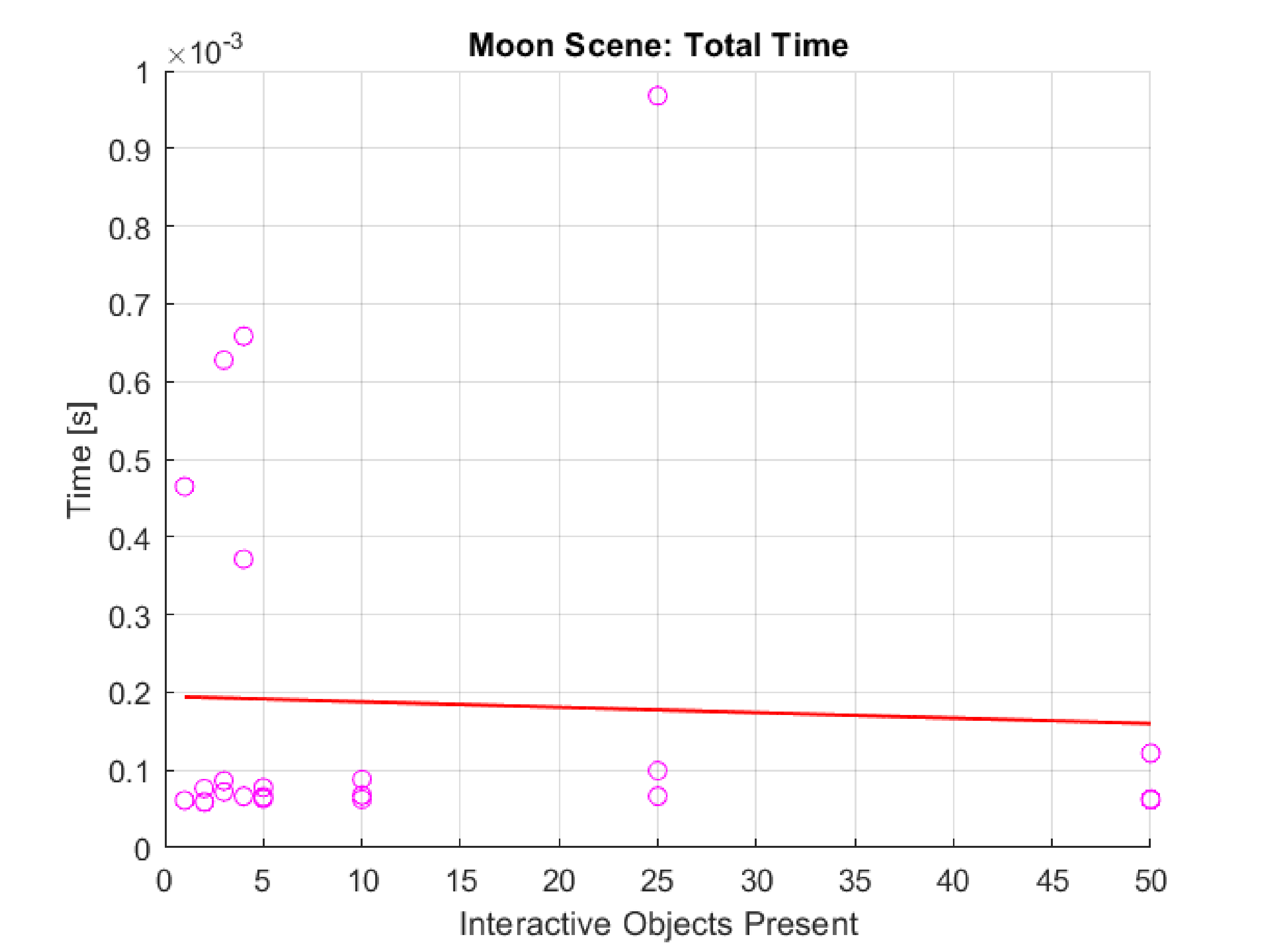
Unity Processing Result Trends (Moon)





Unity Processing Result Trends (Moon)



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Latency Calculations

- Arduino Reads in Data
  - Switch time takes 0.00092ms (from experimentation) to avoid bouncing
- Arduino Processes Data
  - Clock speed of 84MHz ($\frac{1}{84{,}000{,}000} = 0.0119\mu s$ per operation)
- Arduino Baud Rate
  - Must send 4 bits for potentiometer + 9 for buttons + 4 for switches
  - Sends 4800 bits per second
  - Takes $\frac{(4+9+4)}{4800} = \frac{17}{4800} = 0.00354s$
- Unity Reads in Data from Serial Port
  - 0.068ms (from experimentation)
- Unity Processes the Interaction
  - 0.065ms (from experimentation)
- Meta Quest 2 Displays Picture
  - Operating at 120 FPS ($\frac{1}{120} = 8.33\ ms$)
- Total Time $0.00092ms + 2 * 0.0119\mu s + 0.00354s + 1.1ms + 0.16ms + 8.33ms = 13.13ms$

- HTC Base Station Sends State
  - Worst case 60Hz = $\frac{1}{60} = 16.6ms$
- Unity Reads in Data from Bluetooth
  - 0.068 ms (assumption)
- Unity Processes the Interaction
  - 0.065ms (from experimentation)
- Meta Quest 2 Displays Picture
  - Operating at 120 FPS ($\frac{1}{120} = 8.33\ ms$)
- Total Time $16.6ms + 0.068ms + 0.065ms + + 8.33ms = 25.15ms$

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Reaction Time Test

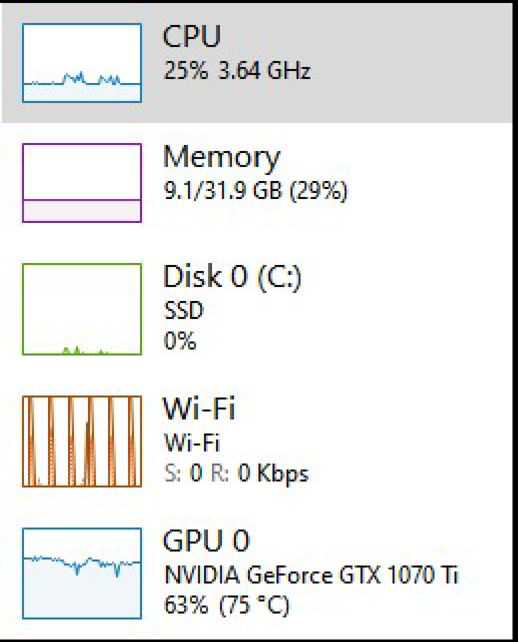
When the red box turns green, click as quickly as you can.
Click anywhere to start.

This is discussed in further detail on the the statistics page. While an average human reaction time may fall between 200-250ms, your computer could be adding 10-50ms on top. Some modern TVs add as much as 150ms!

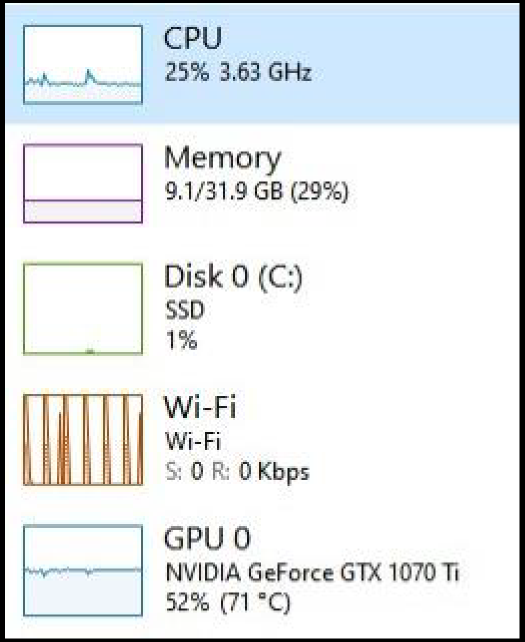
https://humanbenchmark.com/tests/reactiontime

Processing Workload

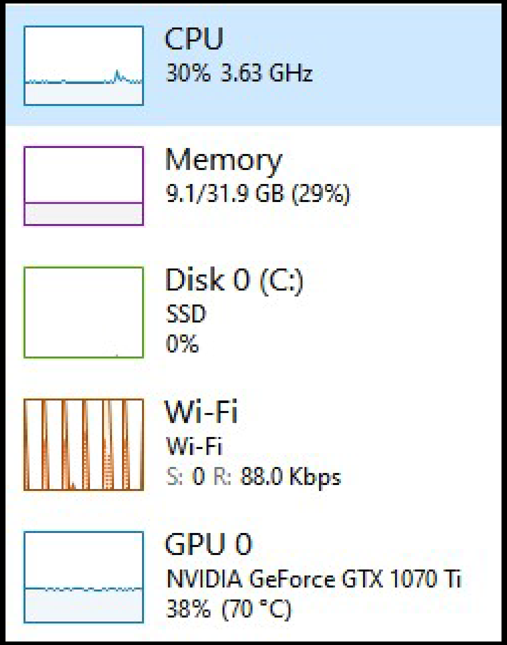
Processing Workload Test



1 Interactable



50 Interactables



200 Interactables

Hardware Used
Processor: AMD Ryzen 5 2600 Six-Core
Graphics: NVIDIA GeForce GTX 1070 Ti
Memory: 32 GB DDR4

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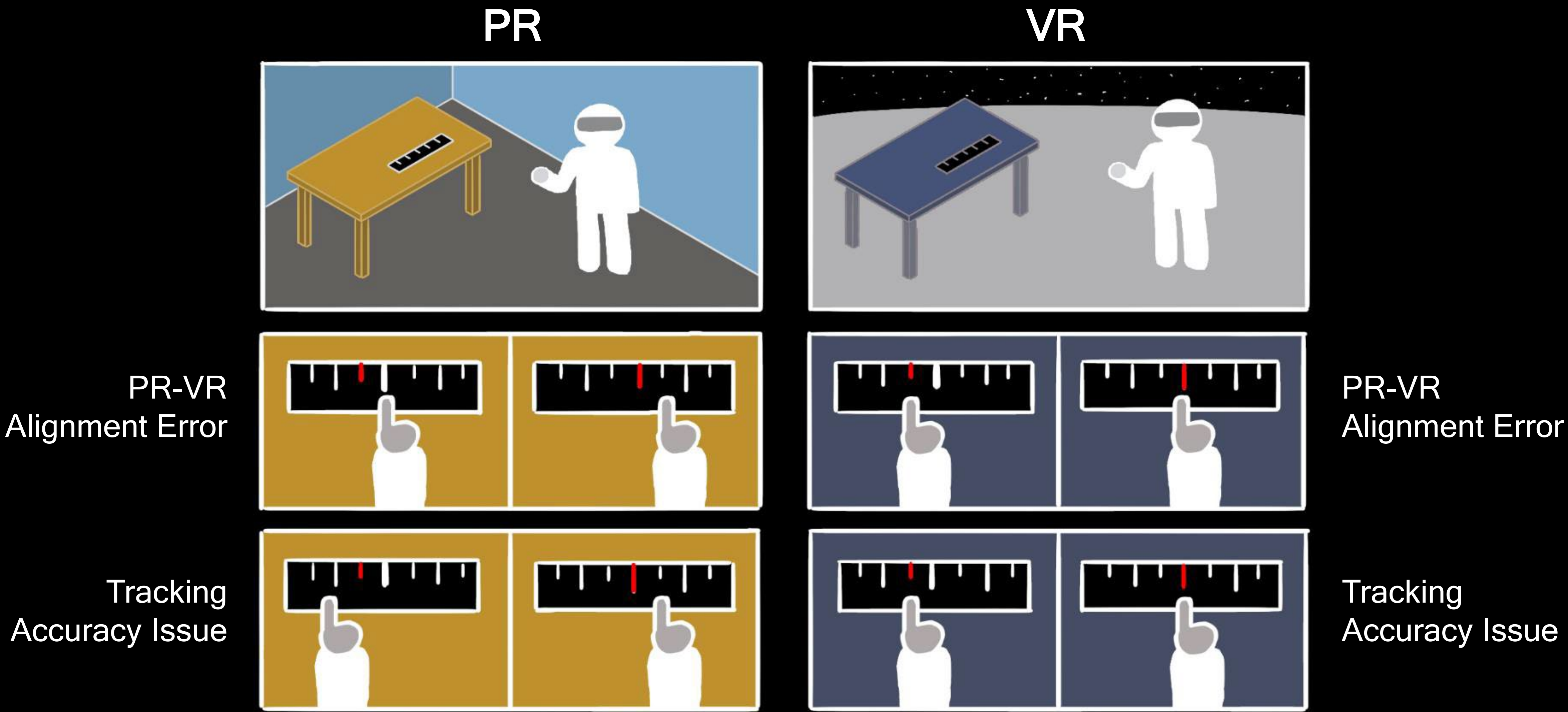
Hand Tracking Accuracy Test

Hand Tracking Accuracy Test Plan



Arm Constraints Backup Slides

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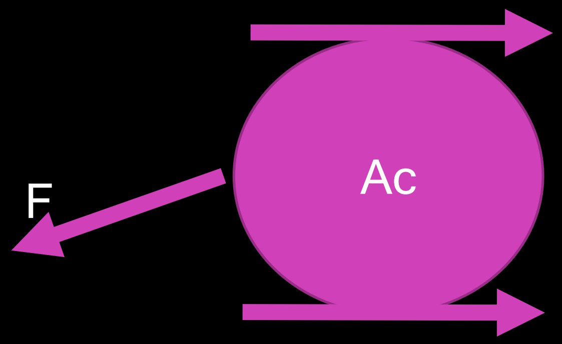
Shear Stress on Cylinder-Band configuration at Maximum Torque

- T = 28 N-m
- Radius =0.50 cm
- Ac = 0.78 cm^2
- F = 124N
- Shear stress = 3.18 MPa
- Shear strength of PLA material is 2.5 MPa. The shear stress is slightly higher than the shear stress of the PLA material, resulting in a FS of 0.78
  - We want a factor of safety of at least 2 so we need to use a different material in final design such as carbon fiber

$$A_c = \pi R^2$$

$$F_x = \frac{T}{d_{23}}$$

$$\tau = \frac{F_x}{A_c}$$



Shear effects on cylinder-band configuration

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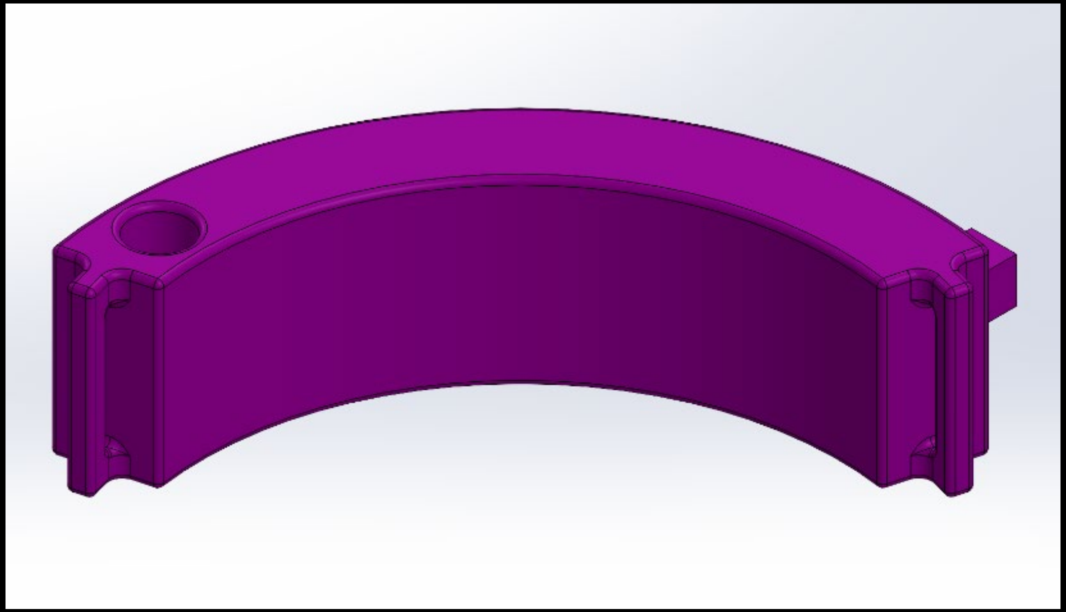
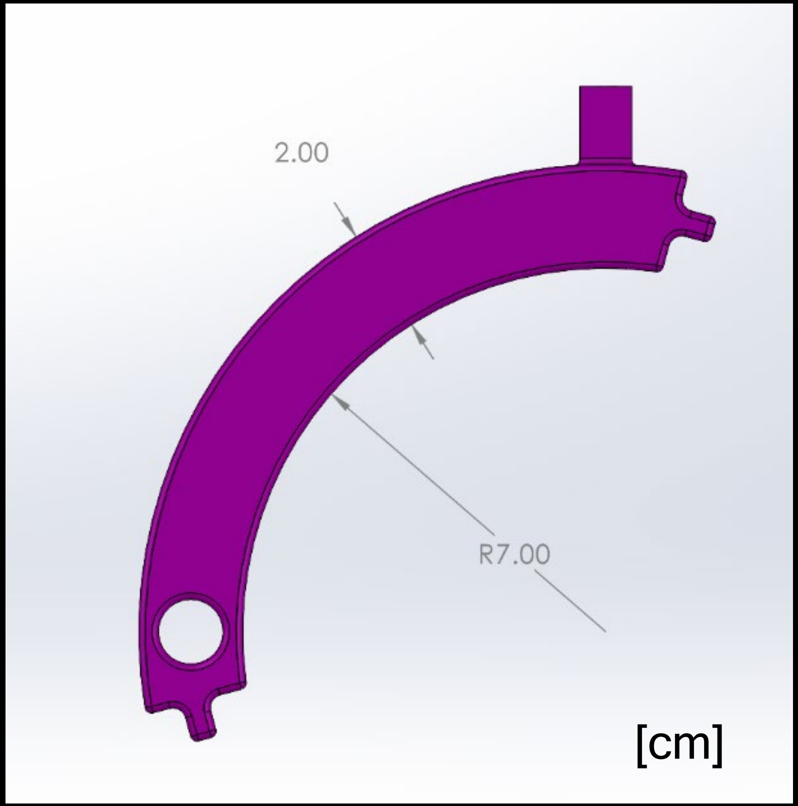
Arm Strap Front View



Arm Strap Top View



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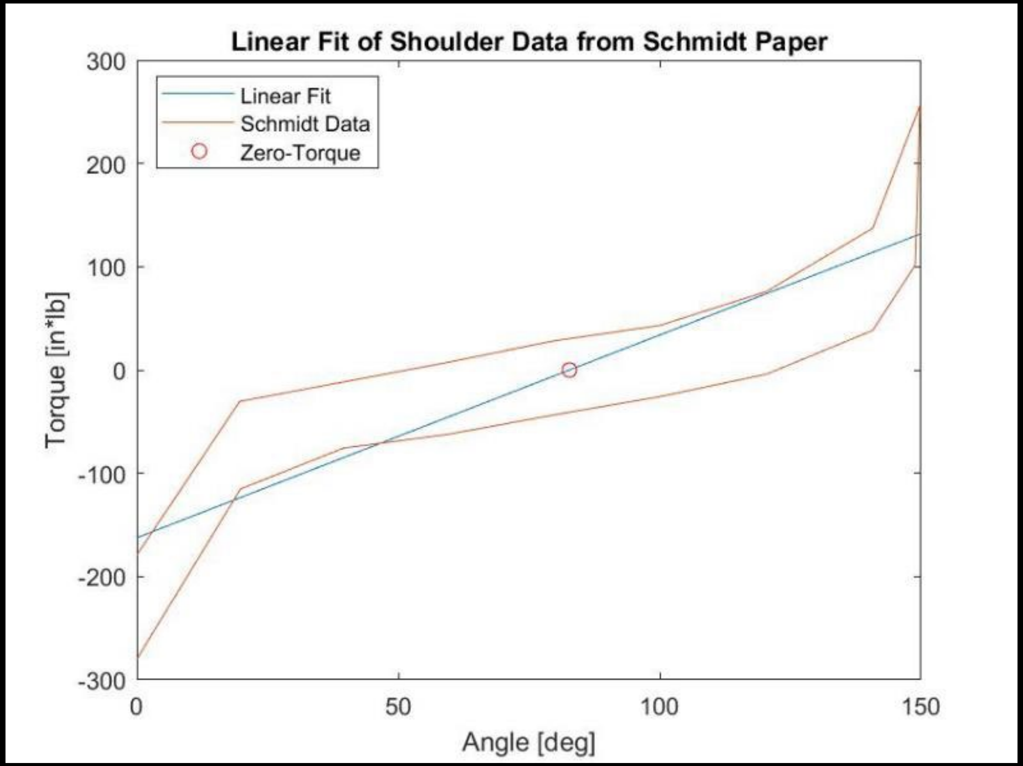
Shoulder Constraint



- Data was taken with an empty, pressurized suit
- Angle of shoulder at zero-torque: 82.7°
- Linear fit is done as it is hard to model hysteresis

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Air Pressurized Sleeve - Manufacturing Feasibility

Requirement	Description
2.1.1.1	The PC shall provide a range of counter-torque to the shoulder of **3.6** Nm.
2.1.2.1	The PCs shall provide counter-torque to the elbow within a range of **26.7 to 31** Nm.
2.1.3	The user shall perform the motor motions of pulling, picking up, and setting down PR elements.

EVA Tool, ORUs, Door & Locking Mechanism Design

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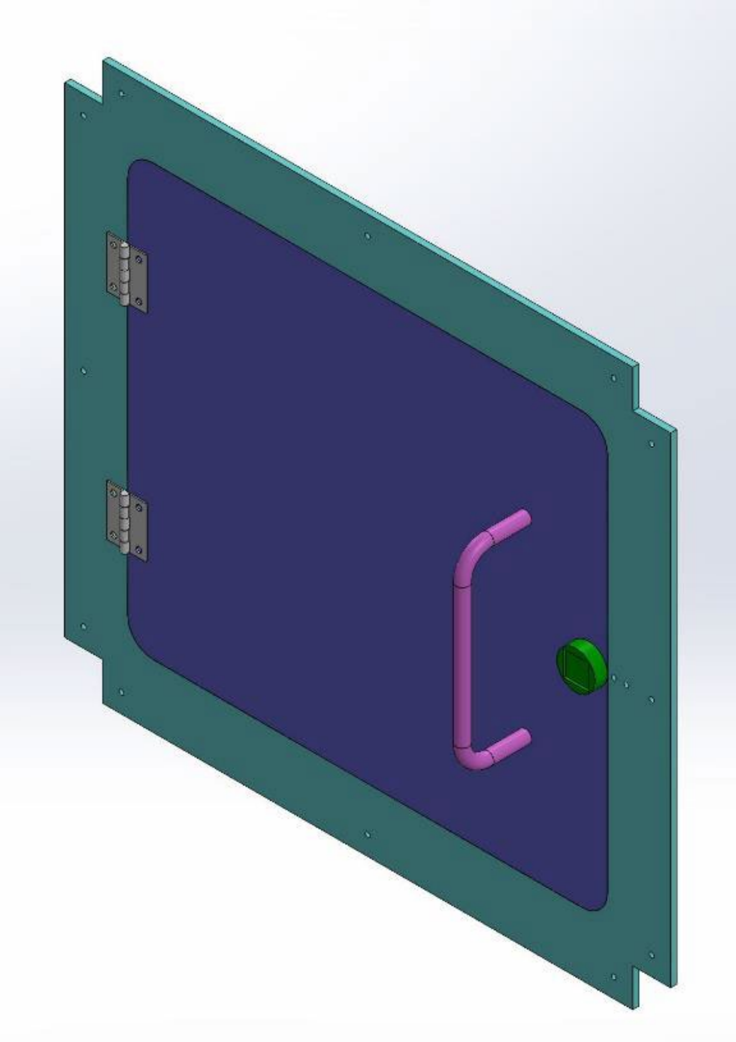
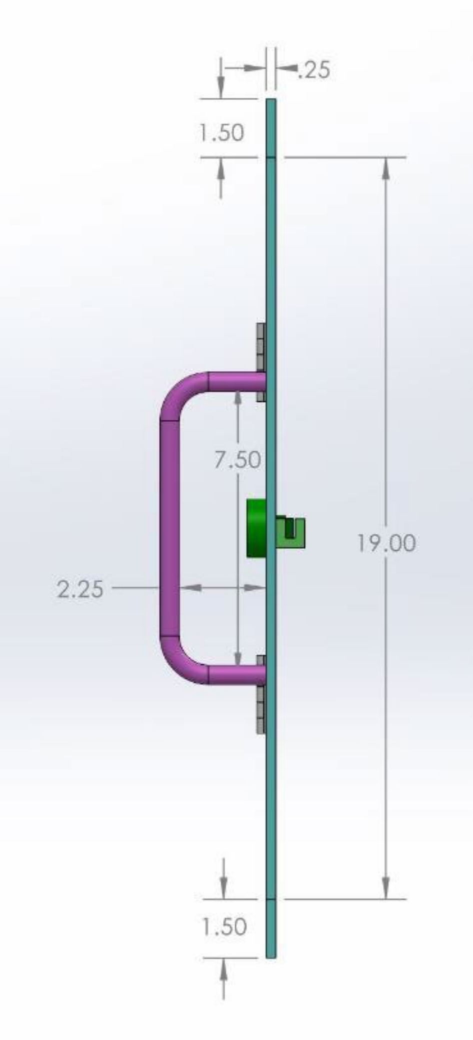
Door Panel

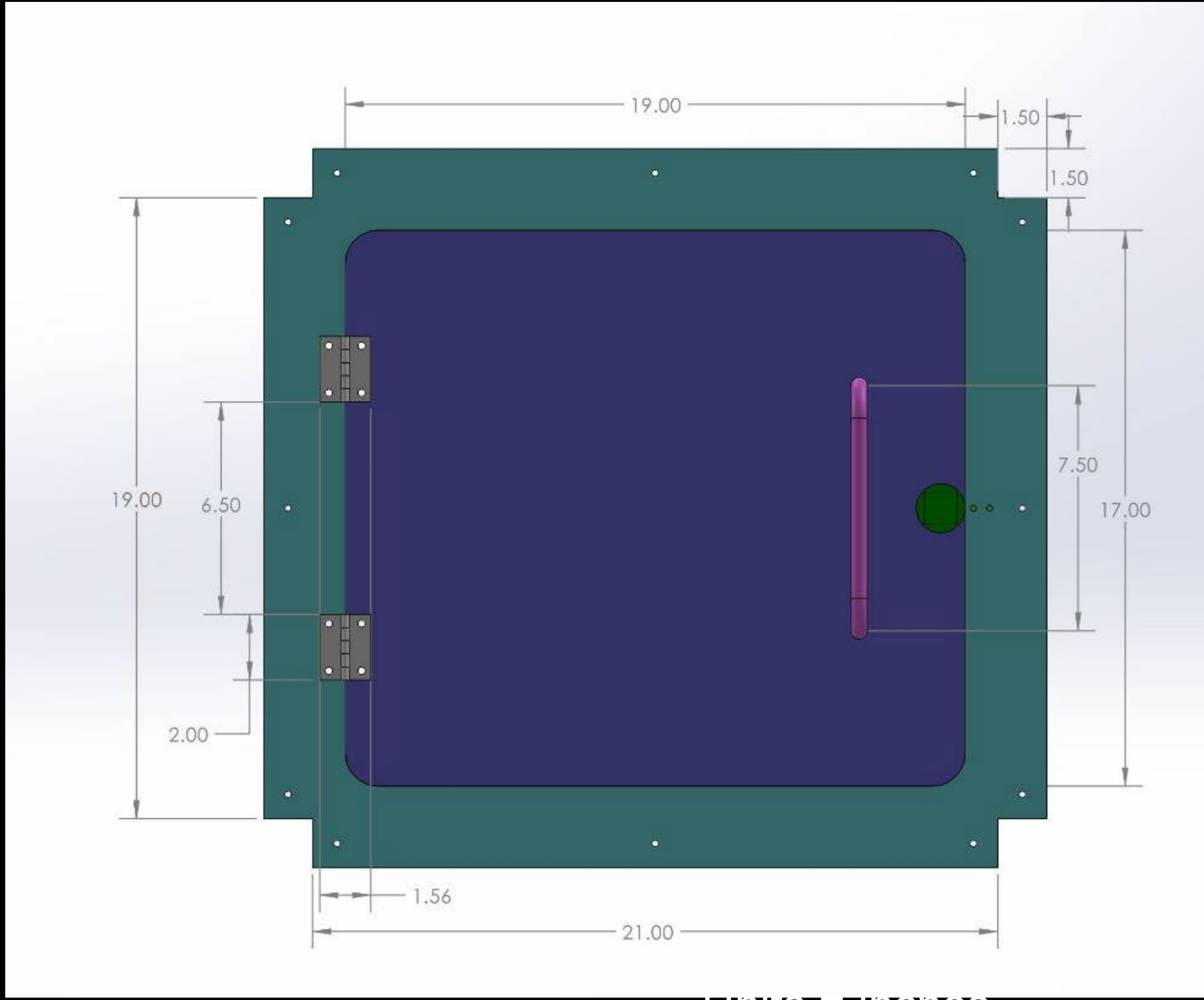
ISO View



Side View



Front View



Units = Inches

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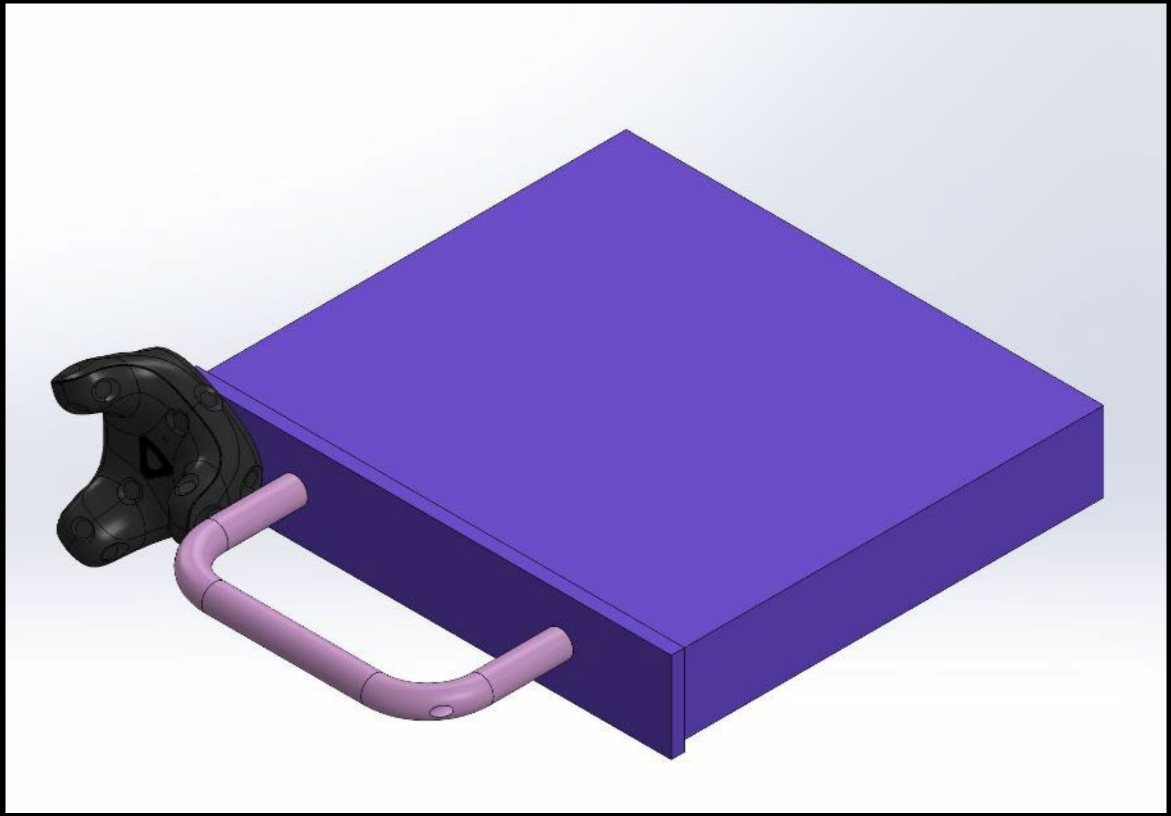
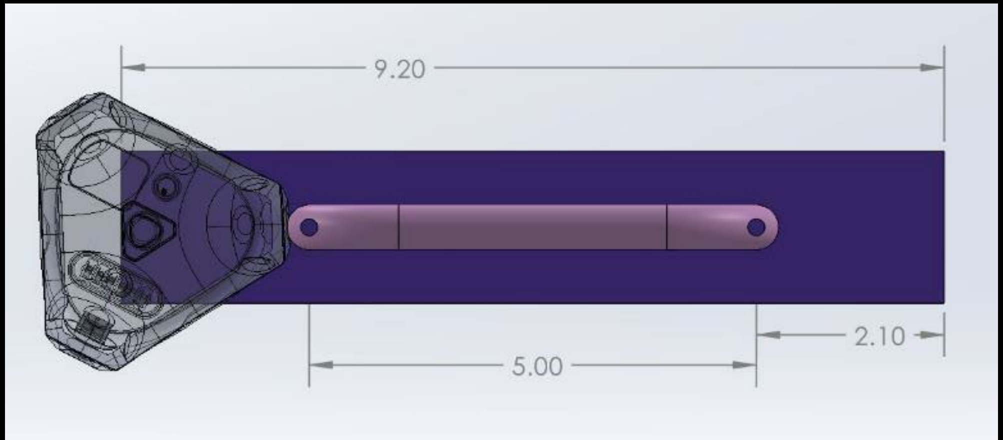
ORUs

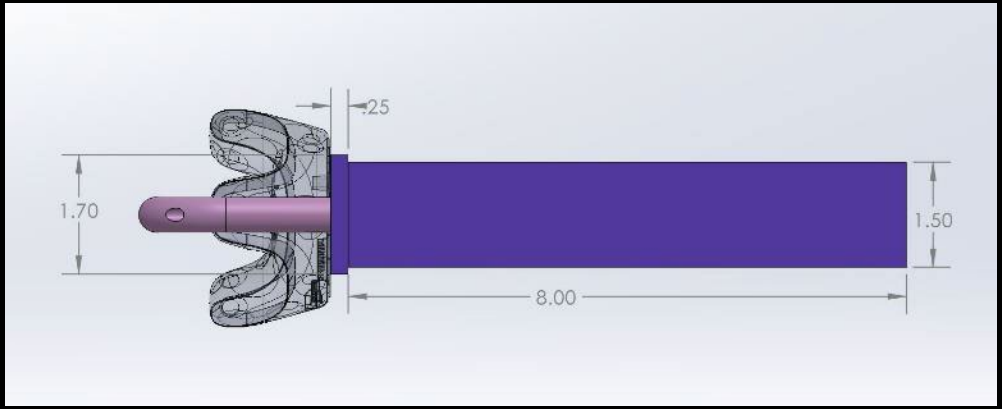
ISO View



Front View



Side View



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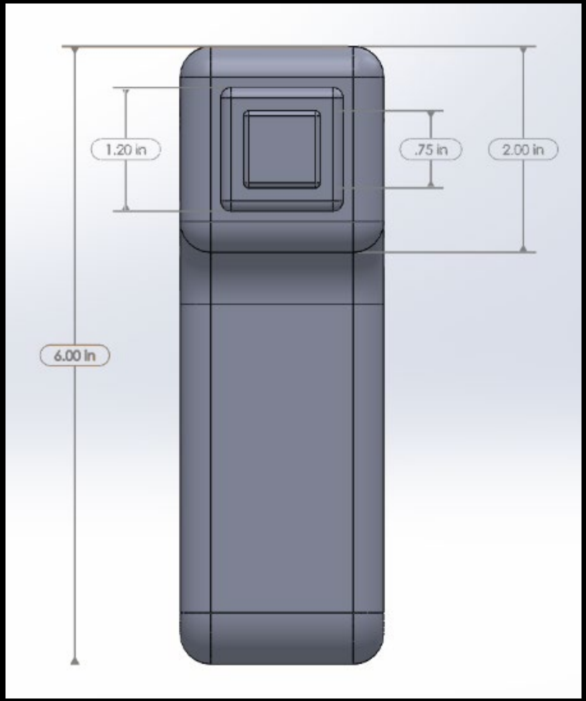
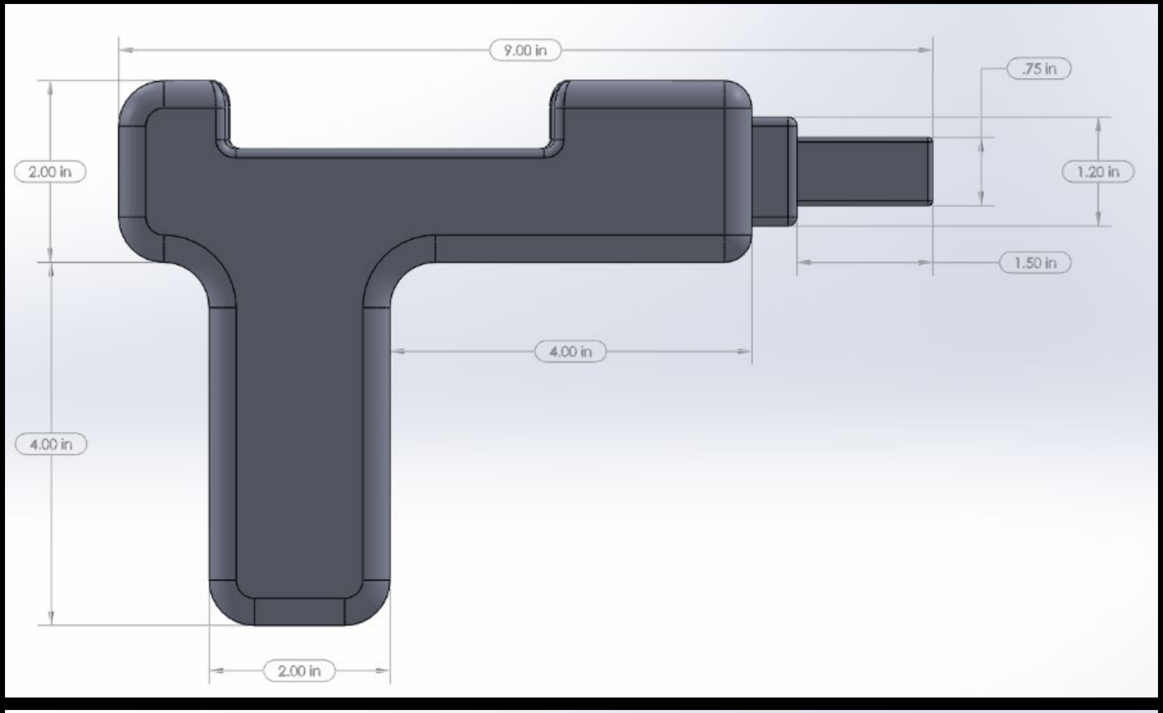
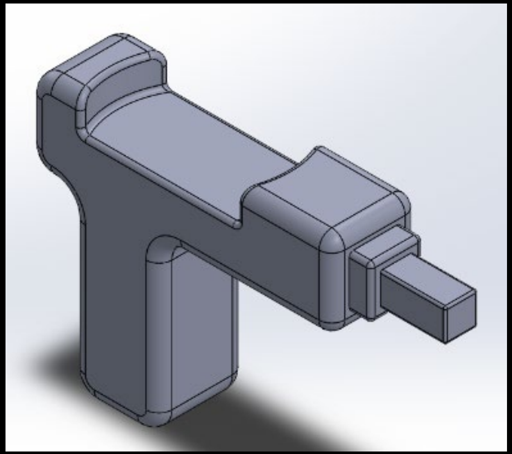
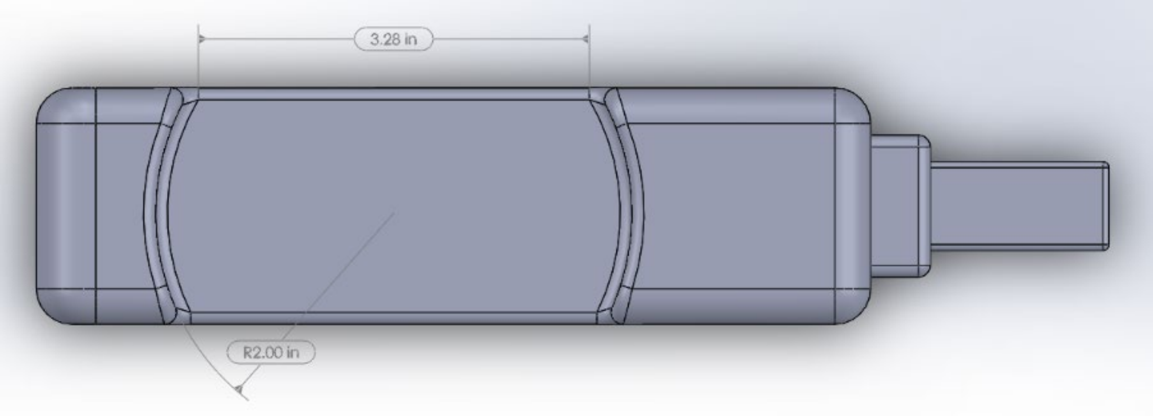
EVA Tool Design









EVA Panel Tipping Model

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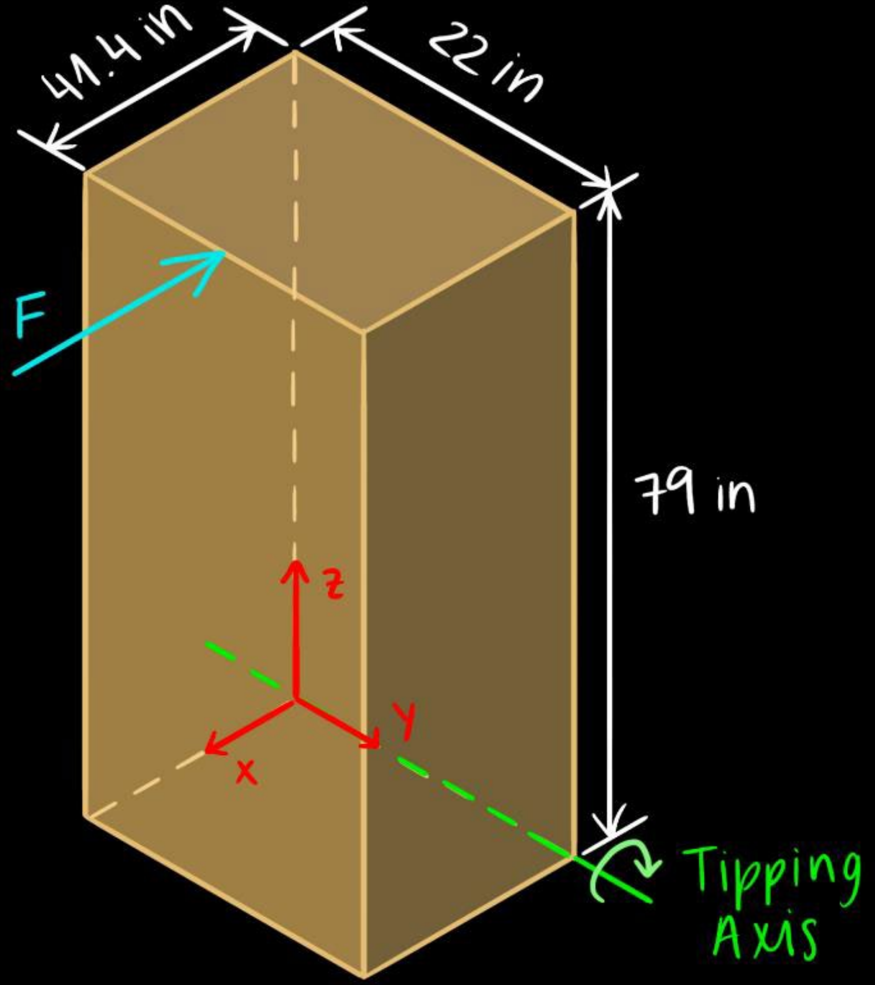
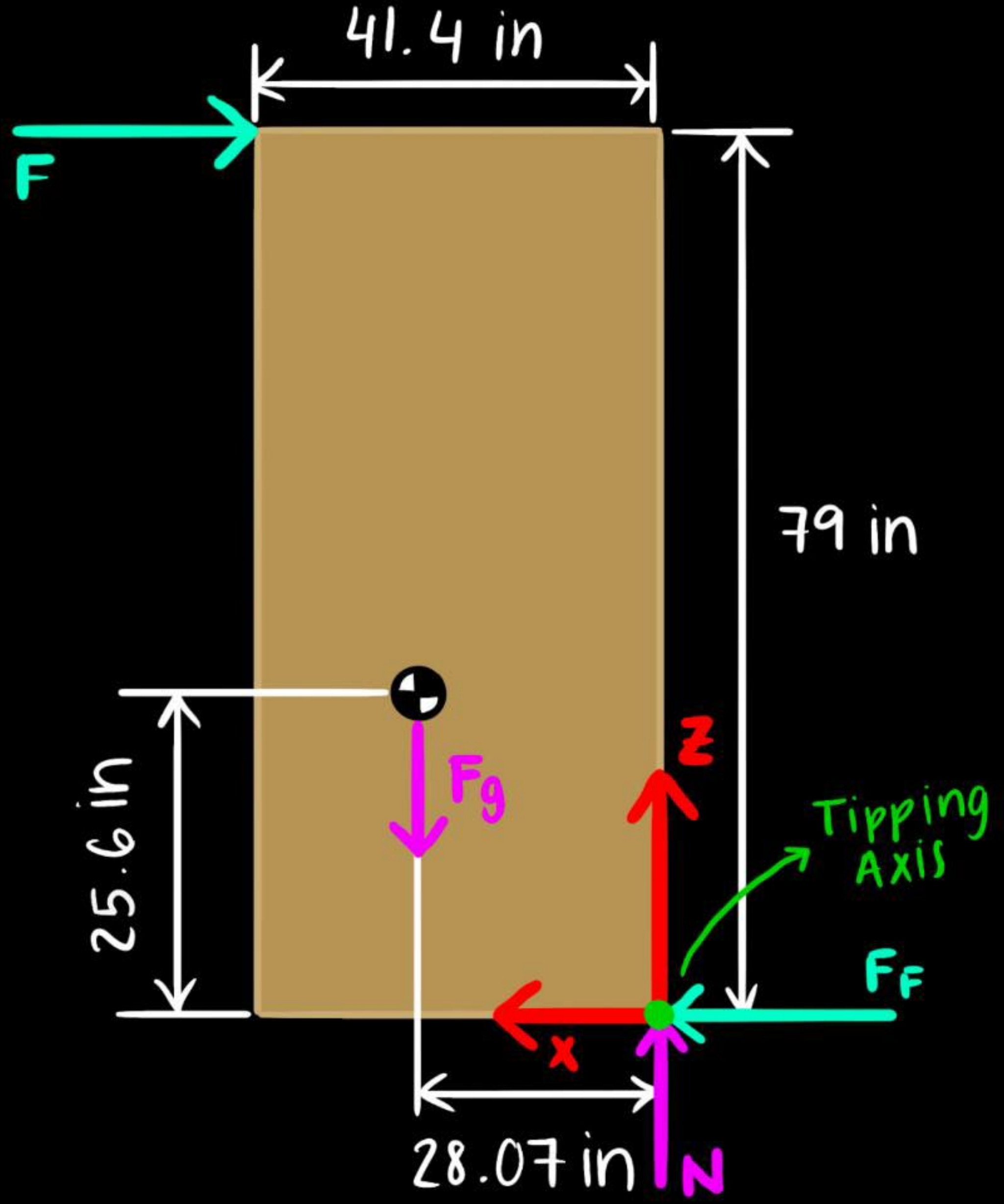
Tipping Model





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Moment Balance - PUSH

Convert to SI: 79 in ≃ 2.01 m
41.424 in ≃ 1.05 m
28.07 in ≃ 0.71 m

Tipping over:

$M_F > M_g + M_W$

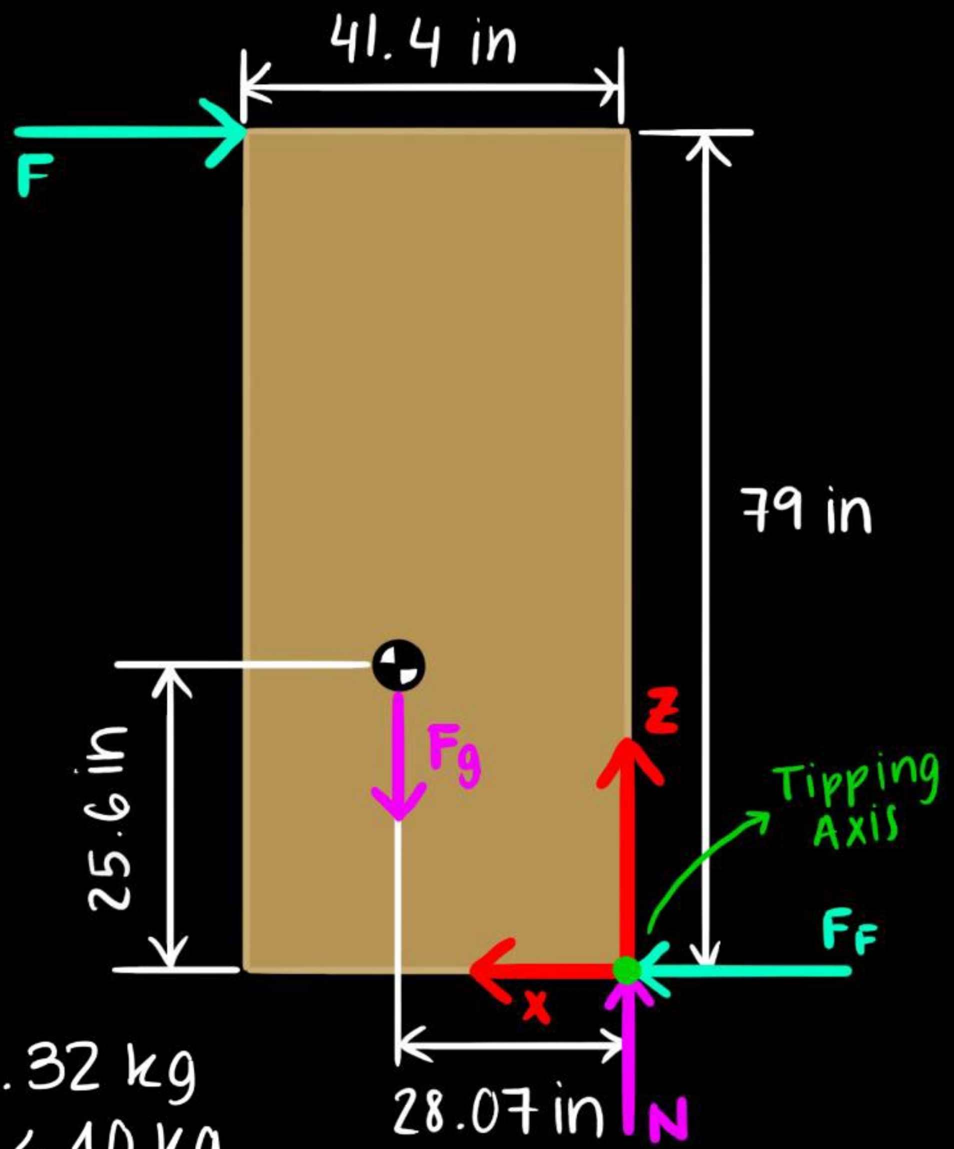
$M_g = F_g(0.71\,m) = mg(0.71\,m)$
$M_g = (26.32\,kg)(9.81\,m/s^2)(0.71\,m) = 184.13\,Nm$

$M_F = F(2.01\,m)$
$M_W = F_{gW}(x_W) = m_W g x_W = m_W x_W (9.81\,m/s^2)$

$F(2.01\,m) > 184.13\,Nm + m_W x_W (9.81\,m/s^2)$

$$F > 91.76\,N + (4.88\,s^{-2})\, m_W x_W$$

Plot F as function of m_W and x_W



$m = 26.32\,kg$
$0 \le m_W \le 10\,kg$
$0 \le x_W \le 1.05\,m$

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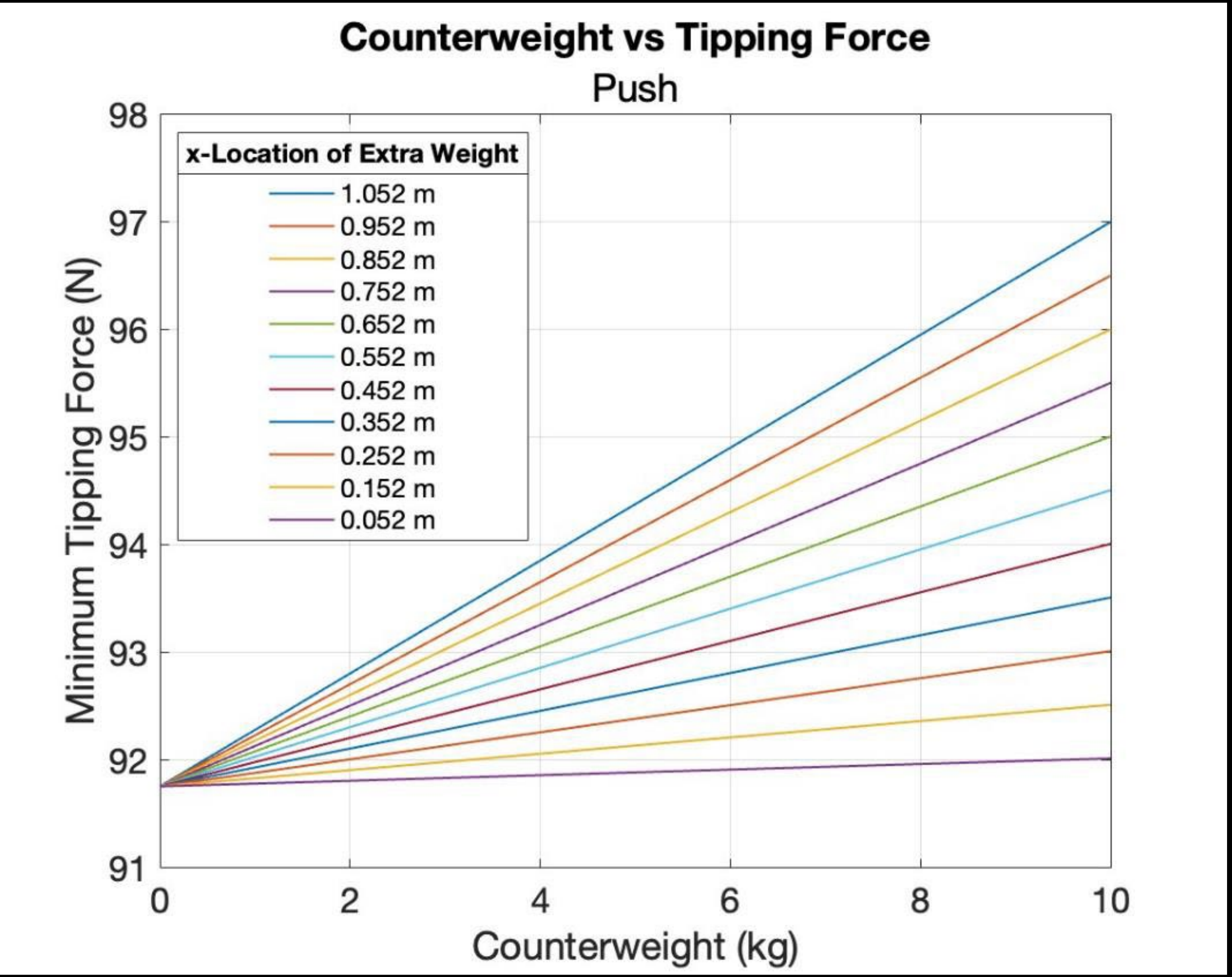
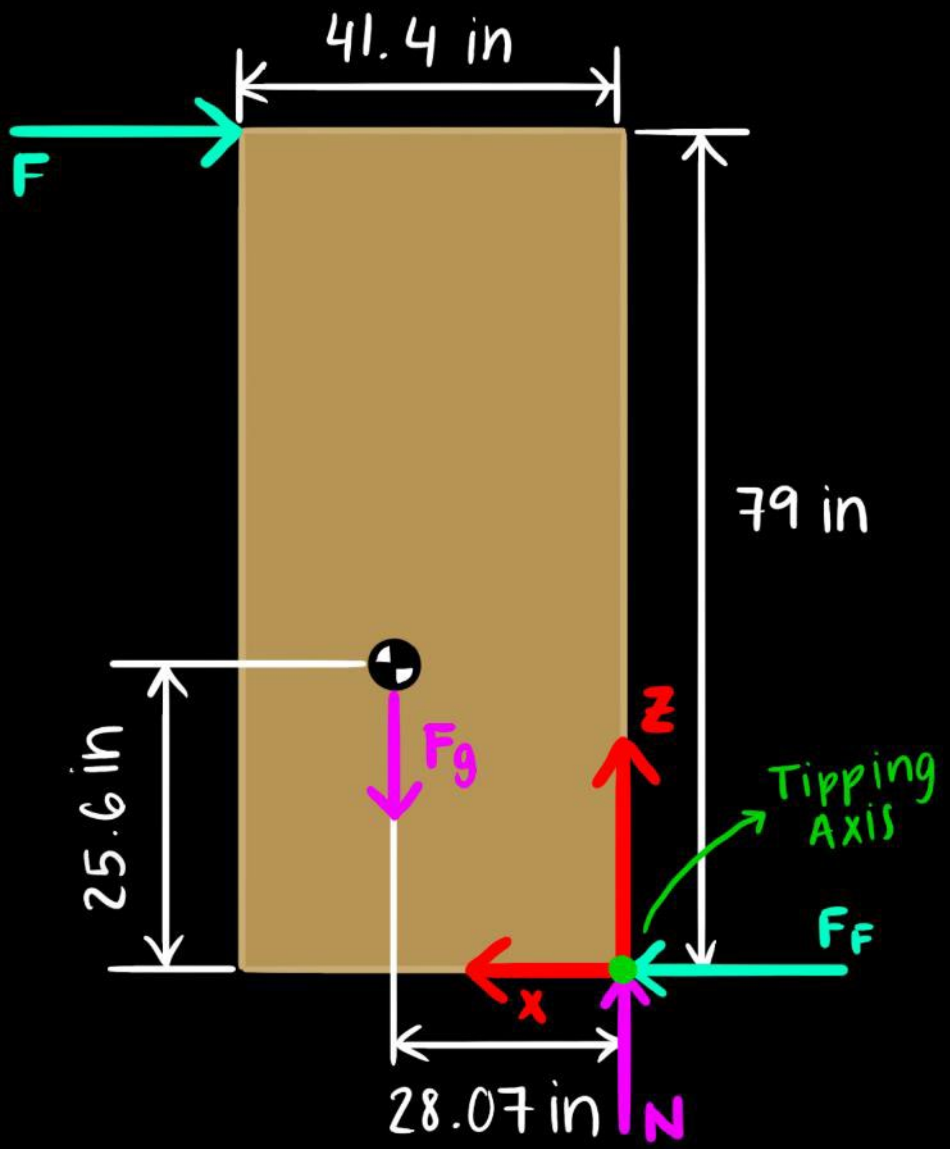
Moment Balance - PUSH





Moment Balance - PULL

Tipping over:

$M_F > M_g + M_w$

$m = 26.32\ kg$

$0 \leq m_w \leq 10\ kg$

$0 \leq x_w \leq 1.05\ m$

$M_g = mg(1.05\ m - 0.71\ m)$

$M_g = (26.32\ kg)(9.81\ m/s^2)(0.34\ m) = 87.60\ Nm$

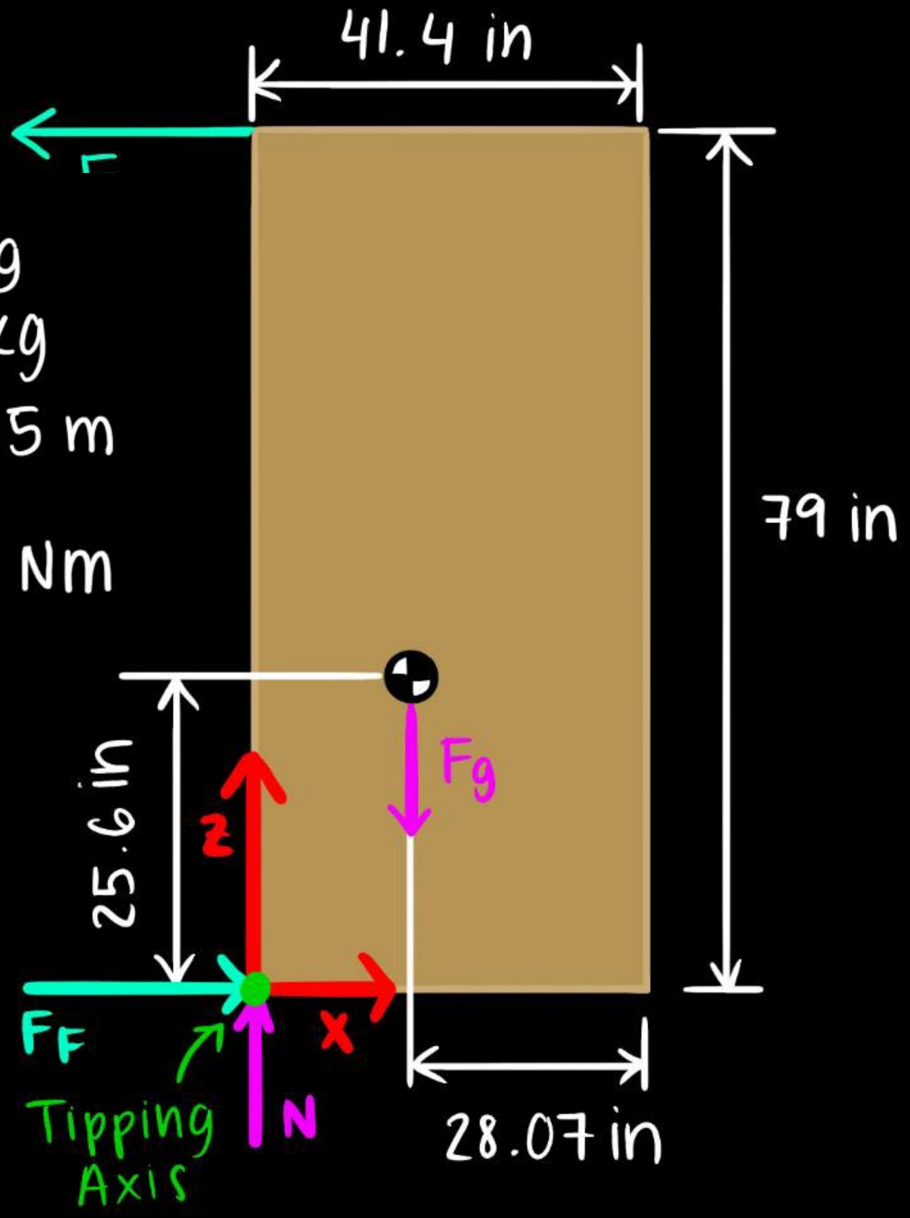
$M_F = F(2.01\ m)$

$M_w = m_w(9.81\ m/s^2)\, x_w$

$F(2.01\ m) > 87.60\ Nm + (9.81\ m/s^2)\, m_w x_w$

$$F > 43.65\ N + (4.89\ s^{-2})\, m_w x_w$$

Plot F as function of m_w and x_w



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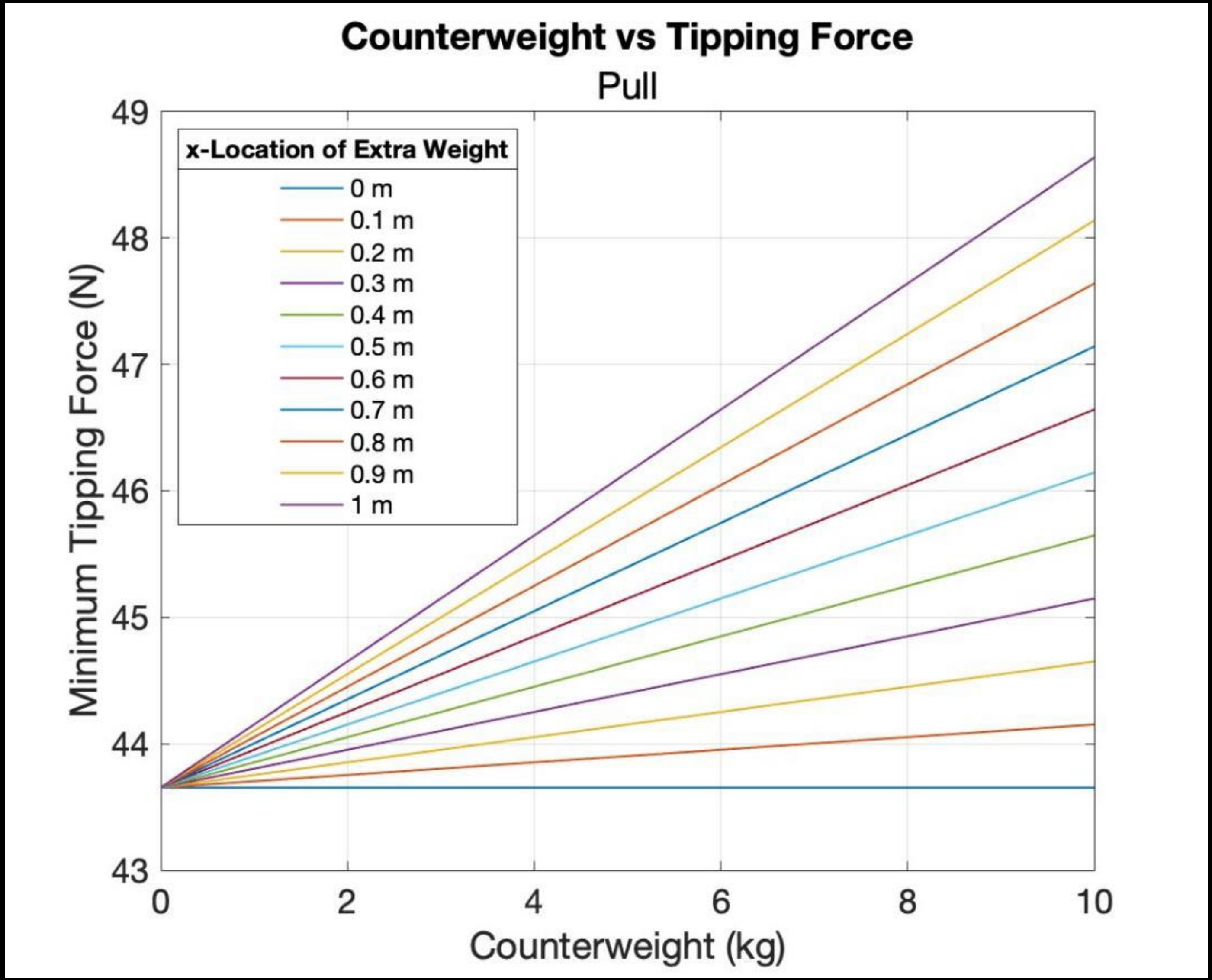
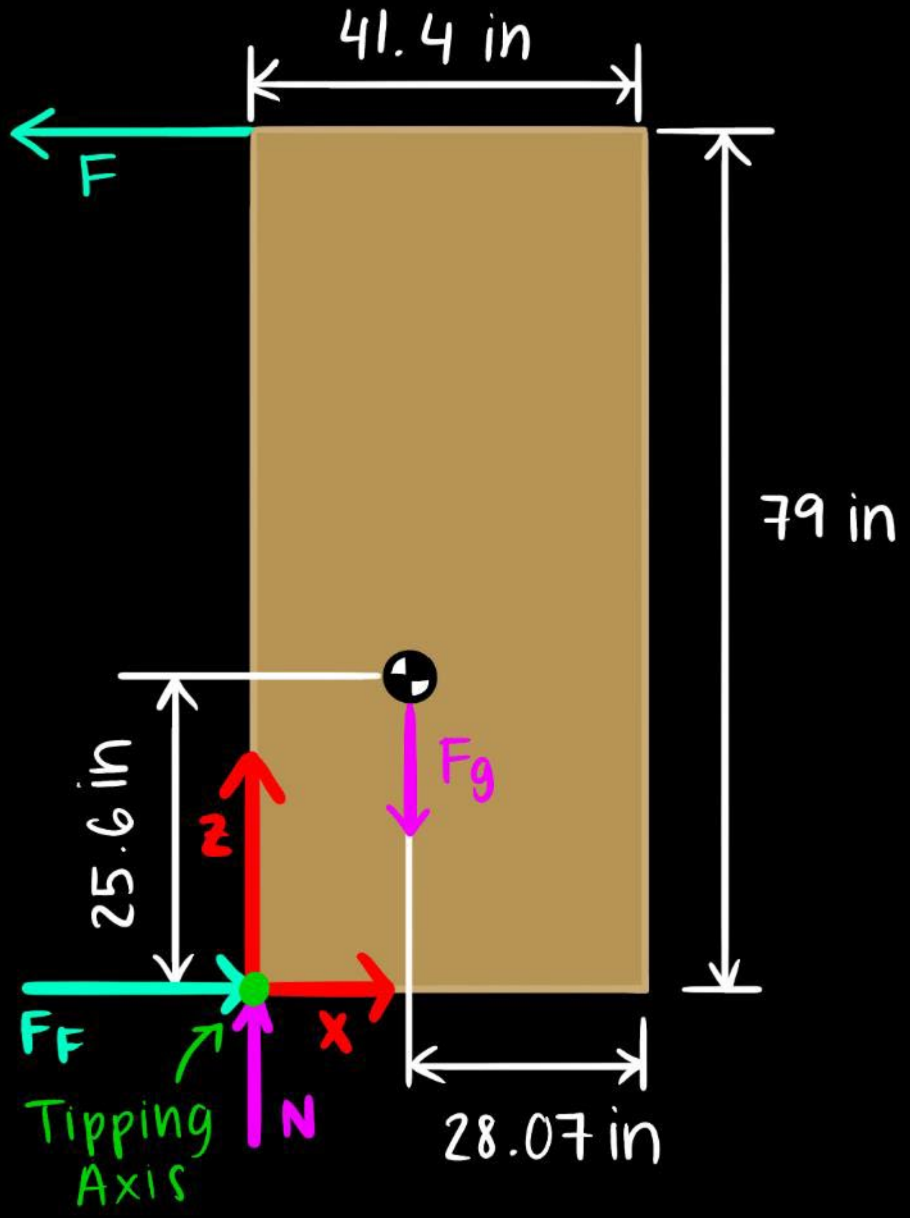
Moment Balance - PULL





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VR Computer Trade Options

TRADE TREE: VR Computer

VR Computer

- Personal Desktop
- Check out from Electronics Shop — ! Does not meet required specifications
- Build Dedicated Computer — ! Expensive, not easily portable, could take months for parts to ship

VR Computer Trade Study Grading

Criteria	Personal Computer	Electronic Shop Computer	Newly Built Computer
Availability	Would need to coordinate whose computer and availability wouldn't exist after projects class ends	Available to anyone in CU to rent a computer when needed	Fully available and dedicated to the project
Cost	Varies	Free	$830 for recommended specifications
Software	Would need access/licensing for required programs	Has required programs pre-installed	Would need access/licensing for required programs
Integration w/ outside electronics	Might need to buy extra components to integrate	Might need to buy extra components to integrate	Components required accounted for in cost
Hardware Requirements	Might not meet minimum or recommended requirements	Meets minimum requirements	Meets recommended requirements

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Software Process Flow

Modeling

- Download or purchase premade models
- Make 3D assets and models
- Export to Unity

Unity

- Import 3D models from modeling software
- Generate lunar terrain asset
- Combine assets and model into full lunar environment
- Implement functionality
- Create user interface

VR Headset

- User runs the program on VR headset
- User interacts with VR program

Development Engine - Constrained

- Unity is a cross platform 3D-2D development software based in C#
- Unity has extensive usage history in VR development
- The use of Unity as the development software for HEIST was given by the project customer, Dr. Allison Anderson.
- The team determined they will be moving forward with a VR headset after it traded favorably.
- Unity is ideal for both the customer constraint and Unity lends itself to the development of HEIST in a VR headset.

DEFINITIONS: Audio Software

- **Mono/Monophonic**: one channel of audio information.
- **Stereo/Stereophonic**: two channels of audio information; usually implies listener can perceive sound images along a line (between loudspeakers or headphone transducers).
- **Surround Sound**: encompasses variety of audio systems that utilize four or more channels of audio information; usually implies listener can perceive sound images between the sources.
- **Binaural**: two-channel audio system that utilizes everyday live spatial hearing cues and provides listener with the perception of three dimensions.
- **Spatial audio**: broader, more inclusive in scope (than 3D audio) and includes the possibility of environmental sound
- **3D audio:** implies perception of point sources in 3D space (could also be 2D plane)

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TRADE TREE: Audio Software

Category	Type	Option	Rating	Assessment
VR Audio	Channel-based	Mono	!	Too limited, breaks user immersion and experience
		Stereo	!	Too limited, breaks user immersion and experience
		Surround	!	Better allocation along x-y plane but no height distinction
		Binaural	!	360-audio around user, no tangible point source
	Sound-field	Spatial	✓	Combines environmental noise and point/object source cues
	Object-based	3D audio	!	Point-source audio in three-dimensional space, limited environmental background noise

Resources

VR/HR Resources 1/2

1. https://www.pcmag.com/news/htcs-vr-hand-tracking-system-just-got-a-lot-better
2. https://www.raywenderlich.com/9189-htc-vive-tutorial-for-unity
3. https://www.vive.com/us/
4. https://soundgearlab.com/how-use-bluetooth-headphones-oculus-quest-2/#:~:text=Although%20Oculus%20quest%202%20has,headphones%20to%20the%20headset%20with
 https://www.biorxiv.org/content/10.1101/2022.02.18.481001v1.full
5. https://learn.microsoft.com/en-us/hololens/hololens-core-components
6. https://www.breezecreative.com/dynamic-floor?gclid=CjwKCAjwg5uZBhATEiwAhhRLHv7BDOQdIQ6NFyaNNPwlXDQECx_ZjURp68v1mIBcf_zOKrb3PoV6sRoCnFQQAvD_BwE
7. https://hi5vrglove.com/store/hi5glove
8. https://www.manus-meta.com/software/polygon
9. https://www.ceva-dsp.com/ourblog/what-is-an-imu-sensor/#:~:text=An%20IMU%20is%20a%20specific,considered%20a%209%2Daxis%20IMU.
10. https://pixycam.com/pixy-cmucam5/
11. www.vr-compare.com
12. https://sid.onlinelibrary.wiley.com/doi/10.1002/jsid.999

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1. https://www.worldbrace.com/custom-best-shoulder-brace-support-manufacturer/
2. https://dunbarmedical.com/wearing-shoulder-brace/
3. https://www.braceability.com/products/shoulder-support-brace
4. https://www.menshealth.com/fitness/g25803874/best-compression-sleeves/
5. https://www.bauerfeind-sports.com/us/compression-sleeves-arm/
6. https://www.compressionstore.com/products/circaid-profile-foam-arm-sleeve
7. https://www.verywellhealth.com/what-is-a-cast-for-broken-bones-made-out-of-2549317
8. https://www.hiltonphoto.co.uk/joby-gorillapod-3k-tripod-with-ball-socket/