KESSLER Critical Design Review

ASEN 4018 Fall 2017

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Agenda

Kinesthetic
Engineered
Solution to
Space
Litter &
Exhausted
Resources

- Project Purpose & Objectives
- Proposed Design & Functionality
- Critical Project Elements for Meeting Success Criteria
- Design Requirements & Their Satisfaction
  - CPE 1: Visual Processing
  - CPE 2: Controls
  - CPE 3: Robotic Arm
- Remaining Risks & Mitigation
- Verification & Validation of Design
- Organization & Remaining Work

Project Purpose & Objectives

Lauren Darling (Electrical Lead)

Project Purpose | **Proposed Design** | **Critical Project Elements** | **Design Reqs.** | **Risks & Mitigation** | **Ver. & Val.** | **Organization**

Project Purpose

Project Motivation

Amount of orbital debris is set to triple by 2030 (More than 500,000 in orbit today). Consists of:

- Pieces of satellite components
- Satellites at EOL
- Malfunctioning satellites

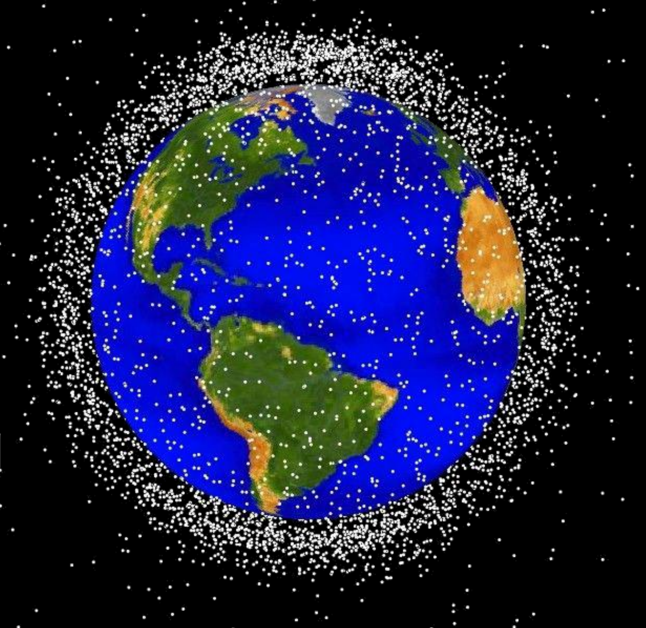


Fig. 1 Space Debris 2013 Model [1]

Sierra Nevada Corporation:

- 'Grappling' feature recognition with an RGB sensor
- Autonomously capture feature with robotic manipulator arm

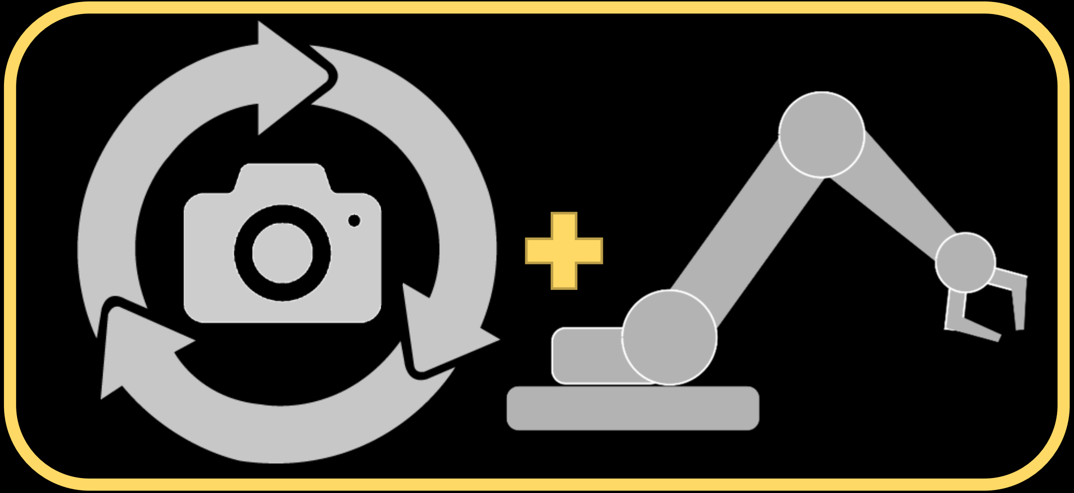
Fig. 2 SNC Developed OrbComm G2 Assets [2]

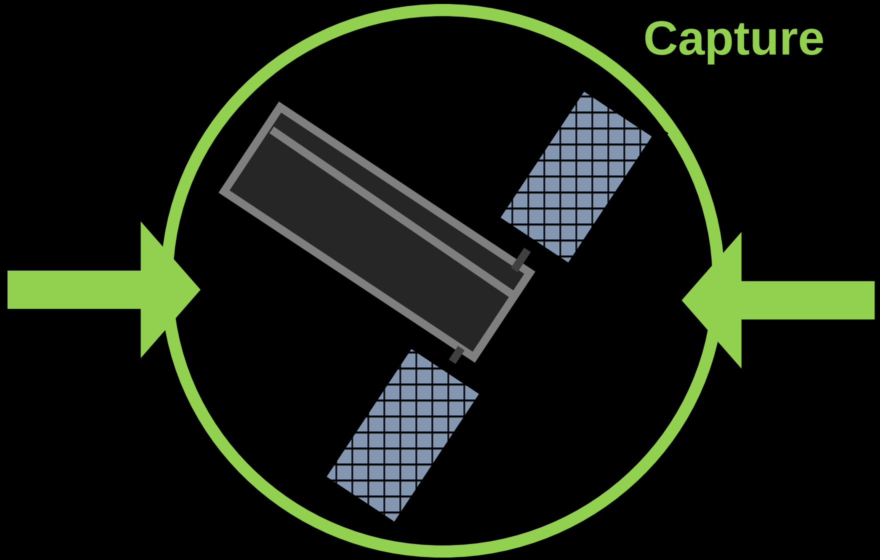
Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization

Project Purpose

Project Statement

KESSLER





The KESSLER Project will design a system that utilizes visual processing and a robotic arm to autonomously capture space debris. This project will be developed using heritage hardware and software from the CASCADE capstone project.

Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization

Project Purpose

- The simulated target satellite is modeled after the Iridium satellite series.
- Model will be 30% scale
- Features are:
  - Solar Panel Joints
  - Bus Structure Support
  - Antenna
- Features on Iridium are commonly found on other satellites as well.

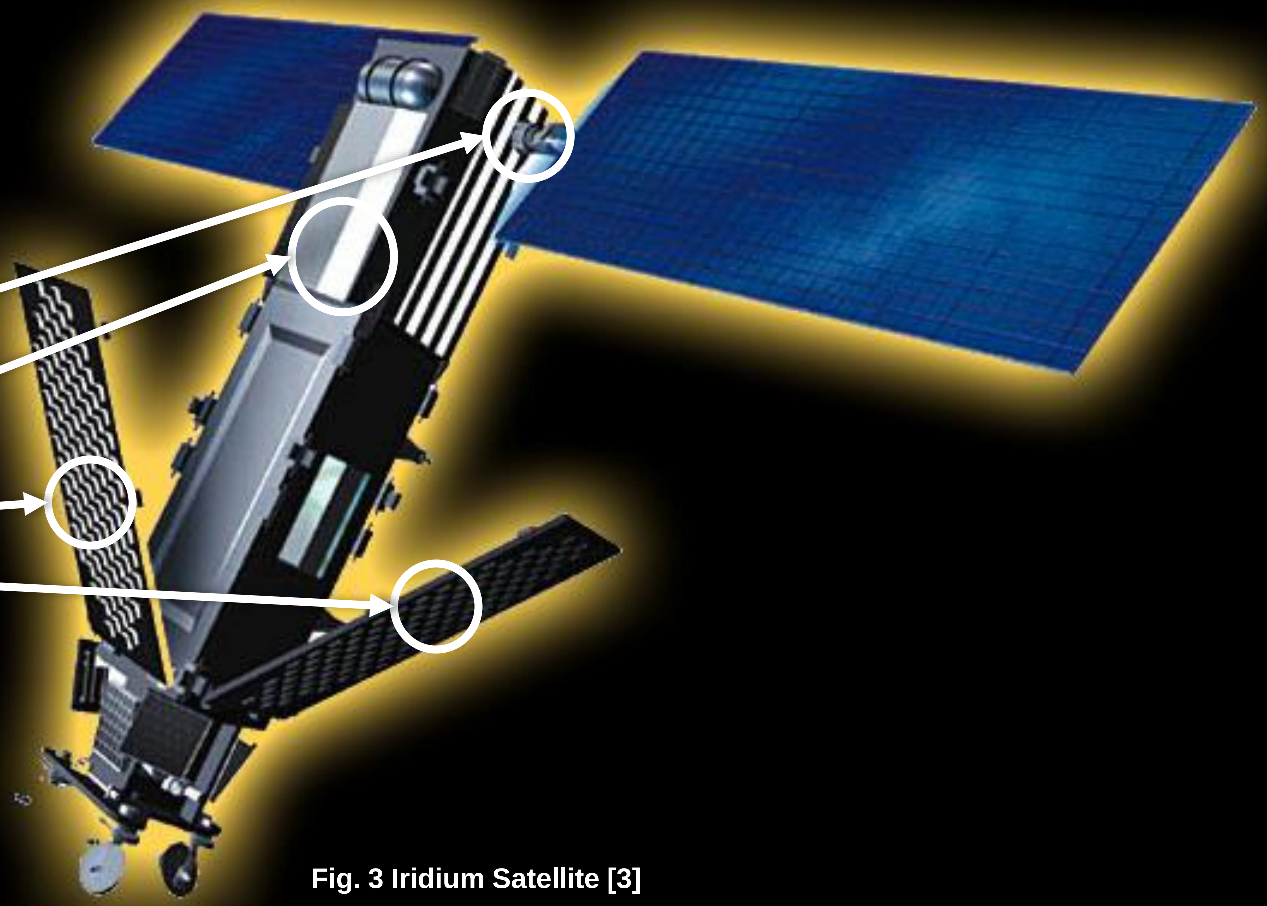


Fig. 3 Iridium Satellite [3]

Project Description

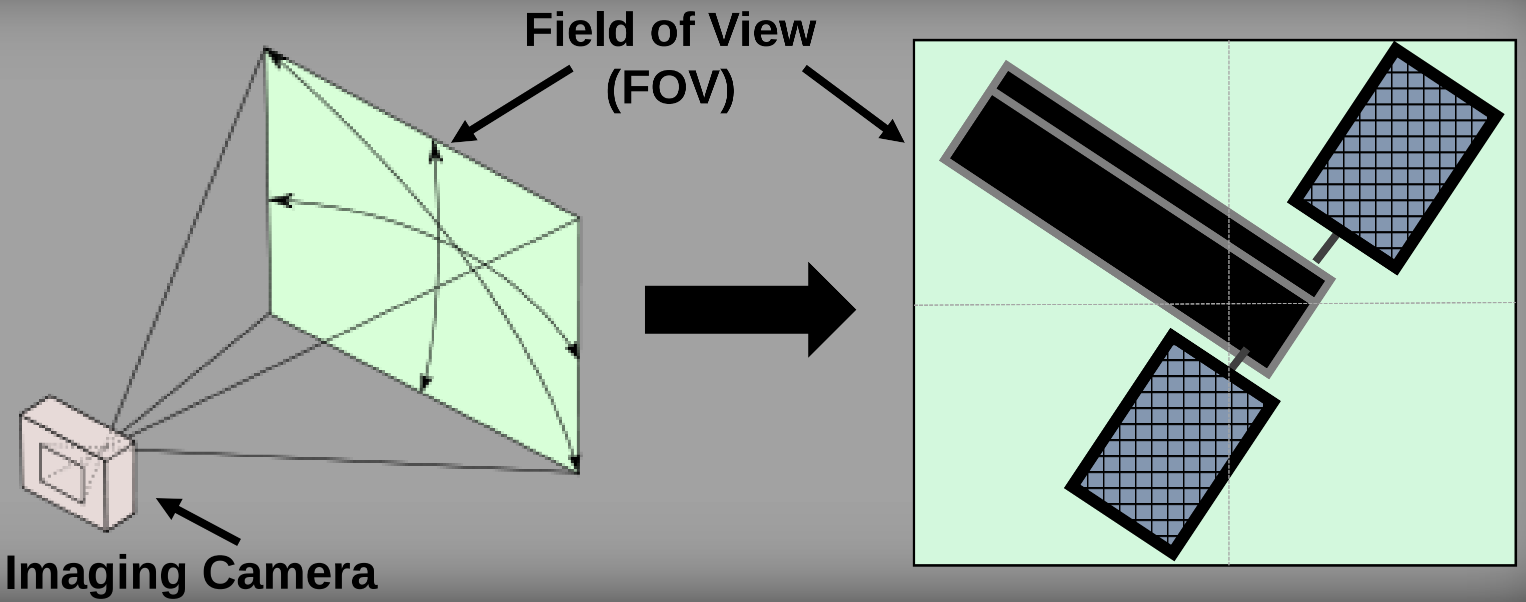
Project Assumptions

- Satellite Position:
  - Object is in front of and within reach of robotic arm.
- Satellite Dynamics:
  - Object is stationary with respect to robotic arm.
- Lighting Conditions:
  - Operations are conducted during Sun-Soak orbital phase.
- Standard Spacecraft Subsystems:
  - Are not in scope of KESSLER project (e.g. ADCS, EPDS, CDH, COM).
- Environment:
  - Controlled test environment at 1G and atmosphere.

All assumptions are approved by project customer.

Project Objectives

1. Take visual data confirming the target object is within FOV.



Project Objectives

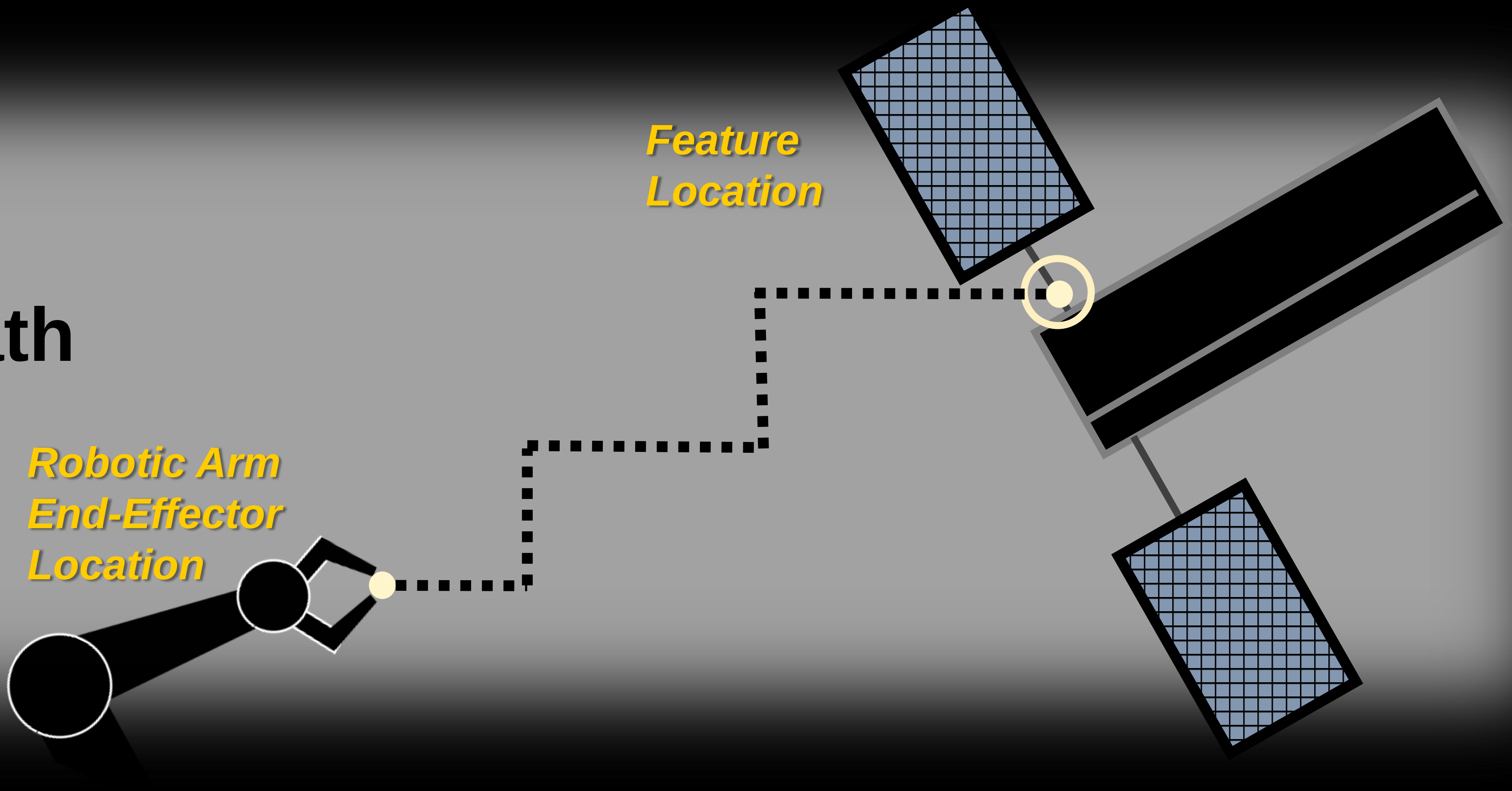
2. Identify pre-defined grappling feature.

Is feature any of the following?

- **Antenna**
- **Solar Panel Joint**
- **Bus Support Structure**

Project Objectives

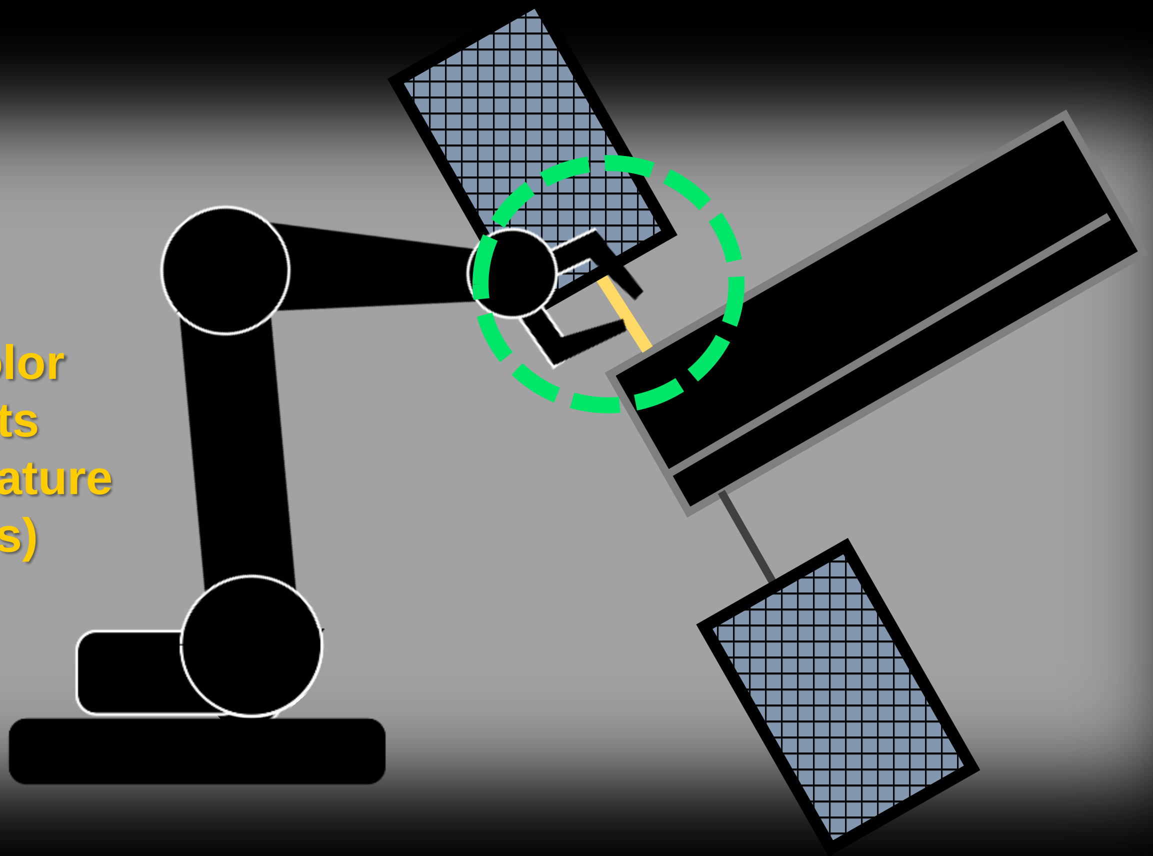
3. Determine prediction path to feature location.



Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization

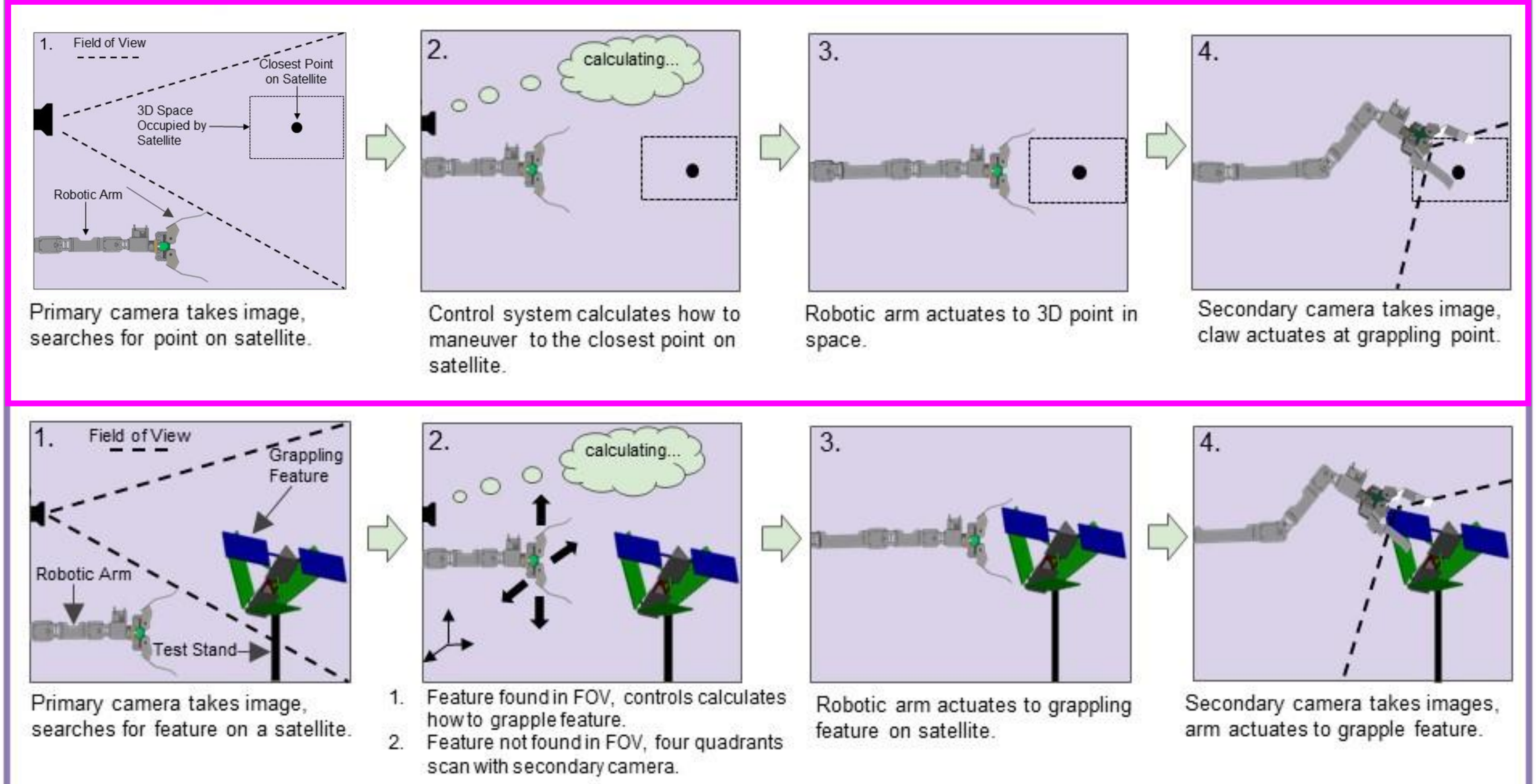
Project Objectives

4. Autonomously capture the feature via robotic arm

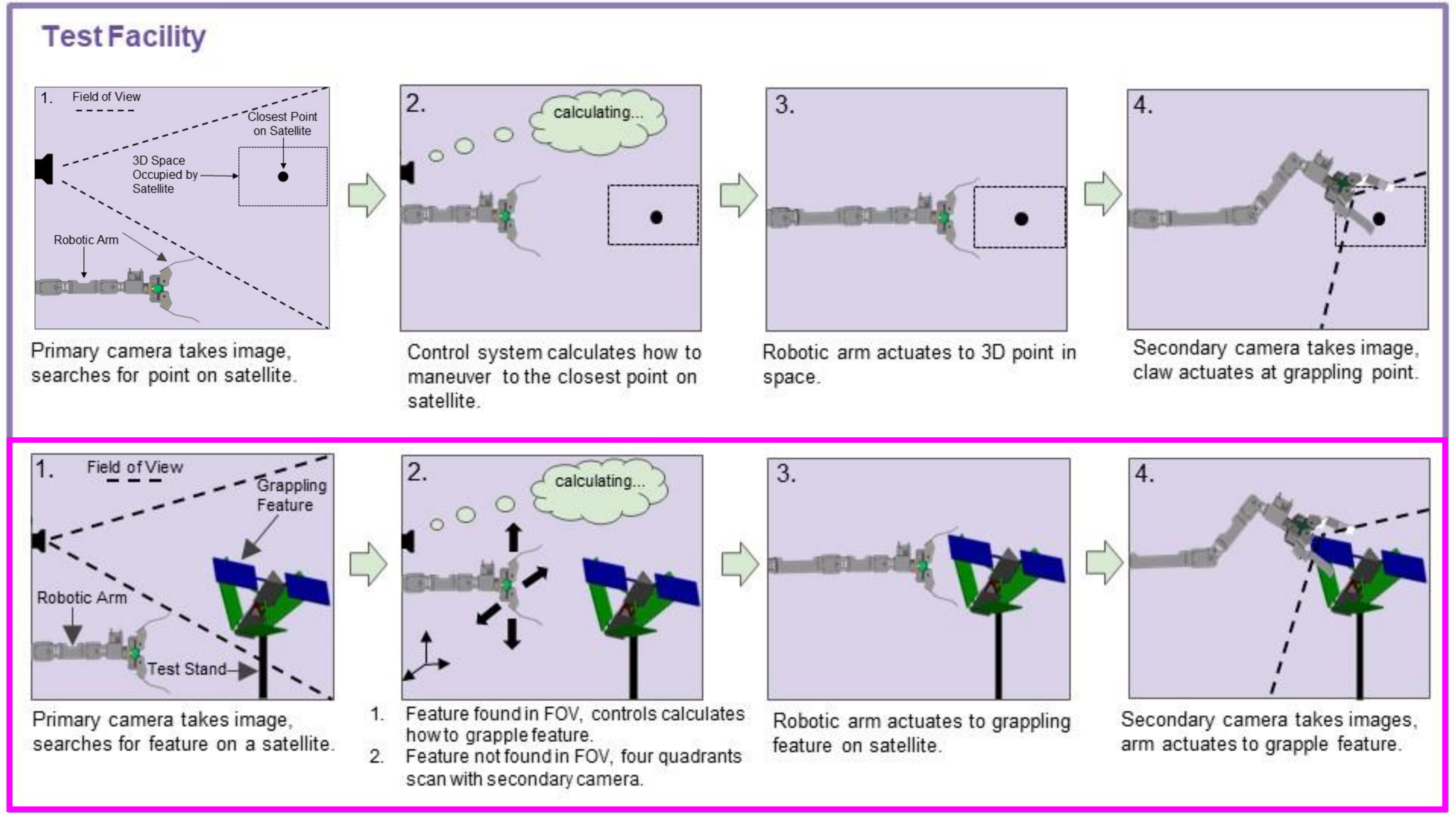


Test Facility

Level 1 Success

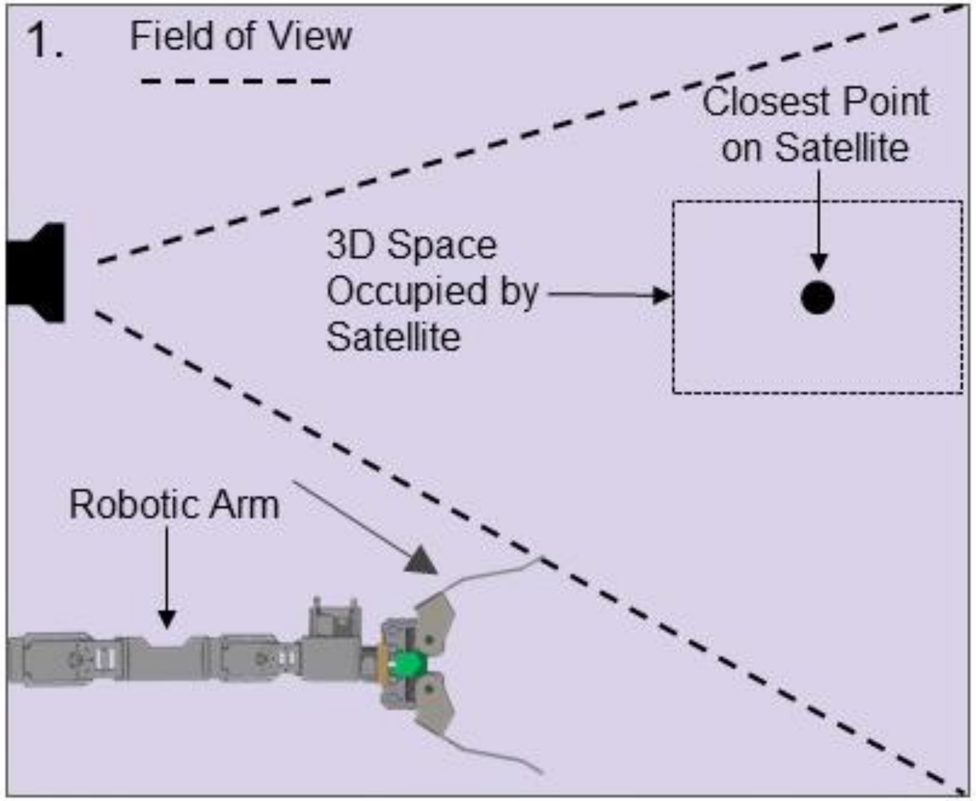


Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization



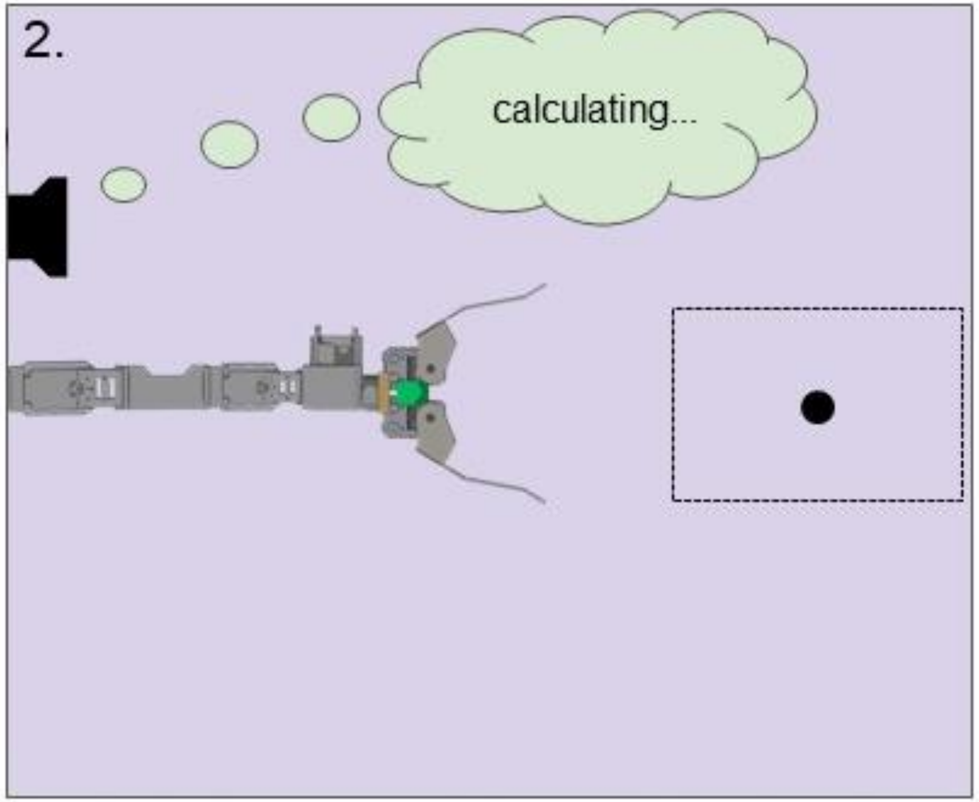
Level 2 Success

Level 1 Success



Robotic arm uses primary camera to search for a point on a satellite with unknown position and orientation.

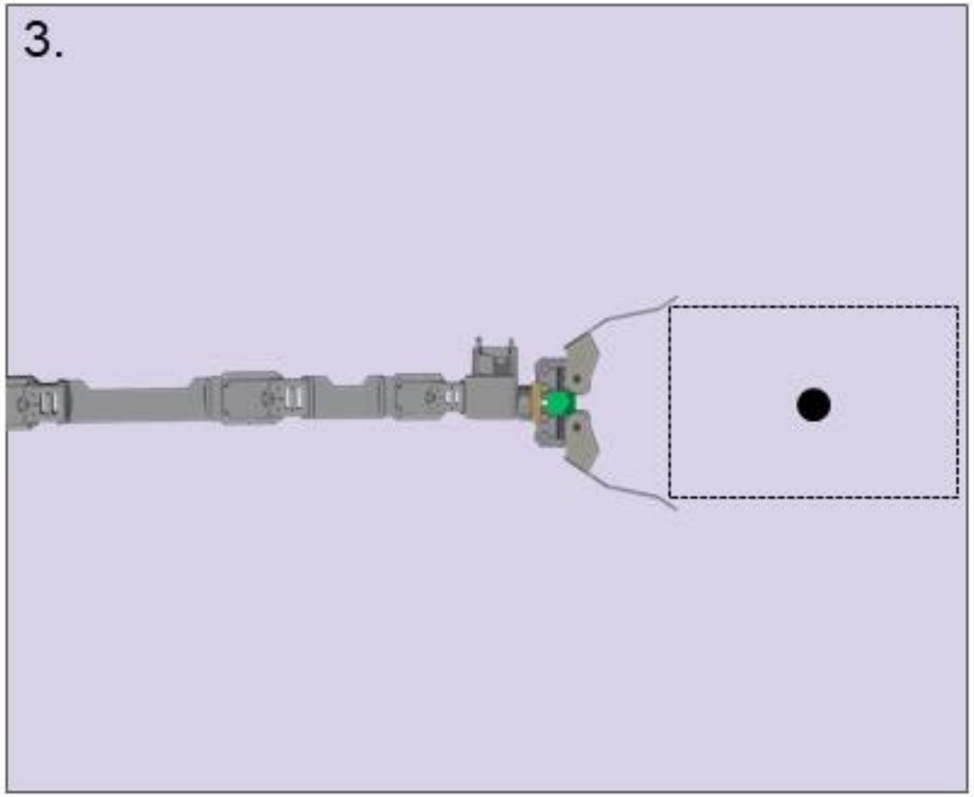
Level 1 Success



Feature is found in FOV, the control system calculates how to maneuver to the closest point on satellite.

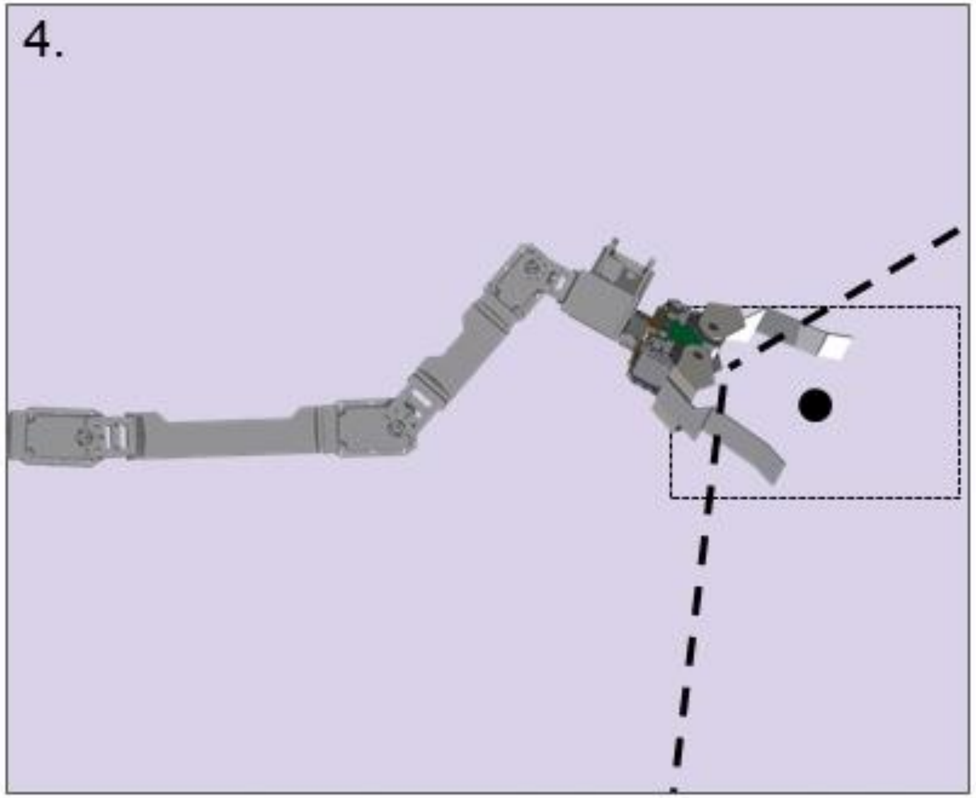
Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization

Level 1 Success



Robotic arm actuates to 3D point in space.

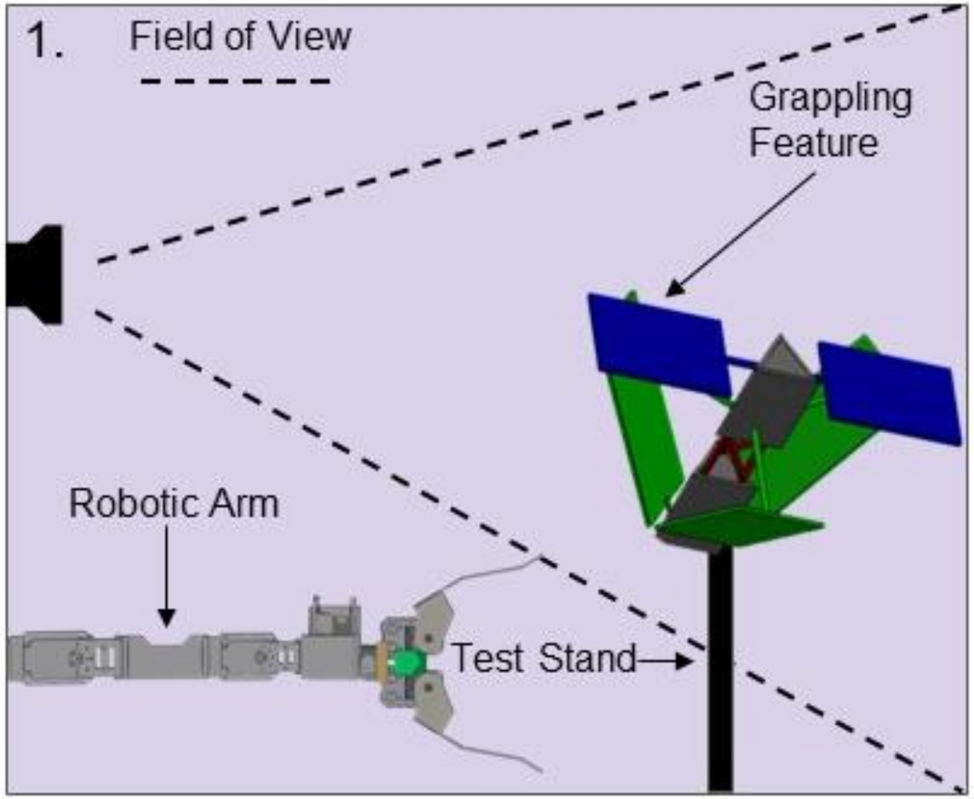
Level 1 Success



Secondary camera takes image to fine tune arm position, claw actuates at grappling point.

Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization

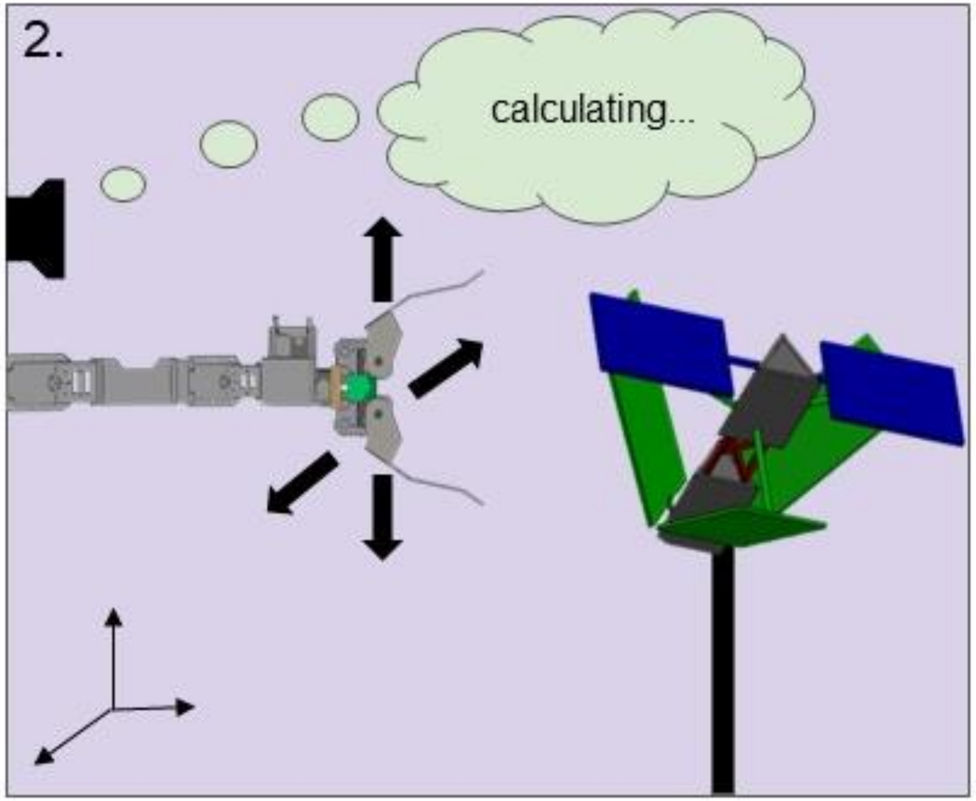
Level 2 Success



Robotic arm uses primary camera to search for grappling feature on a satellite with unknown position and orientation.

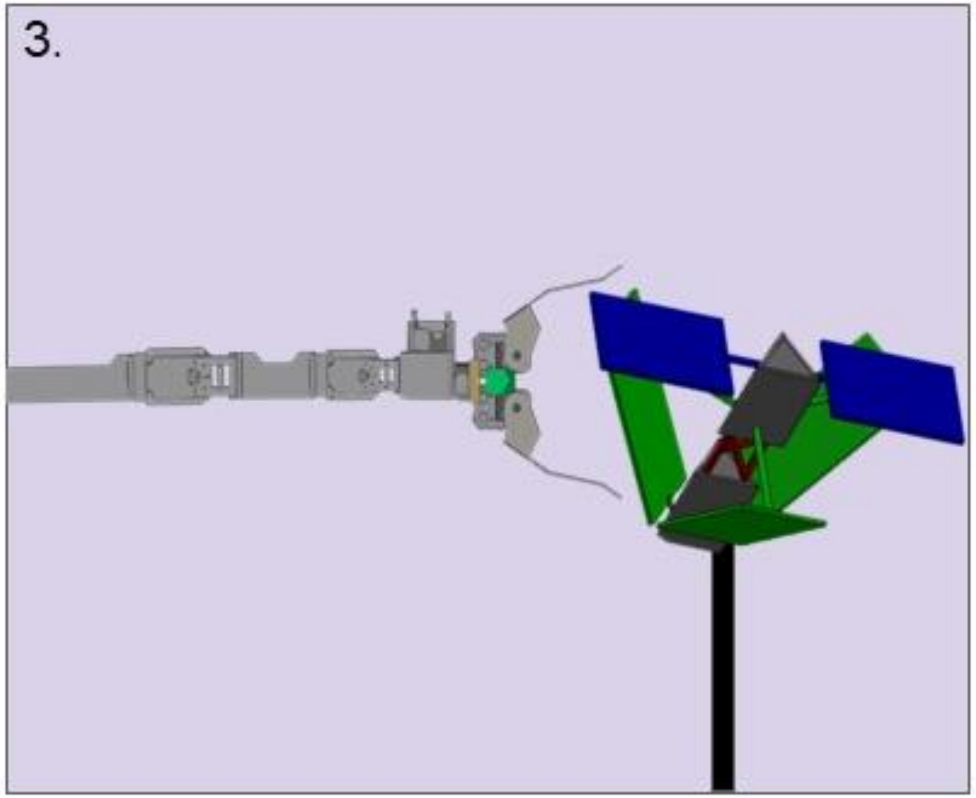
Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization

Level 2 Success



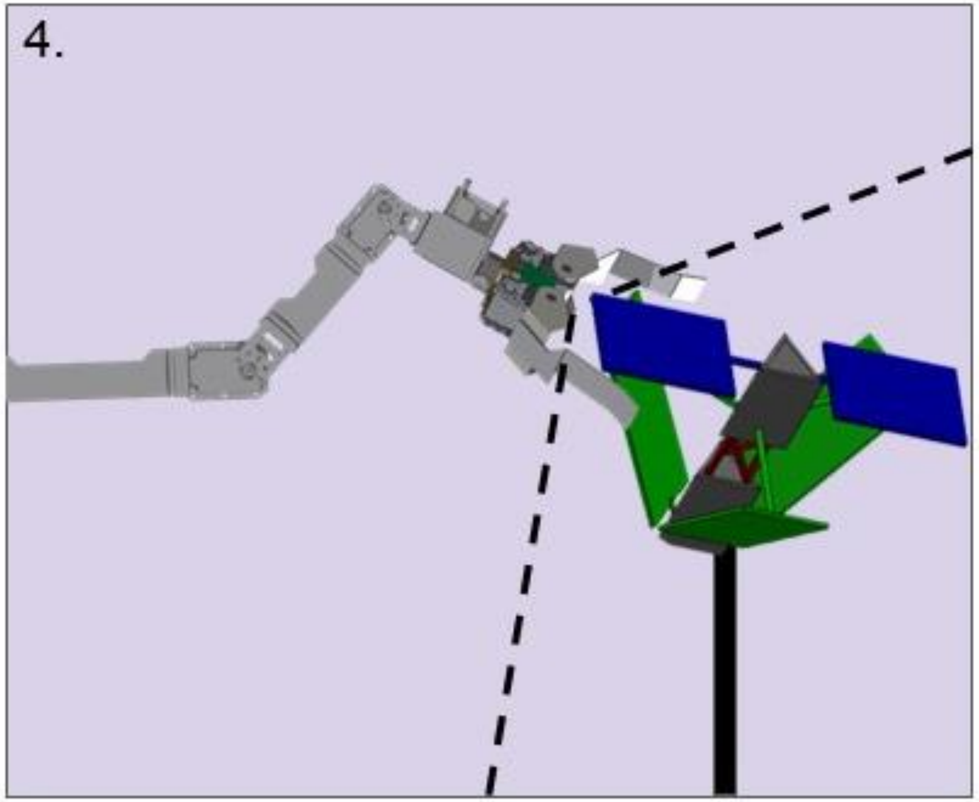
1. Feature found in FOV, the control system calculates how to grapple feature.
2. Feature not found in FOV, robotic arm scans four quadrants using secondary camera.

Level 2 Success



Robotic arm actuates to grappling feature on satellite.

Level 2 Success

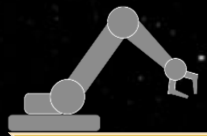


Secondary camera takes images to fine tune arm position, robotic arm actuates as necessary to grapple feature.

Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization

Proposed Design & Functionality

Lauren Darling (Electrical Lead)

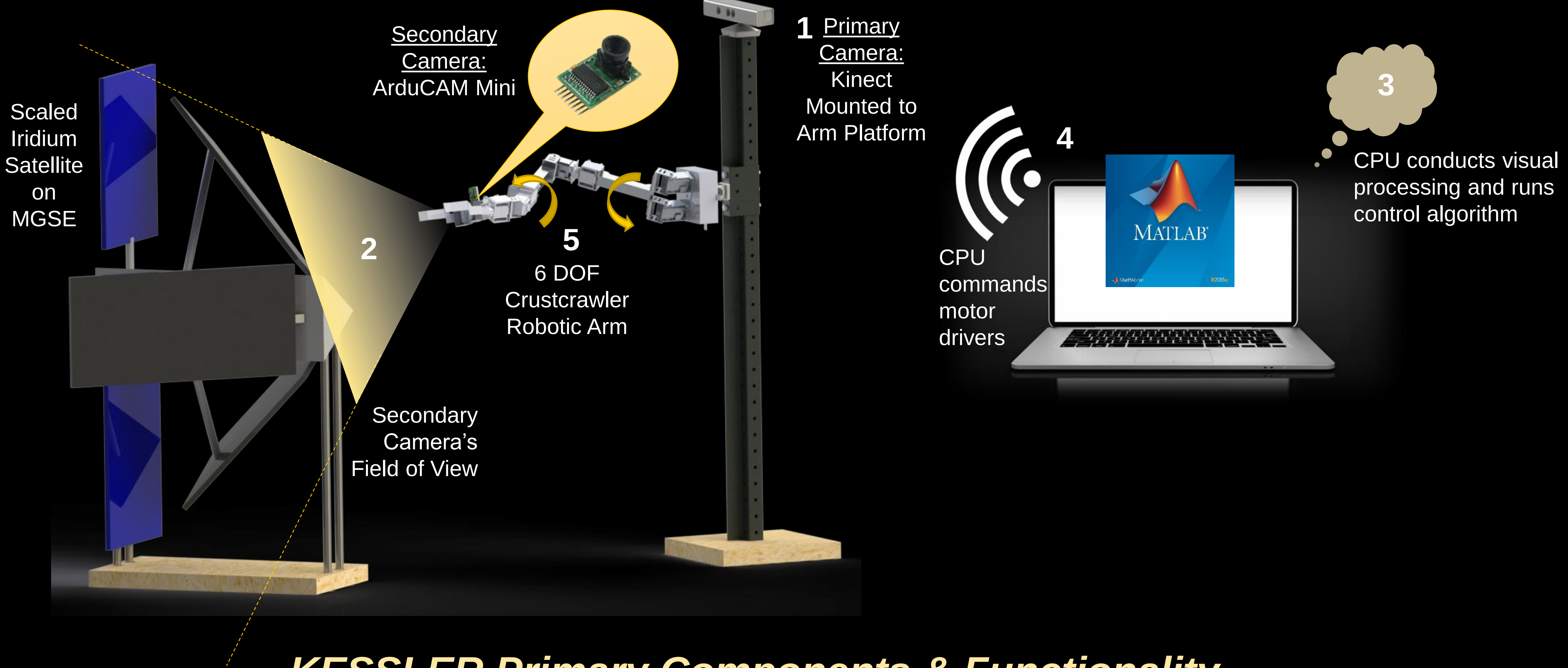


Proposed Design

Functional Requirements

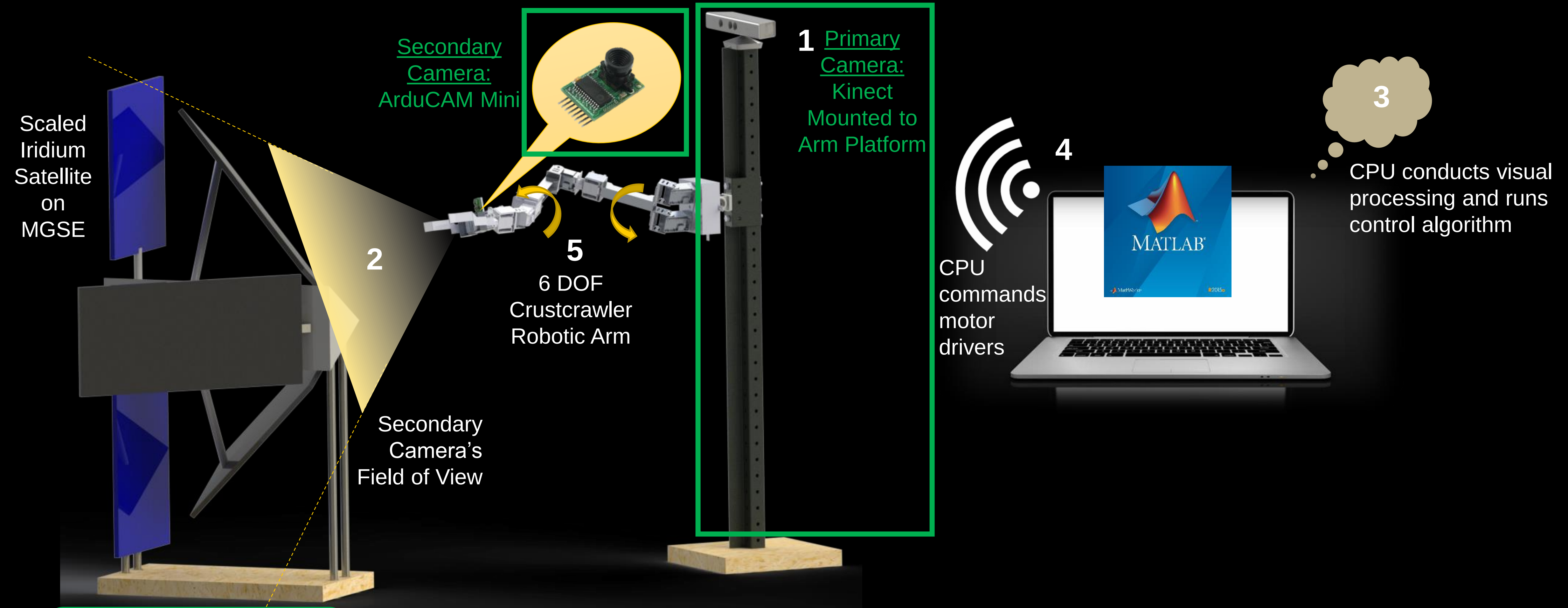
Req. ID	Requirement	Verification Method
F1	The **visual processing algorithm** shall identify the surface of a satellite in the primary camera's (RGB) field of view (FOV) and within the robotic arm's reach.	Imaging Analysis & Visual Inspection
F2	Control **algorithm** shall **define a path** to the location of a grappling feature.	Path Simulation (Experimental vs. Theoretical Location)
F3	Robotic arm shall **autonomously navigate** to at least one preselected grappling feature on the satellite.	Demonstration/Test
F4	The KESSLER system shall have a **total mission** time no greater than **53 minutes.**	Timing Analysis
F5	KESSLER shall **execute** a total of **3 end to end process operations** and succeed at least twice within the total mission time.	Demonstration/Test

Proposed Design



KESSLER Primary Components & Functionality

Proposed Design



1. Visual system searches for grappling feature on satellite

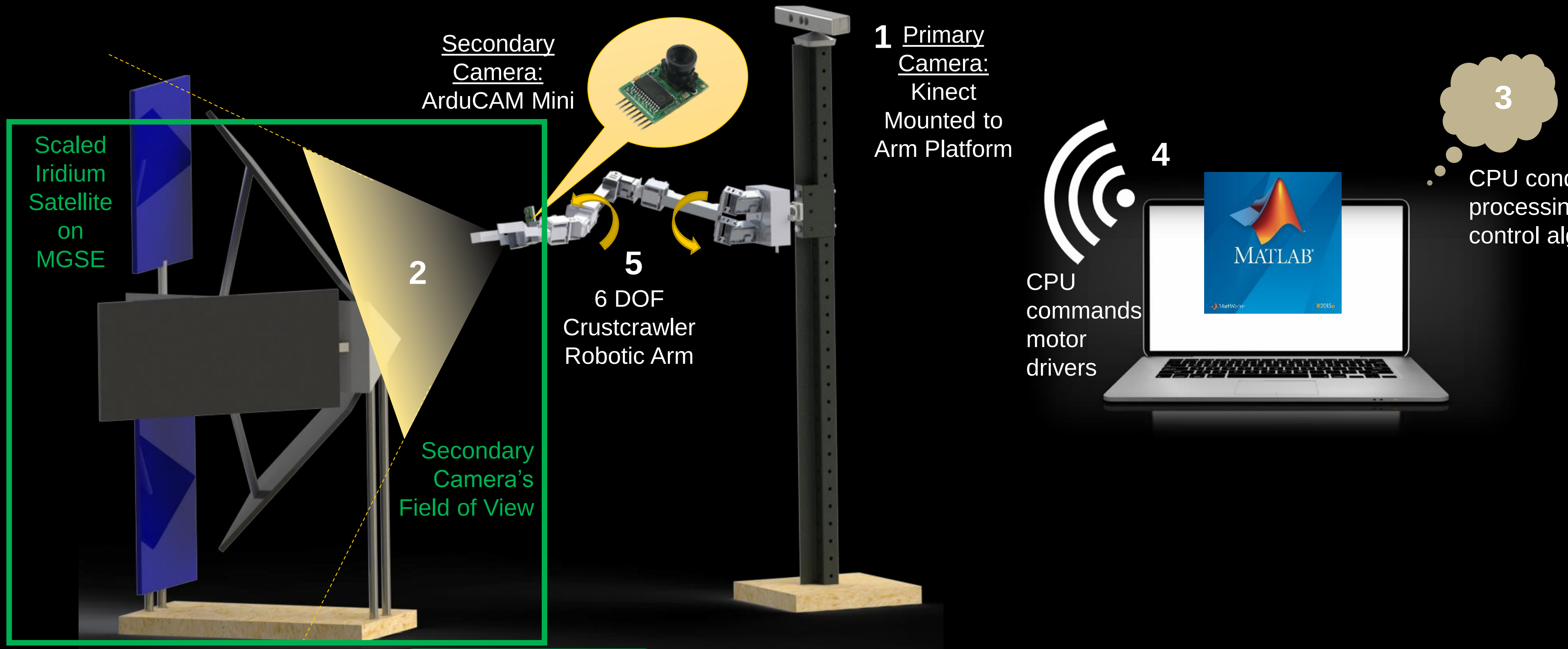
2. Algorithm identifies feature on satellite in FOV

3. Algorithm calculates how to grapple

4. CPU commands arm move as necessary to grapple feature

5. Robotic arm receives commands, rotates as necessary to grapple feature

Proposed Design



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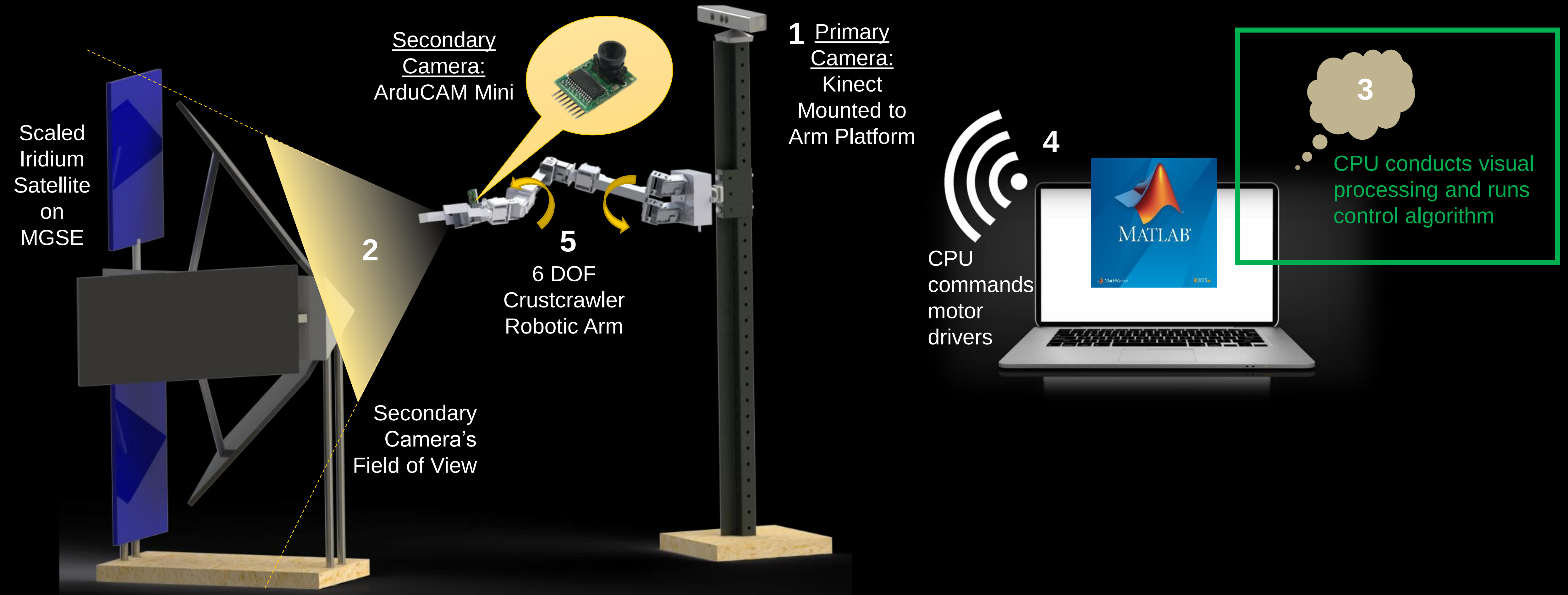

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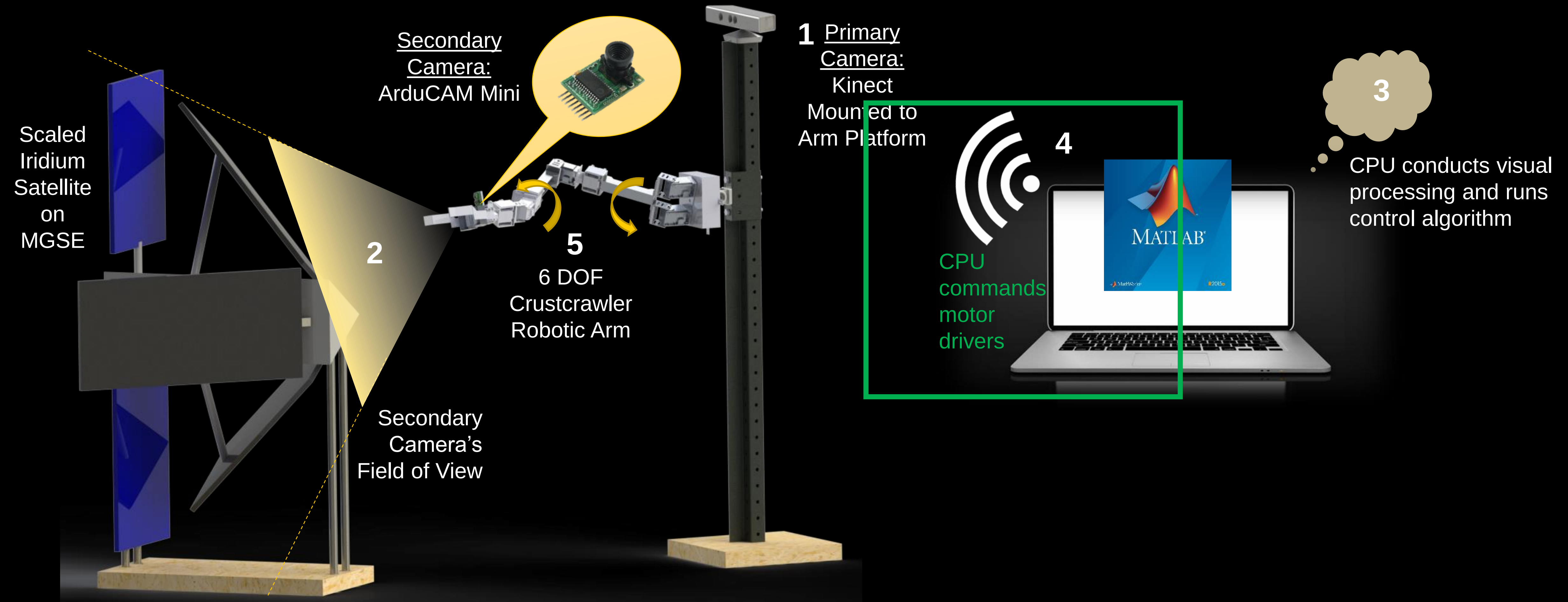

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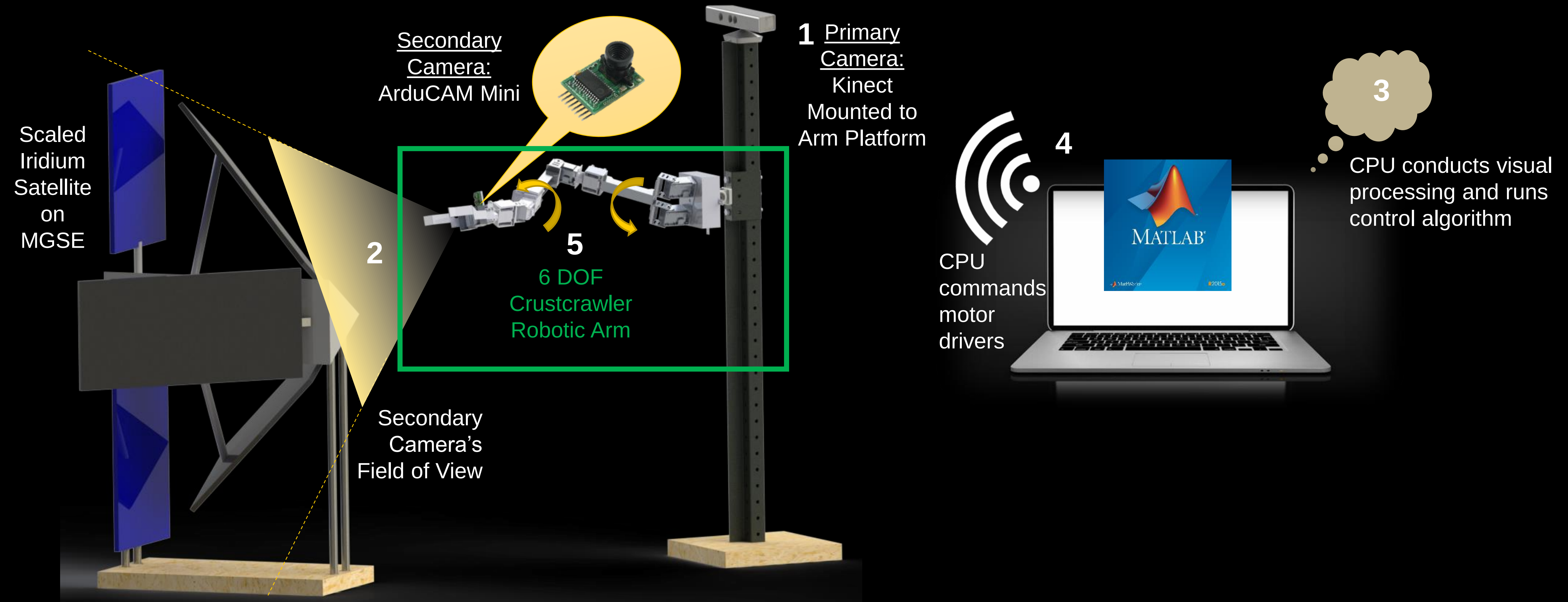

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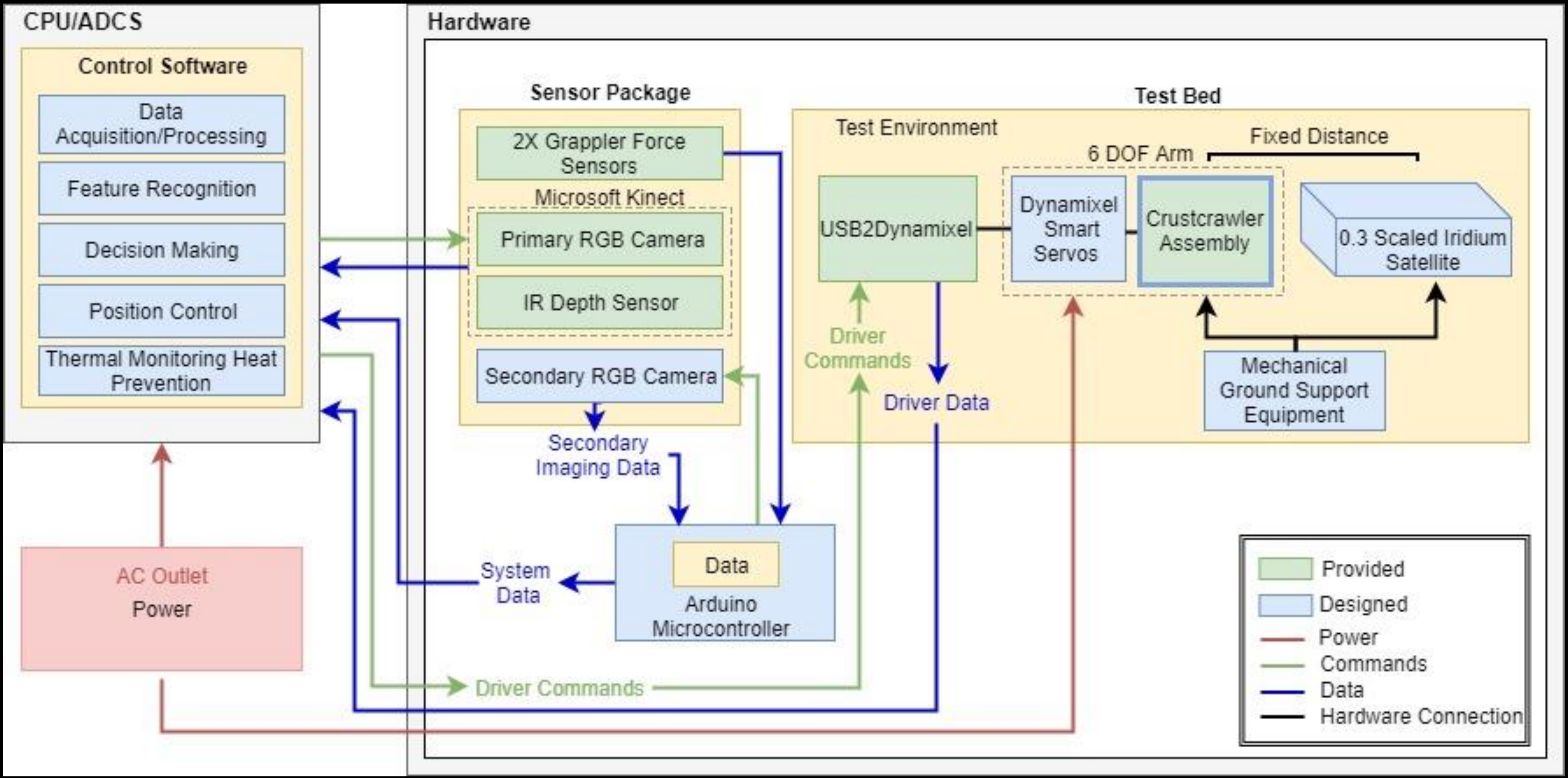
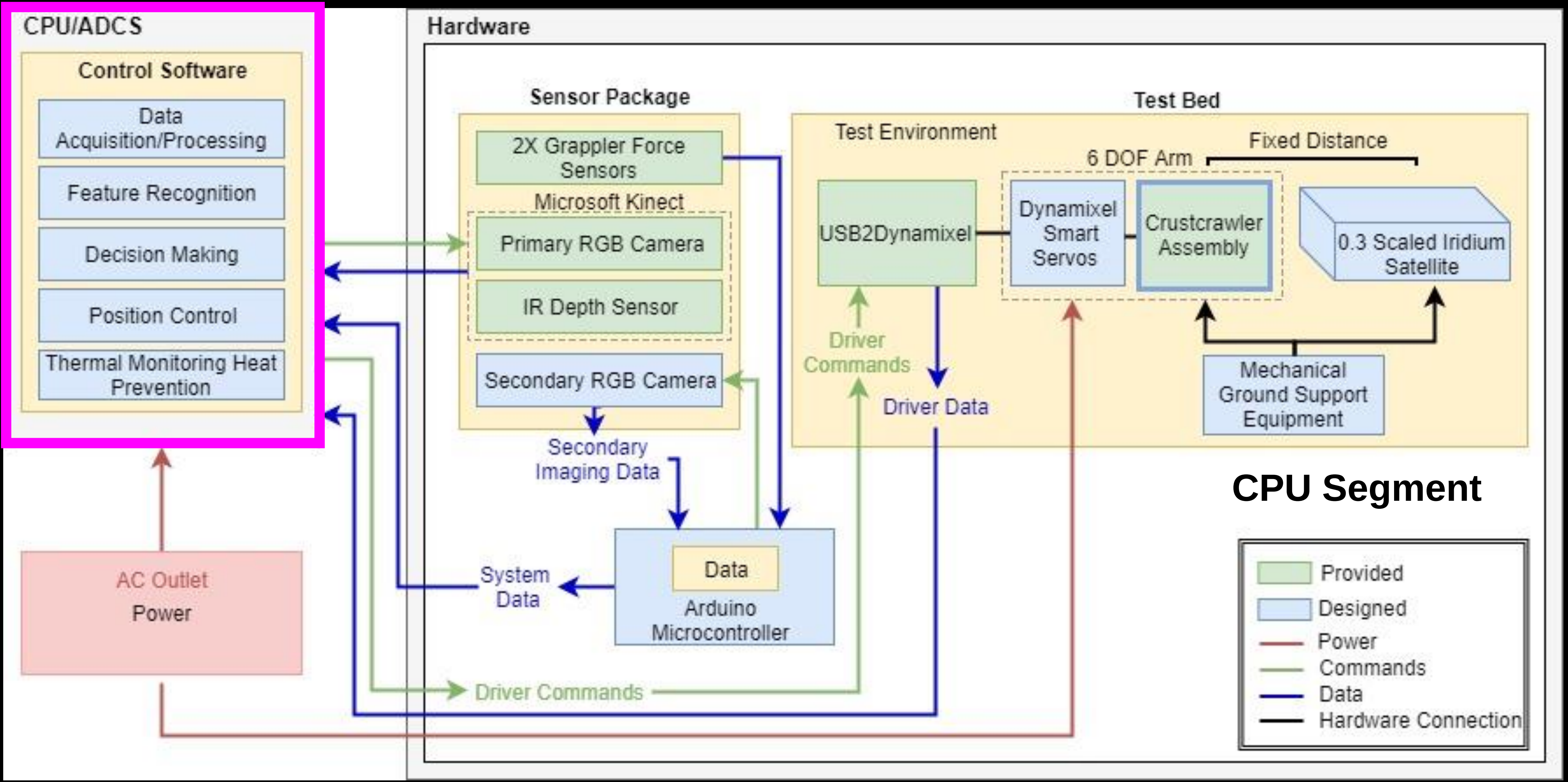
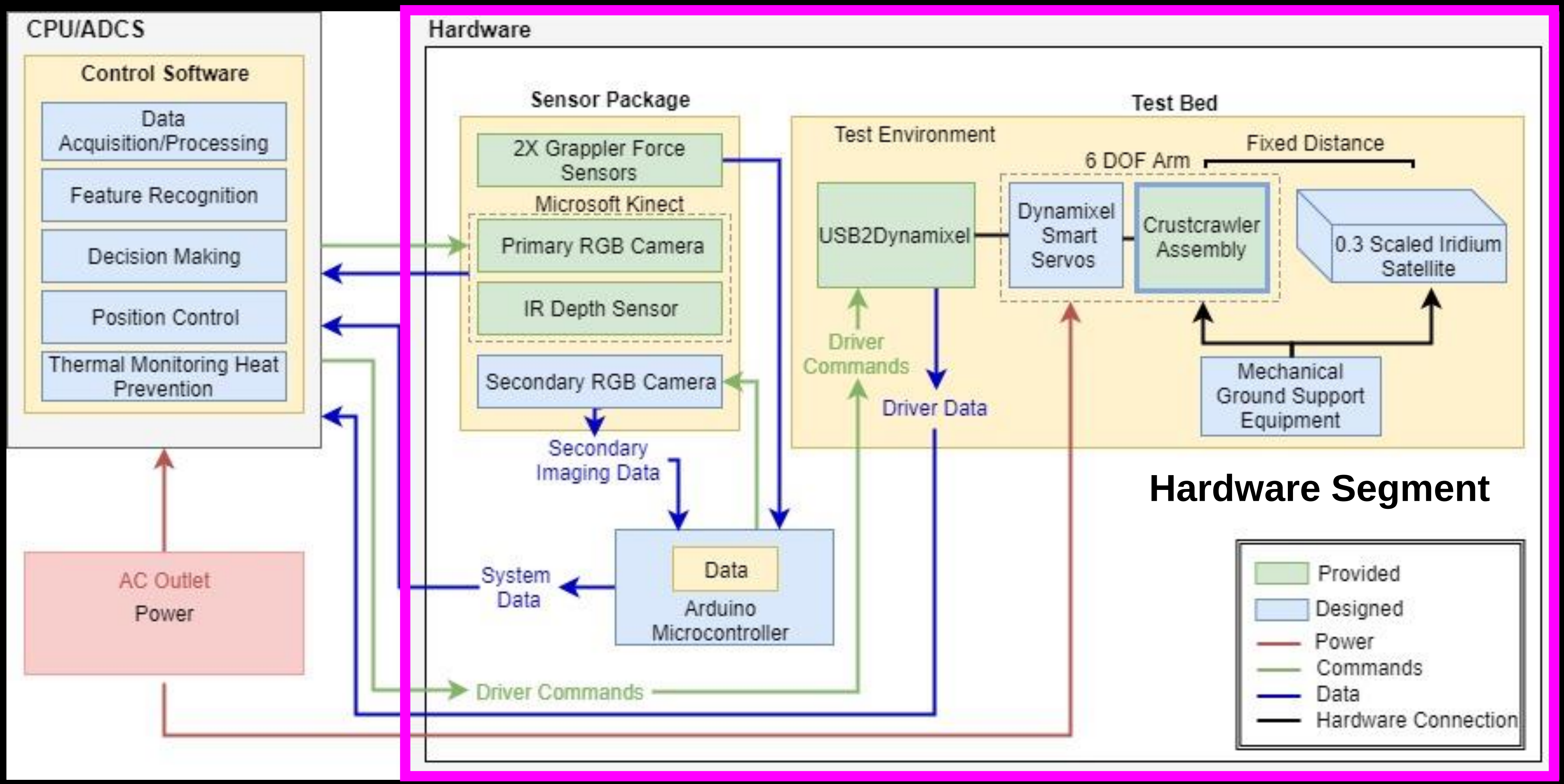


Project Definition | **Baseline Design** | CPE Overview | CPE 1 Feasibility | CPE 2 Feasibility | CPE 3 Feasibility | Status & Future Work


CPU/ADCS
Control Software
Data Acquisition/Processing
Feature Recognition
Decision Making
Position Control
Thermal Monitoring Heat Prevention
Hardware
Sensor Package
2X Grappler Force Sensors
Microsoft Kinect
Primary RGB Camera
IR Depth Sensor
Secondary RGB Camera
Secondary Imaging Data
Test Bed
Test Environment
Fixed Distance
6 DOF Arm
USB2Dynamixel
Dynamixel Smart Servos
Crustcrawler Assembly
0.3 Scaled Iridium Satellite
Driver Commands
Driver Data
Mechanical Ground Support Equipment
System Data
Data
Arduino Microcontroller
AC Outlet
Power
Driver Commands
Provided
Designed
Power
Commands
Data
Hardware Connection

CPU Segment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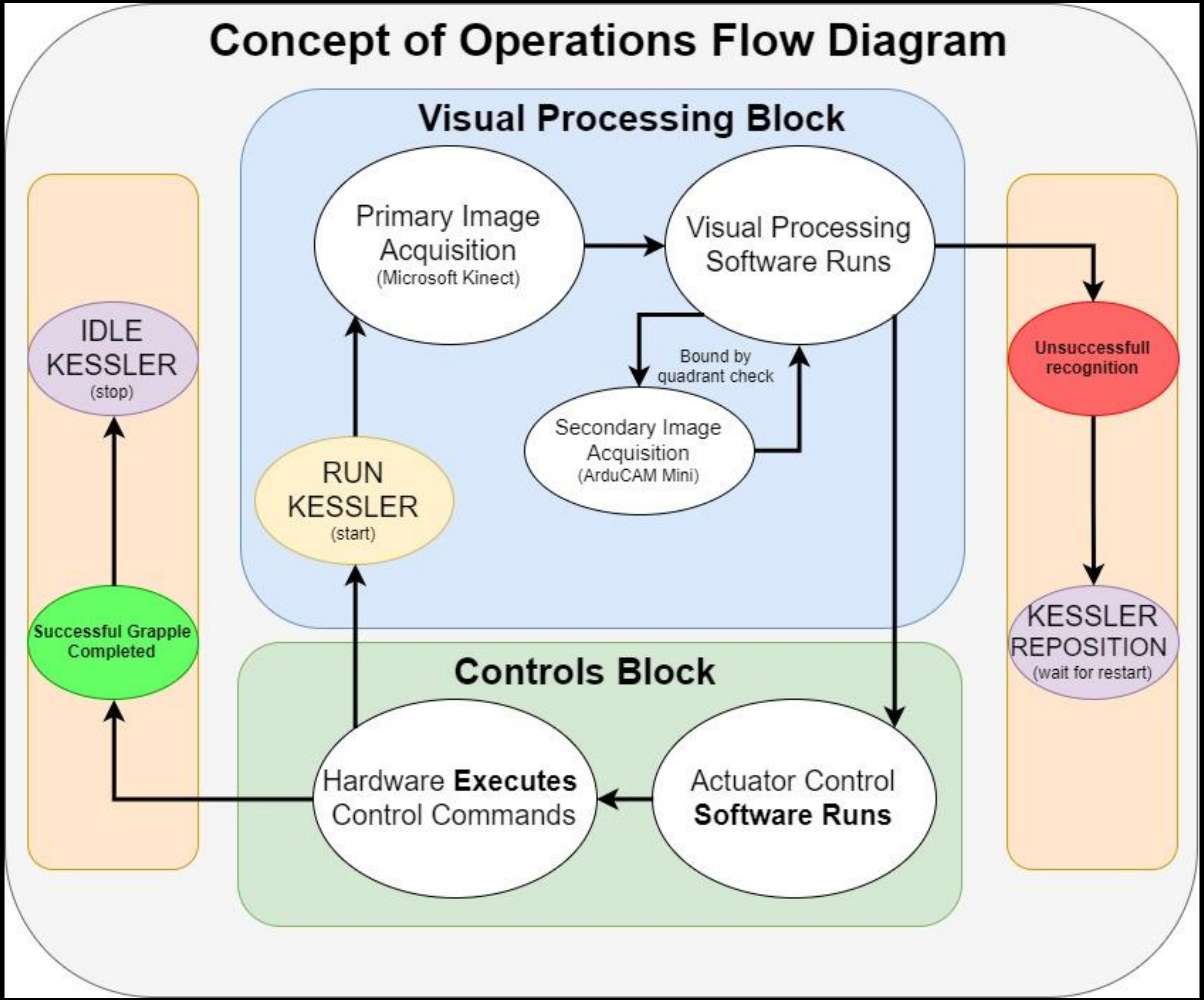
Power
Hardware
Sensor Package
2X Grappler Force Sensors
Microsoft Kinect
Primary RGB Camera
IR Depth Sensor
Secondary RGB Camera
Secondary Imaging Data
Data
Arduino Microcontroller
System Data
Driver Commands
Test Bed
Test Environment
Fixed Distance
6 DOF Arm
USB2Dynamixel
Dynamixel Smart Servos
Crustcrawler Assembly
0.3 Scaled Iridium Satellite
Driver Commands
Driver Data
Mechanical Ground Support Equipment
Hardware Segment
Provided
Designed
Power
Commands
Data
Hardware Connection



- System supported by Robot Operating System (ROS) ‘middleware’
  - Set of software libraries & tools to help build robot applications
  - Modular capability (add/remove attributes)

Critical Project Elements for Meeting Success Criteria

Lauren Darling (Electrical Lead)

Level 1 Success Criteria

***Table 1**: Level 1 Success Criteria*

Identification	Processing	Command Execution
Identify at least two surfaces with varying depths in 3D space.	Identify the distance between the closest point of the satellite and the base of the robotic arm (± 4mm).	Demonstrate end-effector can move to closest point and actuate while facing the parallel plane.

*Three categories decoupled to ensure there is no dependency when meeting mission success criteria

Level 2 Success Criteria

***Table 2**: Level 2 Success Criteria*

Identification	Processing	Command Execution
Identify grappling feature recognition on target satellite.	**Determine grappling feature location and orientation to within ± 4mm & ± 5 degrees.**	**Grapple feature in parallel plane to within ± 90 degree of end-effector roll angle.**

*Three categories decoupled to ensure there is no dependency when meeting mission success criteria

Level 3 Success Criteria

***Table 3**: Level 3 Success Criteria*

Identification	Processing	Command Execution
Identify collision feature on target satellite.	Define keep-out zone to within ± 4mm of collision feature surface, and select grappling feature that causes the smallest collision risk.	Grapple feature in perpendicular plane (demonstrate additional Degree of Freedom).

*Three categories decoupled to ensure there is no dependency when meeting mission success criteria

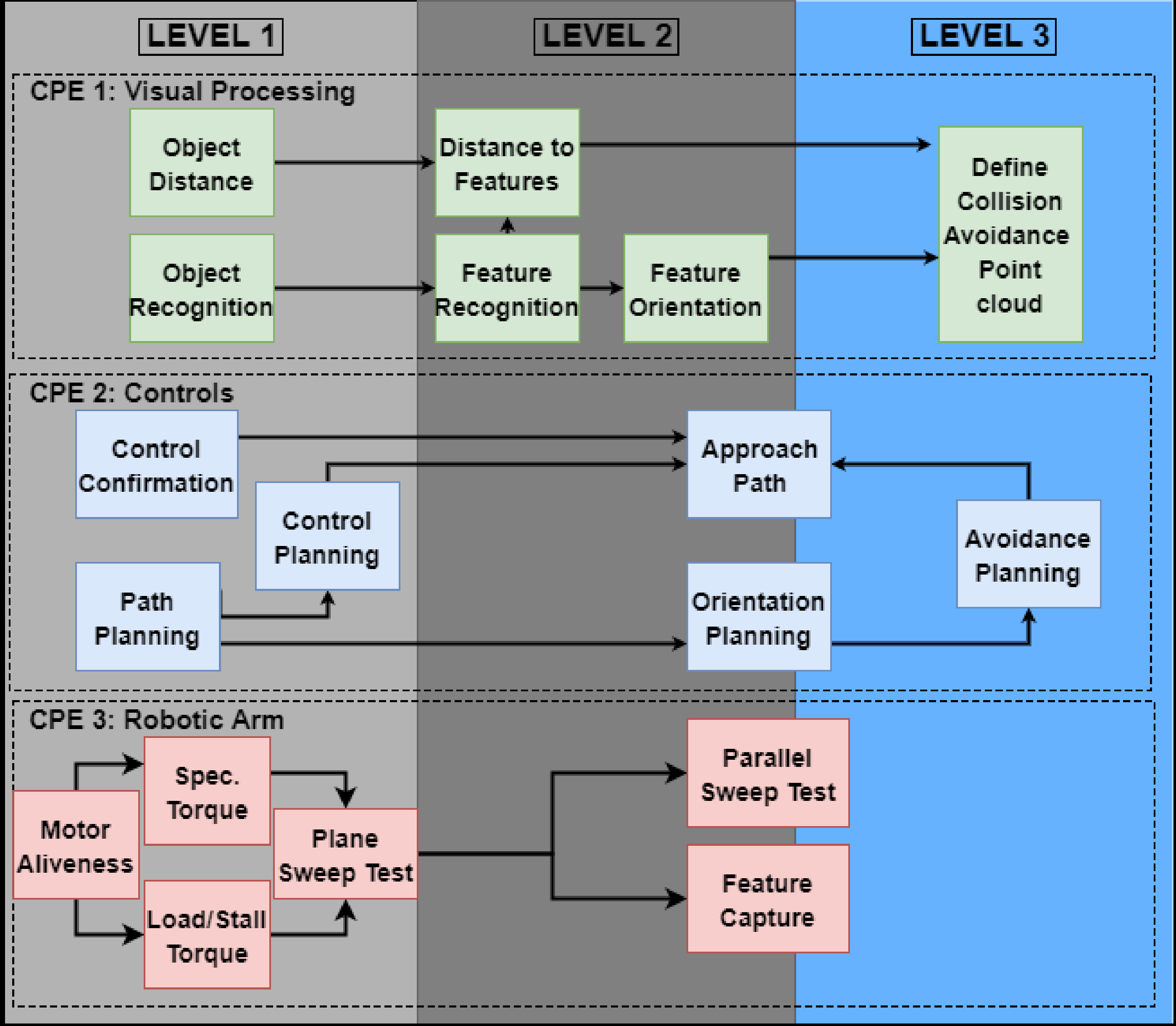
Critical Project Elements Overview

Three Critical Project Elements

- CPE 1: Feature Recognition
  - Addresses Objectives 1 and 2
- CPE 2: Control Systems
  - Addresses Objective 3 and 4
- CPE 3: Robotic Arm
  - Addresses Objectives 4

1. Take visual data confirming the target object is within FOV.	**2. Identify pre-defined grappling feature.**
3. Determine prediction path to feature location.	**4. Autonomously capture the feature via robotic arm**

CPE Mapping to Success Criteria



Design Requirements & Their Satisfaction

CPE Leads

Project Purpose | Proposed Design | Critical Project Elements | **Design Reqs.** | Risks & Mitigation | Ver. & Val. | Organization

CPE 1: Visual Processing

Taylor Way (Financial Lead)

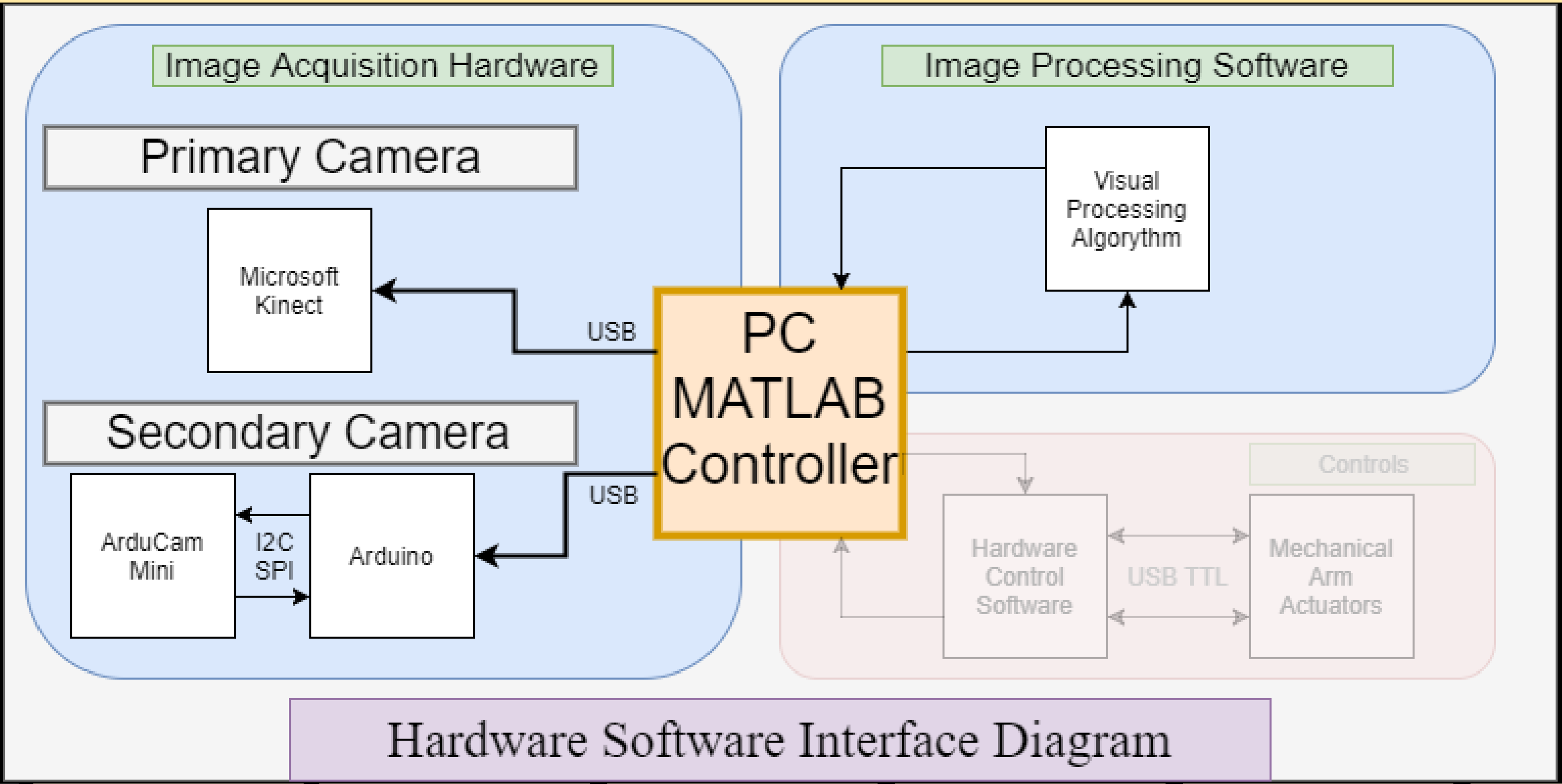
Lauren Darling (Electrical Lead)

Project Purpose | Proposed Design | Critical Project Elements | **Design Reqs.** | Risks & Mitigation | Ver. & Val. | Organization

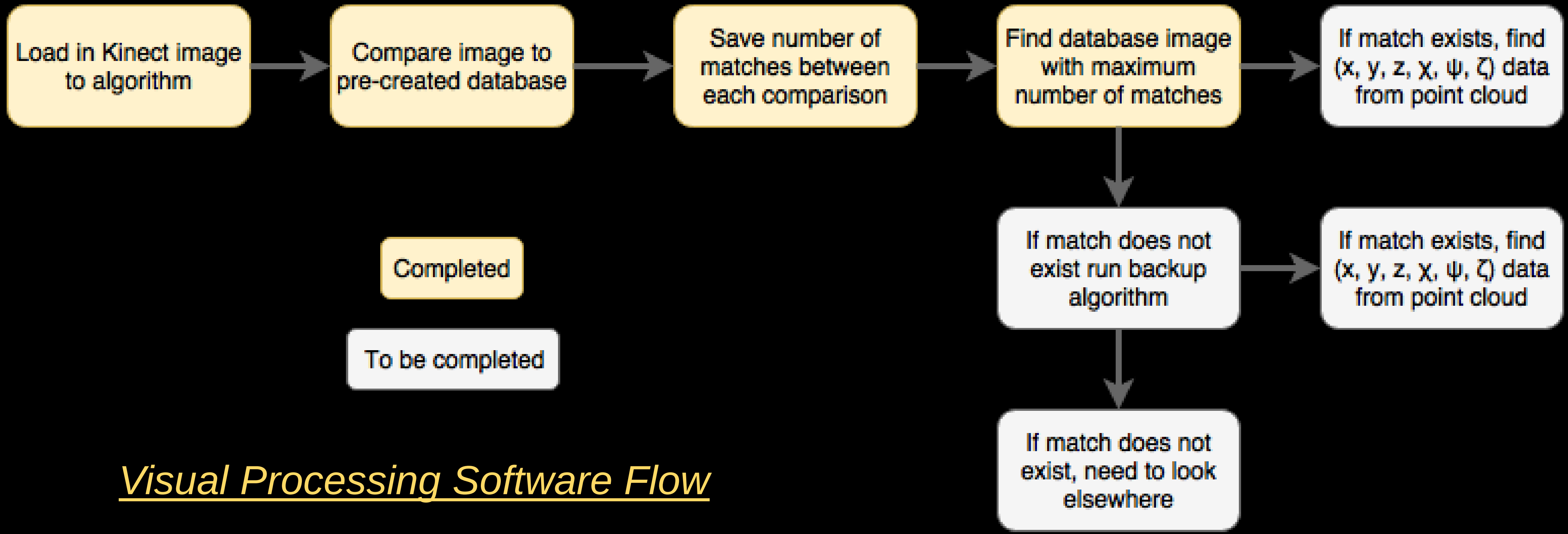
F1: Design Requirements

REF ID	Description	Verification Method
D1.1	The visual processing algorithm shall be capable of detecting a feature at a minimum distance of 20 inches.	Demonstration/Test
D1.2	The visual processing algorithm shall be capable of identifying the main characteristics of a satellite with a level of confidence greater than or equal to 75%.	Image Analysis
D1.3	The visual processing algorithm shall identify the position (x,y,z) and orientation (Euler angles) of an object in 3D space.	Image Analysis
D1.4	The visual system shall be capable of communicating with the control system.	Demonstration/Test

Design & Functionality



Design & Functionality



Visual Processing Software Flow

Design & Functionality

Computer Vision Systems Toolbox

- Object detection and recognition
- Tracking
- Camera calibration and 3D vision
- Display and graphics
- Analysis
- Code generation

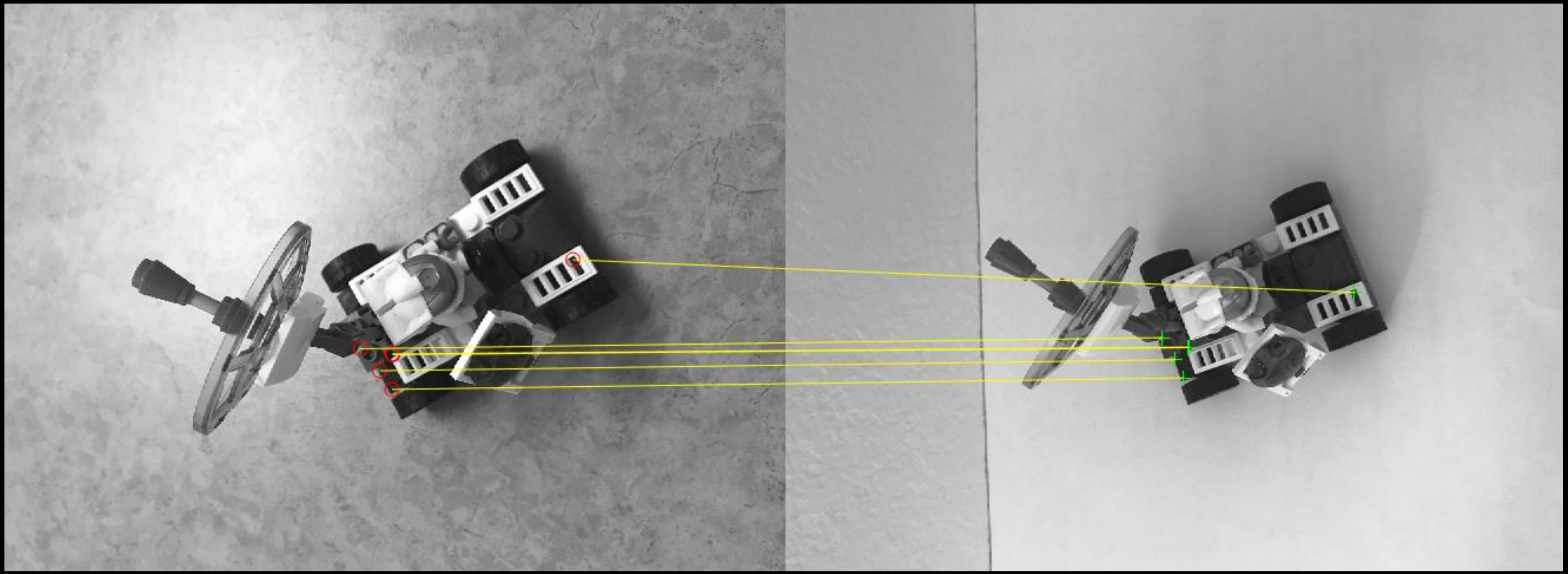
Image Processing Toolbox

- Deblurring and enhancement
- Image registration
- Transformations
- Image segmentation
- Measuring image features
- Working with large images

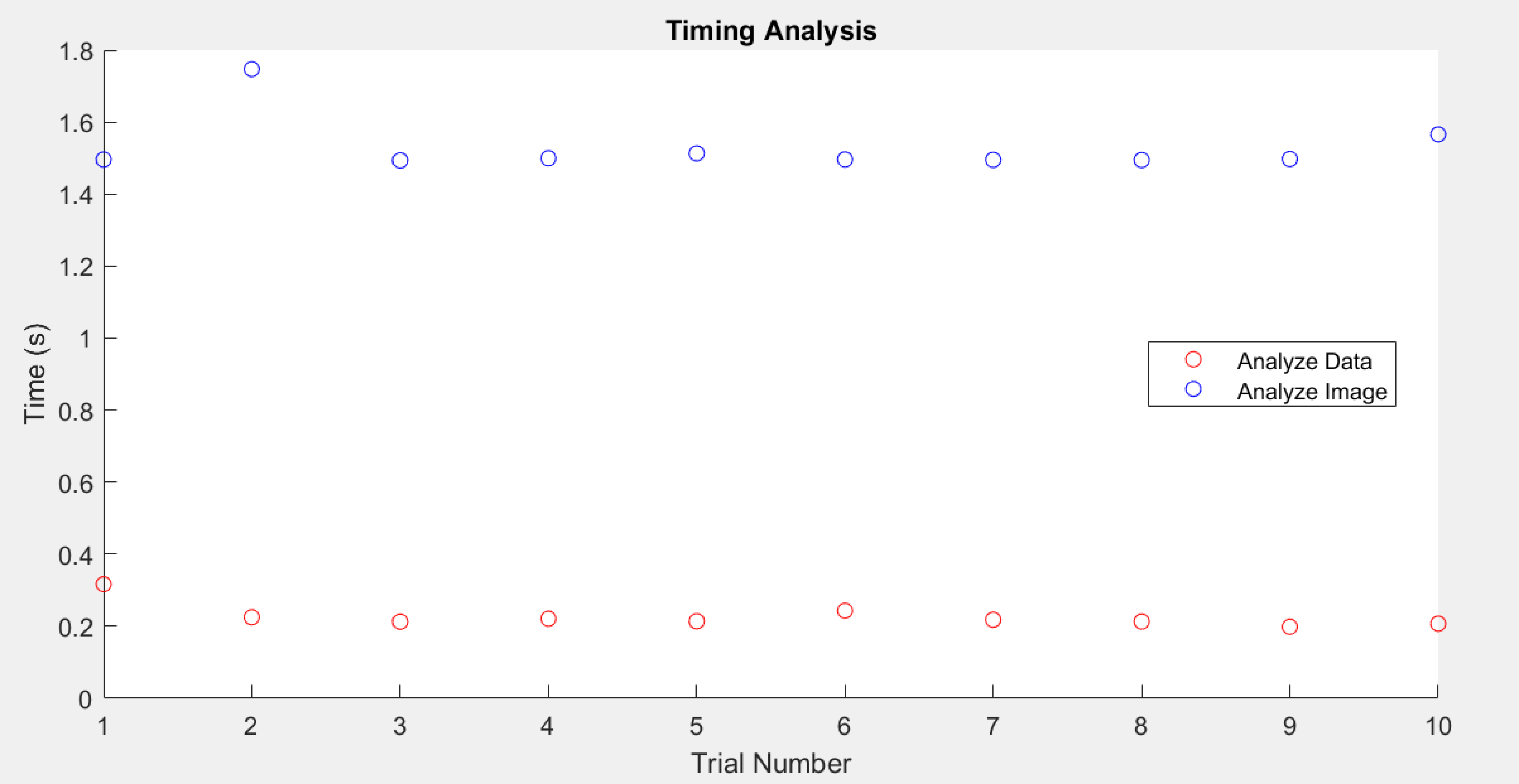
Design & Functionality

Database Testing in MATLAB

- Minimum of 4 matches needed
- Found with confidence level of 99%
- Database of 157 images
- 3 objects in database



Design & Functionality



Project Purpose | Proposed Design | Critical Project Elements | **Design Reqs.** | Risks & Mitigation | Ver. & Val. | Organization

Design & Functionality

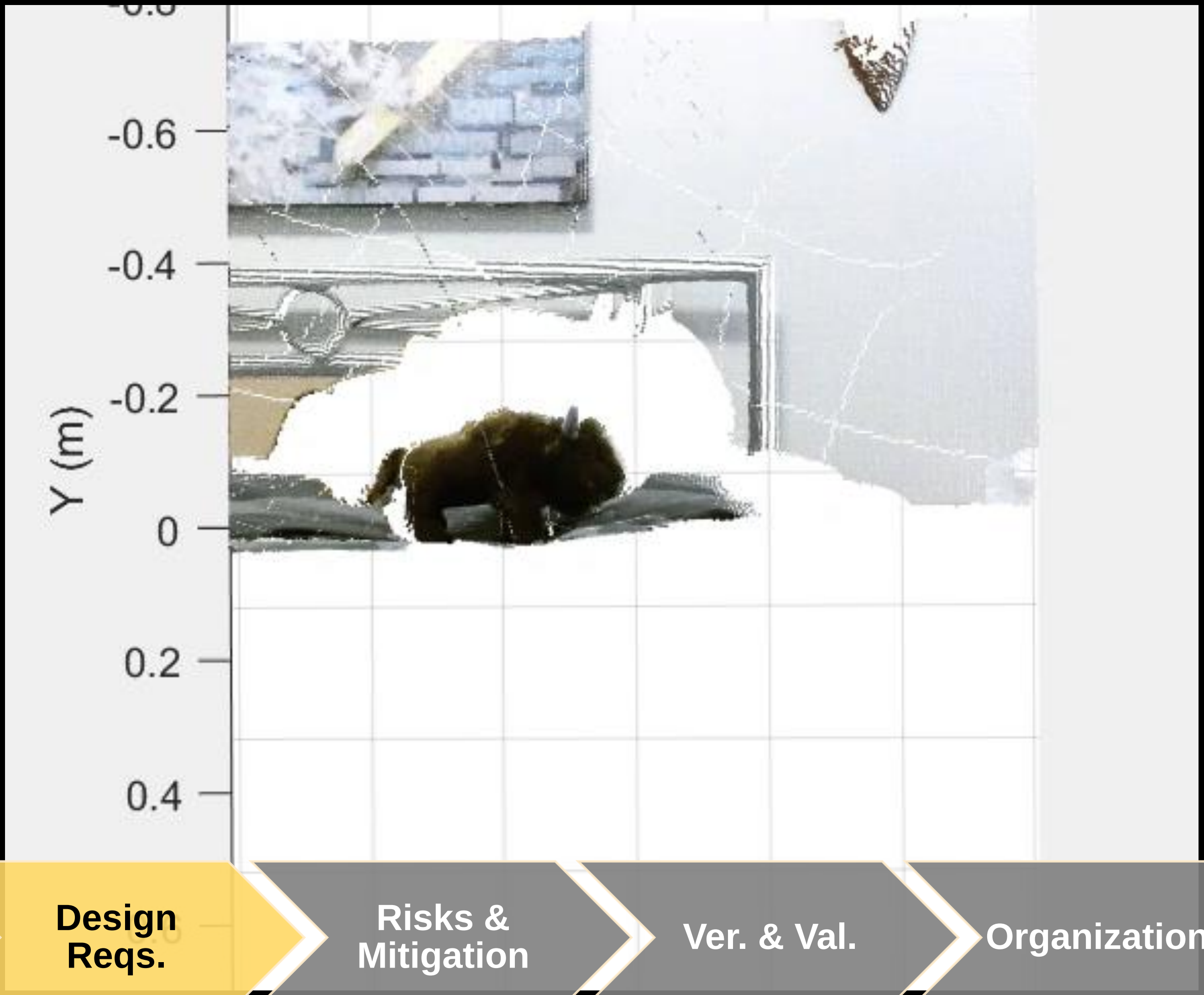
Additional algorithm searching techniques:

- Machine learning
- Confidence interval association
  - Unique index structuring to jump in database to find image with better confidence
- Binary search tree that triggers the match of an object
  - Associate all of them to each other and use a BST to reach an individual indexing of the orientation

Design & Functionality

3D Point Cloud from Kinect:

- IR and RGB cameras
- Used for localization
- Outputs {x, y, z} coordinates
- Will be used to know location of feature(s)

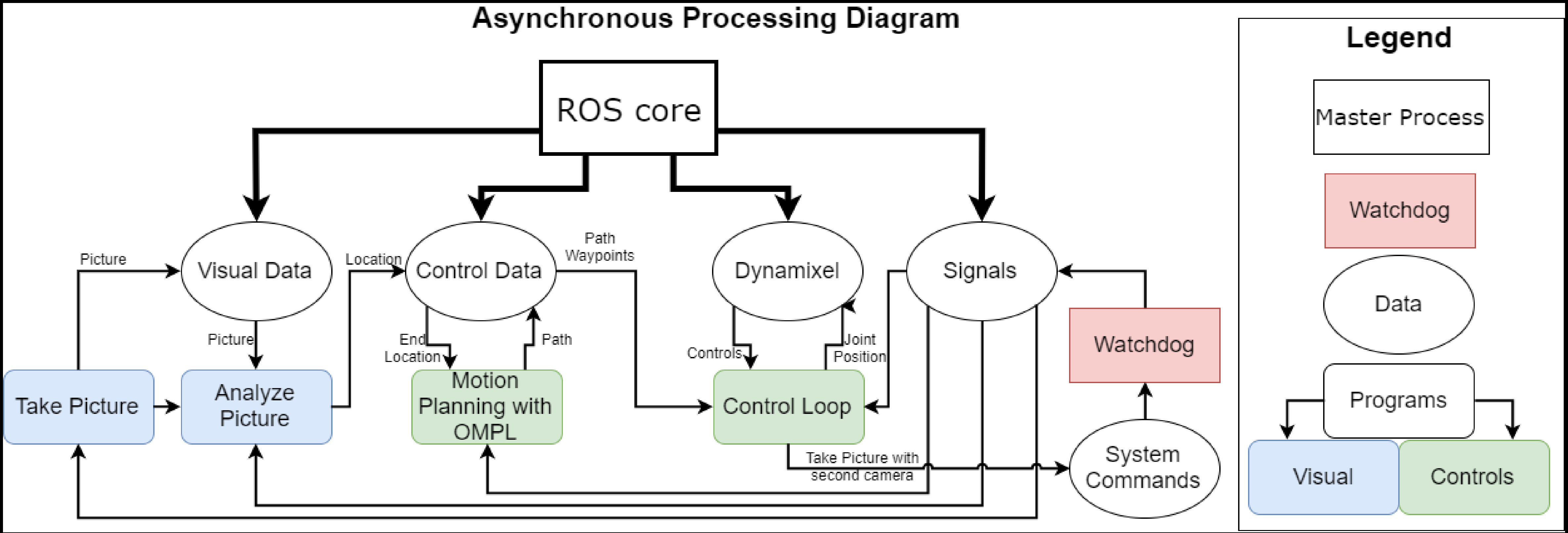


Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization

CPE 2: Controls

Nicholas Thurmes (Software Controls Lead)

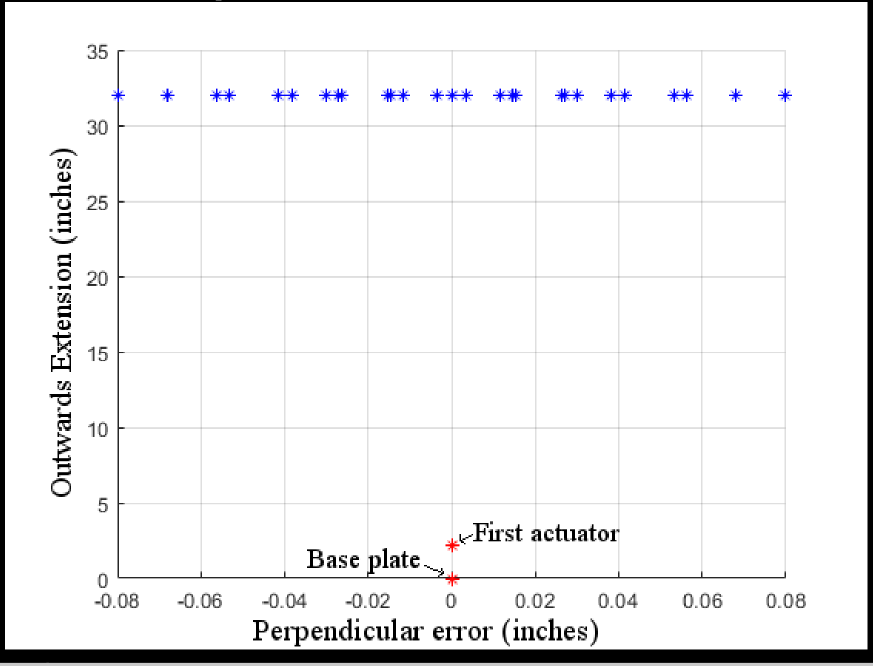
Design & Functionality

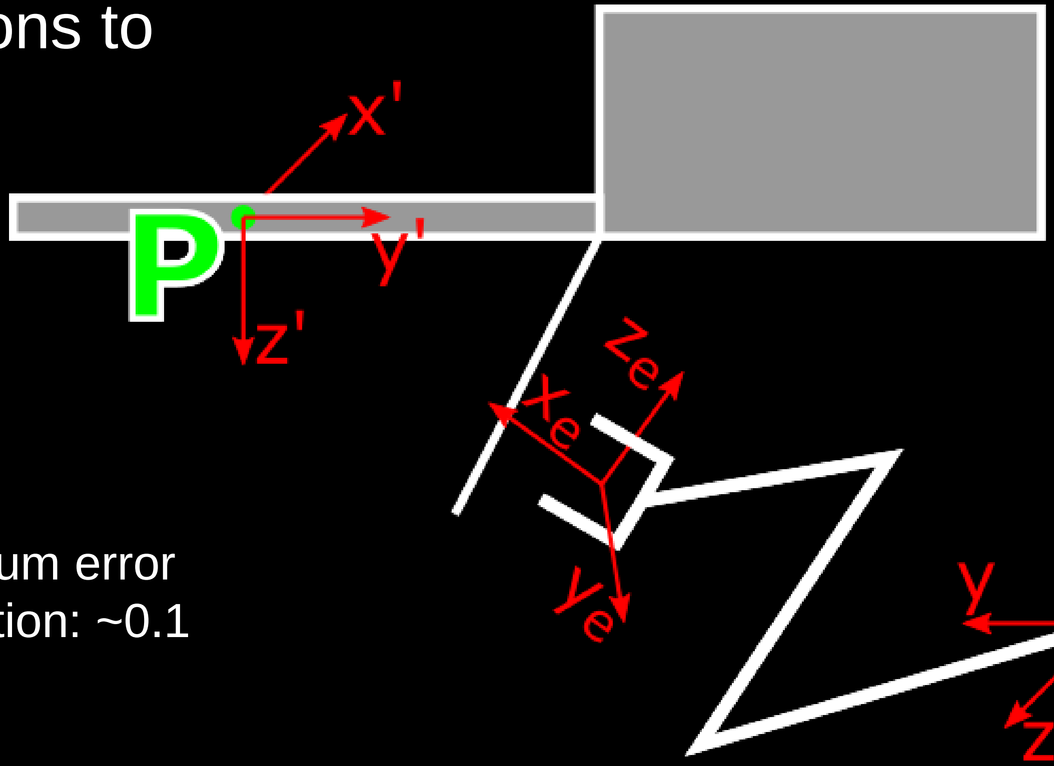


D1.4	The visual system shall be capable of communicating with the control system.

Design & Functionality

Forward kinematics convert joint positions to Cartesian position and orientation

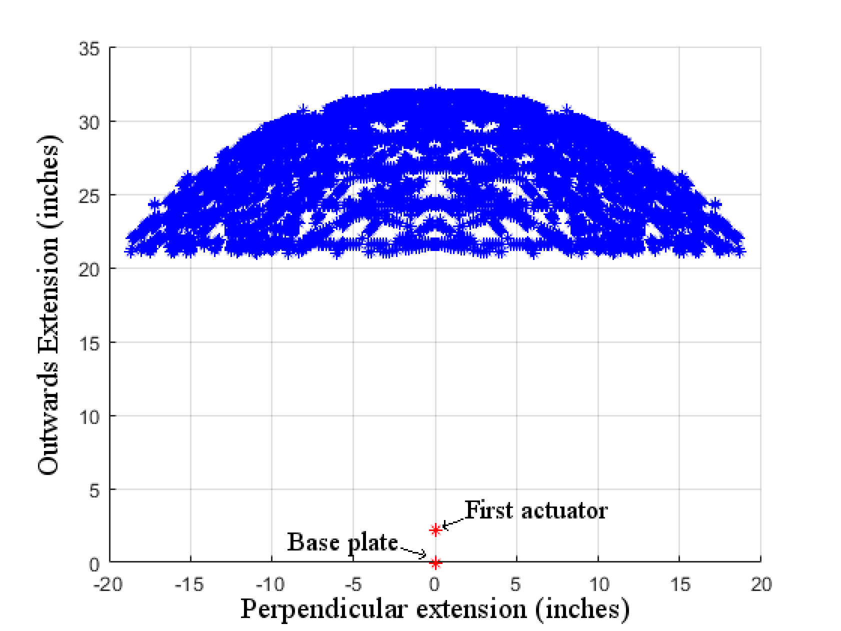




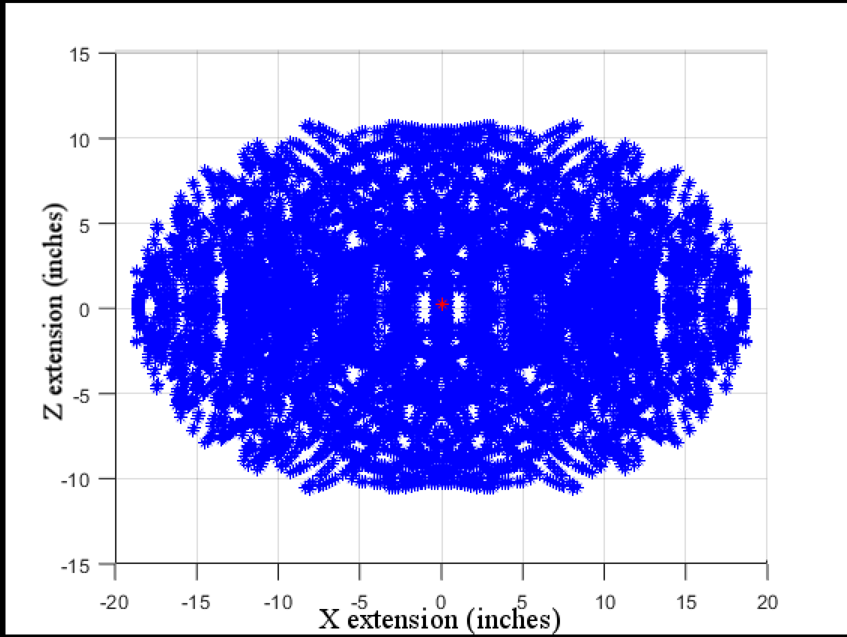
Maximum error simulation: ~0.1 inches

D2.1	The end-effector orientation and location shall be determined in 3D space to within ± 0.15 inches and ± 5 degrees.

Design & Functionality



Top view: Parallel plane workspace area



Point of View: Parallel plane workspace area

D3.5	The arm shall be capable of capturing a feature at a finite displacement in x,y,z, and roll within 0.15 inches and 5 degrees.

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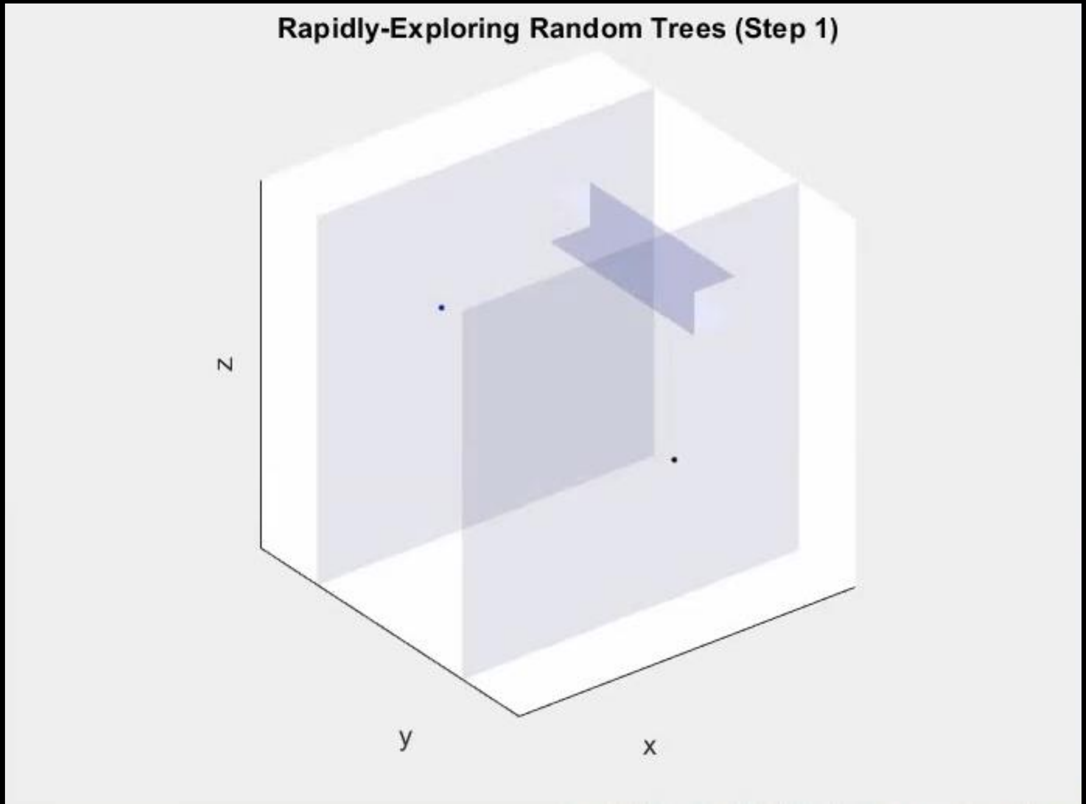
Design & Functionality

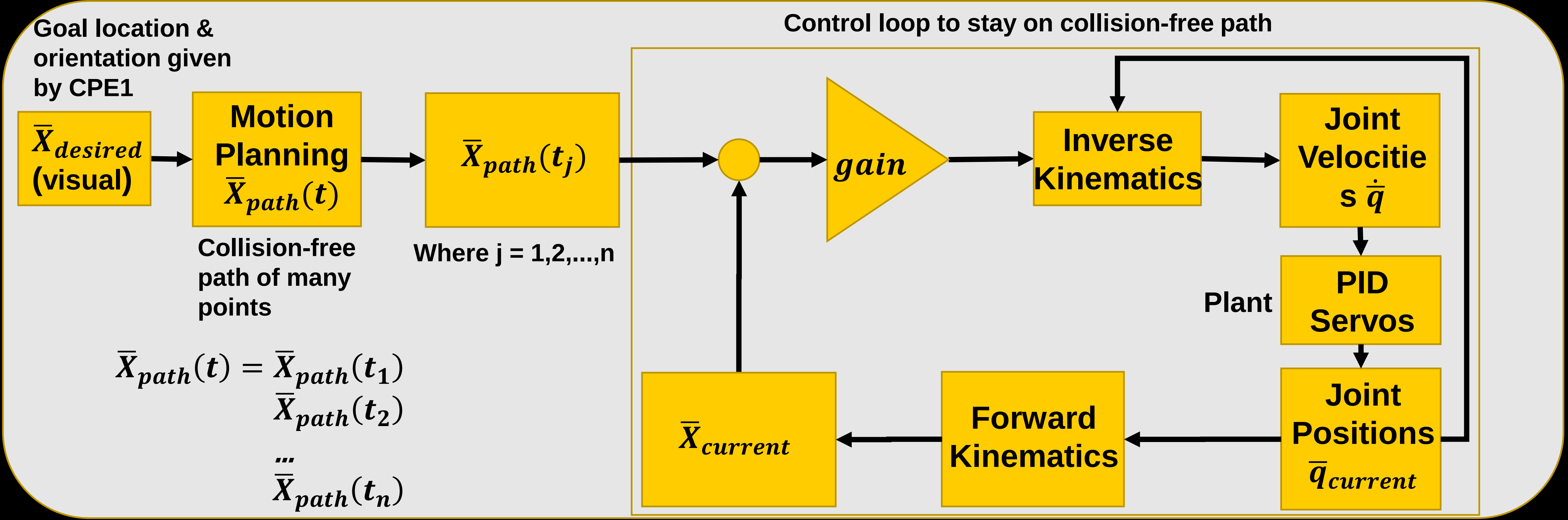


Rapidly Exploring Random Tree (RRT)

- Pick random sets of joint angles then project into physical space
- Connect into single tree
- Optimize final path

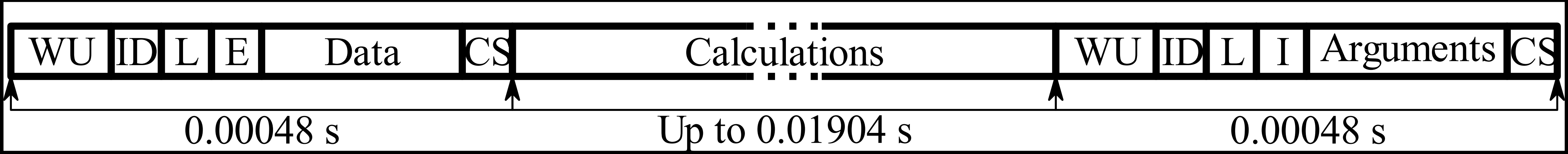
D2.3	The robotic arm path shall be constrained by the arm's joint limitations.

Design & Functionality



D3.3	Robotic arm shall execute path defined by control algorithm with an error no greater than ±0.15 inches.

Design & Functionality



With baud rate = 1 MHz and required update rate = 50 Hz

- Calculation takes only 0.0029 s
- Margin 6.565 (factor)

D3.3	Robotic arm shall execute path defined by control algorithm with an error no greater than ±0.15 inches.

CPE 3: Robotic Arm

Christopher Choate (Manufacturing Lead)

Design & Functionality

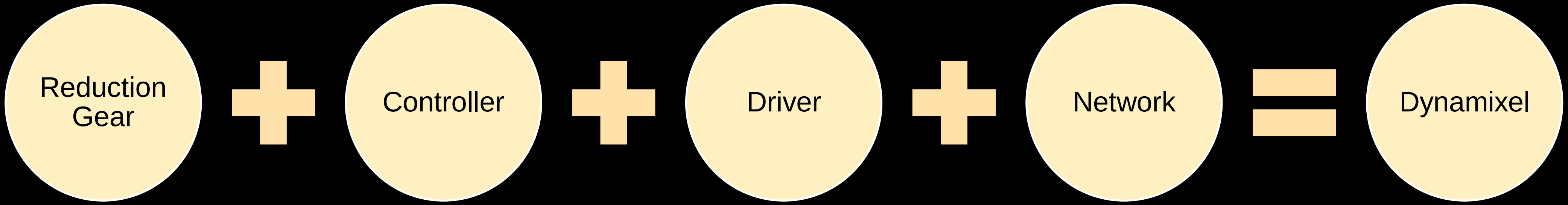
REF ID	Description	Verification Method
D3.1	The robotic arm shall receive commands from the control system	Demonstration/Test
D3.2	Grappling features shall be representative of features on the Iridium Satellite form factor	Inspection Test
D3.3	Robotic arm shall execute path defined by control algorithm	Demonstration/Test
D3.4	End effector shall have a full deployable range of 9 inches.	Demonstration/Test
D3.5	The arm shall be capable of capturing feature at a finite displacement of 30inch arm radius, ± 180 degree roll, in x,y,z, and roll	Demonstration/Test

Design & Functionality

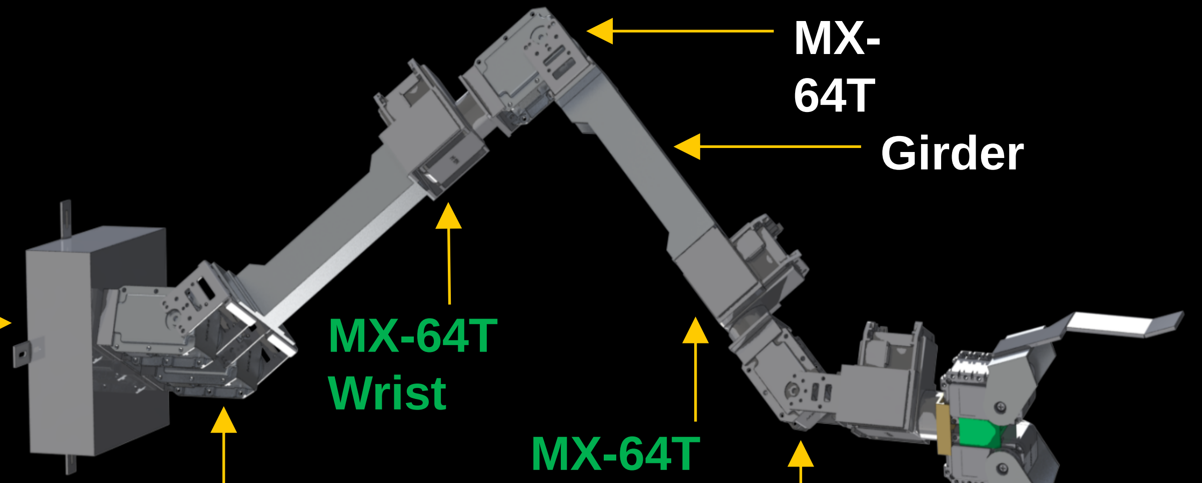
What is a Dynamixel: All in One Actuator design family

- Each individual servo unique ID
- Communication is directed to individual servo along same data transfer cable.

All in One Modular Design



Design & Functionality



Actuators

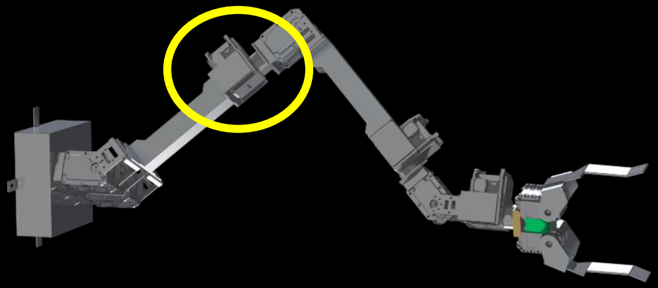
- MX-64T DA
- MX-64T Wrist (3)
- MX-64T
- MX-28T
- AX-12A (End-Effector)

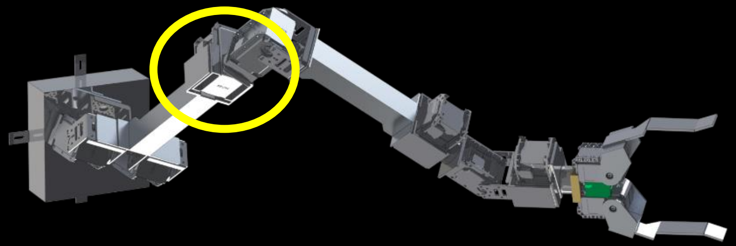
Max Length: 33.2 in.
Minimum Grapple Radius: 20 in.

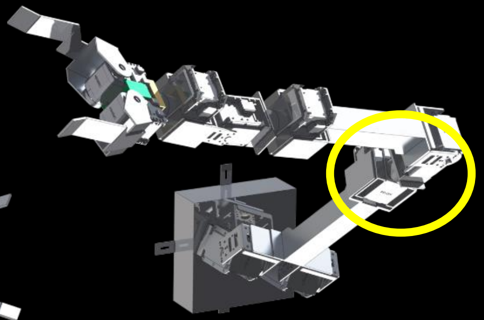
Base Rotating Platform (ROLL) → MX-64T DA (PITCH) → MX-64 Wrist (ROLL) → MX-64T (PITCH) → MX-64 Wrist (ROLL) → MX-28T (PITCH)

Design & Functionality

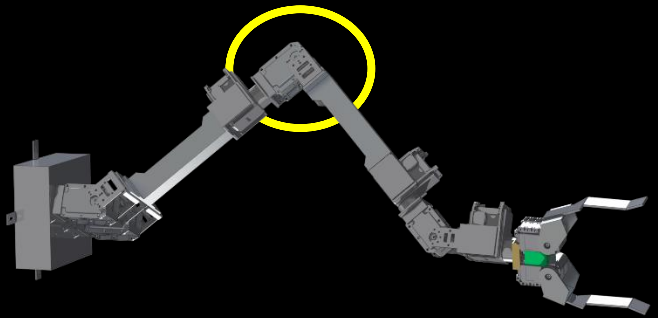
Roll

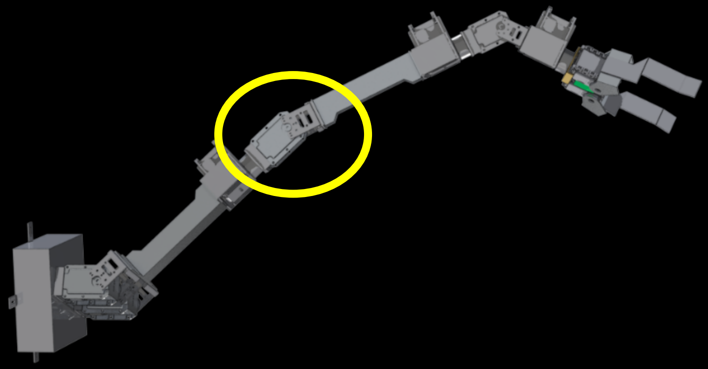






Pitch

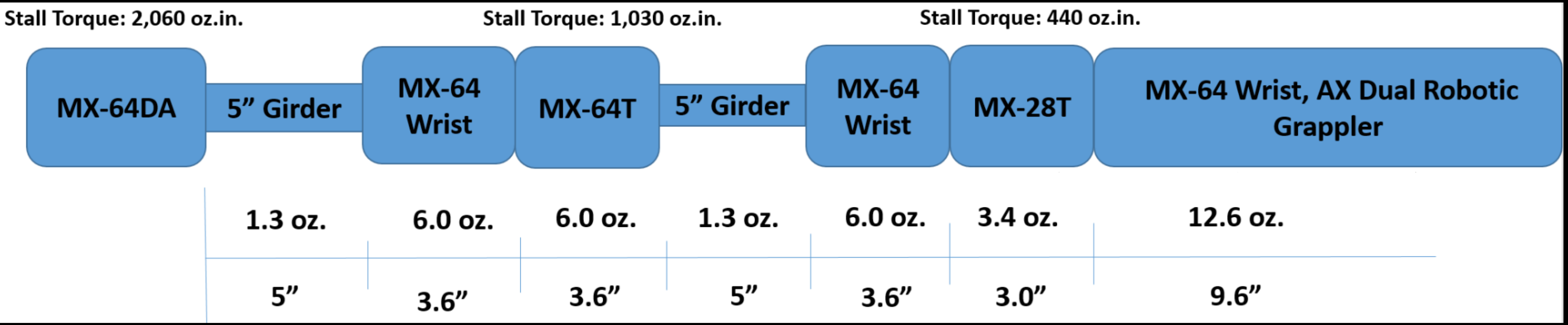




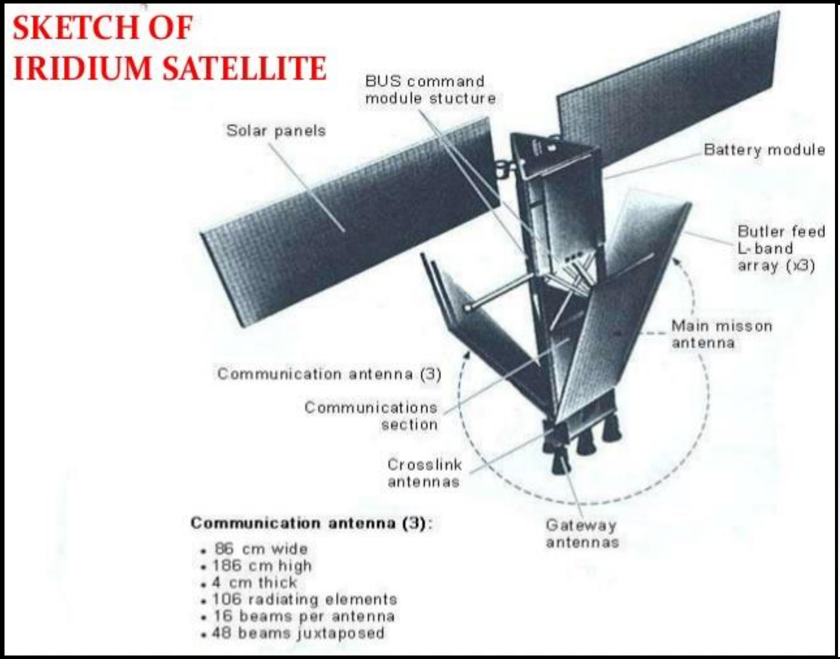
Design & Functionality

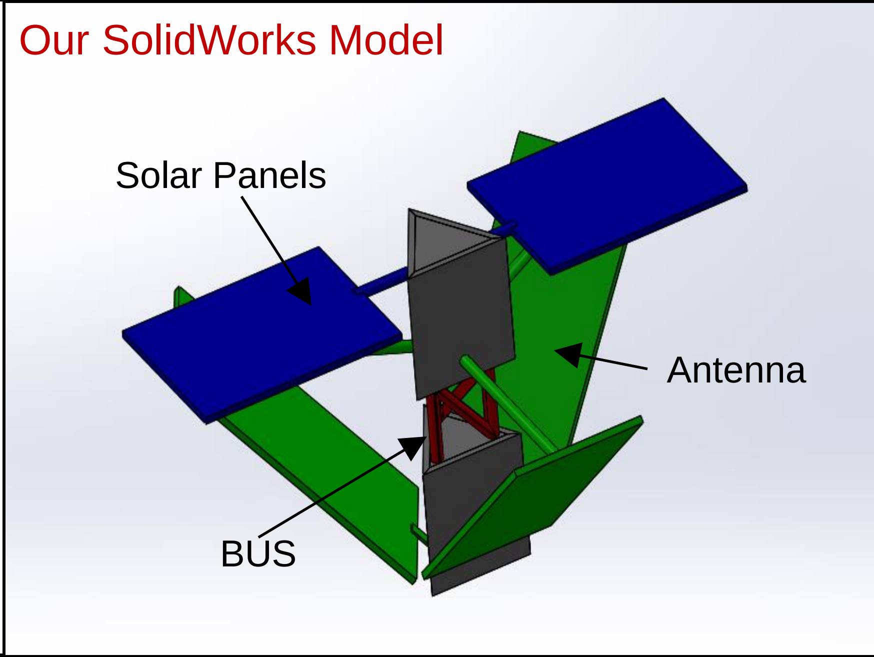
Performance

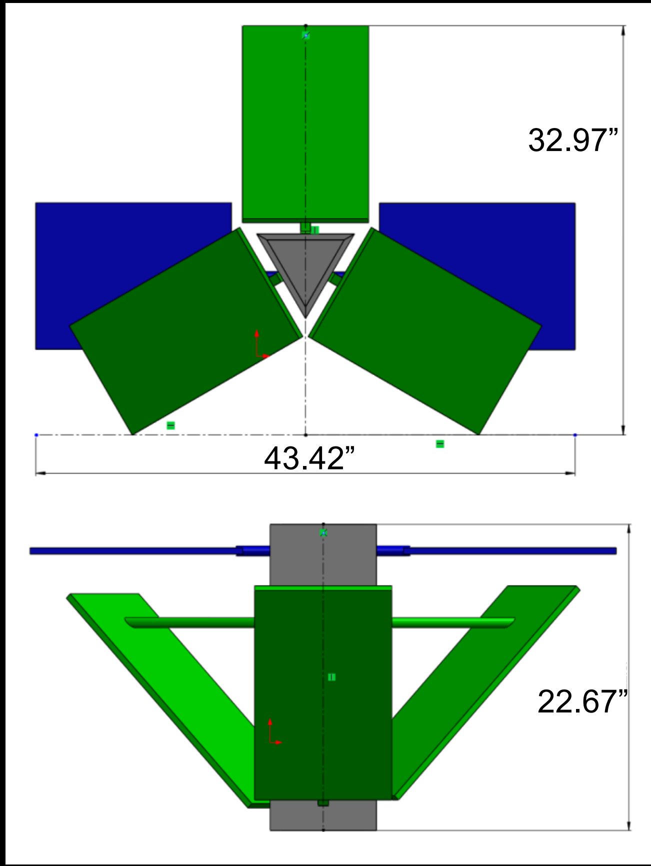
Actuator	Stall Torque (oz.in.)	Torque Experienced (oz.in.)	Factor of Safety (FOS)
MX-64 DA	2,060	1,200	1.7
MX-64T	1,030	500	2
MX-28T	440	120	3.6



Design & Functionality





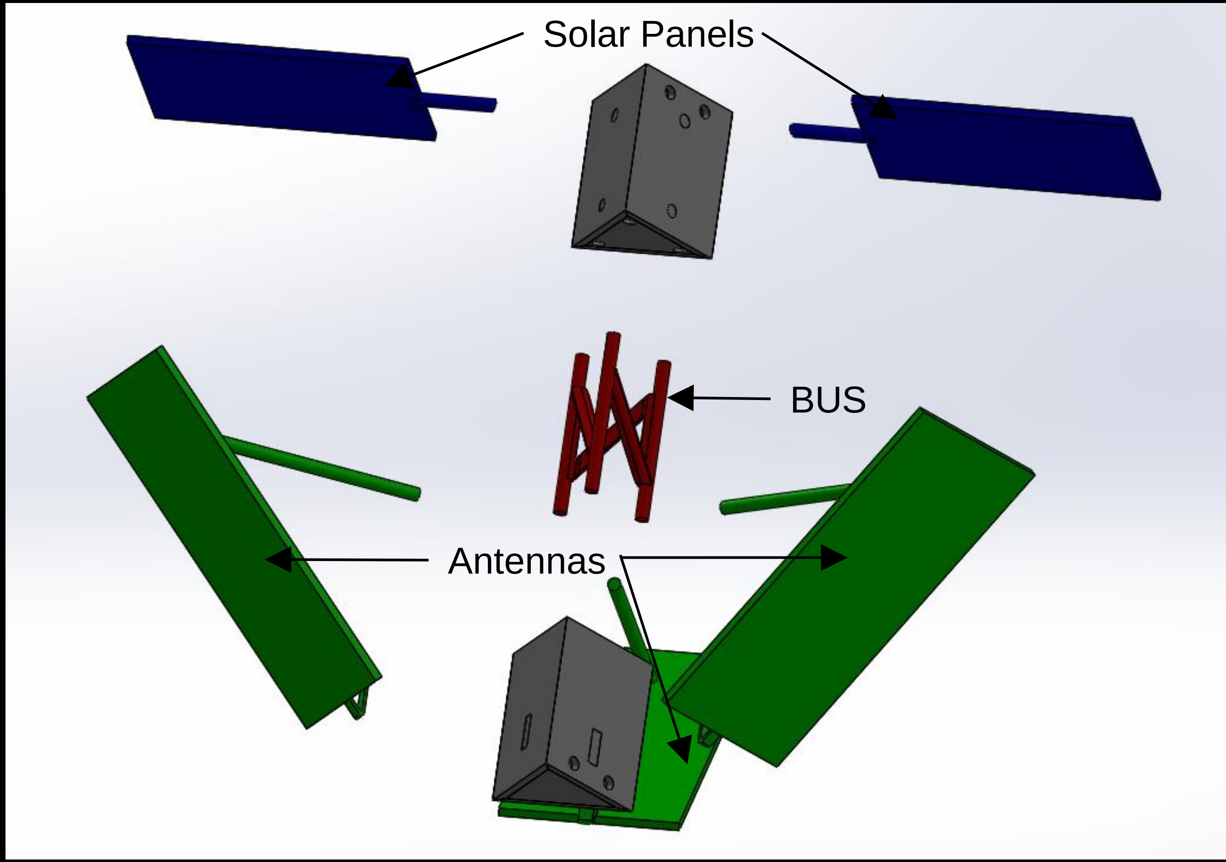


Sample Diagram of the Iridium Satellite compared to Renderings of the Iridium Satellite

Project Purpose | Proposed Design | Critical Project Elements | **Design Reqs.** | Risks & Mitigation | Ver. & Val. | Organization

Design & Functionality

- Features Included:
  - Solar Panels
  - Primary Antennas
  - BUS Structure
  - Slots for Stand Rods
- Features Omitted:
  - Secondary Antennas
  - Battery Modules
- Design Changes
  - Shorter Overall Length
  - Larger Antenna Angle



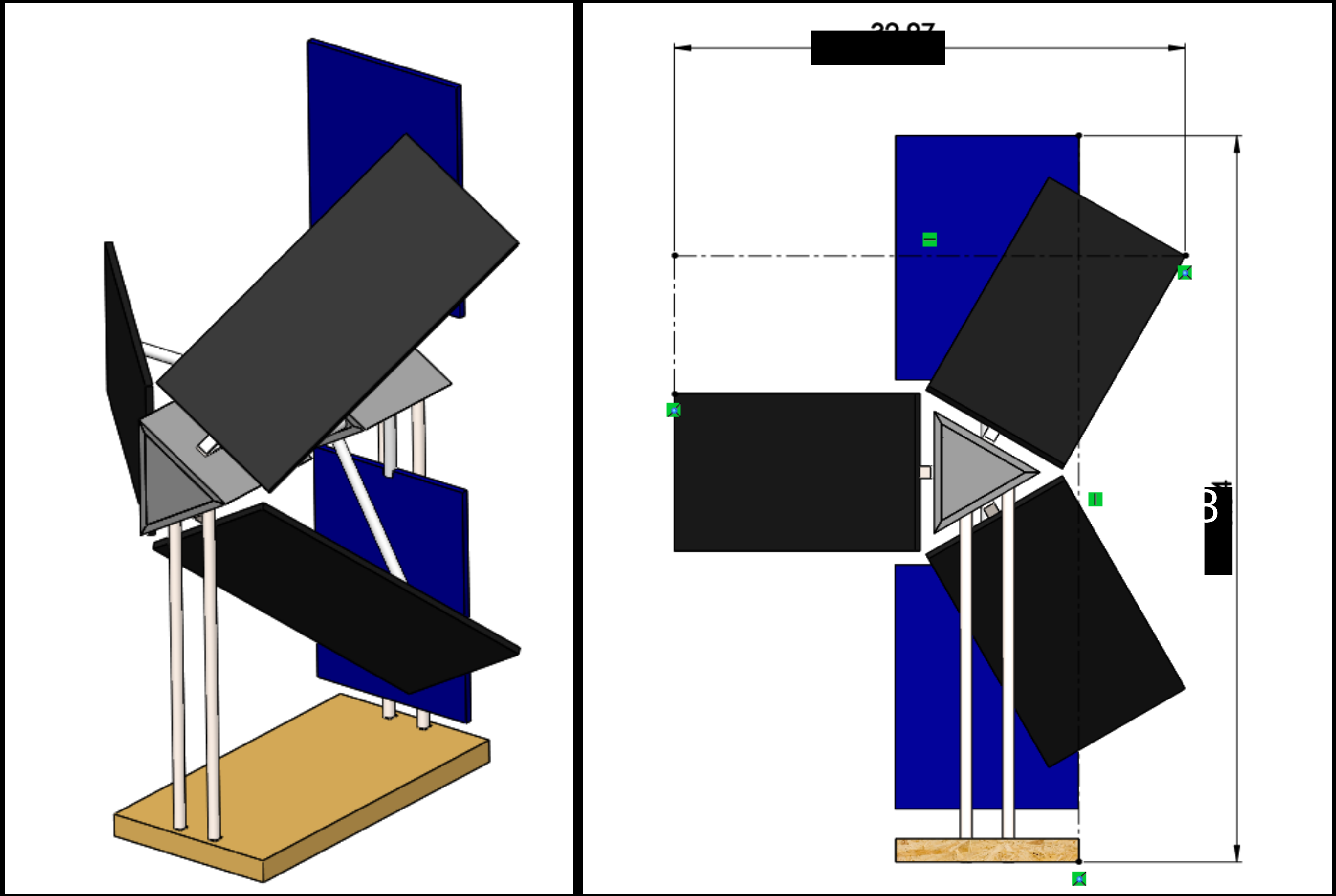
D3.2	The grappling features shall be representative of features on the Iridium Satellite form factor

Design & Functionality

- Driving Dimensions
  - Width and Length driven by satellite scale
  - Height allows for clearance of the Solar Panels

- Angled at 30 Degrees
  - Low angle variation of the arm
  - Minimum volume requirement

Iridium Satellite on Test Stand



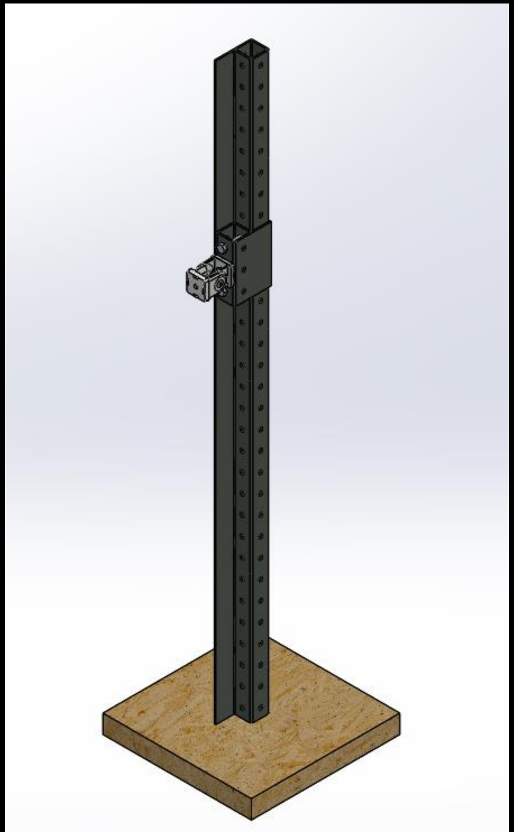
Design & Functionality

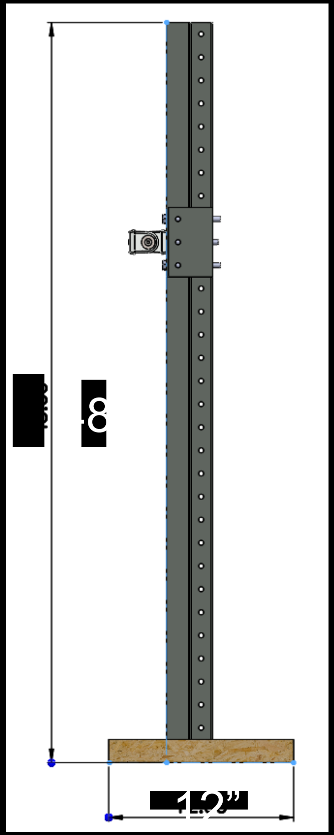
- Adjustable Railing
  - Allows for variety of approaches

- Locking Pivot Mount
  - Set an approach angle
  - Allen Key to secure

- Mobile Base
  - Capable of repositioning for each feature

Robotic Arm Support Equipment





Inter-CPE Design Requirements

Christopher Choate (Manufacturing Lead)

Project Purpose | Proposed Design | Critical Project Elements | **Design Reqs.** | Risks & Mitigation | Ver. & Val. | Organization

Design & Functionality

D4.1	KESSLER shall have an individual operation time duration of 17 ± 2 minutes.

- Timing analysis factors:
  - Visual Processing (VP) – image capture, image analysis, data transfer to ROS (CTRL)
  - Controls (CTRL) – data transfer from ROS (VP), path planning, data transfer to ROS (RA)
  - Robotic Arm (RA) – data transfer from ROS (CTRL)

Current modeling & analysis indicate operation time will be below 4 min.

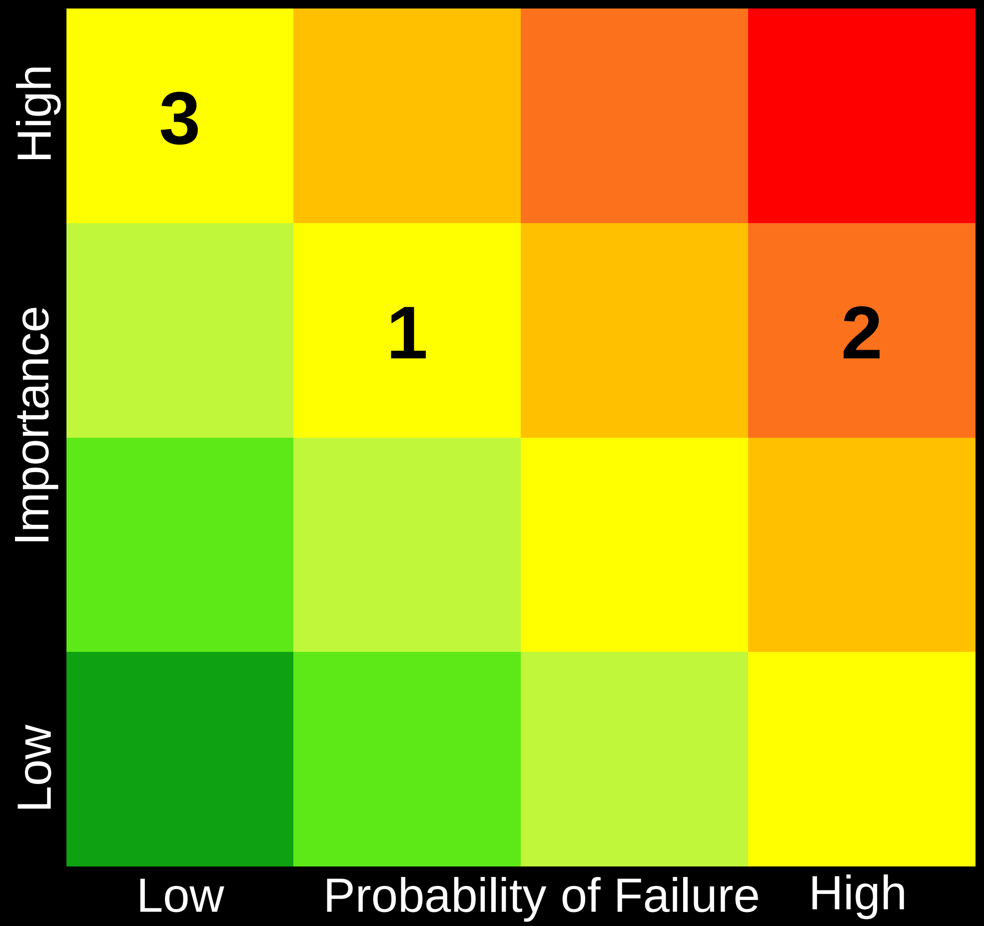
- Primary unknown at CDR – ROS Data Handling (low risk)

Remaining Risks & Mitigation

Christopher Choate (Manufacturing Lead)

Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization

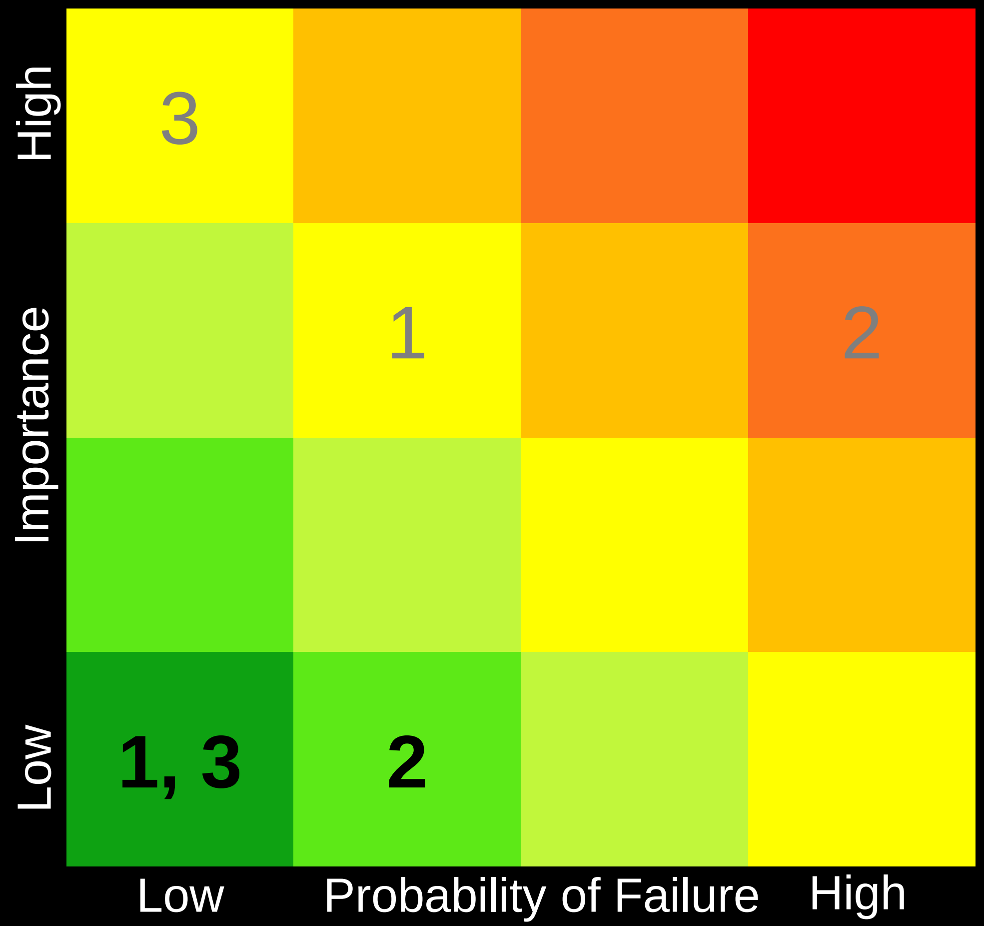
CPE 1: Risks & Mitigation



Visual Processing Risks

1. Algorithm Timing
   - Run-time increases as database size increases.
2. Image Database
   - Feature may not be found in database
3. Integration with Control Software
   - MATLAB ROS interface

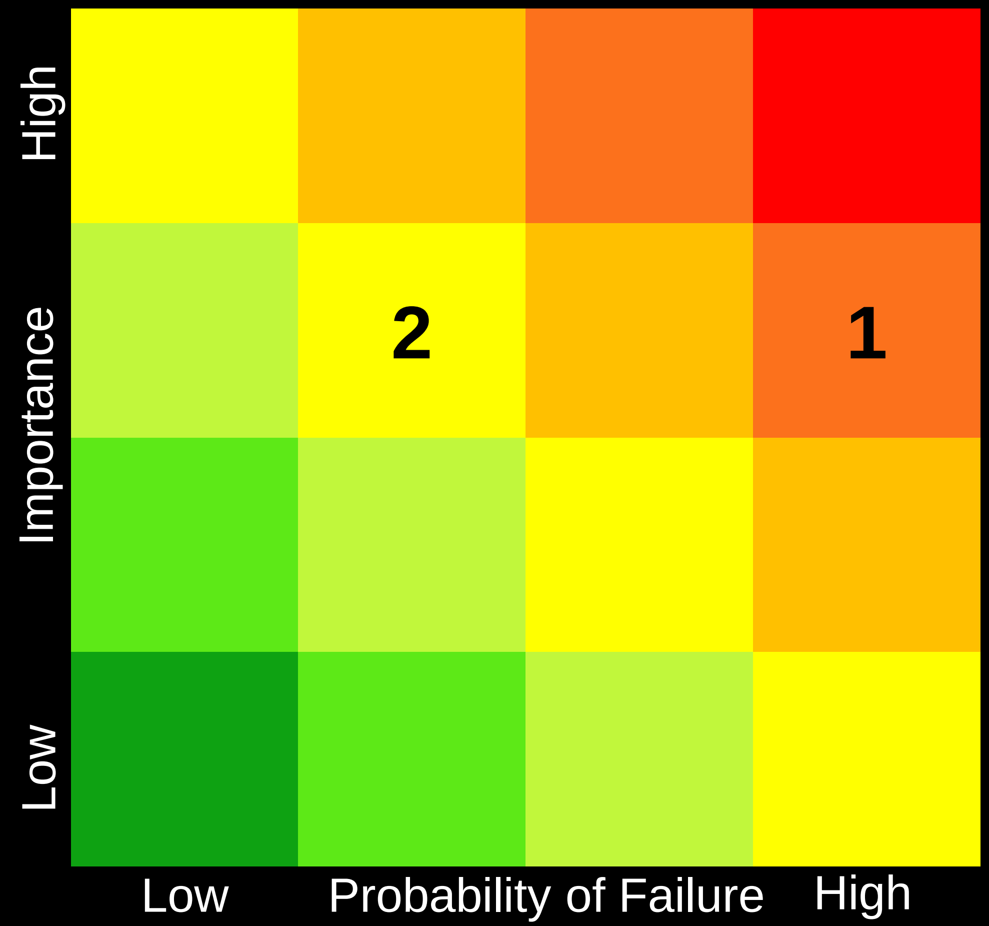
CPE 1: Risks & Mitigation



Visual Processing Mitigation

1. Algorithm Timing
   - Pre-processed data matching is faster
   - Optimized search algorithm
2. Image Database
   - Backup algorithm
3. Integration with Control Software
   - MATLAB has a toolbox for ROS integration

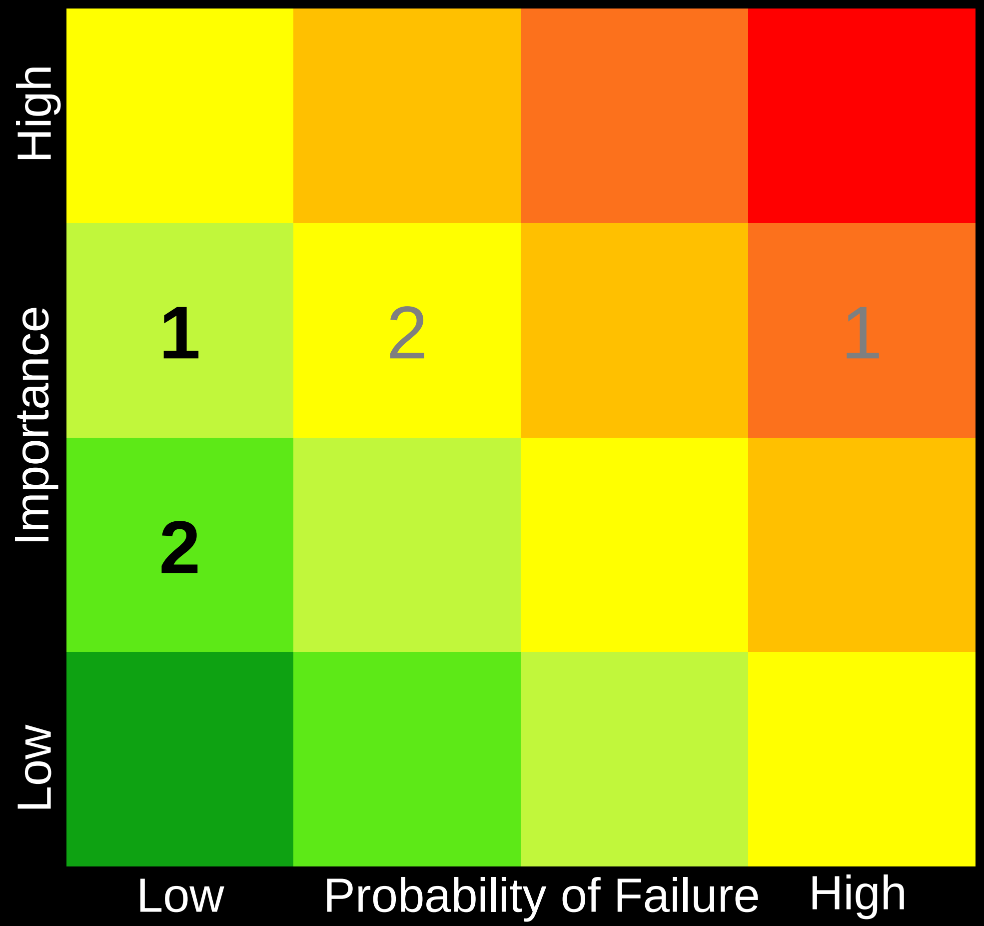
CPE 2: Risks & Mitigation



Controls Risks

1. Singularity
   - Taking inverse of Jacobian with 0 values
   - Matrix singularities cause velocities to go to infinity
   - Velocity caps
2. Communications
   - Serial packet drops.

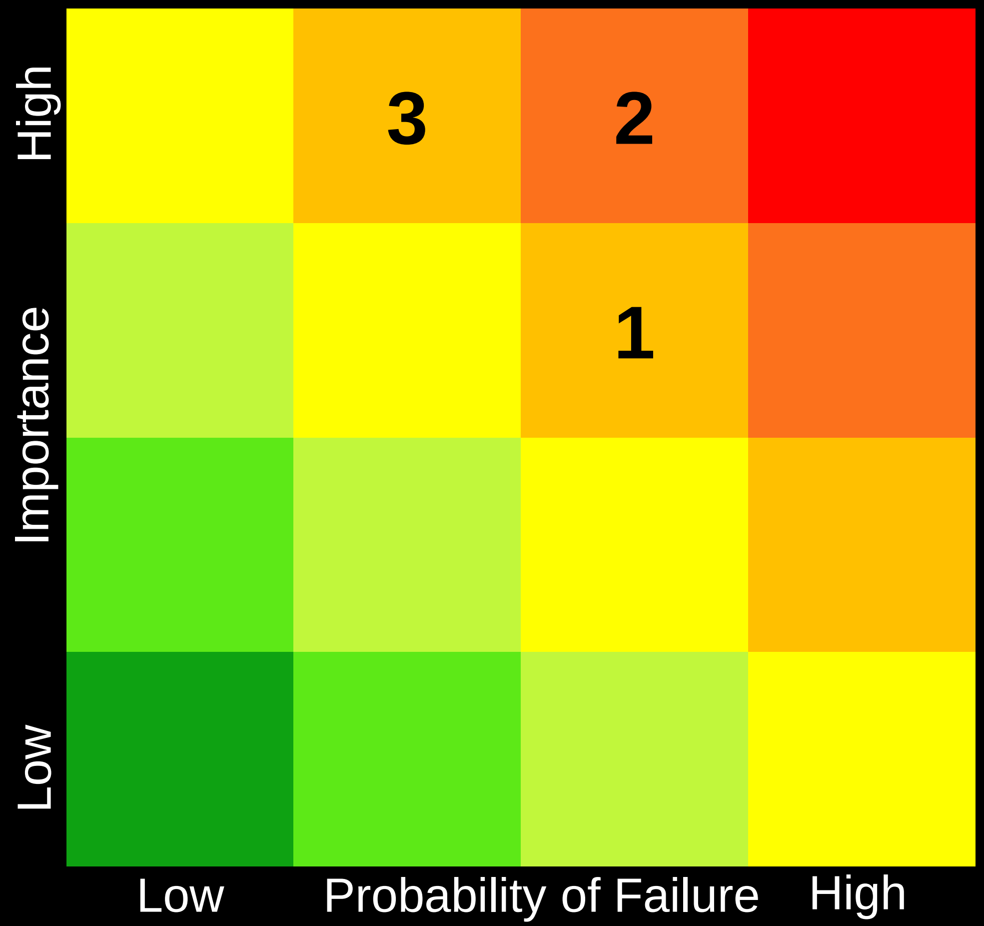
CPE 2: Risks & Mitigation



Controls Mitigation

1. Singularity
   - Models predict path validity
     - Simulate problem before actuating
     - If it fails, choose a different path
2. Communications
   - Move slowly so that missed packets do not result in much drift
     - At 10 in/s, minimum update rate is 50 Hz
     - At lower velocities (expected) same update rate gives higher resolution
   - Have update rates faster than this minimum

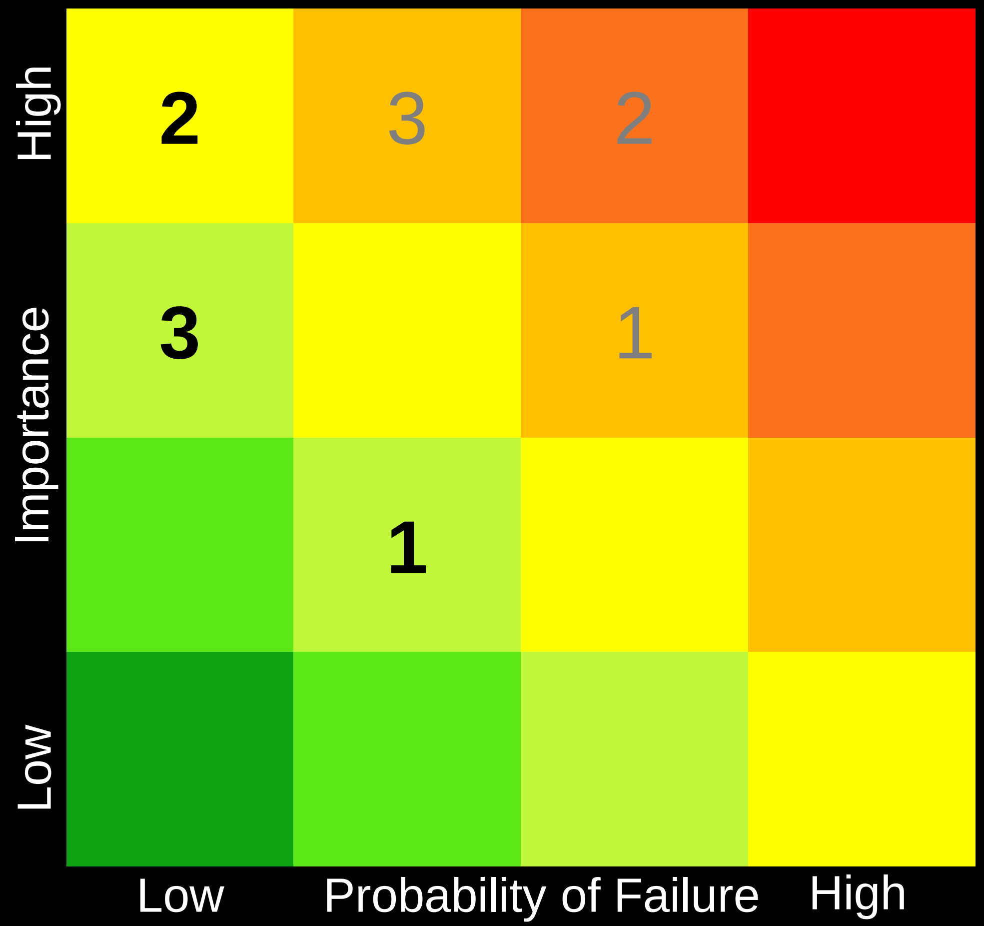
CPE 3: Risks & Mitigation



Robotic Arm Risks

1. Physical integration errors
   - Discrepancy between physical and control model
2. Tolerance stack-up
   - Due to potential CAD error
   - Result in end-effector positioning error
3. Hardware lifetime
   - Heritage hardware may approach age limits.

CPE 3: Risks & Mitigation



Robotic Arm Mitigation

1. Physical integration errors
   - System Integration Procedures
   - Presence of Test & Safety Lead
   - Update control model to match physical
2. Tolerance stack-up
   - Informal Design/Drawing Reviews
3. Hardware lifetime
   - Quality assurance inspection of hardware

Verification & Validation of Design

Sergey Derevyanko (Test and Safety Lead)

Verification & Validation

Test Facilities

- Absolute Position Determination System: KESSLER is designing a system which can be used accurately and precisely measure the position of certain points on the arm and test object. Test can be conducted anywhere with 23” X 33” X 44” of open space.
- Contacted VICON Laboratory, KESSLER will be able to use their facilities if KESSLER system is unsatisfactory.

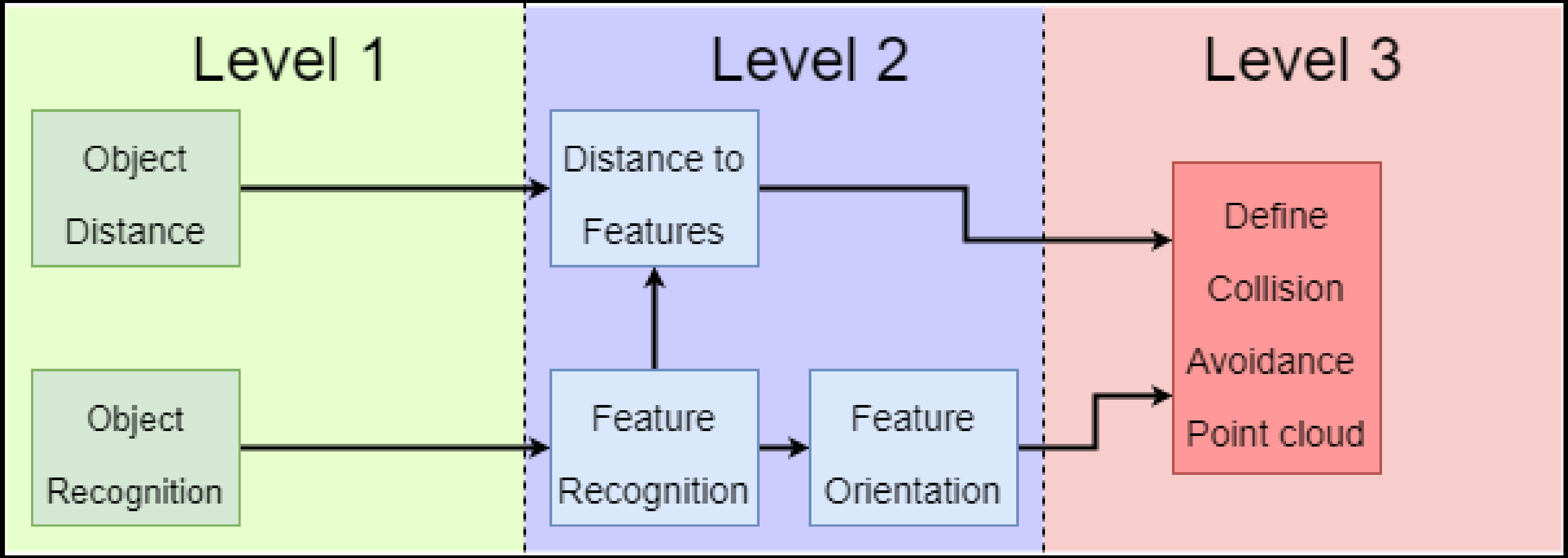
Verification & Validation

Hardware Verification

- Actuator Spec Torque Analysis: insure that the torque output versus the input voltage is consistent with the design specification.
- Actuator Stall Torque Analysis: Verify at what torque the motor stalls. This test will be scaled, so as not to actually stall the motor.

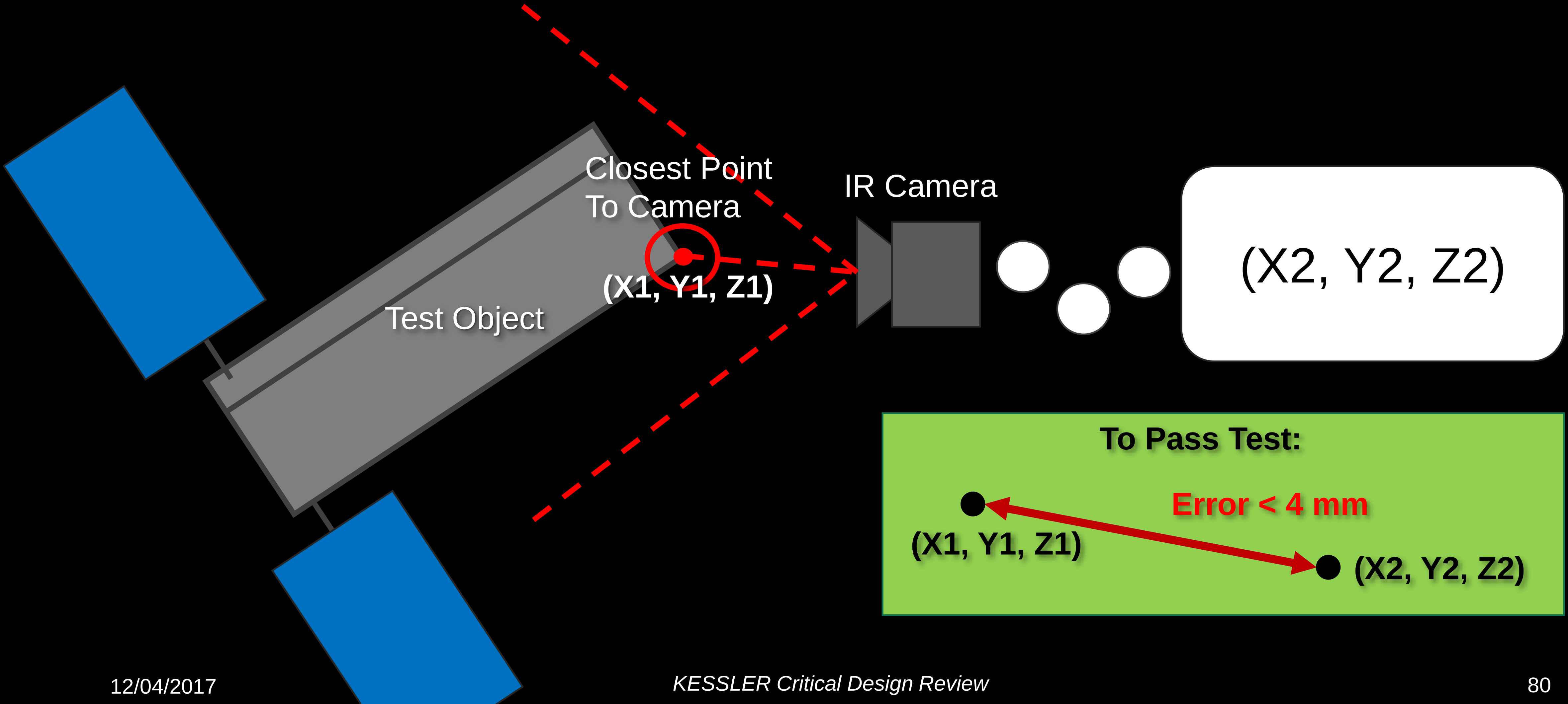
Verification & Validation

Visual Processing Test Plan Overview



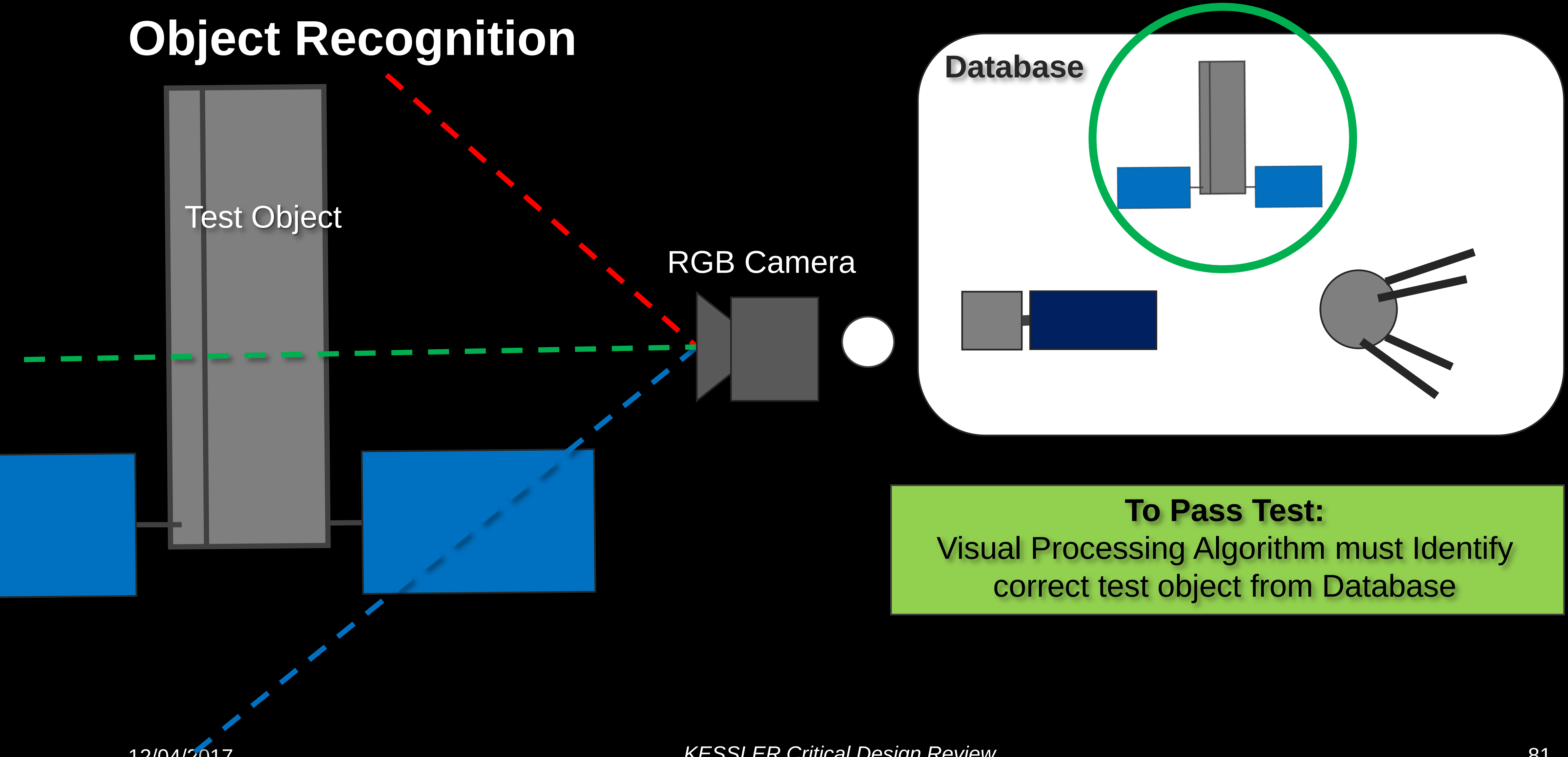
Verification & Validation

Object Distance



Verification & Validation

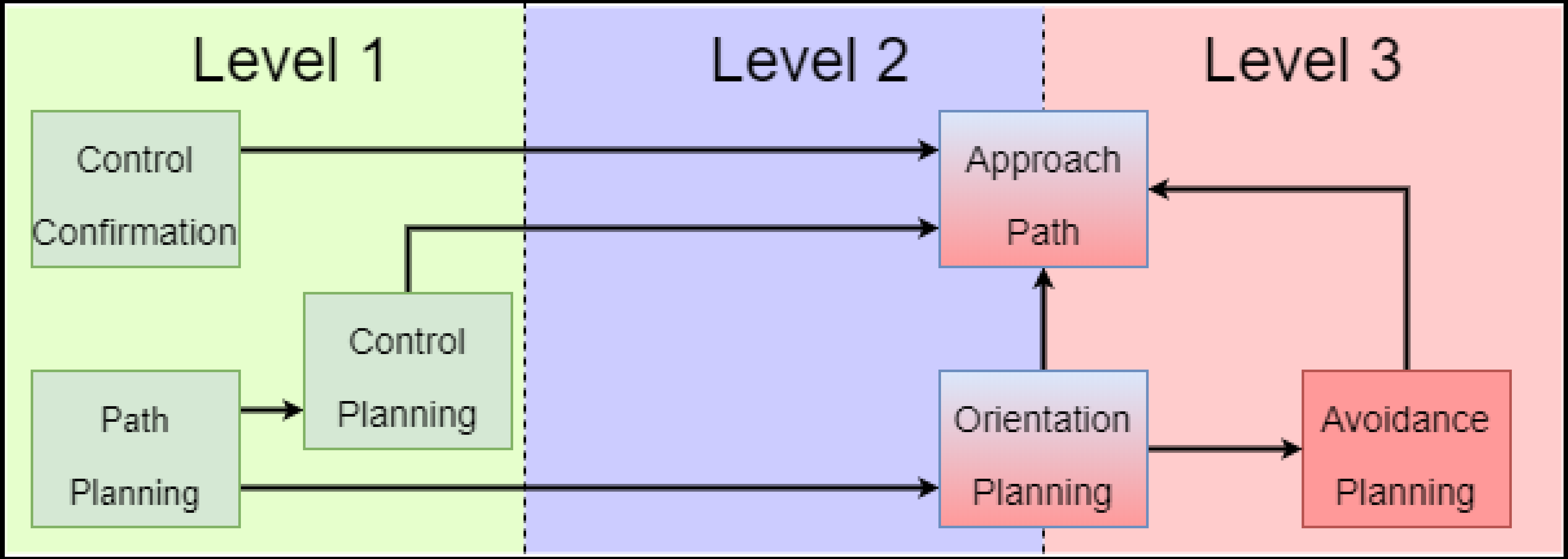
Object Recognition



To Pass Test:
Visual Processing Algorithm must Identify correct test object from Database

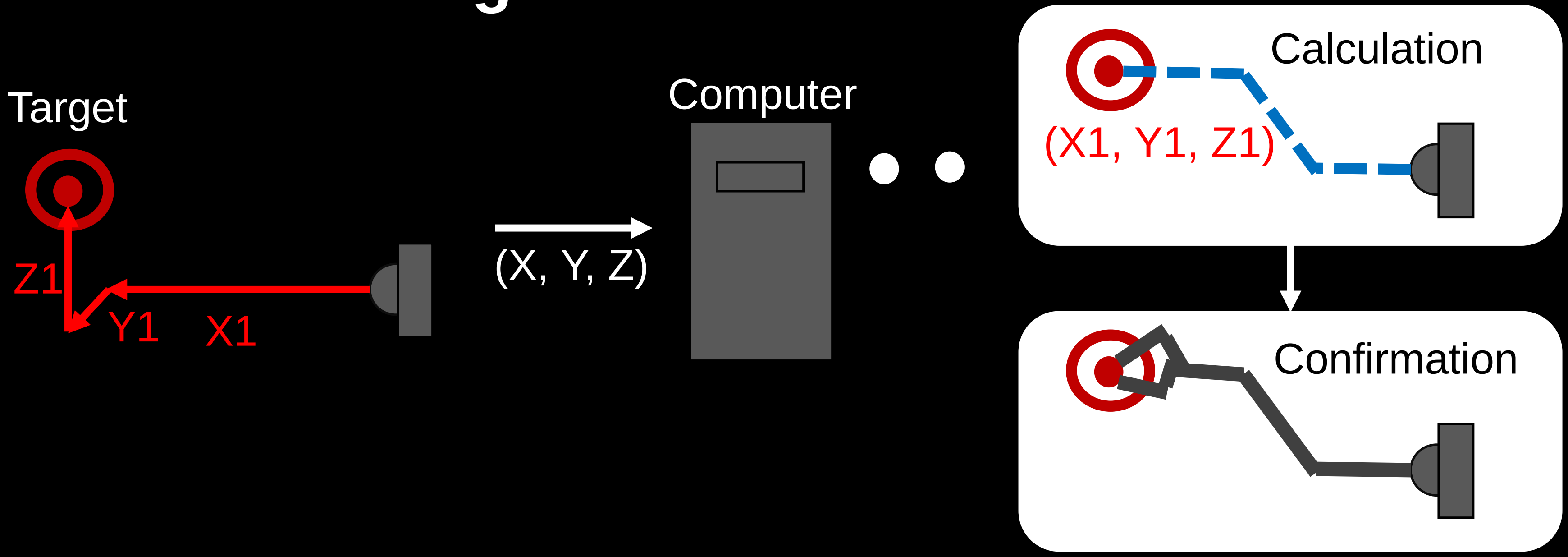
Verification & Validation

Controls Test Plan Overview



Verification & Validation

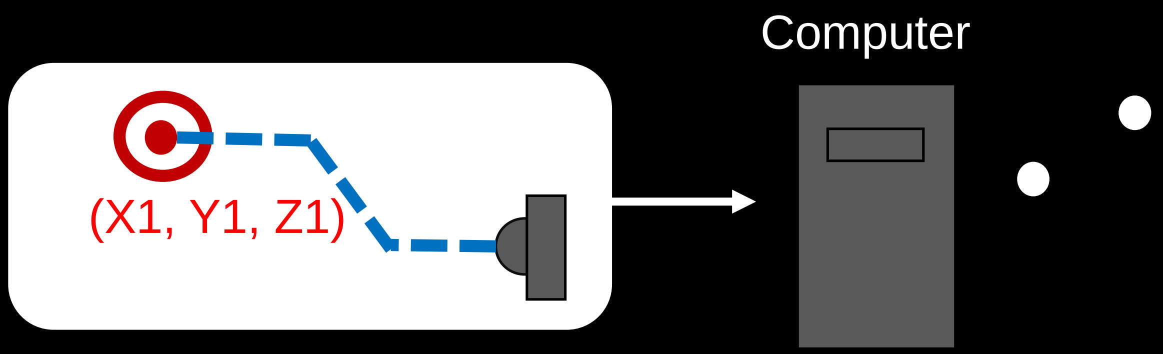
Path Planning

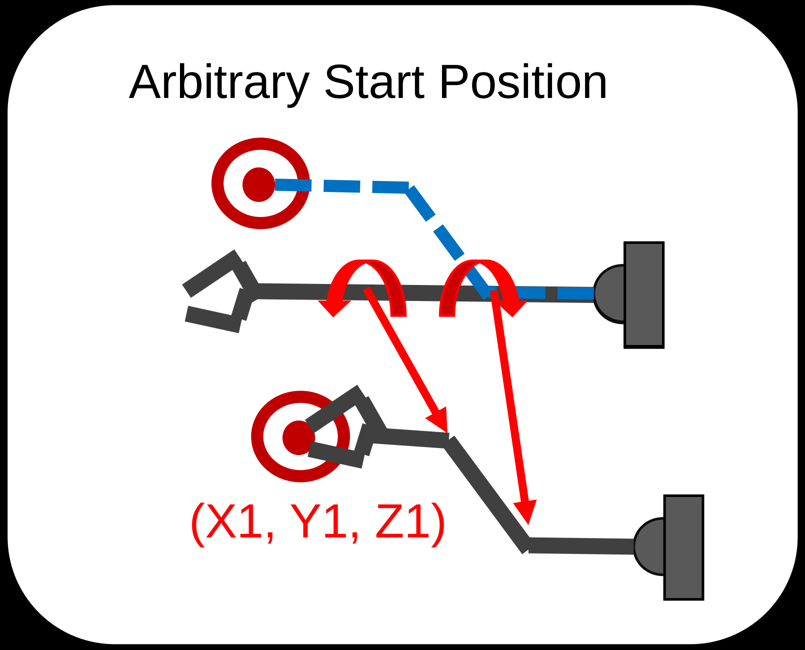


To Pass Test:
Final pose calculated should be achievable by the physical arm. The angles should be achievable, and the arm should not collide with itself.

Verification & Validation

Control Planning

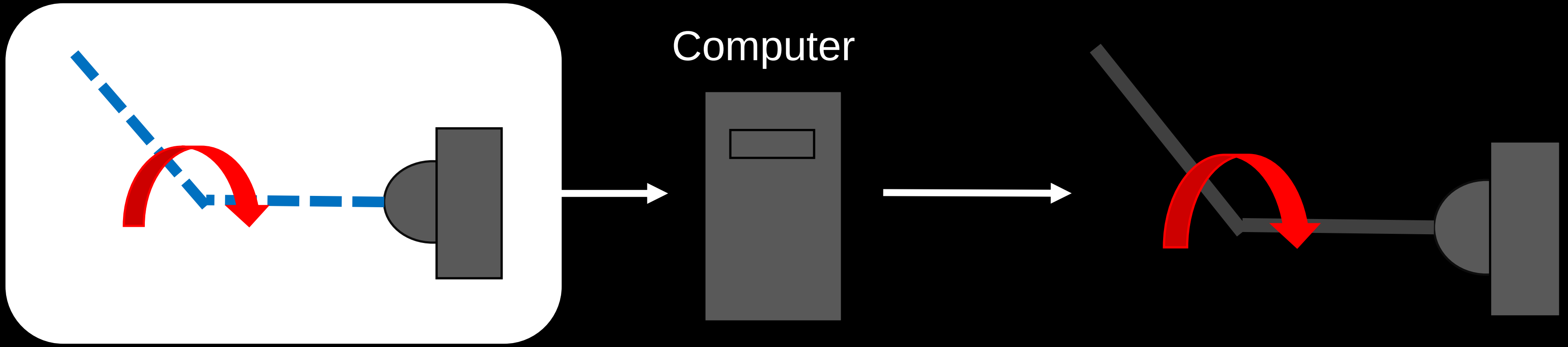




To Pass Test:
The control algorithm must generate a series of commands that can get the arm to the end pose from any starting pose that is valid.

Verification & Validation

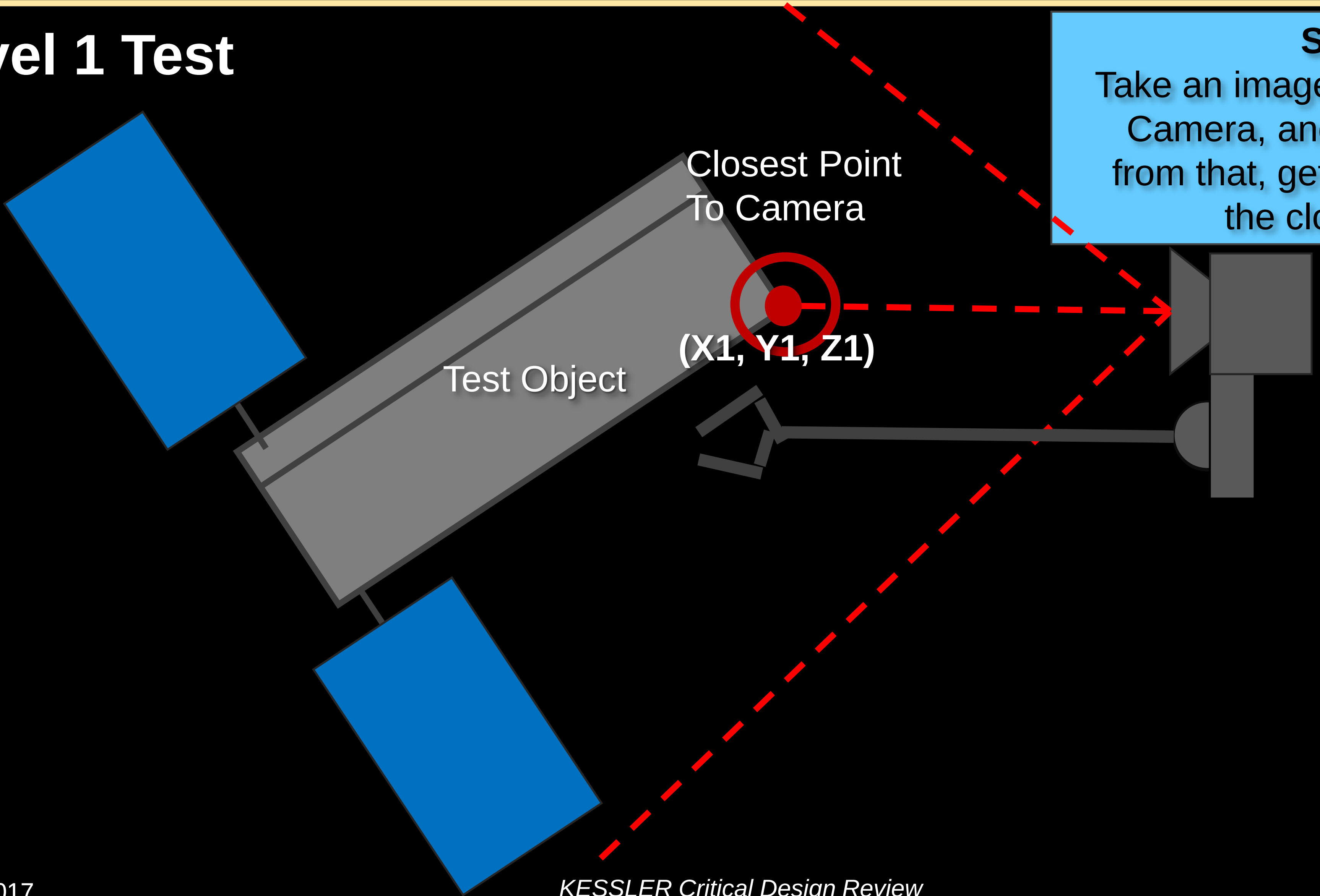
Control Actuation



To Pass Test:
Command algorithm will be able send commands to physically manipulate the arm.

Verification & Validation

Level 1 Test

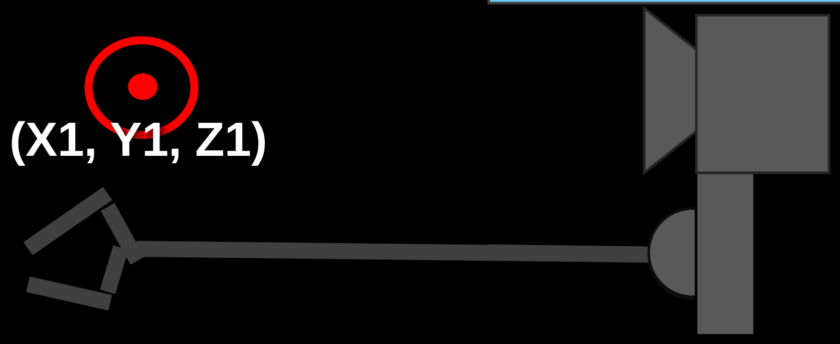


Step 1:
Take an image with the Kinect IR Camera, and get the position from that, get the coordinate of the closest point.

Verification & Validation

Level 1 Test

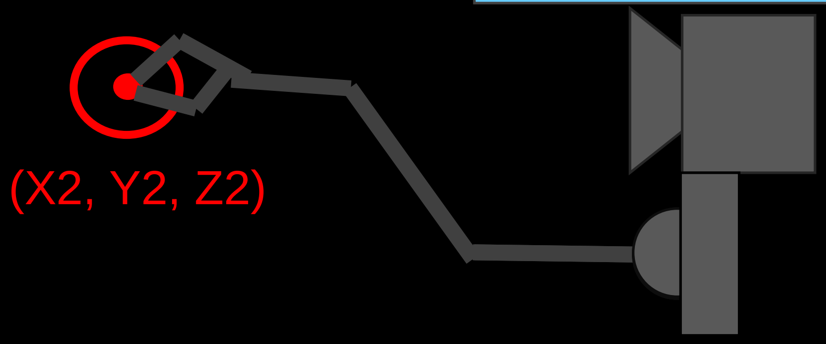
Step 2:
Remove the test object, after the target position has been saved by the program.



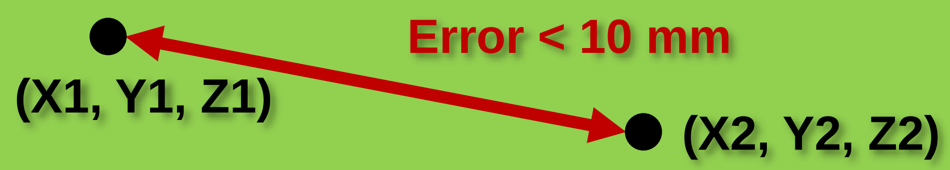
Verification & Validation

Level 1 Test

Step 3:
Have the control algorithm move the end effector to the saved position and close the claw.



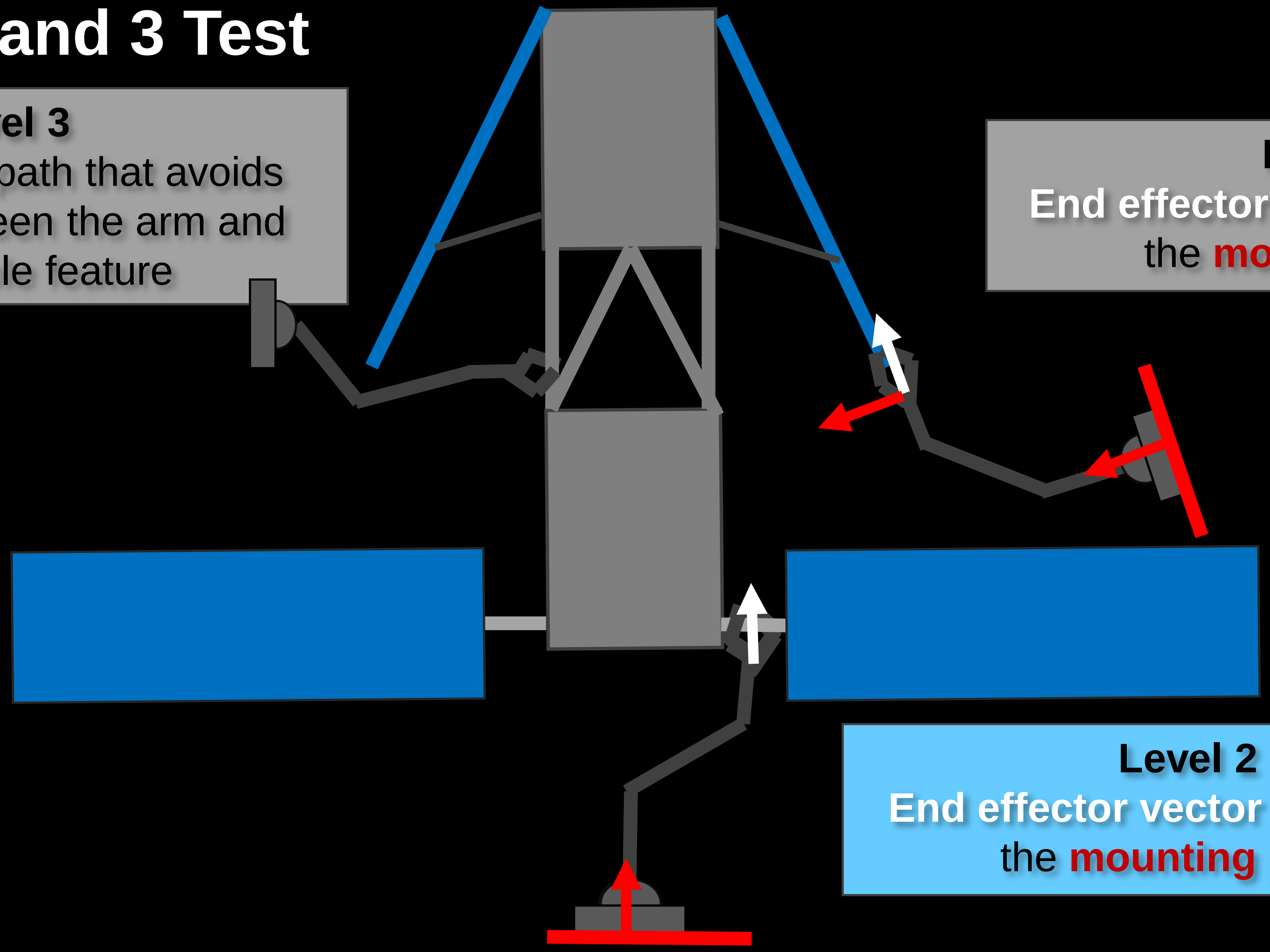
To Pass Test:



Verification & Validation

Level 2 and 3 Test

Level 3
Arm can plot a path that avoids obstacles between the arm and the grapple feature



Level 3
End effector vector is parallel to the **mounting plane**

Level 2
End effector vector is normal to the **mounting plane**

Organization & Remaining Work

Sergey Derevyanko (Test & Safety Lead)

Team Organization

KESSLER

Customer
Sierra Nevada Corporation – Joshua Stamps

Advisor
Dr. Jade Morton

Project Manager
Glenda Alvarenga

Systems Engineer
Jannine Vela

Test & Safety
Sergey Derevyanko

Financial
Taylor Way

Manufacturing
Christopher Choate

Mechanical
Abdiel Agramonte-Moreno

Electrical
Lauren Darling

Visual Processing
Cassidy Hawthorne

Controls
Nicholas Thurmes

Software I&T
Abigail Johnson

Hardware I&T
Thanh Cong Bui

Work Breakdown Structure

Course Deliverables
- CDR
- FFR
- MSR
- TRR
- AIAA Paper
- SFR
- PFR

Management
- Schedule
- WBS
- Budget
- Risk Matrix
- Expenditure Plan

Systems Engineering
- Objective Definition
- Req. Verification Matrix
- Concept of Operations
- Functional Block Diagram
- Interface Control

Integration & Test
- Hardware – MGSE Selection
- Hardware – Test Facility Reqs.
- Hardware – EGSE Selection
- Command & Data Handling
- Software Integration (VP & Ctrl)

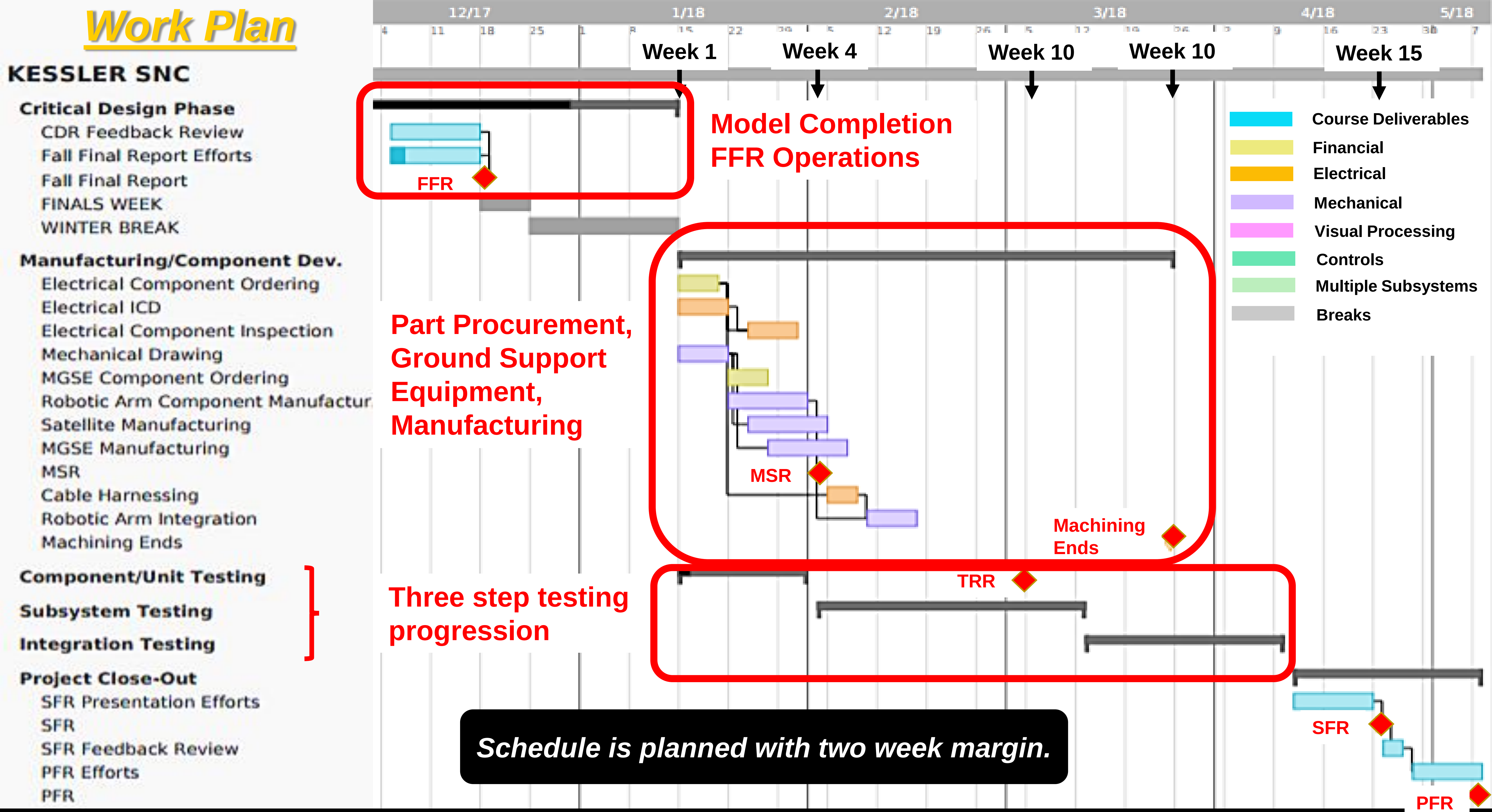
Visual Processing
- Sensor Selection
- Electrical Interface
- Object Detection
- Object Identification
- Object Classification

Controls
- Workspace Analysis
- Control Loop Simulation
- Command & Data Handling Arch.
- Path Planning
- Actuator Control

Mechanical
- Robotic Arm MGSE
- Mock Satellite MGSE
- Manufacturing
- Electrical Harness

CDR Status
- Complete
- Incomplete

Work Plan



Schedule is planned with two week margin.

Cost Plan

Subsystem	Cost
Visual Processing	$516.00
Mechanical	$757.00
Software Control	$0.00
Ground & Test Support	$675.00
Electrical	$670
Misc	$0.00
% Margin	15%
Total Projected Cost	$3,010

- Starting Budget: $5,000.00
- Remaining Budget: $1,990
- Heritage hardware saves ~$800.00
- Worst Case estimates
- Percent Margin:
  - Decreased to from 25% to 15%

Test Plan

KESSLER SNC

Critical Design Phase

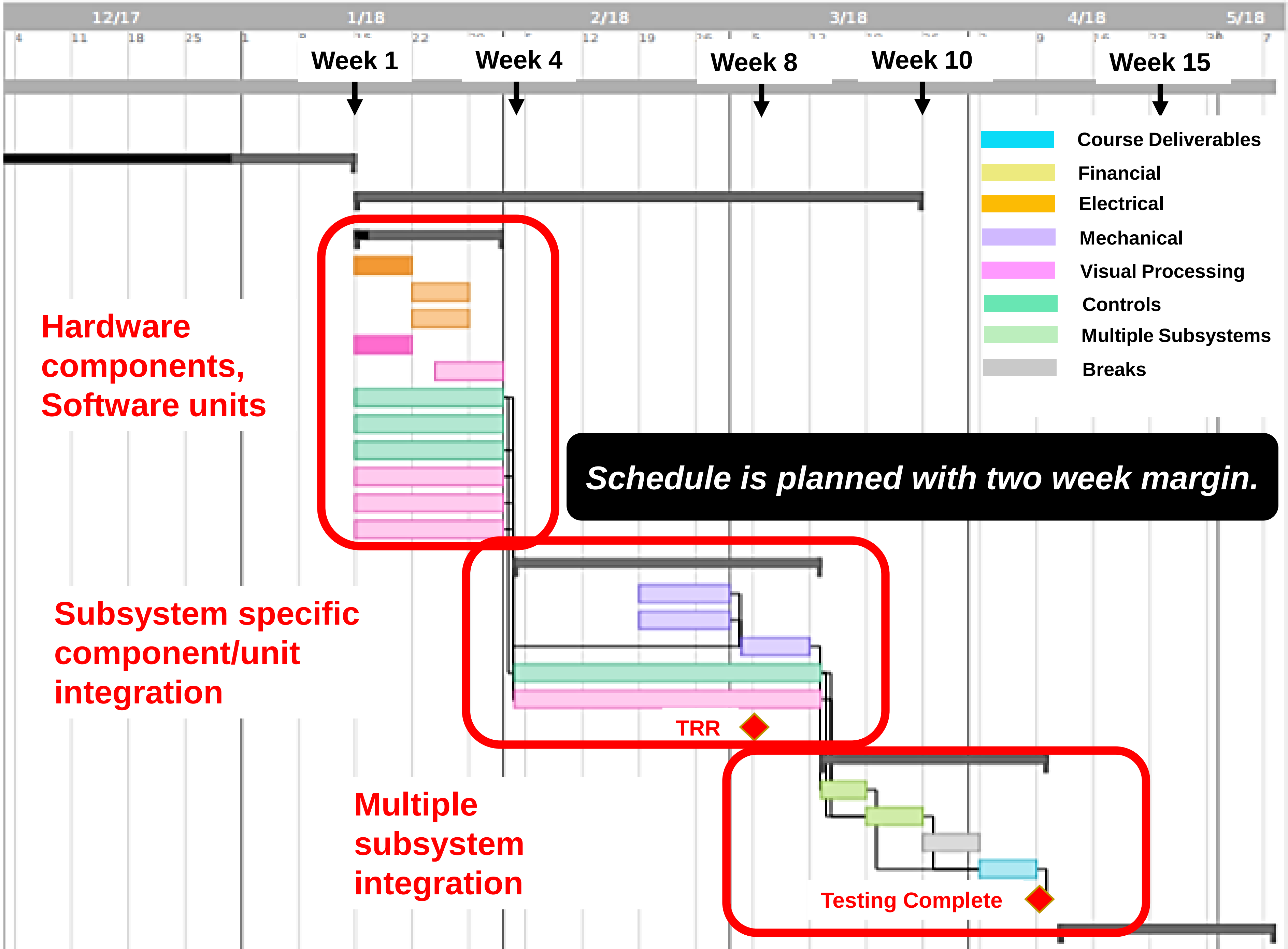
Manufacturing & Component Deve...

Component/Unit Testing
- Motor Aliveness
- Spec Torque Test
- Stall Torque Test
- Kinect Functionality
- Secondary Camera Functionality
- Control Loop
- Path Planning
- ROS Data (ctrl)
- Object Detection
- Objection Location Determination
- ROS Data (visual processing)

Subsystem Testing
- Robotic Arm Spec Torque
- Robotic Arm Stall Torque
- Robotic Arm Plane Sweep
- Unit Integration (ctrl)
- Unit Integration (visual processing)
- TRR

Integration Testing
- CTRL & RA Integration
- VP & CTRL Software Integration
- SPRING BREAK
- Full System Integration
- Testing Complete

Project Close-Out



Thank You!

Questions?

References

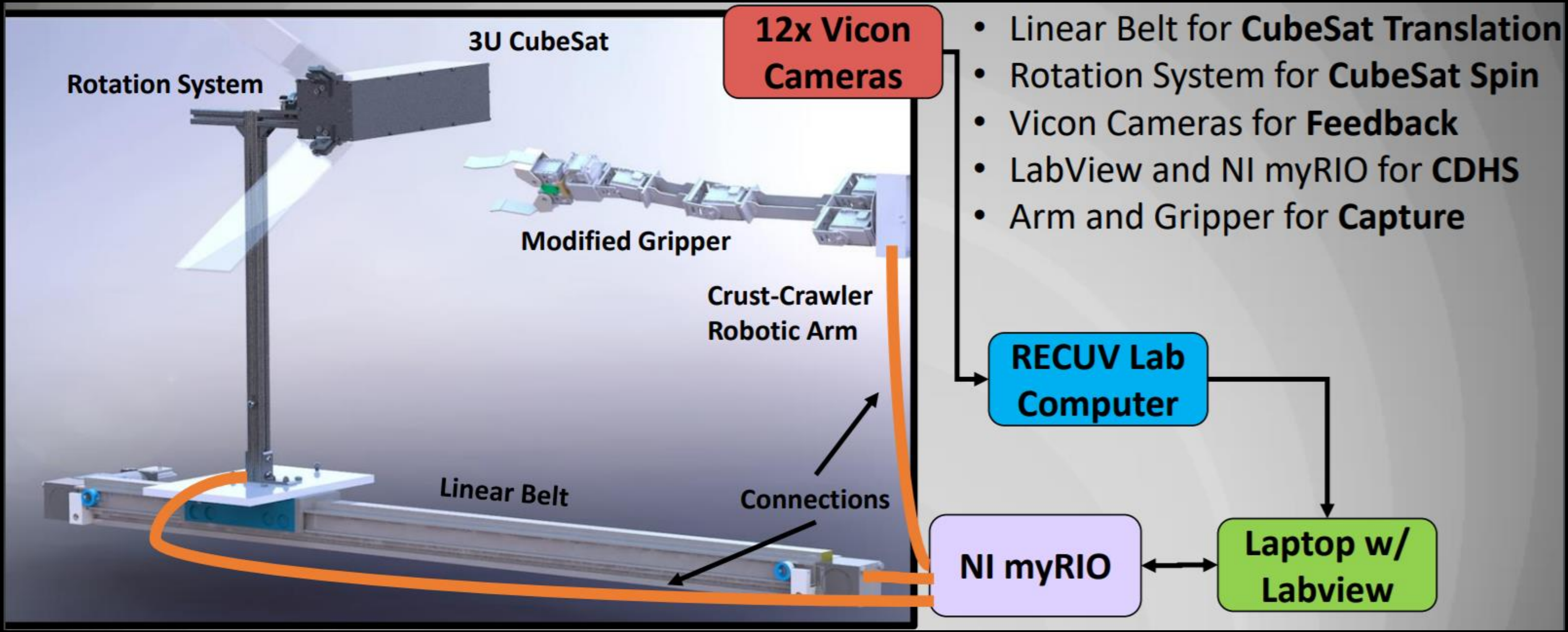
1. https://www.nasa.gov/mission_pages/station/news/orbital_debris.html
2. http://spaceflight101.com/falcon-9-orbcomm-flight2/orbcomm-g2-satellites-finish-in-orbit-checkouts-adjust-orbital-positions/
3. http://seradata.com/SSI/wp-content/uploads/2013/10/iridiumoriginal.jpg
4. http://geo.tuwien.ac.at/opals/html/ref_odm.html
5. http://www.crustcrawler.com/
6. http://pointclouds.org/documentation/tutorials/kdtree_search.php
7. http://msl.cs.uiuc.edu/rrt/
8. https://www.mathworks.com/products/computer-vision.html
9. https://developer.microsoft.com/en-us/windows/kinect/develop

Back-Up Charts

Sec 1: Back-Up

Project Definition

CASCADE Overview



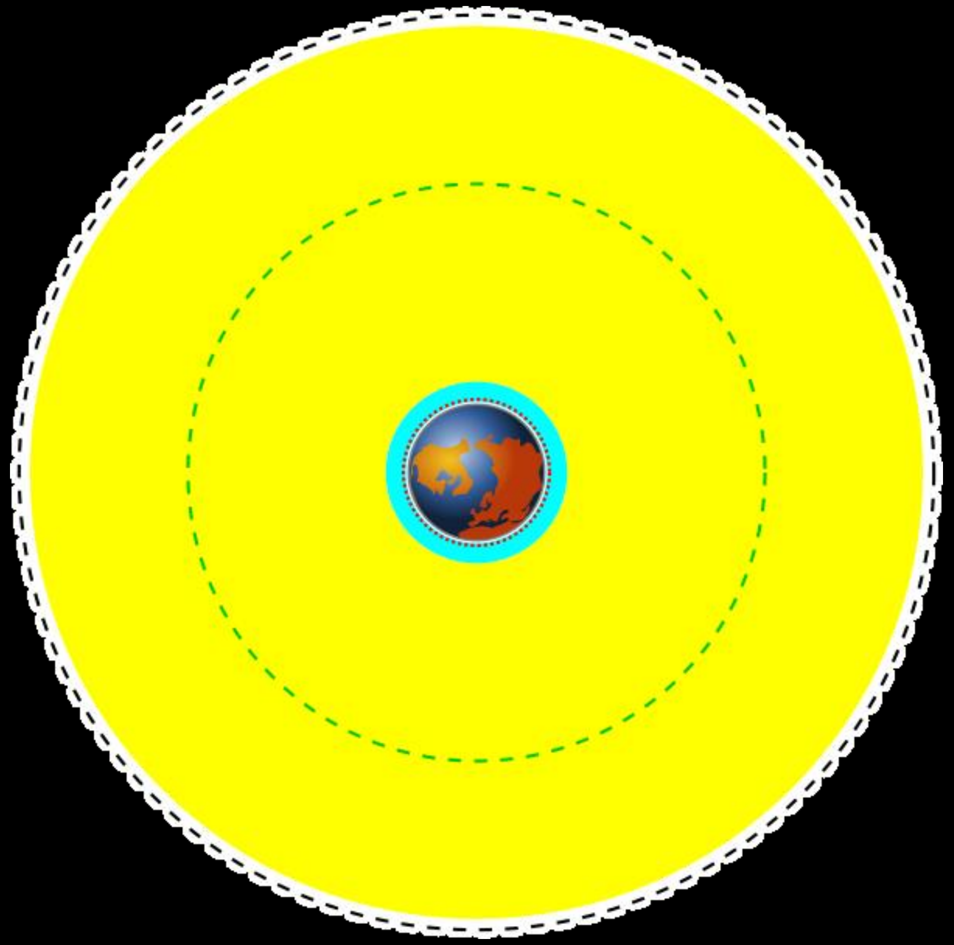
Project Definition

Project Assumptions

- Target object is in-front & within reach of the robotic arm; this entails that this scenario is valid if the target object and the chase vehicle are in the space orbit and in proximity to each other.
- Target object is stationary wrt the chase vehicle; this entails that this scenario is valid if the target object is 3-axis stabilized (or the chase vehicle has matched rotation at one axis if 2-axis stabilized)
- Chase vehicle operations (target and capture) occurs during Sun-soak in LEO

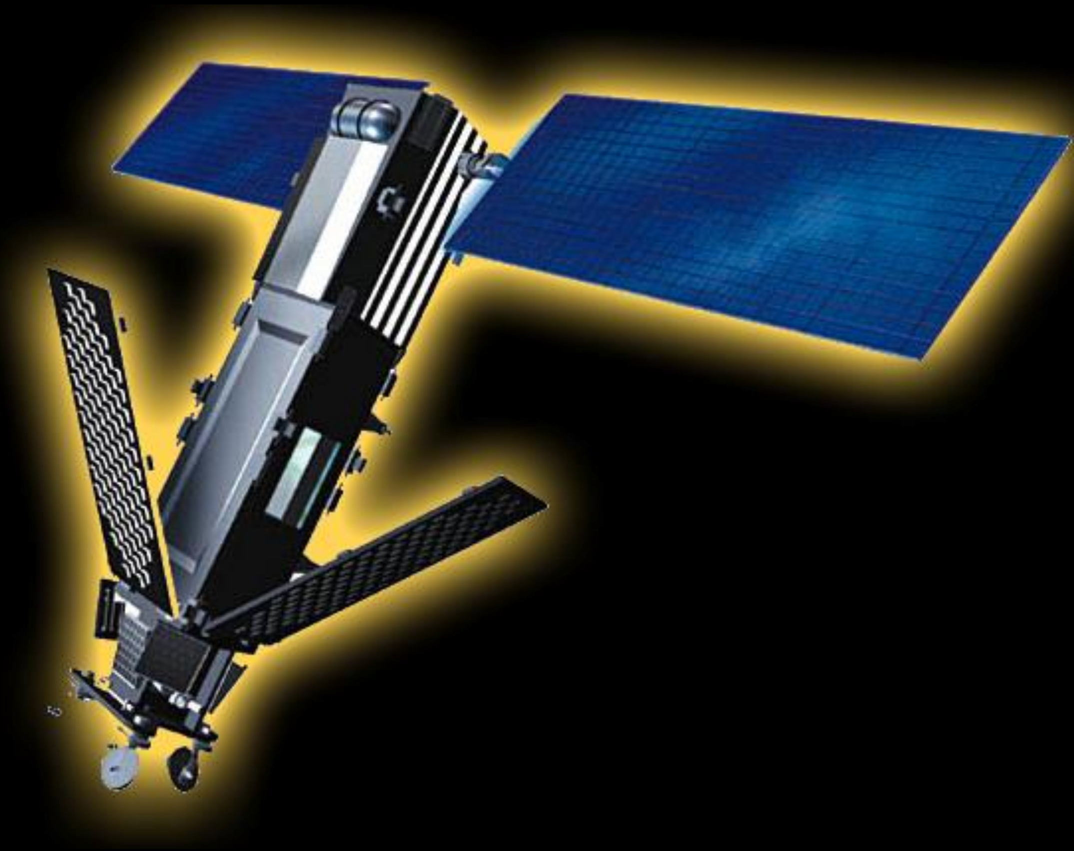
Baseline Design

- There are 1459 active satellites in orbit around the Earth
  - 804 satellites in Low Earth Orbit (150-2000 km)
  - 96 satellites in Medium Earth Orbit (2000-35785 km)
  - 518 satellites in Geosynchronous Earth Orbit (>35785km)
  - 41 satellites in Eccentric Orbits
- Of the 804 satellites in Low Earth Orbit, the most common series are:
  - The **Iridium series** with 67 Satellites
  - The ORBCOMM FM series with 40 satellites
  - The Yaogan series with 36 satellites
  - The Rodnik series with 21 satellites



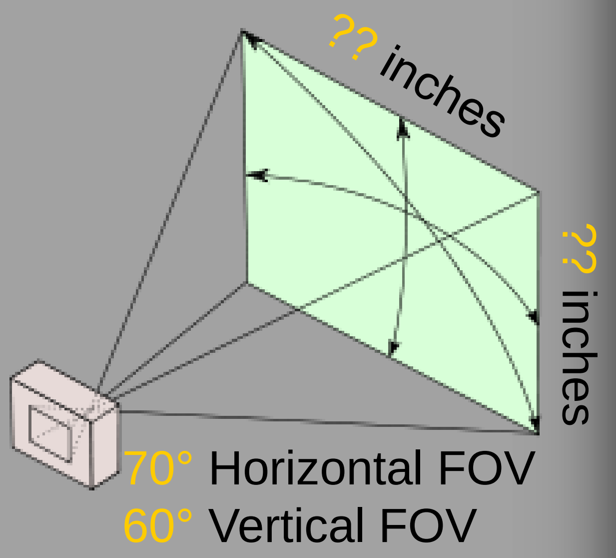
Baseline Design

- Iridium is the single most common type of satellite in Low Earth Orbit
- 8.33% of Satellites in Low Earth Orbit are of the Iridium Series
- Contains all 3 grapple features from grapple feature trade study
  - Solar Panel Joints
  - Bus Support Structure
  - Antenna
- Easiest satellite to find information about.

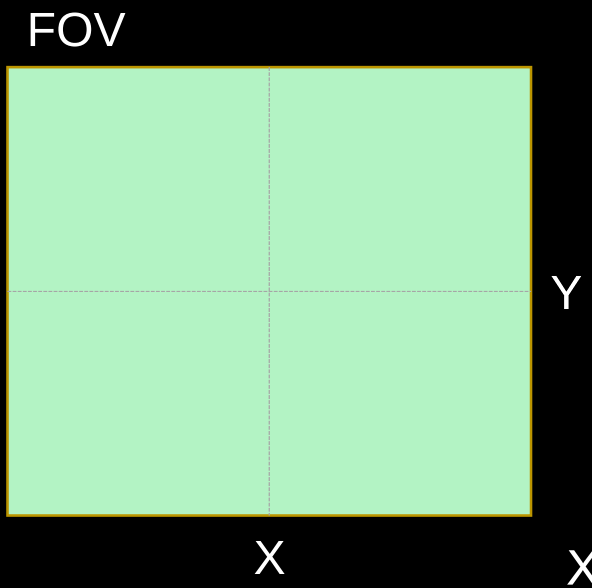


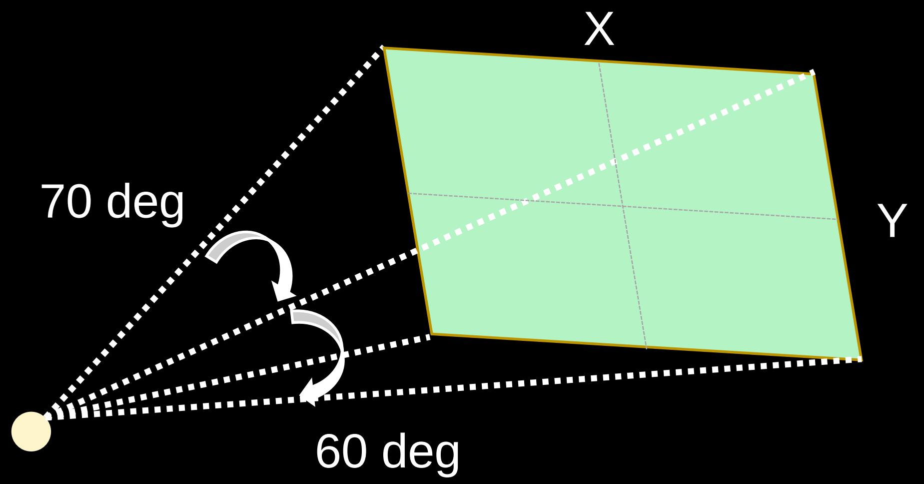
Baseline Design

- One of Iridium Antenna's is 6'1" tall by 2'10" wide
- Using visual approximation, Iridium's Bus is about 12' 2" tall, from the top to the base
- Mockup is 30% scale, so it will be 43.8" tall
- Kinect has field-of-view (FOV) of 70° by 60°
- At maximum arm range of 31", the Kinect can see a 42" by 35" area
- Kinect will be able to see the entire bus of the Iridium model for distances greater than 31"

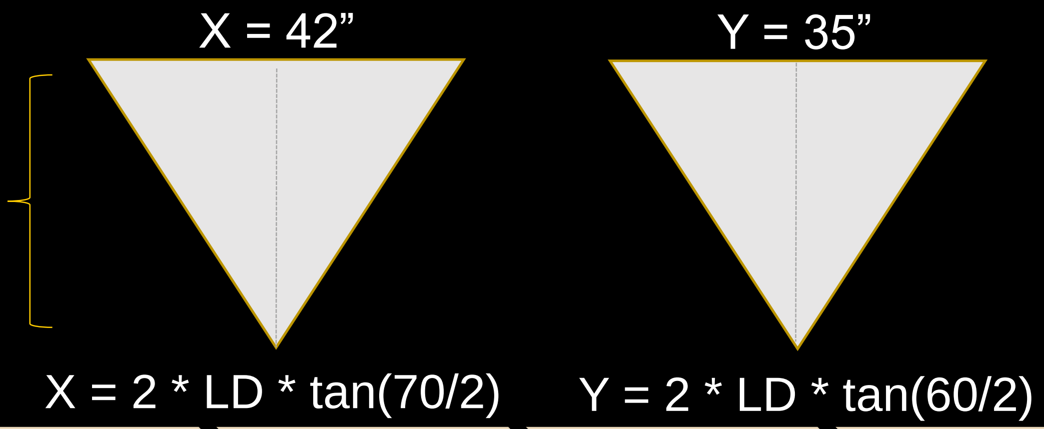


Levels of Success Metric Determination





Linear Distance < 31”



Max Dim on Satellite = 1.86*2 m = 146.45”

Scale = 42/147 = .29 ~ 0.3 = 30%

Project Description

Project Assumptions

#	Description
1	Target object is in-front & within reach of the robotic arm; this entails that this scenario is valid if the target object and the chase vehicle are in the same orbit and in proximity to each other.
2	Target object is stationary with respect to the chase vehicle (robotic arm base plate); this entails that this scenario is valid (in an orbital case)if the target object is 3-axis stabilized (or the chase vehicle has matched rotation at one axis if 2-axis stabilized).
3	Chase vehicle operations (target and capture) occurs during Sun-soak in an average Lower Earth Orbit (LEO); this entails that lighting conditions are not in the scope of KESSLER.
4	KESSLER mission will be demonstrated in a controlled test environment (1G & atmosphere).
5	KESSLER will not design the "chase vehicle's" system; this entails that electrical power system, command & data handling, attitude determination & control, etc. will not be in the scope of the KESSLER project.
6	Main characteristics of the KESSLER mission include antennas, solar panel joints, and bus structure supports.

Sec 2: Back-Up

Sec 3: Back-Up

CPE 1 & Success Criteria

- CPE 1 Feature Recognition
  - Addresses Objective 1 & 2.
  - RGB-based visual algorithm
    - Responsible for recognizing stationary pre-selected grappling features at an unknown orientation.
    - Responsible for identifying features that may collide with mechanical arm
  - This CPE also includes the imaging and processing hardware required to execute feature recognition.

CPE 2 & Success Criteria

- CPE 2 Controls
  - Addresses Objective 3 & 4.
  - ROS based control algorithm
    - Responsible for determining prediction path to PGF and commanding robotic arm to actuate.
    - Responsible for creating optimized path inclusive of keep-out zones.
  - This CPE includes the visual processing data packets and central processing unit CPU.

CPE 3 & Success Criteria

- CPE 3 Robotic Arm
  - Addresses Objective 4.
  - CrustCrawler assembly
    - Responsible for autonomously capturing the PGF on the target object.
    - Responsible for executing optimized path to PGF.
  - This CPE includes integrated robotic arm, mechanical ground support equipment (MGSE), and the scaled Iridium Satellite.

Sec 4: Back-Up

CPE 1

CPE 1: Risks & Mitigation

1. Algorithm Timing
   - Run timing analysis to determine if this is an issue for larger databases
2. Image Database
   - Add **more images** with more orientations
   - Add **CAD model** images
3. Integration with Control Software
   - Integrate MATLAB data into ROS to debug issues early
   - Prove we can deliver data controls software needs

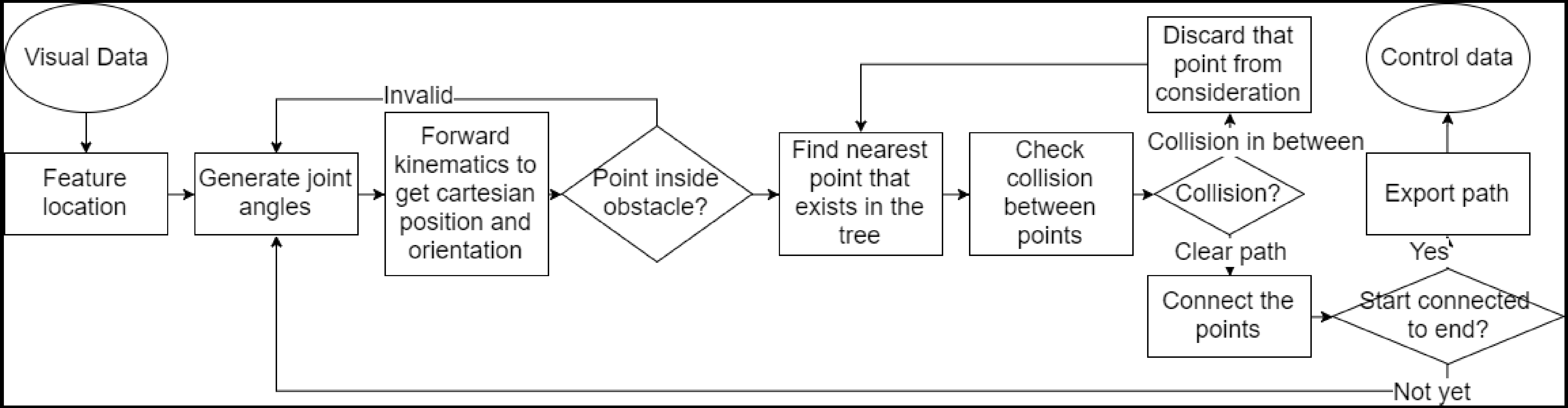
CPE 1: Design & Functionality

Feature Matching Algorithm Code:

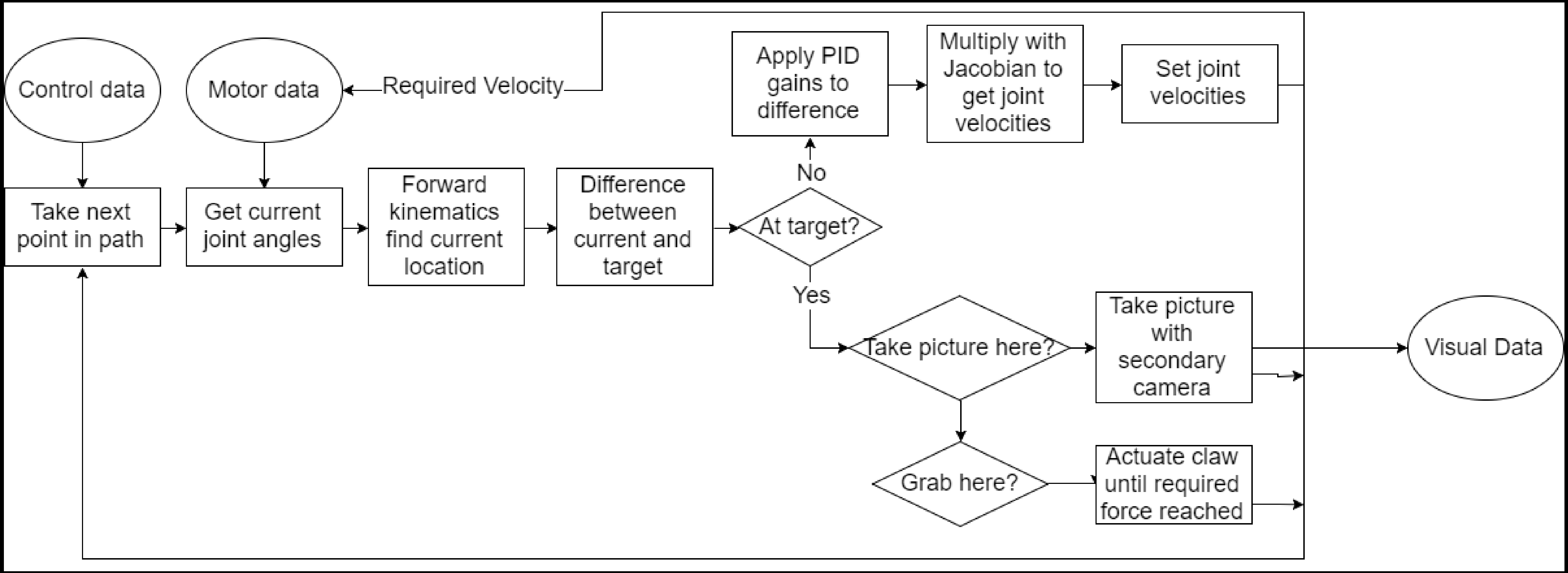
- detectSURFFeatures
  - Analyzes image and returns data based on similarly grouped pixels:
    - Number of points held by object (count)
    - Array of [x, y] point coordinates (location)
    - Value describing strength of detected feature (metric)
    - Sign of Laplacian determined in the detection process (sign of Laplacian)
    - Orientation of the detected feature as an angle (orientation)
- extractFeatures
  - Returns extracted feature vectors and their locations
  - Vector derived from pixels surrounding an interest point
- matchFeatures
  - Returns what matches between two given vectors

CPE 2

D1.4: Subsystem communications



D1.4: Subsystem communications



D3.3: Timing analysis

- Mechanical error has range of ~0.1 inches (0.08 degrees/joint)
- Constrained arm drift error to 0.15 inches

$$minimum\ frequency = \frac{maximum\ velocity}{maximum\ error}$$

  - Assumed arm moves at 7.5 in/s

$$50\ Hz = \frac{7.5\frac{in}{s}}{0.15\ inches}$$

$$Baud\ rate = update\ frequency * \frac{bytes\ passed}{update} * 8\frac{bits}{byte} * 6\ motors$$

Requires baud rate of at least 48 kHz

D3.3: Timing analysis

- Current calculation time: 0.0029 seconds
- Leaves less time for data transmission
- Minimum baud rate goes up to

56 kHz

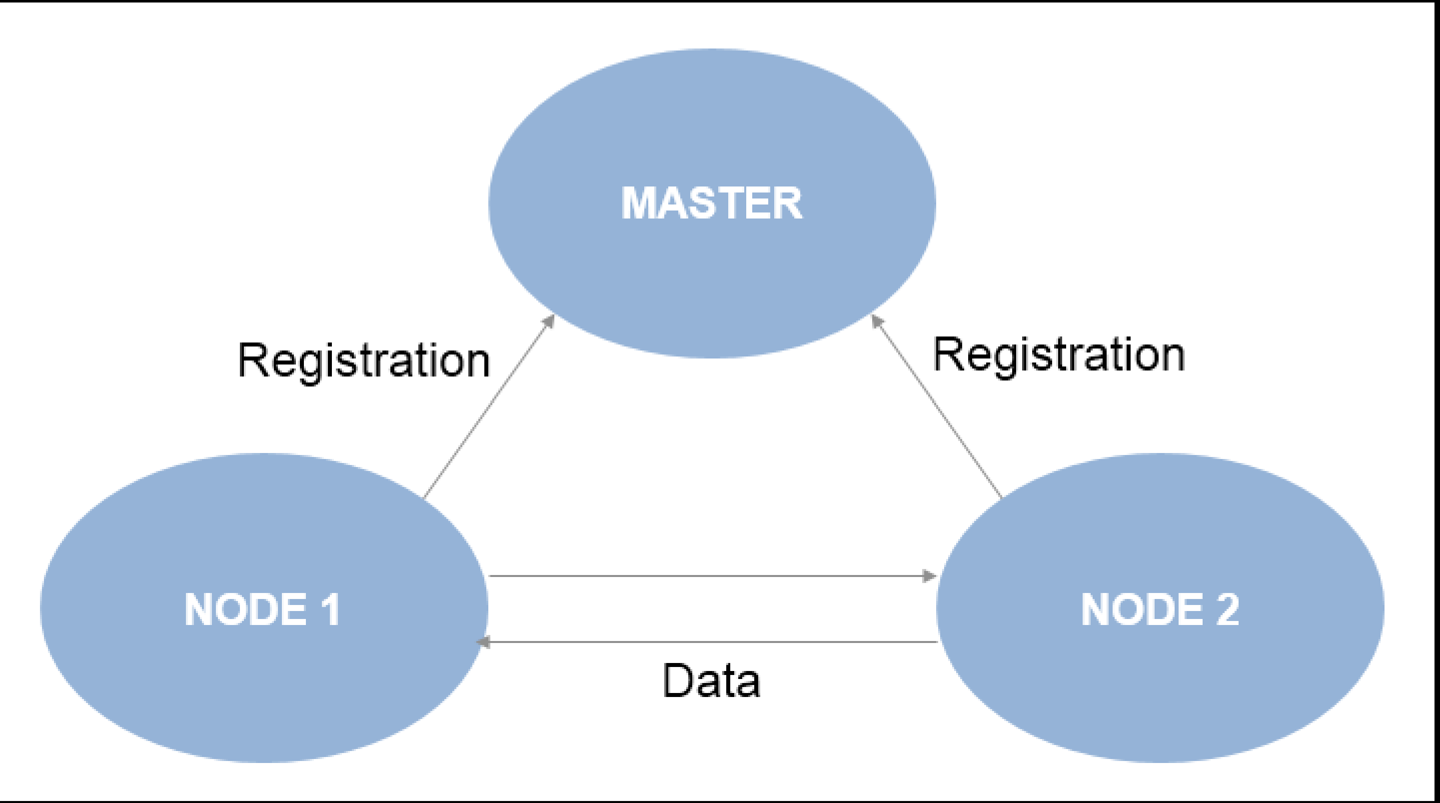
D3.3: Timing analysis

- Baud rates of multiple MHz are supported
- At 1 MHz the data takes 0.00096 seconds to send
  - Leaves 0.01904 seconds for calculations
  - More than 6 times the current calculation time: margin

Design & Functionality

MATLAB and ROS Compatibility:

- Robotics System Toolbox in MATLAB
- Extensive documentation online

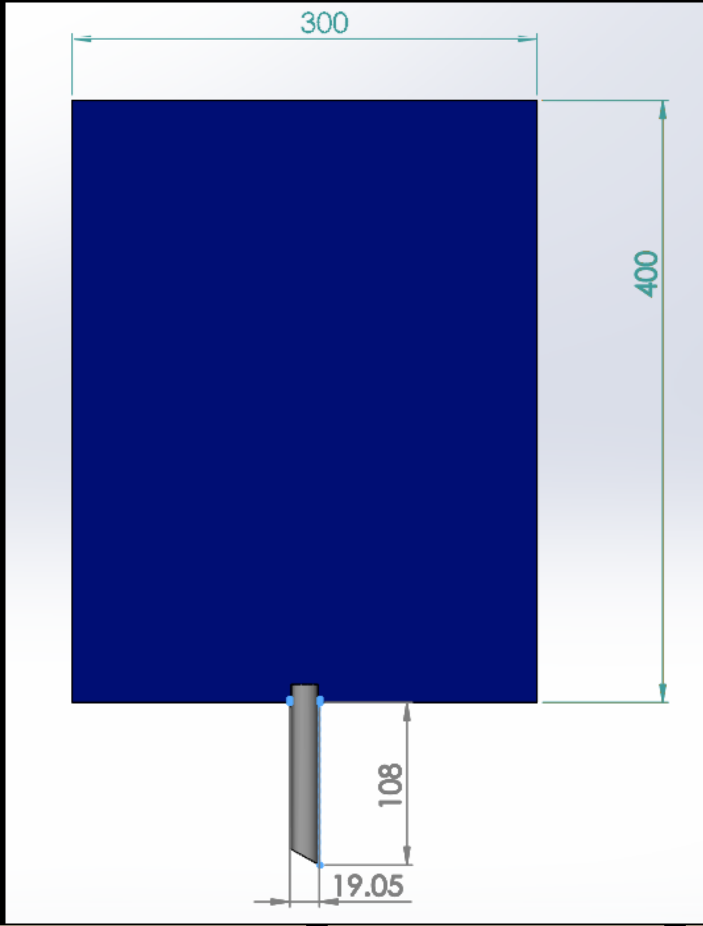


CPE 3

Sub-Assembly – Solar Panel

- Solar Panel: Acrylic Sheet
  - 12mm Thickness
  - Dark Blue -- Glossy
- Bar: HDPE Rod
  - ¾” Thickness
  - Grey -- Matte

Solar Panel and Bar from Side View



Project Purpose | Proposed Design | Critical Project Elements | Design Reqs. | Risks & Mitigation | Ver. & Val. | Organization

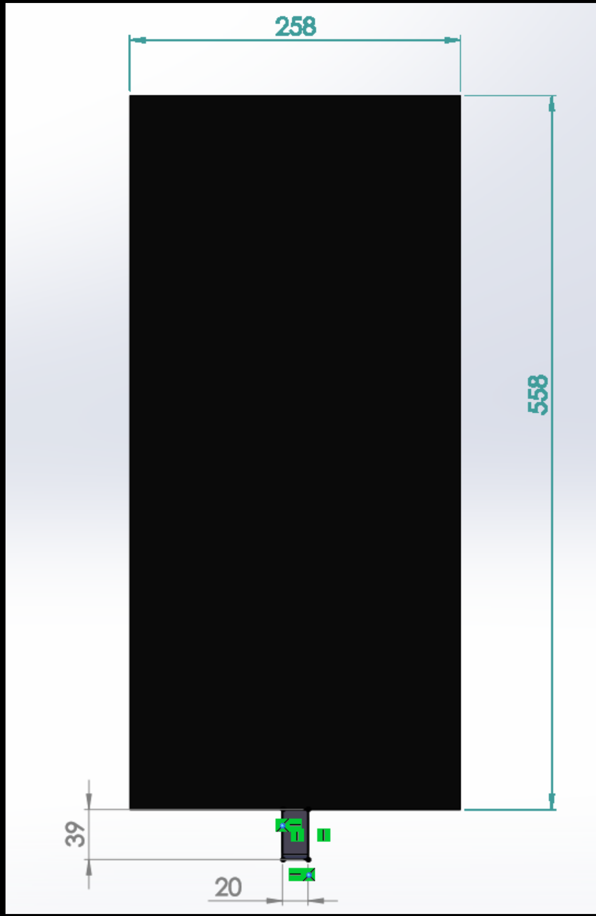
Sub-Assembly – Antenna

- Antenna: Acrylic Sheet
  - 12mm Thickness
  - Black -- Glossy

- Support: HDPE Rod
  - ¾” Thickness
  - Grey – Matte

- Bracket: Aluminum 3030
  - 45” Angle
  - Aluminum -- Matte

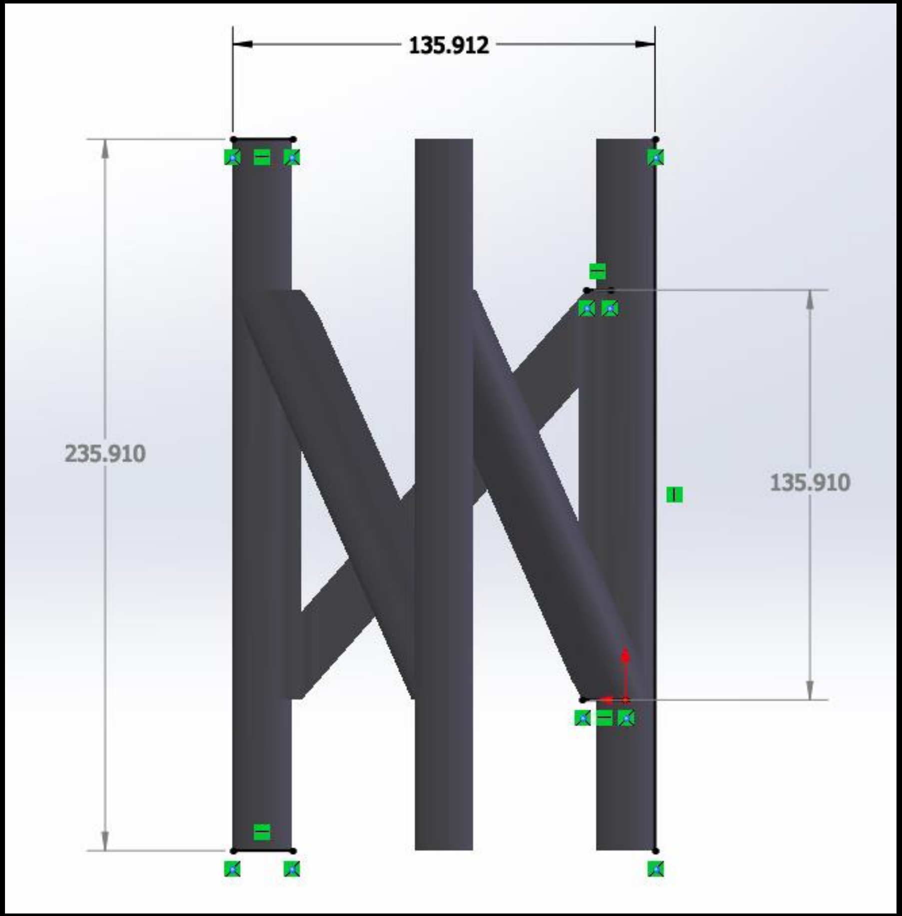
Primary Antenna from View Parallel to Surface



Sub-Assembly – Bus

- Rods: HDPE
  - ¾” Thickness
  - Grey – Matte
  - Bars at 45 Degrees
  - Driven by Body Interior

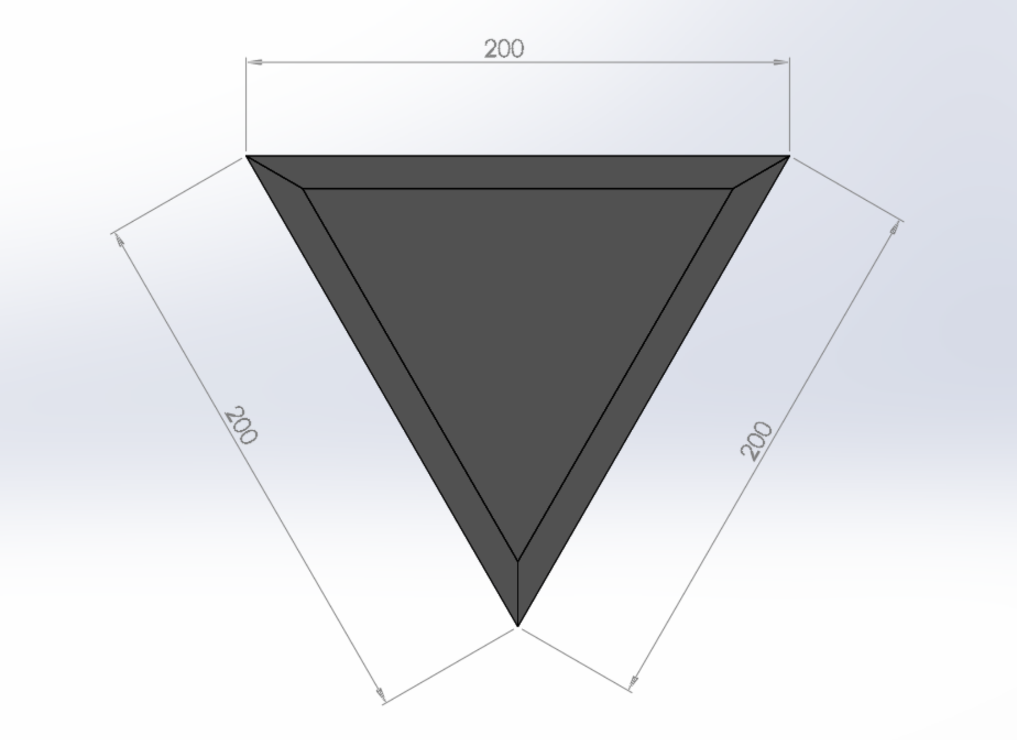
BUS Support Structure from Front View



Sub-Assembly – Body

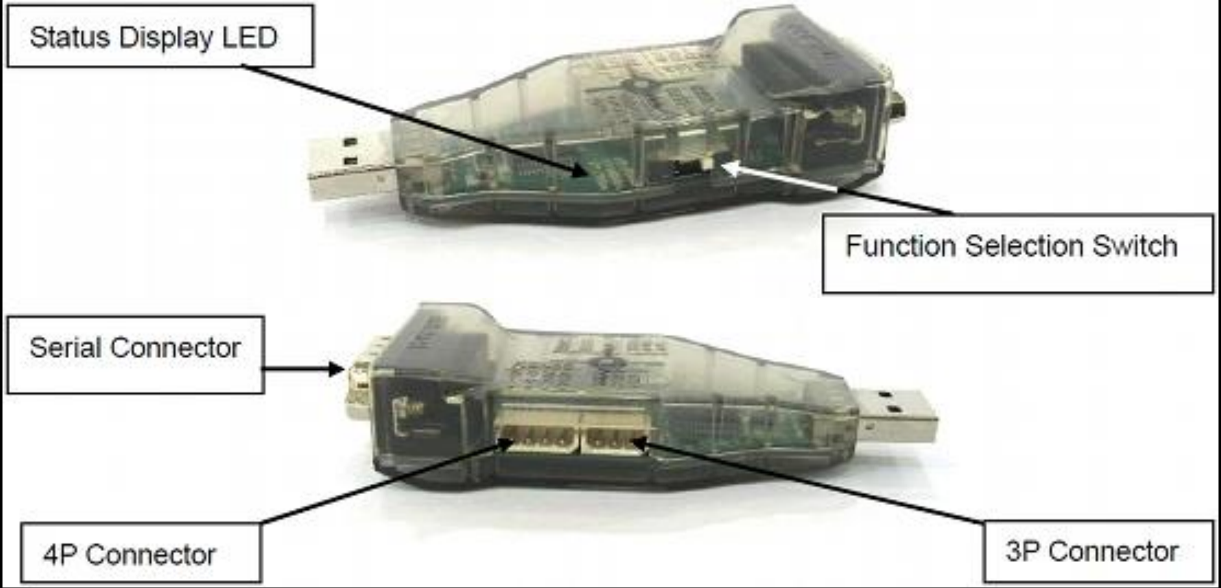
- Side Pieces: Acrylic Sheets
  - 12mm
  - Grey – Matte
  - 220mm Long
  - Triangular Prism

Body of the Iridium Satellite from Top View



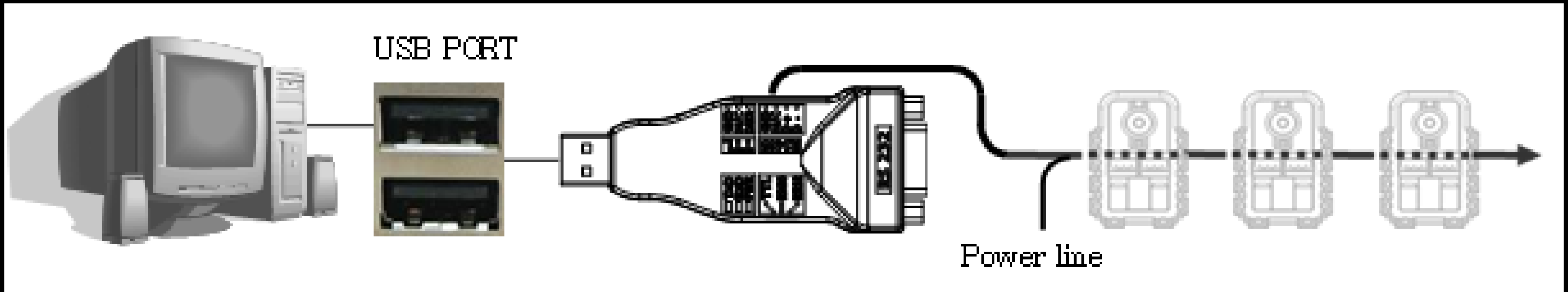
How to Connect with a Dynamixel

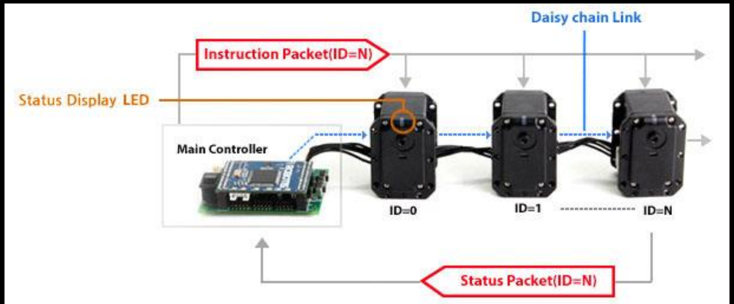
USB2Dynamixel



Function Switch Position 1 Operates Dynamixel directly using TTL (3P

3 Pin Cable		
Pin No.	Signal	Pin Figure
1	GND	3 2 1
2	NOT Connected	
3	DATA (TTL)	





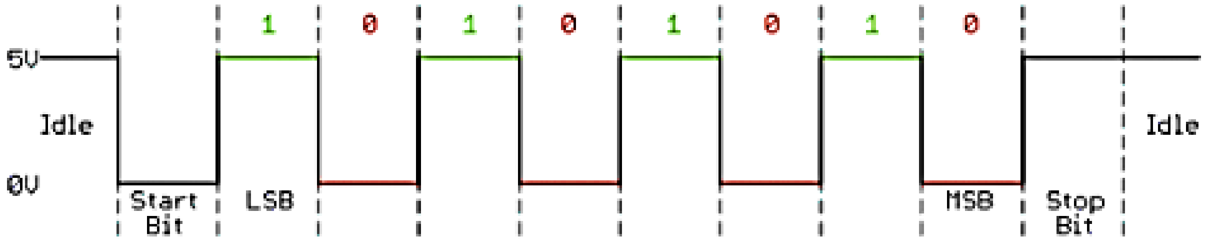
TTL Communication

Transistor-Transistor Logic

Most microcontrollers these days have built in UARTs (universally asynchronous receiver/transmitter) that can be used to receive and transmit data serially. UARTs transmit one bit at a time at a specified data rate (i.e. 9600bps, 115200bps, etc.). This method of serial communication is sometimes referred to as TTL serial (transistor-transistor logic). †

BIT	15~11	10	9	8	7	6	5	4	3	2	1	0
Value	0	Load Direction	Data (Load Ratio)									

Load Direction = 0 : CCW Load,   Load Direction = 1: CW Load



This timing diagram shows a TTL signal sending 0b01010101, notice its LSB first.

Commanding a Dynamixel

Instruction Packet

OxFF	OxFF	ID	Length	Instruction	Parameter 1	…	Parameter n	Check Sum

OxFF, OxFF	ID	Length	Instruction	Parameter 1 … Parameter n	Check Sum
This signal notifies the beginning of the packet	Specific or Broadcast ID	Packet Length	Ping Read_Data Write_Data Reg Write Action Reset Sync Write	Parameter is used when Instruction requires ancillary data.	Check if Packet is damaged

Status Packet

OxFF	OxFF	ID	Length	Error	Parameter 1	…	Parameter n	Check Sum

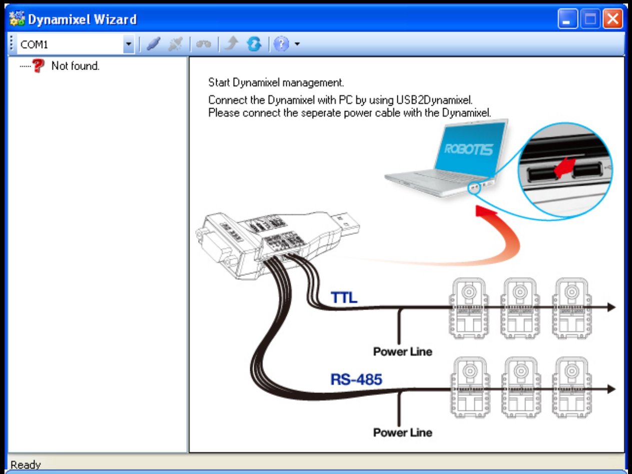
OxFF, OxFF	ID	Length	Error ★	Parameter 1 … Parameter n	Check Sum
This signal notifies the beginning of the packet	Specific or Broadcast ID	Packet Length	0 Instruction Err Overload Err Checksum Err Range Err Overheating Angle Limit Input Voltage	Parameter is used when Instruction requires ancillary data.	Check if Packet is damaged

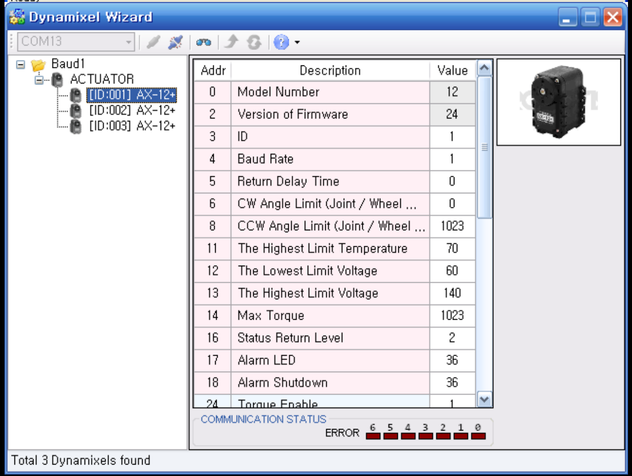
★ Represented in Bits 7 to 0

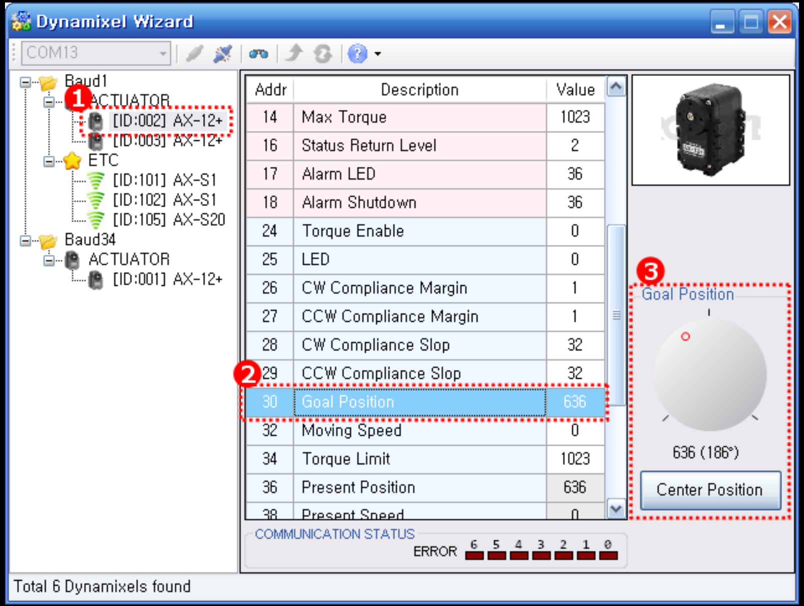
Verifying Current Dynamixel hardware

- Physical
  - Continuity checks for each Dynamixel, and their 3pin connectors
  - Continuity of 6 pin breakout to 3 pin connectors
  - Force Cell wiring chassis must be repaired if to be reused
  - Base signal to barrel jack and USB2Dynamixel will be rebuilt for durability. No hot glue.

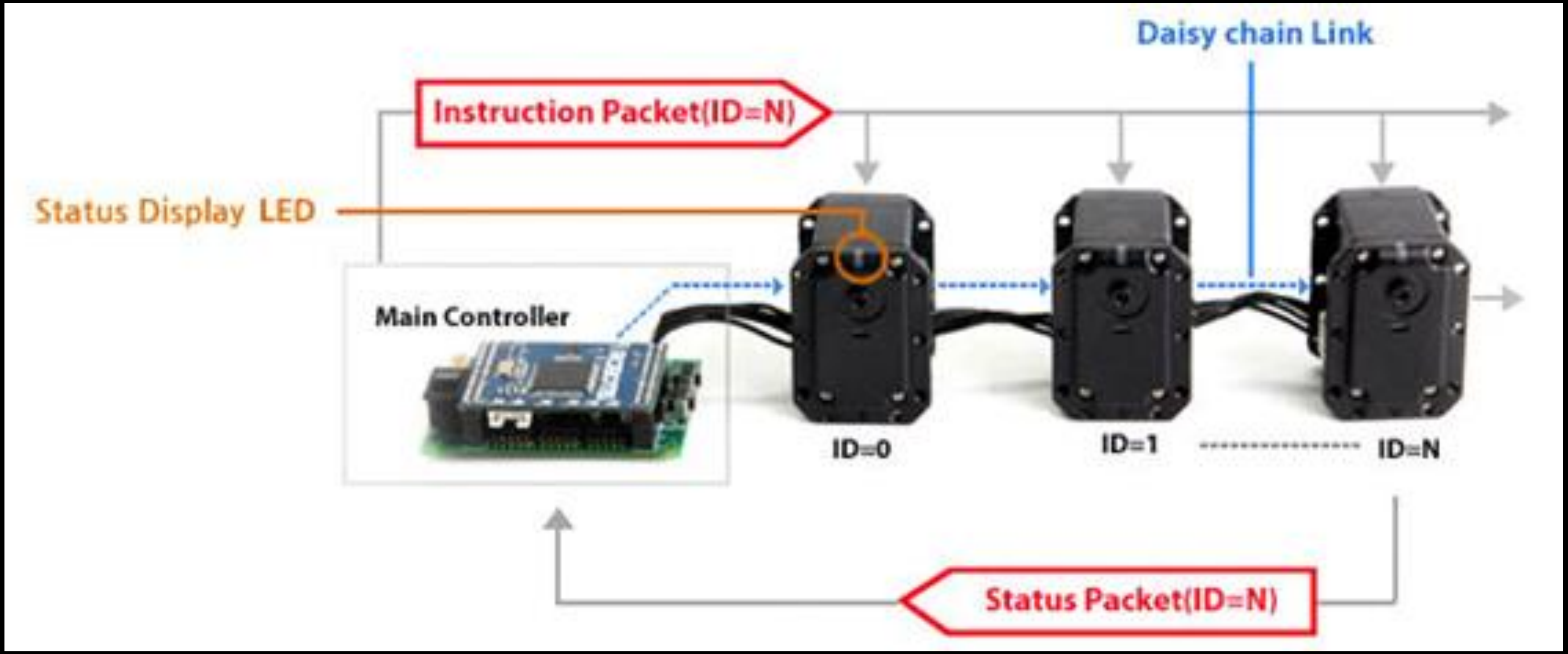
- Communication & Actuation







Identification Daisy-Chain

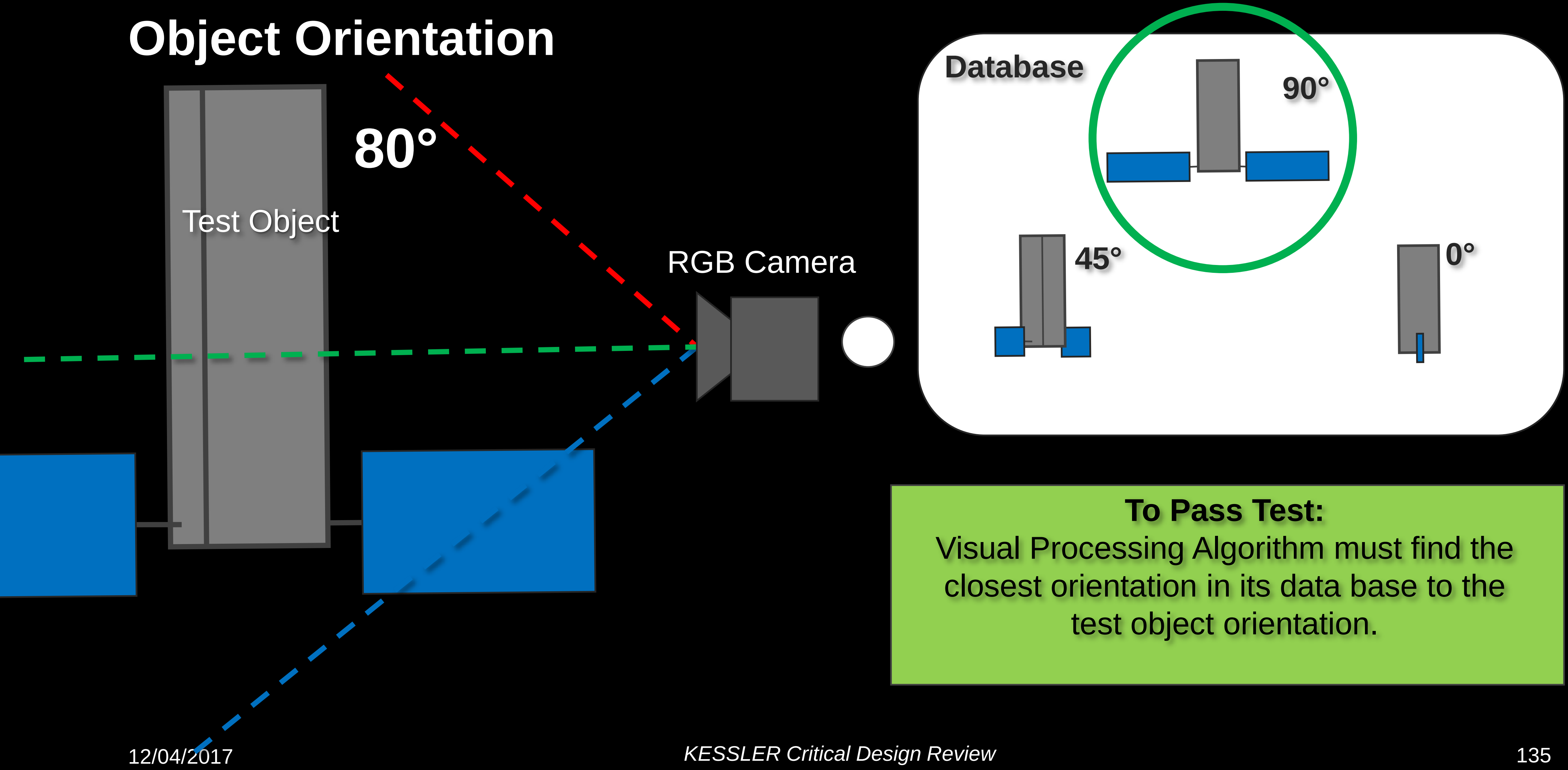


Sec 5: Back-Up

Sec 6: Back-Up

Verification & Validation

Object Orientation



To Pass Test:
Visual Processing Algorithm must find the closest orientation in its data base to the test object orientation.

Sec 7: Back-Up

Organization

Course Defined

- Project Manager
  - Glenda Alvarenga
- Systems Engineer
  - Jannine Vela
- Financial Lead
  - Taylor Way
- Test & Safety Lead
  - Sergey Derevyanko
- Manufacturing Lead
  - Christopher Choate

KESSLER Defined

- Mechanical Design Lead
  - Abdiel Agramonte-Moreno
- Electrical Design Lead
  - Lauren Darling
- Image Processing Lead
  - Cassidy Hawthorne
- Software Control Lead
  - Nicholas Thurmes
- Software I&T Lead
  - Abigail Johnson
- Hardware I&T Lead
  - Thanh Cong Bui

CPE 1: Remaining Work

Fall 2017

- Expansion of image database
  - Add more images to database
  - Add more features to database
- Continued visual processing code testing
  - Tabulate timing and success rates
- Possible implementation of CAD images

Spring 2018

- Create database with physical features
- Test database with physical features
- Extract (x, y, z, χ, ψ, ζ) data
- Create back-up algorithm
- Test back-up algorithm
- Integration with control software

CPE 2: Remaining Work

Date	Milestone
01-22	Individual servo commands created
01-26	Servo commands tested
01-29	Mass servo commands created
02-02	Mass servo commands tested
02-05	ROS framework set up
02-19	Preliminary visual integration into ROS
02-23	Adapted PID controller
02-26	Path planning created
03-19	Path planning unit tested
04-09	System integration done
04-21	System testing done

CPE 3: Previous Work

- Meeting with Matt Rhode
  - Identify key MGSE features
  - Discuss potential pitfalls
- SolidWorks 3D Modeling
  - First step in producing machining drawings
  - Help prepare for more meaningful meetings
- Feedback from Test and Safety

CPE 3: Manufacturing Reviews

- Tap into the expertise of local support
  - Ensure that drawing are acceptable for use
  - Seek advice on potential approaches
- Reduce the error in manufacturing
  - Using appropriate tools and techniques
  - Advice on materials and connection methods
- Incorporate feedback with the team

CPE 3: Quality Assurance Reviews

- Inspect the subsystem for failure
  - Structural health compromise
  - Signs of wear and tear
- Troubleshoot problems ahead of times
- Ideally a brief check of the equipment
- Worst case identify repair and enhancement plans

CPE 3: Remaining Work: Fall 2017

- Nov 17th -- Finalize material choices for MGSE
- Nov 17th -- Structural Load Analysis (Testbed / Arm)
- Dec 1st -- Establish a Bill of Materials
  - Dec 8th -- Initial documentation for Integration
  - Dec 8th -- Initial documentation for Testing
- Dec 8th -- Initial documentation for Manufacturing
- Dec 8th -- Initial documentation for Quality Assurance

CPE 3: Remaining Work: Spring 2018

- Jan 19th -- Quality Assurance Review 1
- Feb 9th -- Machine prototype Iridium Satellite
- Feb 16th -- Manufacture arm mount system
- Feb 16th -- Complete arm additions
- Feb 16th -- Quality Assurance Review 2
- Feb 23rd -- Manufacture test stand
- Mar 16th -- Quality Assurance Review 3
- Apr 20th -- Quality Assurance Review 4