KESSLER

Manufacturing Status Review

ASEN 4018 Spring 2018

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Agenda

Kinesthetic
Engineered
Solution to
Space
Litter &
Exhausted
Resources

- Overview
  - Project Purpose & Objectives
  - Baseline Design & Functionality
  - Critical Project Elements & Design Updates from Fall 2017
- Schedule
- Manufacturing
  - Hardware: Mechanical/Electrical
  - Software: Controls/Visual Processing
- Budget

Project Overview

Project Overview | Schedule | Mechanical | Software: Visual | Software: Controls | Electrical | Budget

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

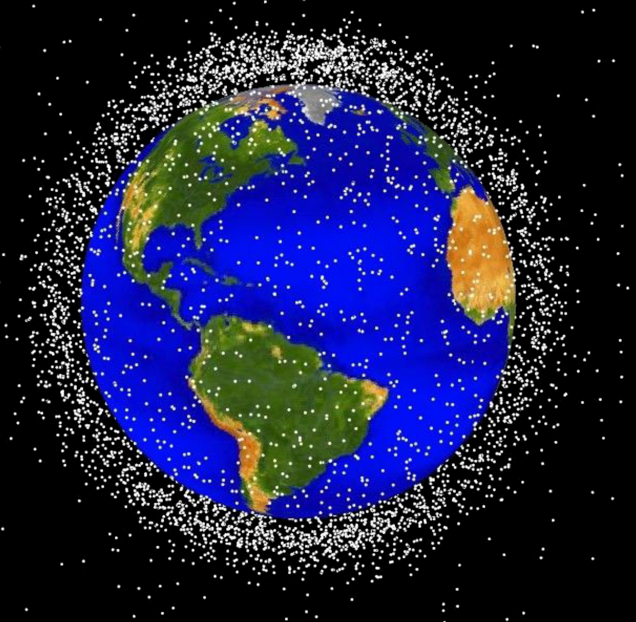


Fig. 1 Space Debris 2013 Model [1]

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

Project Statement

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 from the CASCADE capstone project.

Level	Shortened Description
1	Identify Satellite, articulate arm to closest point on satellite
2	Identify features on satellite, capture feature via robotic arm
3	Identify keep out zone, articulate arm on collision avoidance path and capture feature.

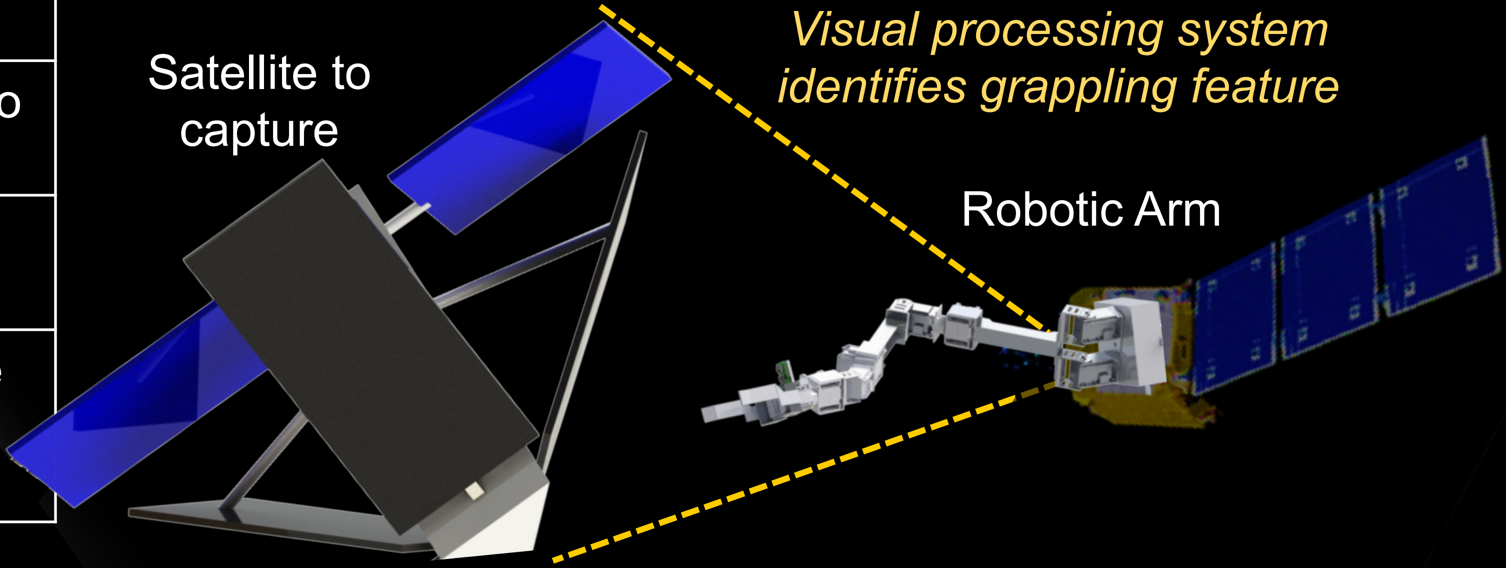
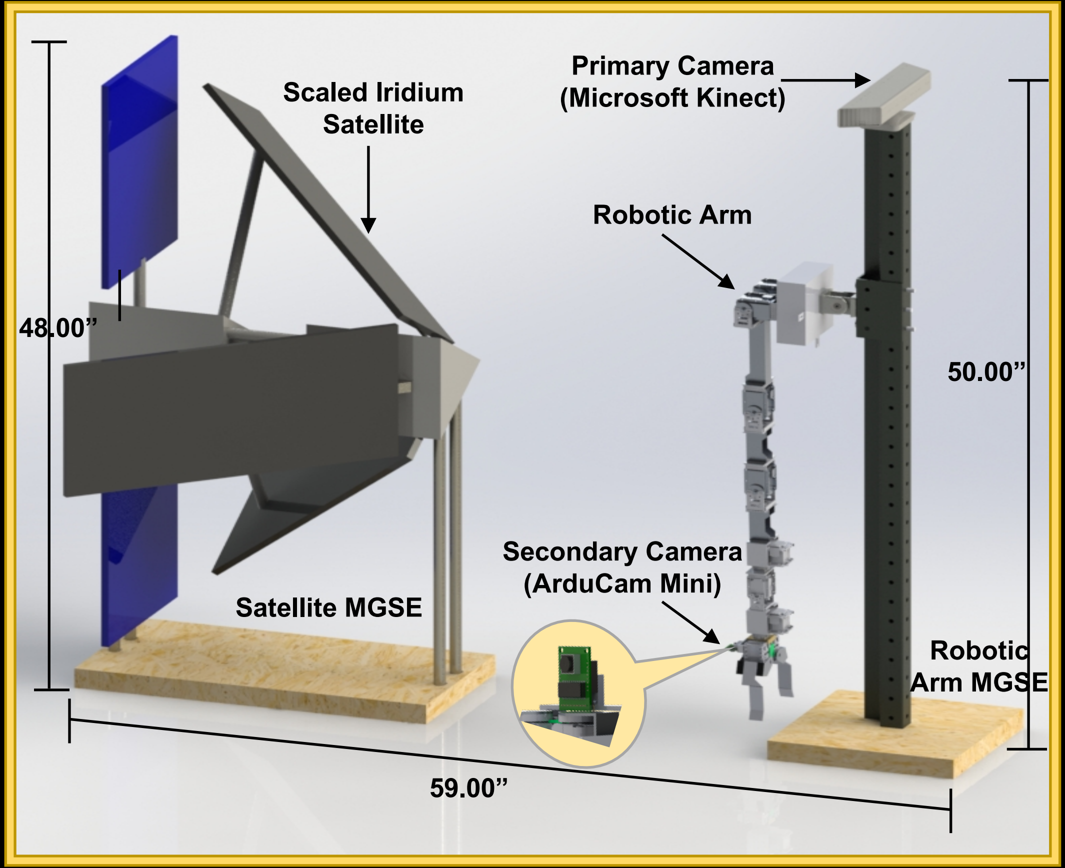


Fig. 3 KESSLER Robotic arm and vision system in process of capturing satellite in LEO

Concept of Operations

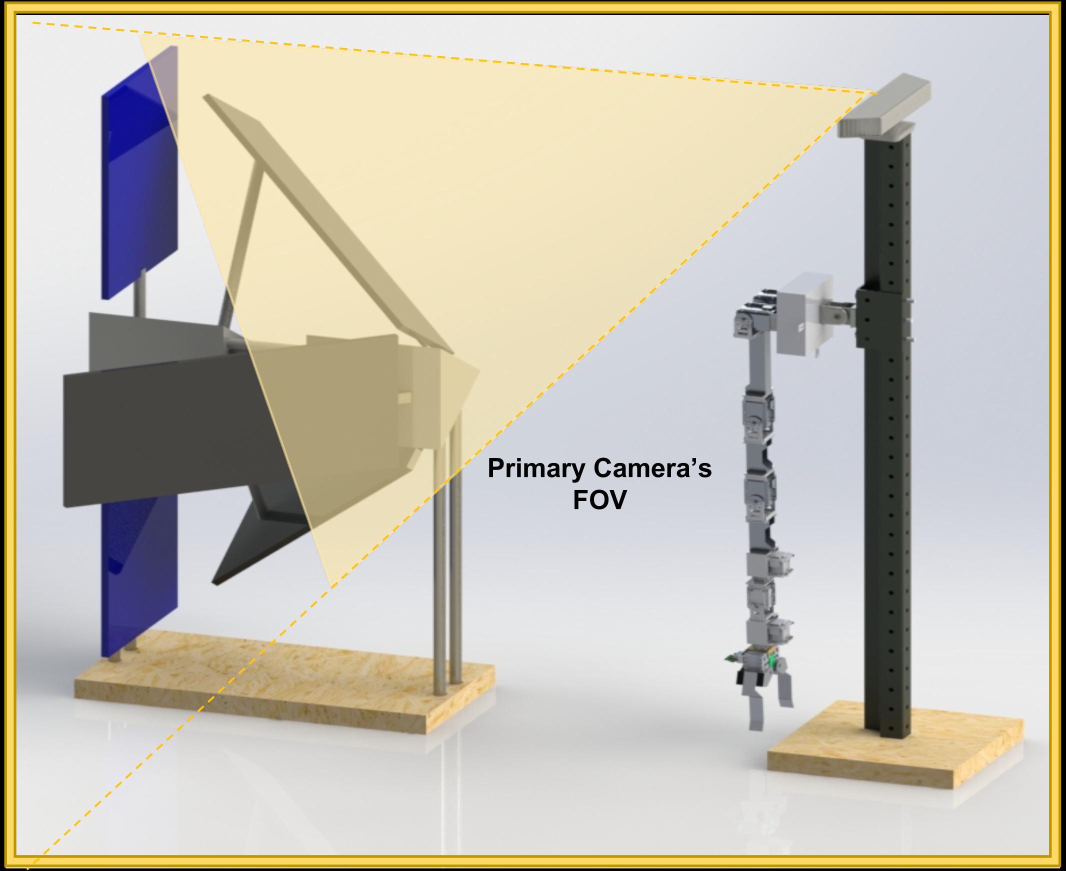
Baseline Design



0. Demonstration Initiation

Robotic arm positioned in a neutral position and subjected to uniform lighting conditions.

Concept of Operations

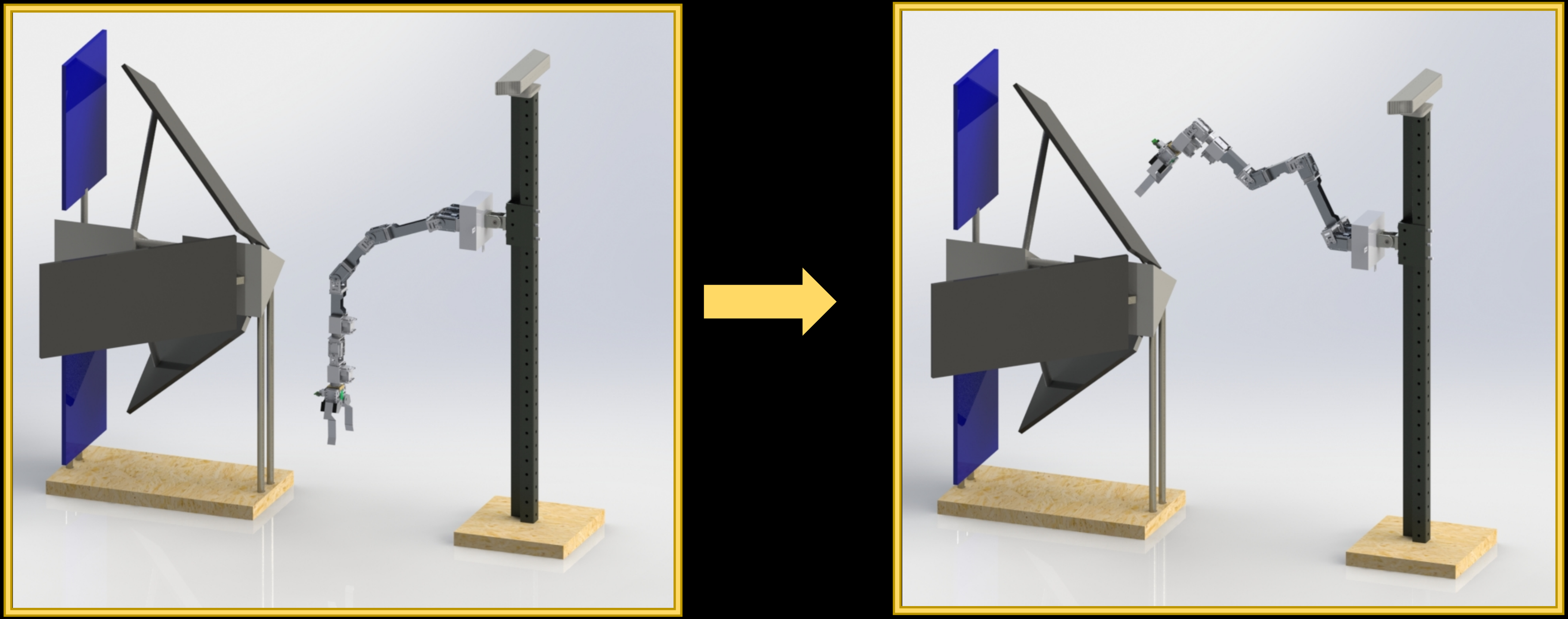


1. Identification of Feature

Kinect takes primary image and identifies a feature in Field of View (FOV).

Project Overview | Schedule | Mech. | Elec. | Software: Controls | Software: Visual | Budget

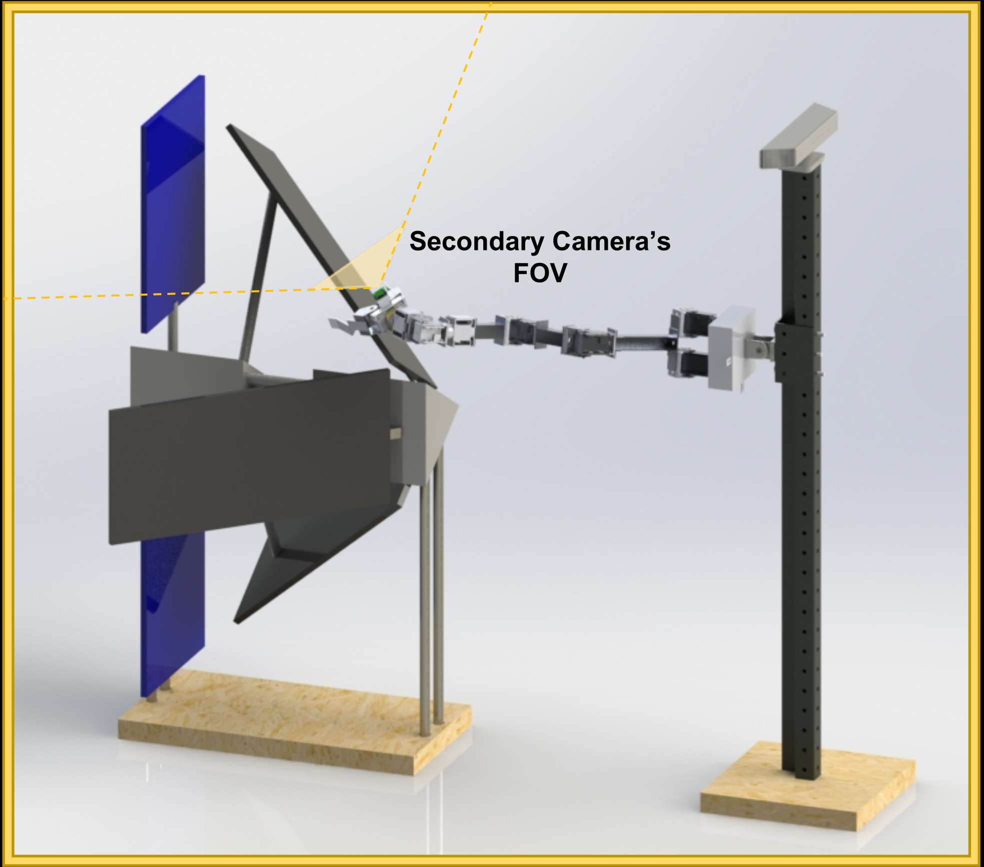
Concept of Operations



3. Primary Positioning

Robotic arm actuates to the relative position and orientation of the predetermined grappling feature (PGF)

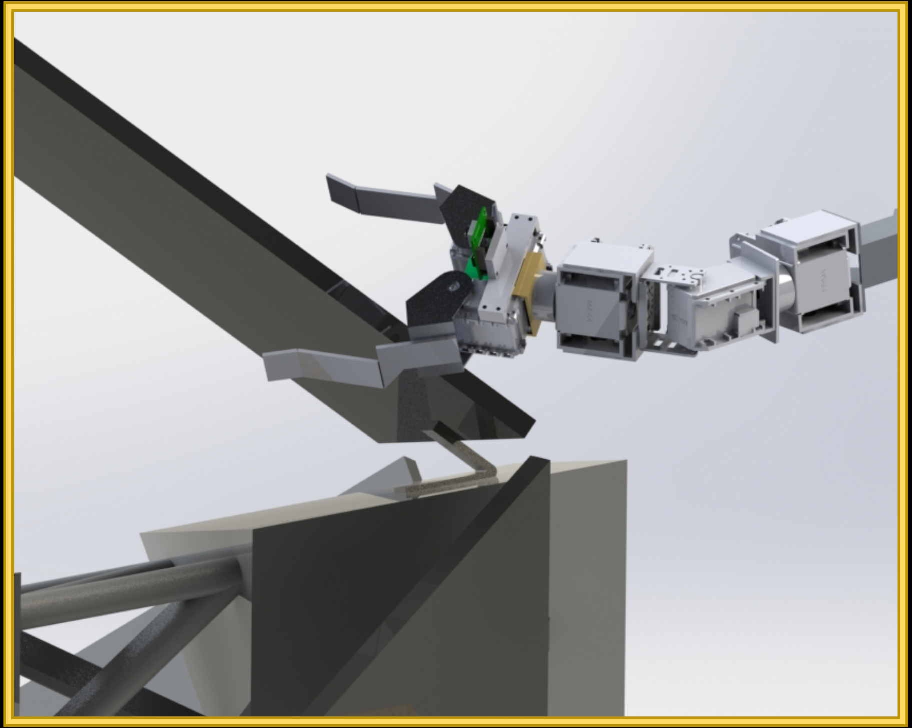
Concept of Operations

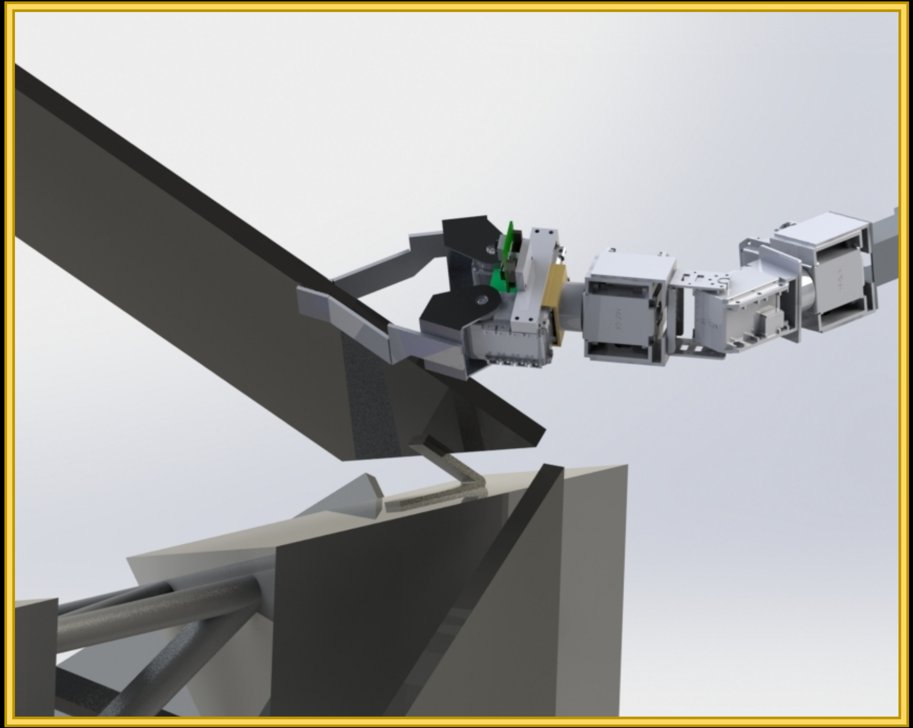


4. Secondary Positioning

- ArduCam Mini takes secondary images to fine tune position of robotic arm
- Robotic arm actuates to the adjusted position and orientation of the PGF

Concept of Operations

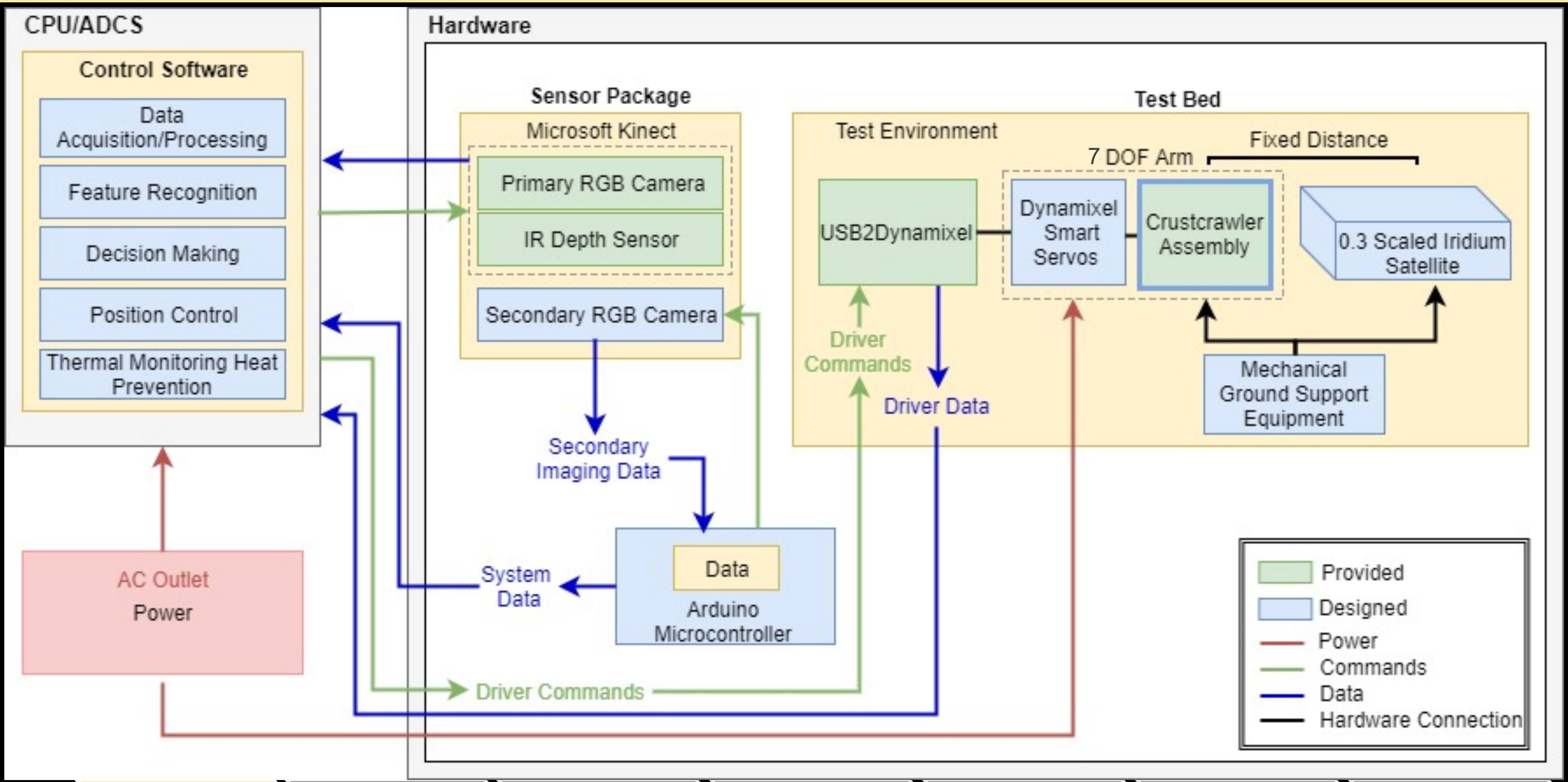




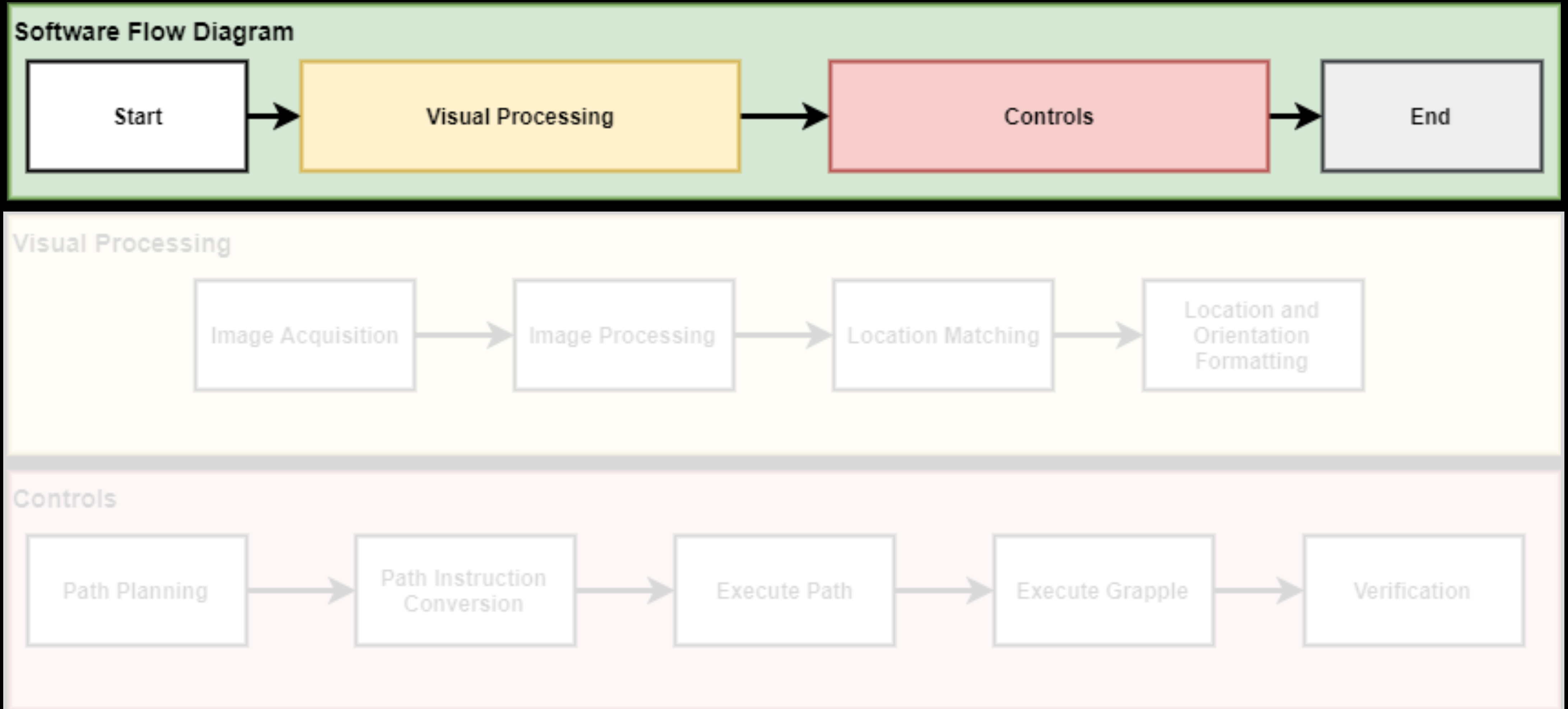
5. Capture

Control software commands robotic claw to close on and capture PGF

Functional Block Diagram

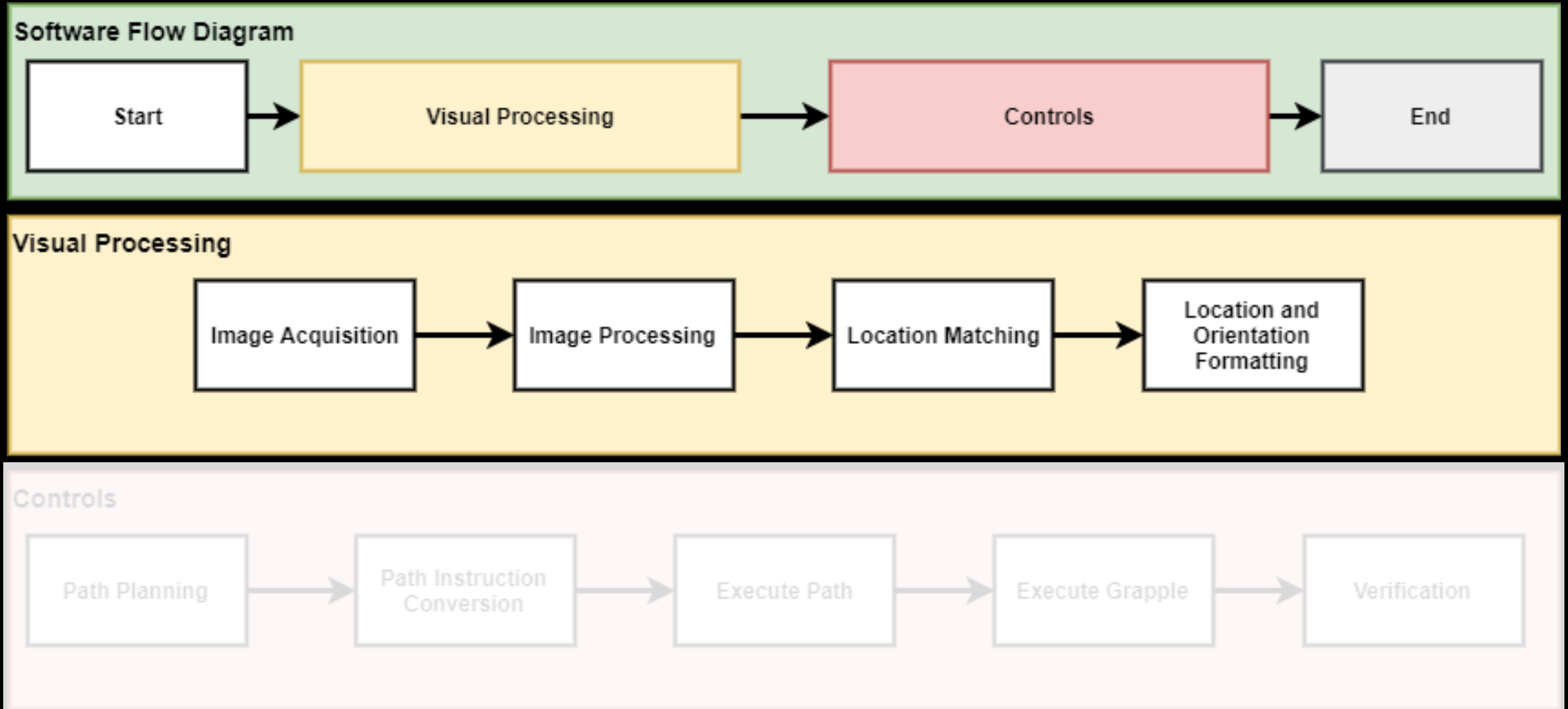


Software Flow



Project Overview | Schedule | Mech. | Elec. | Software: Controls | Software: Visual | Budget

Software Flow



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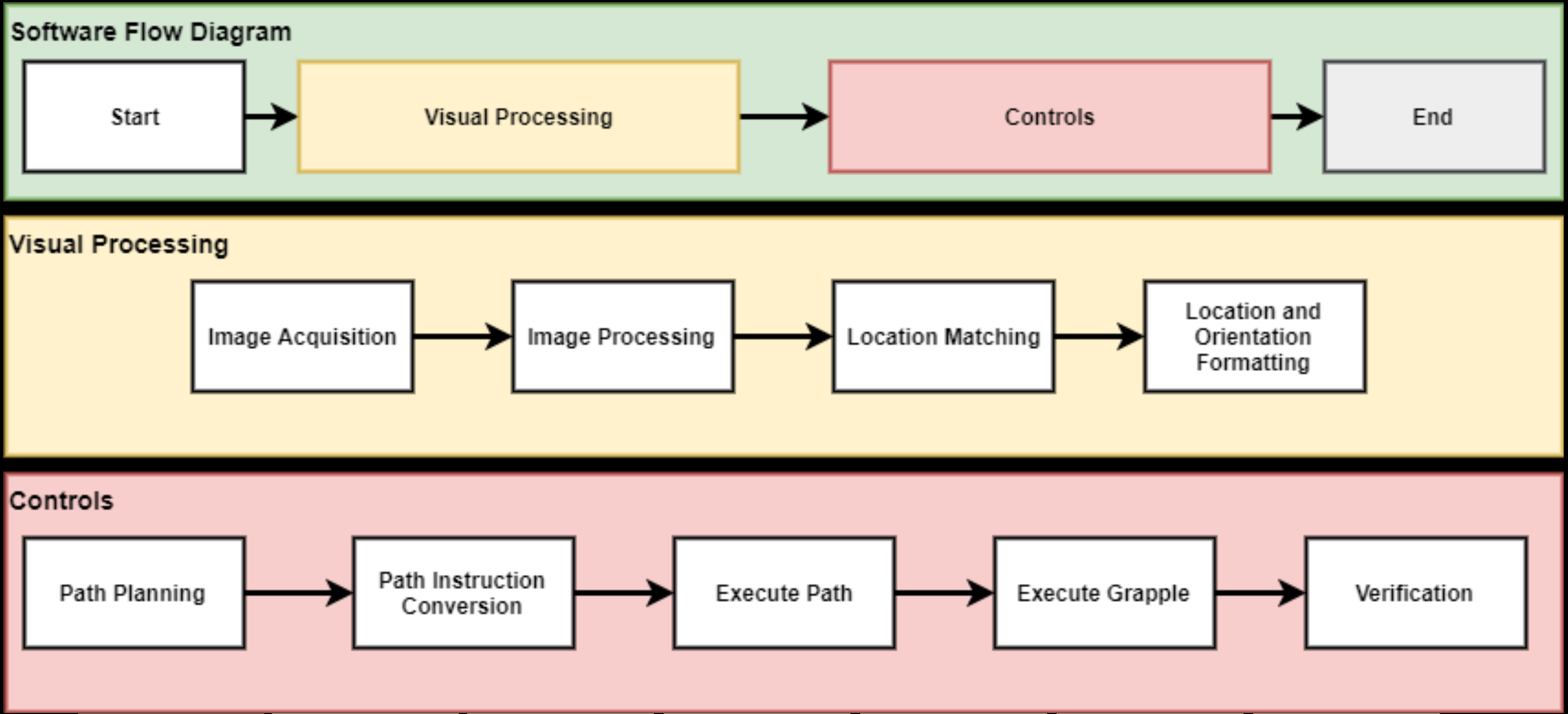
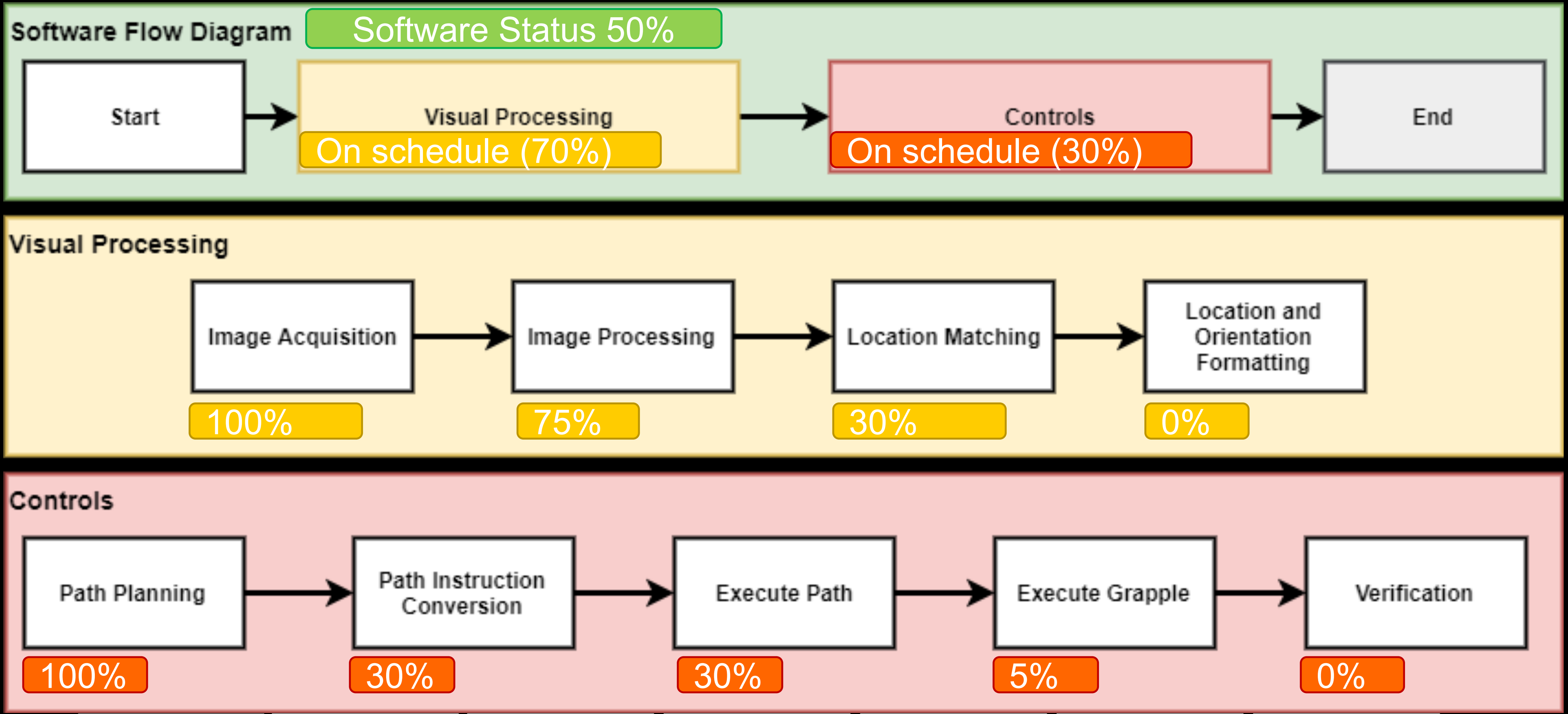


Software Flow & Status



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

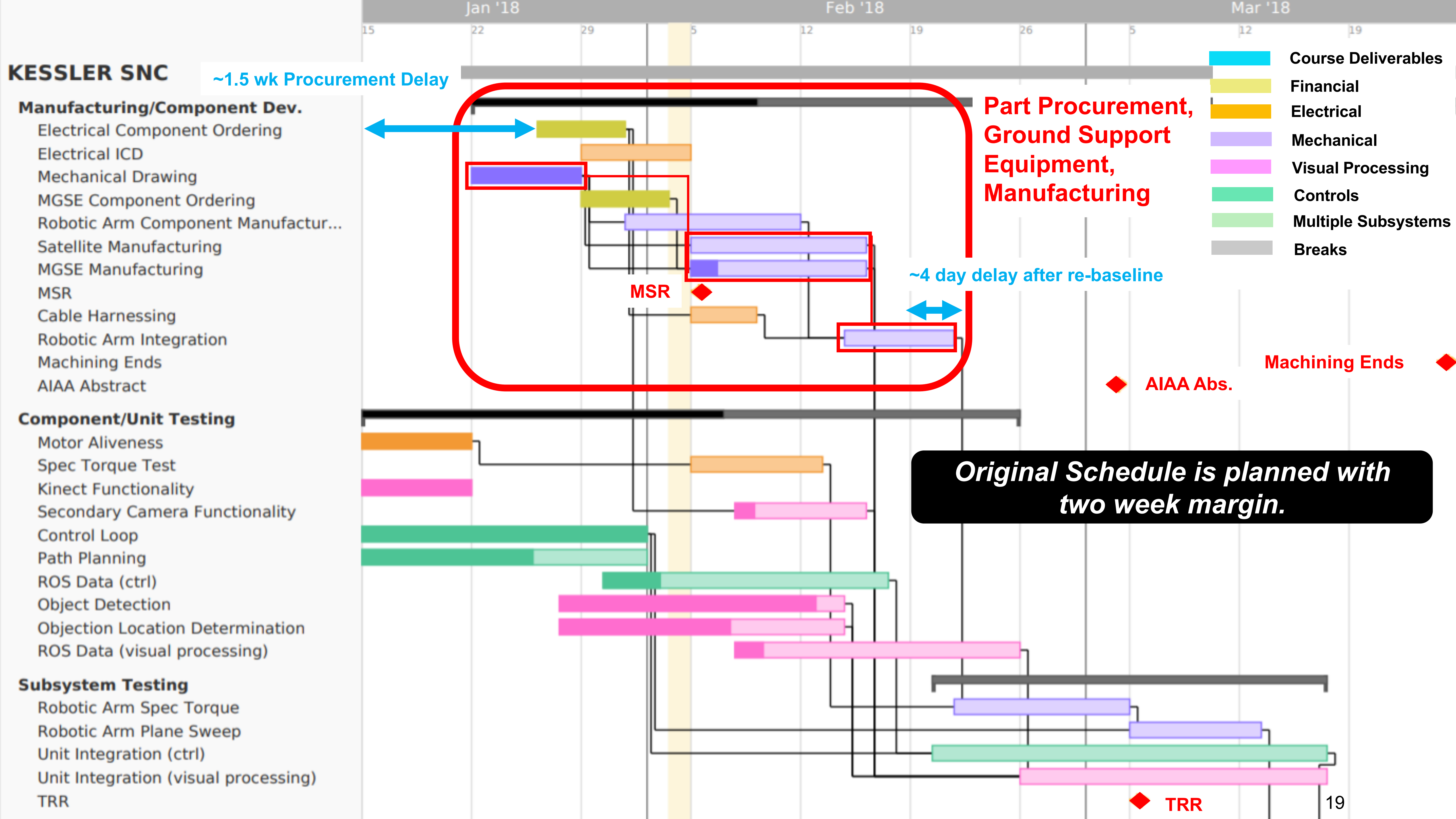
KESSLER Project Objectives

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**

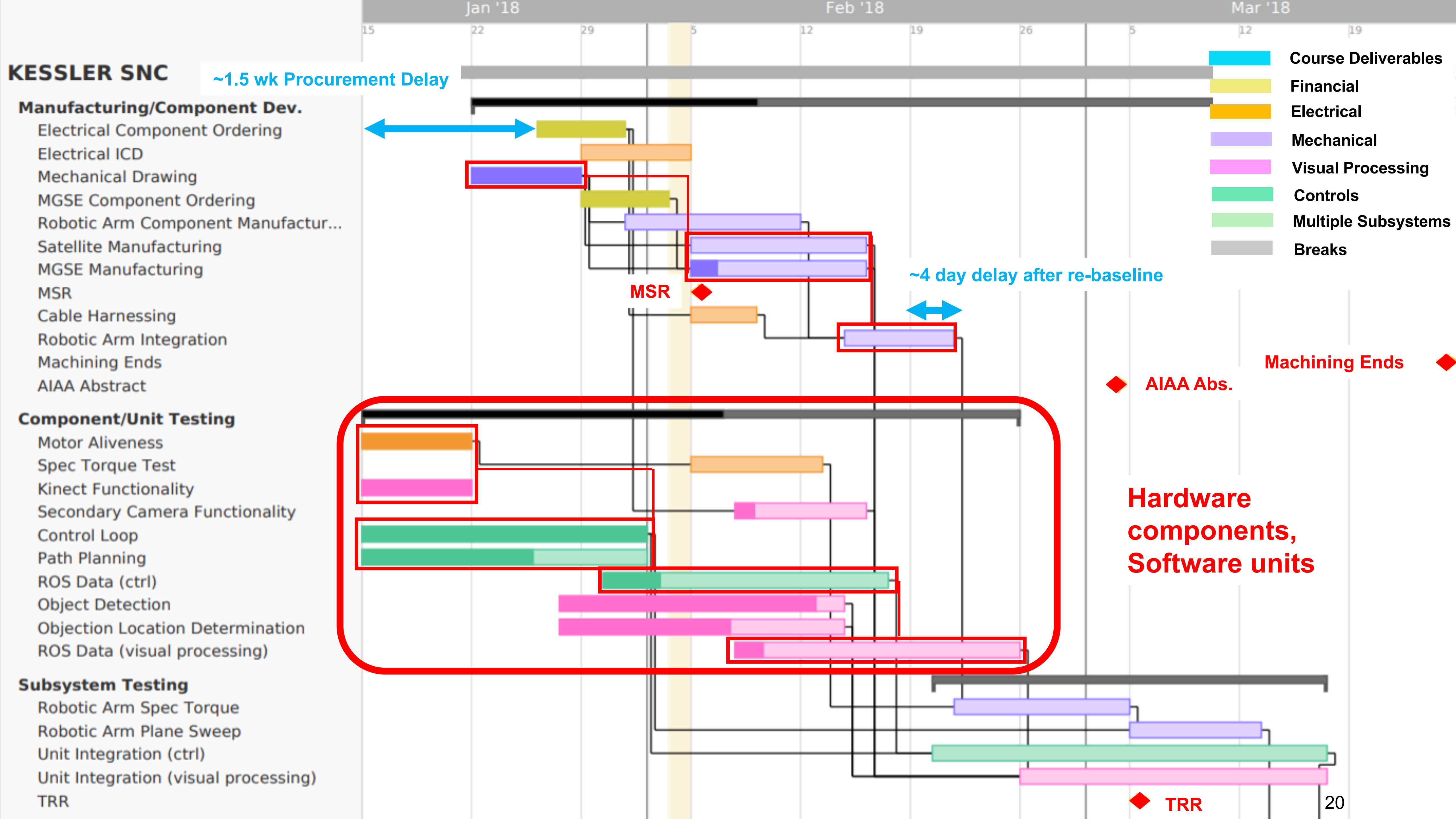
Updates Since CDR/FFR

- Technical
  - KESSLER will not build a VICON-like system, currently coordinating with on-site VICON lab for access
  - Visual Processing has a new method for feature detection (will be discussed further)
  - Controls has decoupled path planning and trajectory execution (will be discussed further)
- Monetary
  - Robotic Arm (mechanical & electrical) components shipped
  - Satellite Model & MGSE components ordered
  - Visual Processing components delivered
- Logistical
  - Two week schedule delay in manufacturing & hardware-based unit testing (circumvented with initial schedule margin, with margin still remaining)

Project Schedule



KESSLER SNC
~1.5 wk Procurement Delay
Jan '18
Feb '18
Mar '18
15
22
29
5
12
19
26
5
12
19
Manufacturing/Component Dev.
Electrical Component Ordering
Electrical ICD
Mechanical Drawing
MGSE Component Ordering
Robotic Arm Component Manufactur...
Satellite Manufacturing
MGSE Manufacturing
MSR
Cable Harnessing
Robotic Arm Integration
Machining Ends
AIAA Abstract
Component/Unit Testing
Motor Aliveness
Spec 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 Plane Sweep
Unit Integration (ctrl)
Unit Integration (visual processing)
TRR
Part Procurement, Ground Support Equipment, Manufacturing
Course Deliverables
Financial
Electrical
Mechanical
Visual Processing
Controls
Multiple Subsystems
Breaks
~4 day delay after re-baseline
MSR
Machining Ends
AIAA Abs.
Original Schedule is planned with two week margin.
TRR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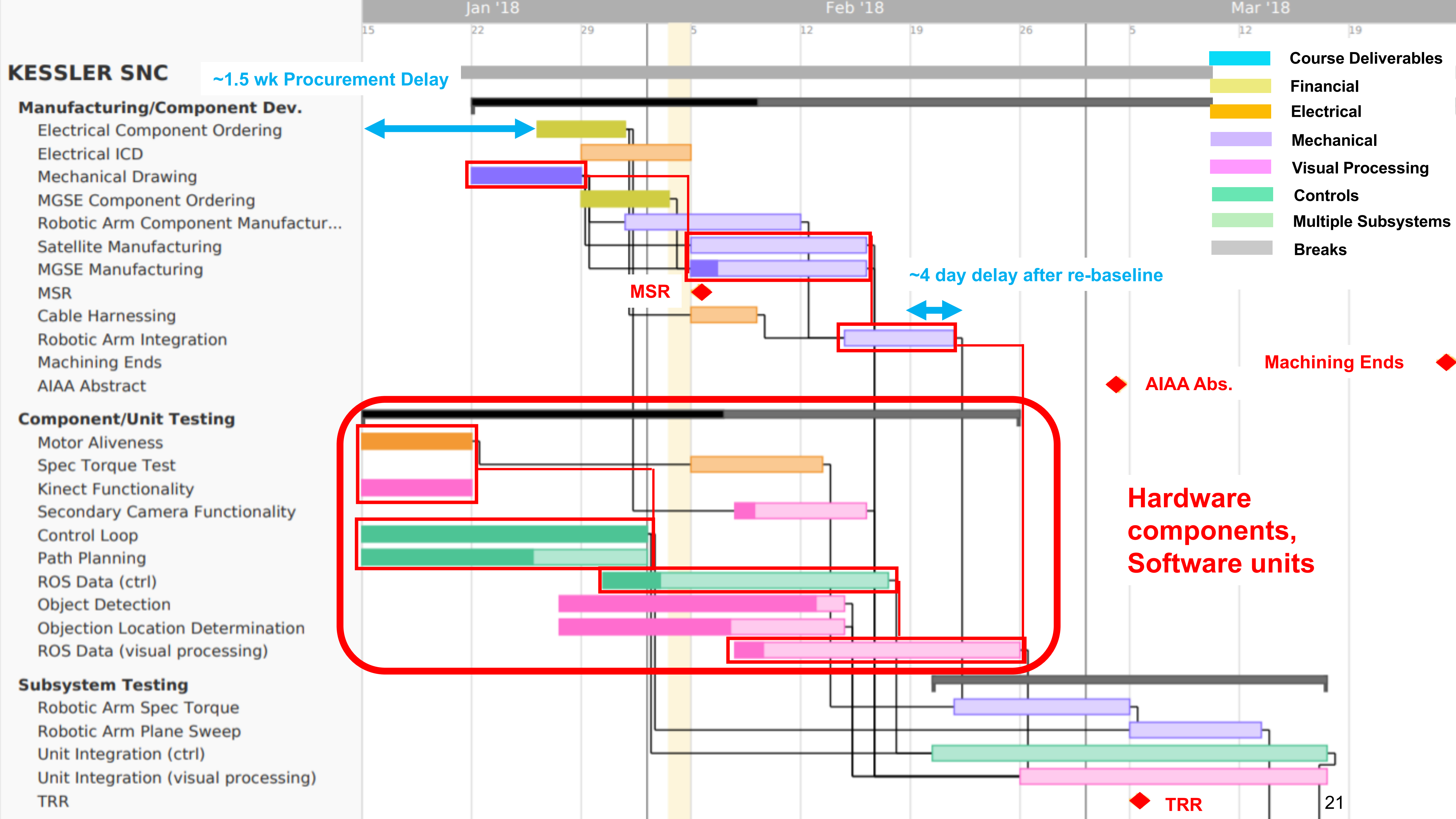
Hardware components, Software units
TRR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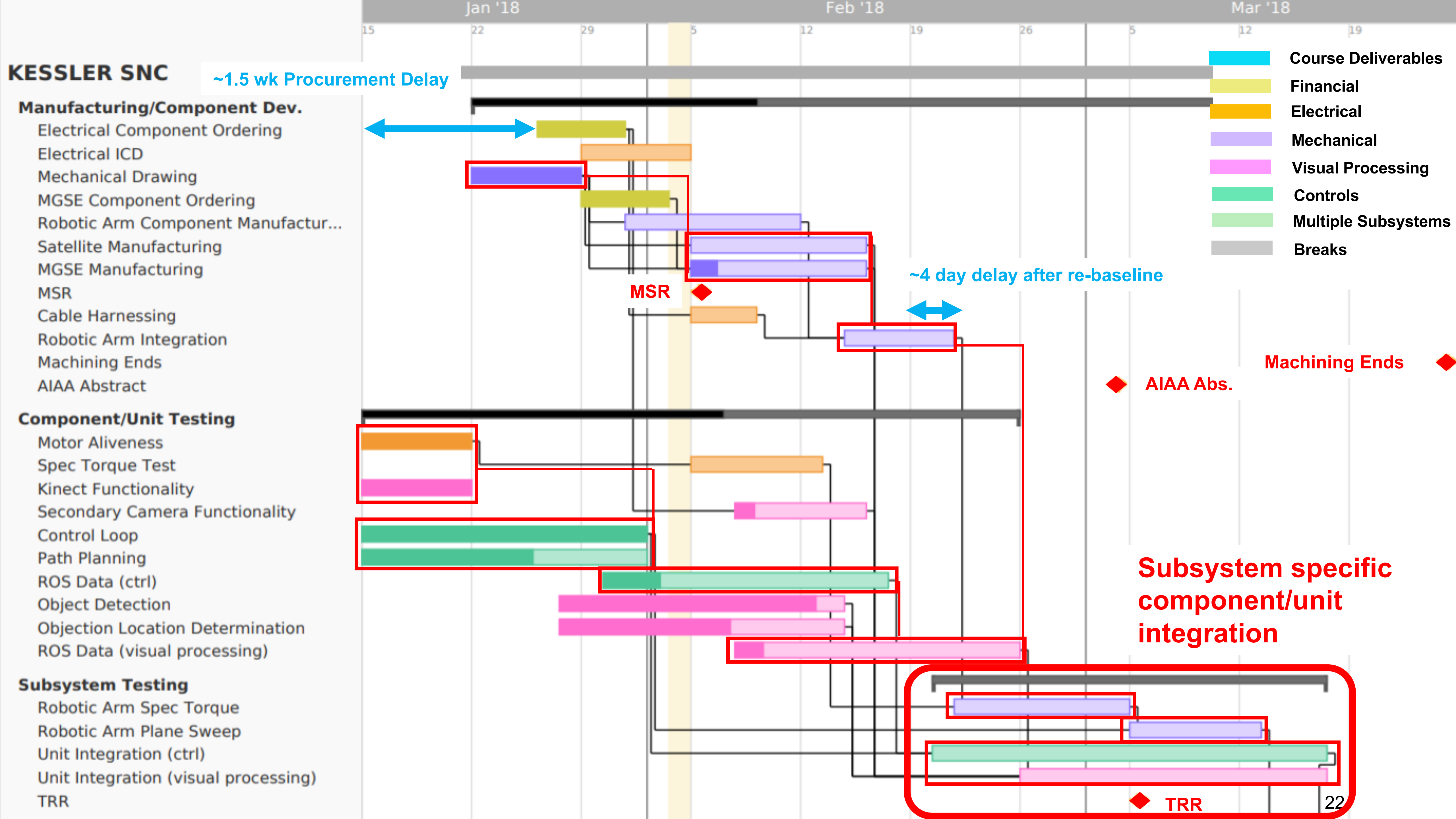

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Financial
Electrical
Mechanical
Visual Processing
Controls
Multiple Subsystems
Breaks
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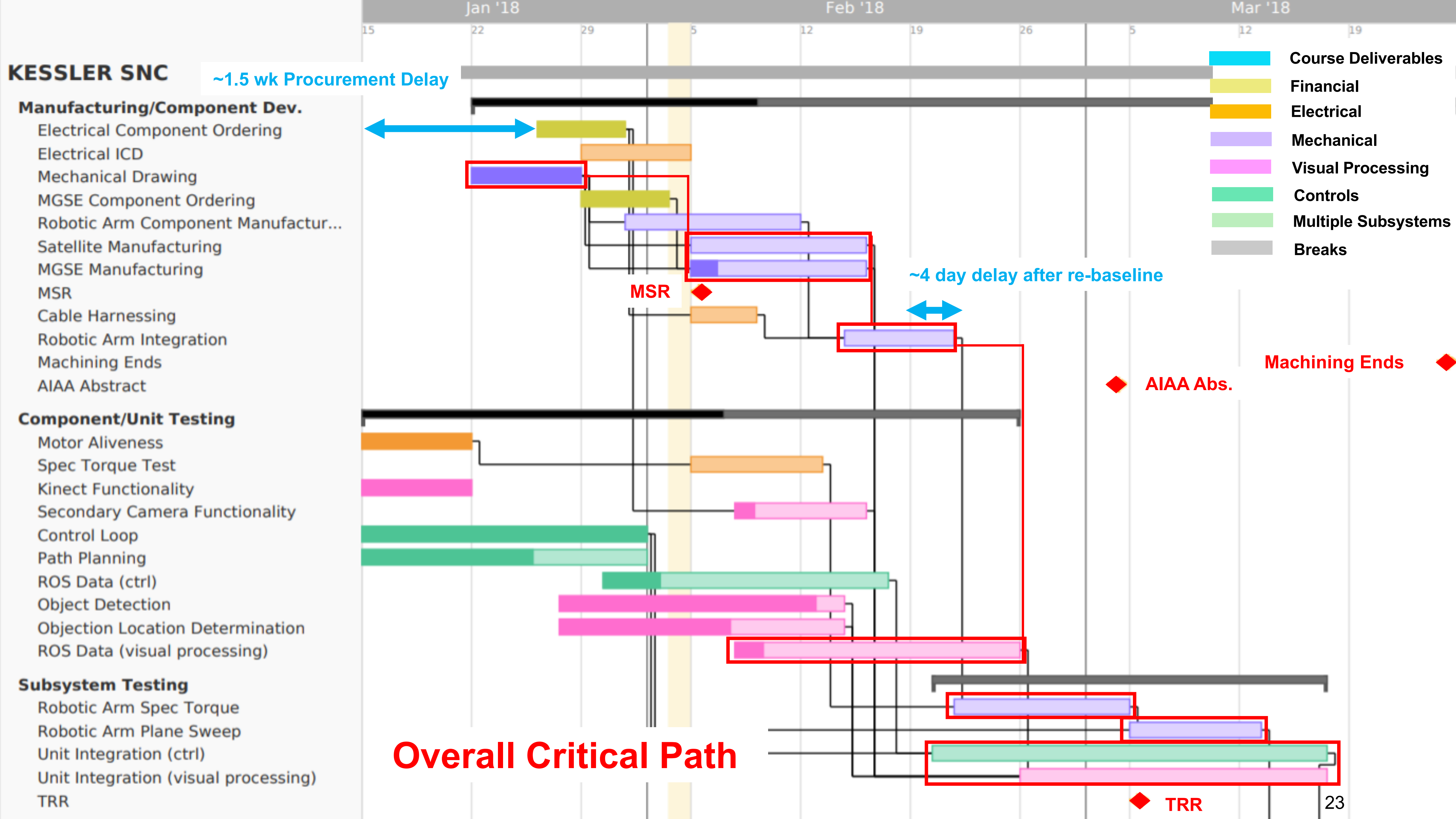
MSR
Machining Ends
AIAA Abs.
Subsystem specific component/unit integration
TRR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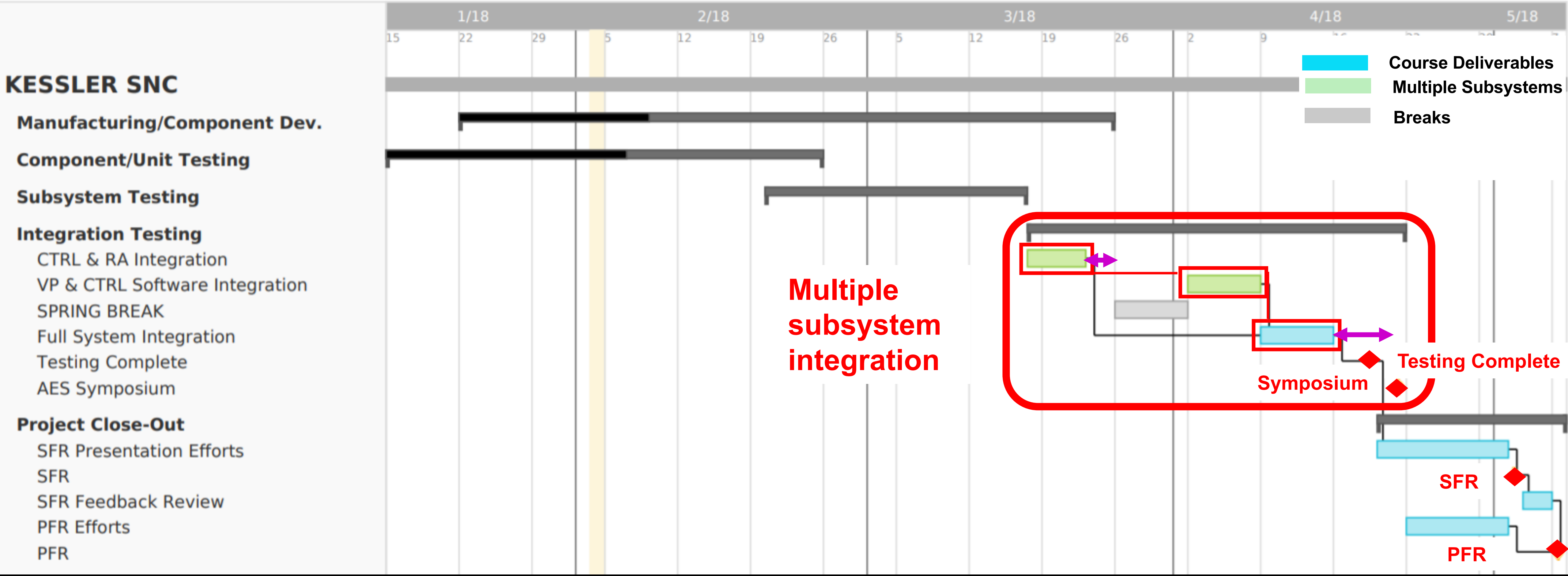
MSR
Machining Ends
AIAA Abs.
Overall Critical Path
TRR



Current Schedule is planned with 1.5 week margin.

- 1 week net margin
- 0.5 week conservative scheduling for integration
- Spring Break not counted but usable time (extra week)

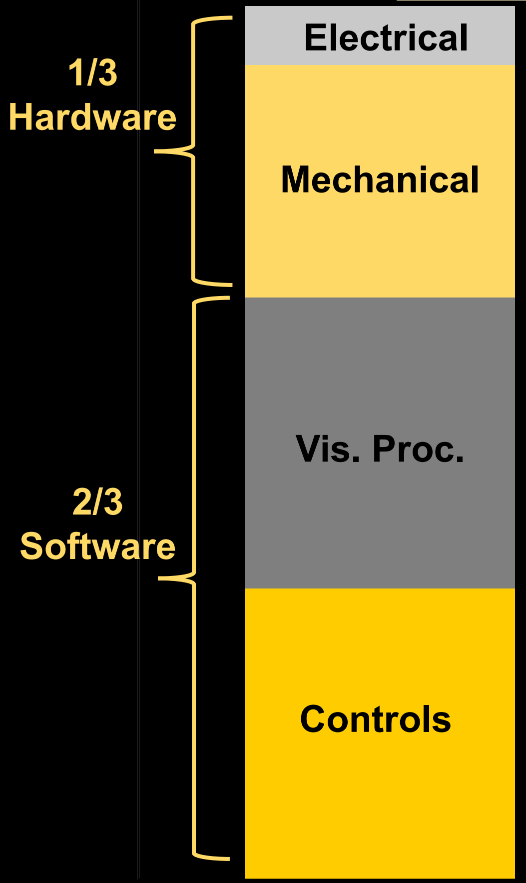
Project Overview | Schedule | Mech. | Elec. | Software: Controls | Software: Visual | Budget

Manufacturing Status

Project Overview | Schedule | Mechanical | Electrical | Software: Controls | Software: Vis. Proc. | Budget

System Status Overview

KESSLER efforts are split between Hardware & Software

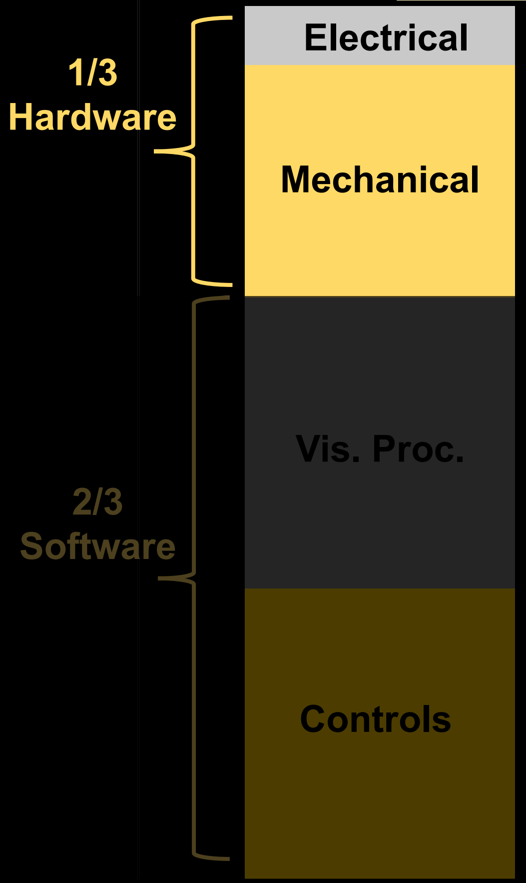


Subsystem Level of Effort

- **Electrical**: Robotic arm actuators, visual processing sensor interface, electrical ground support equipment.
- **Mechanical**: Robotic arm, mechanical ground support equipment, and simulated satellite.
- **Visual Processing**: Identification of satellite and grappling feature. Sends position, orientation, and satellite 3D point cloud.
- **Controls**: Path planning and executing robotic arm control.

Hardware Status Overview

KESSLER efforts are split between Hardware & Software



Subsystem Level of Effort

Mechanical

- 20% Scale Iridium Satellite
- Iridium Satellite
- Arm addition/brackets
- Robotic Arm MGSE (stand)
- Iridium Satellite MGSE (stand)

Electrical

- Actuator Characterization — Actuator & Secondary Camera
- Arm Assembly Harnessing — CPU to: u-ctrlr, Kinect, & UART converter (actuators)
- Electrical Ground Support Equipment — Uniform lighting system, power to PC and Kinect
- Secondary Camera Interface Software
- Testbed 5

Project Overview | Schedule | Mech. | Elec. | Software: Controls | Software: Visual | Budget

Manufacturing: Hardware Mechanical

Mechanical: System Overview

Category	Finish	Status
Iridium Satellite	2/16	Behind
Arm Additions	2/16	Early
Arm Stand	2/23	On Time
Satellite Stand	2/28	On Time

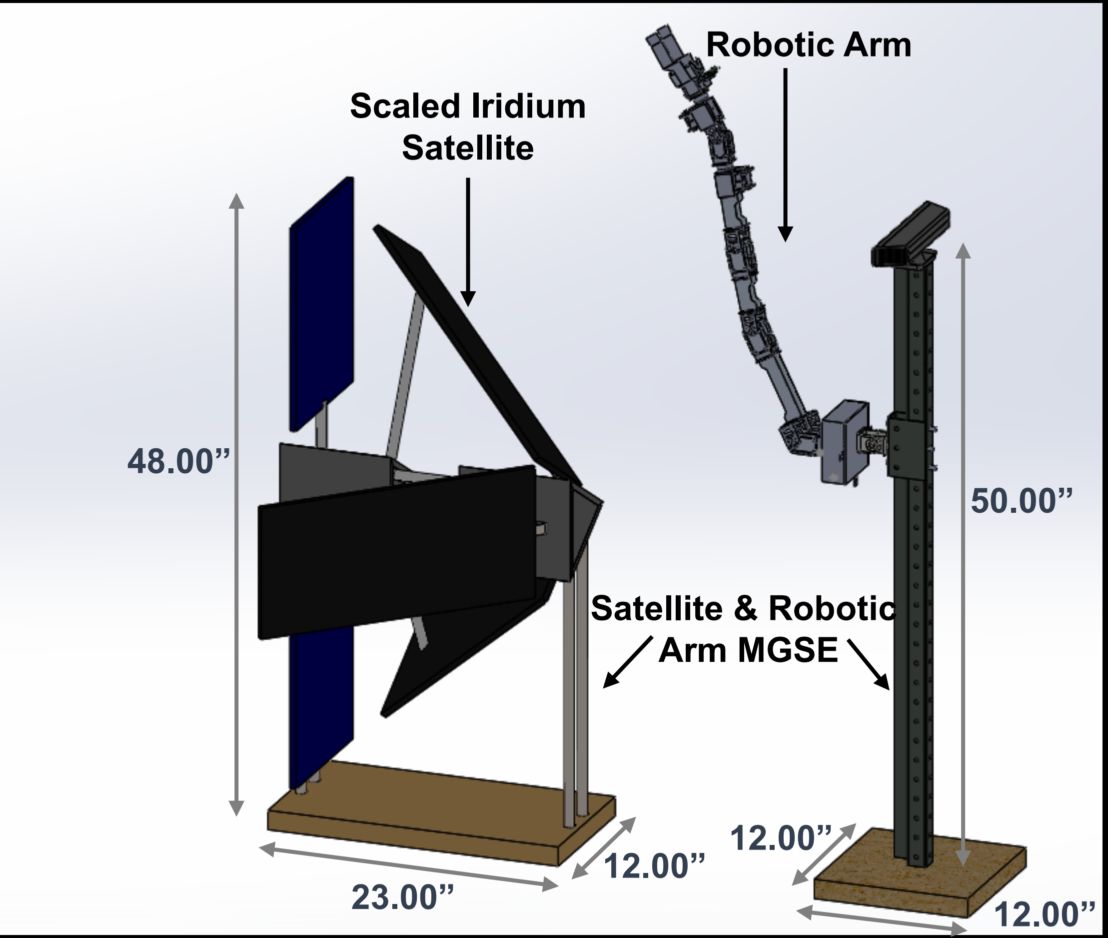


Fig. 4 KESSLER Mechanical Design

Project Overview | Schedule | **Mech.** | Elec. | Software: Controls | Software: Visual | Budget

Hardware Status: Iridium Satellite

Schedule Status: Behind

- Total Schedule Slip: 1 Week
  - Requires Manufacturing in Parallel
  - Recovery Date: February 19th

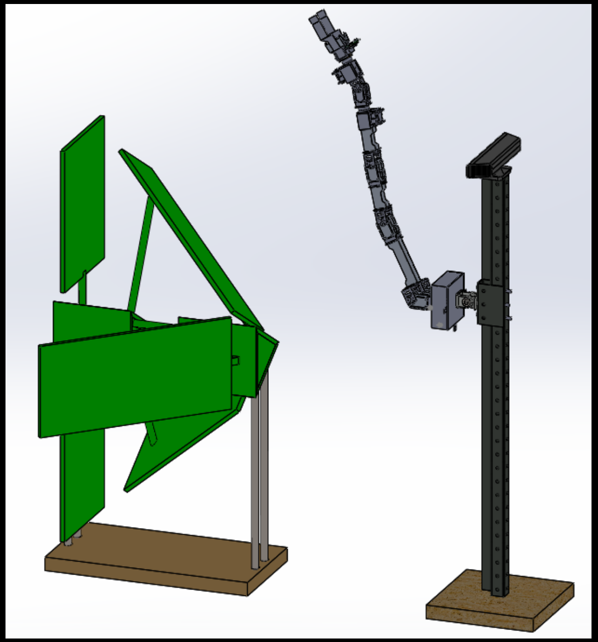


Fig. 5 Iridium Satellite Model

Category	Task	Modeling			Build			Integration	
Status		Design	CAD	3D Print	Procured	Machined	Assembled	Inspection	Delivery
Model Iridium Satellite	Body								
	Panels								
	Antenna								
	BUS								

Modeled

Built

Integrated

Planned 02/05

Project Overview | Schedule | **Mech.** | Elec. | Software: Controls | Software: Visual | Budget

Hardware Status: Robotic Arm

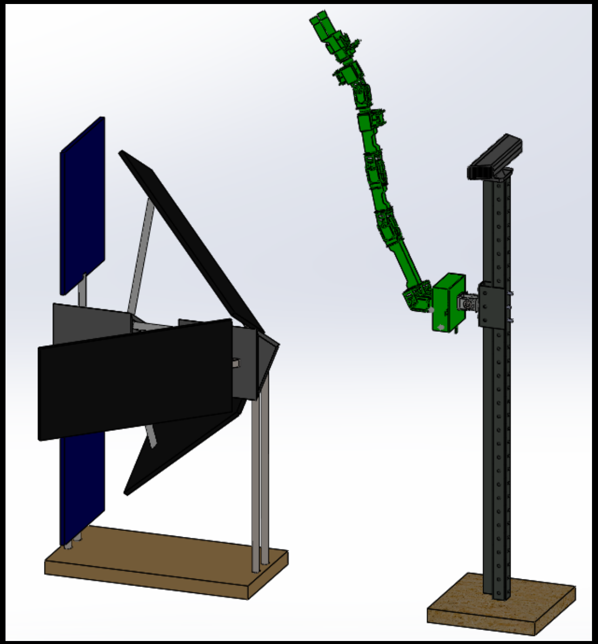


Fig. 6 Robotic Arm

Schedule Status: Ahead

- Total Schedule Slip: 0 Weeks
  - Donated Aluminum (AES Dept.)
  - COTS Crust Crawler Parts

Category	Task	Modeling			Build			Integration	
Status		Design	CAD	Cam Model	Procured	Machined	Assembled	Inspection	Delivery
Robotic Arm	Girders								
	Servos								
	ArduCam								
	Turntable								

Modeled
Built
Integrated
Planned 02/05

Project Overview | Schedule | **Mech.** | Elec. | Software: Controls | Software: Visual | Budget

Hardware Status: Support Stands

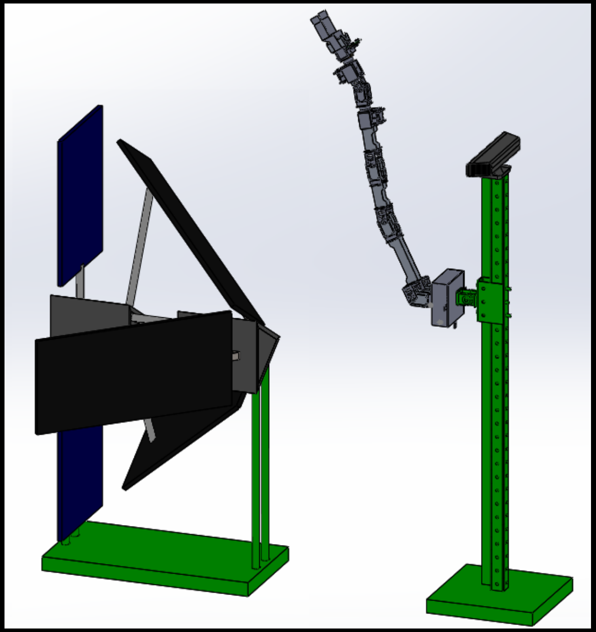


Fig. 7 Support Stands

Schedule Status: On Schedule

- Total Schedule Slip: 0 Weeks
  - Delivered Before Required Deadline
  - Low Time Commitment

Category	Task	Modeling			Build			Integration	
Status		Design	CAD	3D Print	Procured	Machined	Assembled	Inspection	Delivery
Arm Stand	Tubing								
	Base								
Satellite Stand	Rods								
	Base								

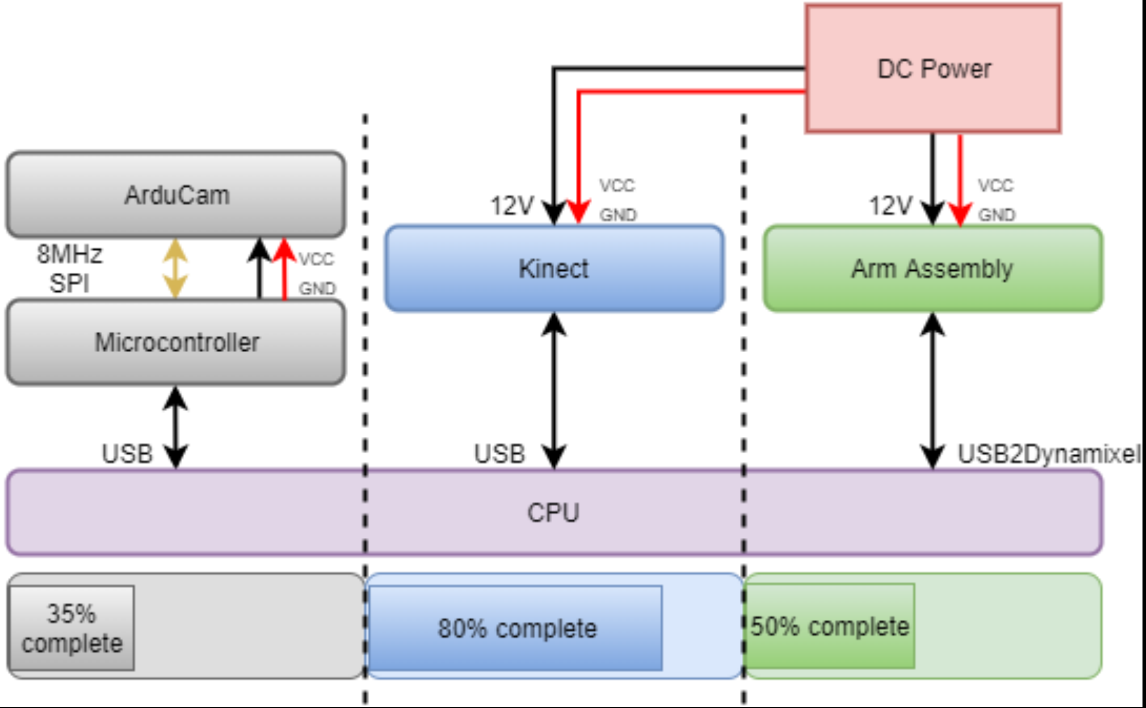
Modeled
Built
Integrated
Planned 02/05

Manufacturing: Hardware Electrical

Electrical: Overview

Electronics Hardware Housing and Integration

- ArduCAM / Microcontroller - purchased and received
- Kinect - heritage
- Arm Assembly - heritage, purchased but not received



Category	Critical Path Requirement	Status
ArduCam & MCU Assembly	Medium	On Schedule
Kinect	Low	On Schedule (Completed)
Arm Assembly Harnessing	High	On Schedule (Pending Early!)
Servo Torque Testing	Medium	On Schedule

Project Overview | Schedule | Mech. | **Elec.** | Software: Controls | Software: Visual | Budget

Electrical Status

- Hardware Status: On Schedule

Modelled | Integrated | Planned 02/05

Category	Design			Build			Integration	
Status	Power Line	Signal Line	Harnessing	Procured	Machined	Assembled	Inspection	Delivery
Arm Assembly								
ArduCam Assembly								

- Software Status: On Schedule

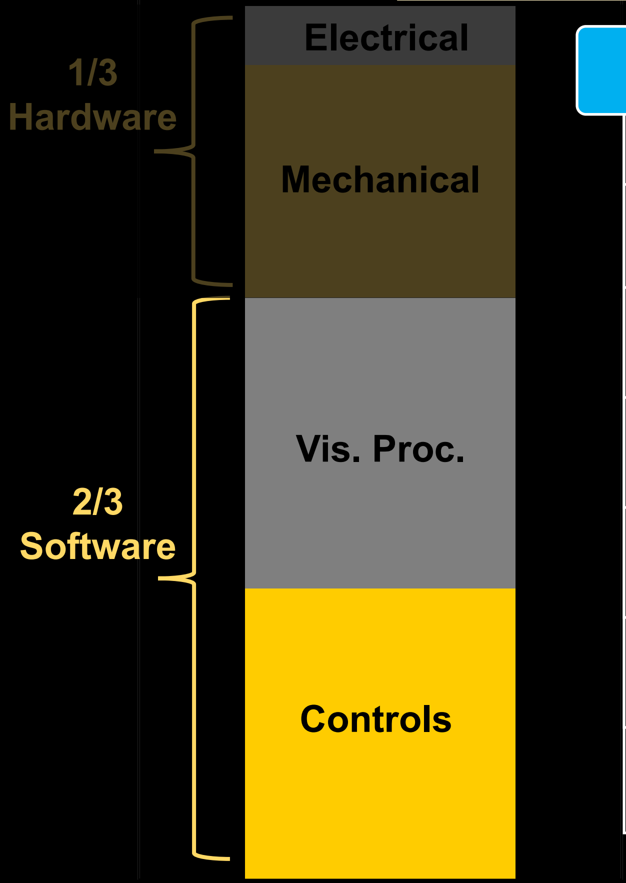
Built | Integrated | Planned 02/05

Category	Pseudo Code			Development			Integration	
Status	Flow	Open Source	Skeleton	SPI	I2C	Assembled	Testing	Delivery
ArduCam Assembly								

Project Overview | Schedule | Mech. | **Elec.** | Software: Controls | Software: Visual | Budget

Software Status Overview

KESSLER efforts are split between Hardware & Software



Subsystem Level of Effort

Controls

- Software Concept of Operations — Write motion planning
- Robot workspace analysis — Integrate motion planning
- Robot orientation analysis — Write controllers
- Robot mech./drifting error analysis — Integrate controllers
- Robot joint-link configuration — Write watchdog
- Control loop/motion planning timing — Integrate watchdog
- CAD to ROS Description — ROS data configuration

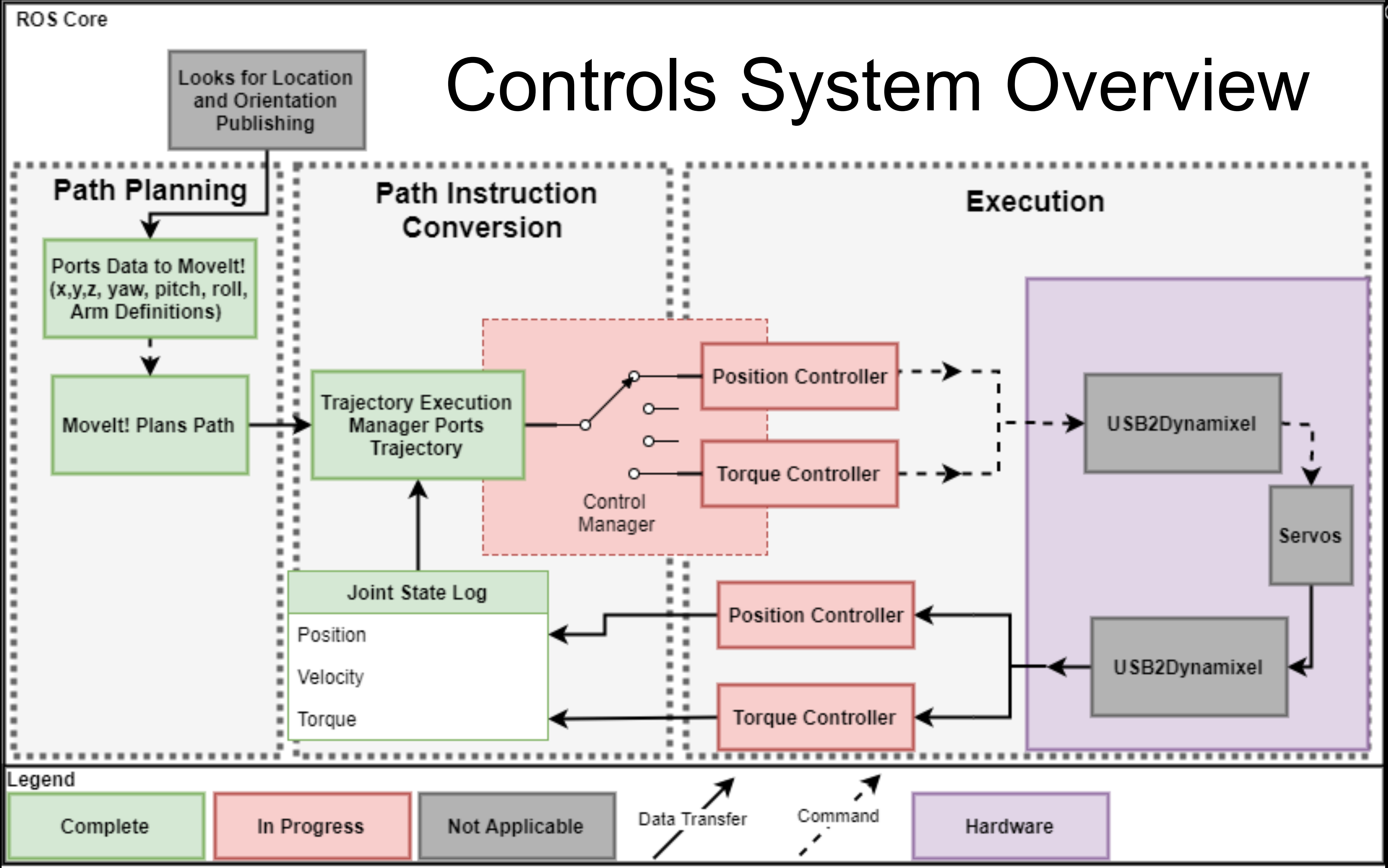
Visual Processing

- Image Capture
- Identify Satellite in FOV
- Identify features (RGB)
- Find feature orientation
- Identify Closest Feature
- Determine grappling location
- Send Data to Controls

Manufacturing: Software Controls

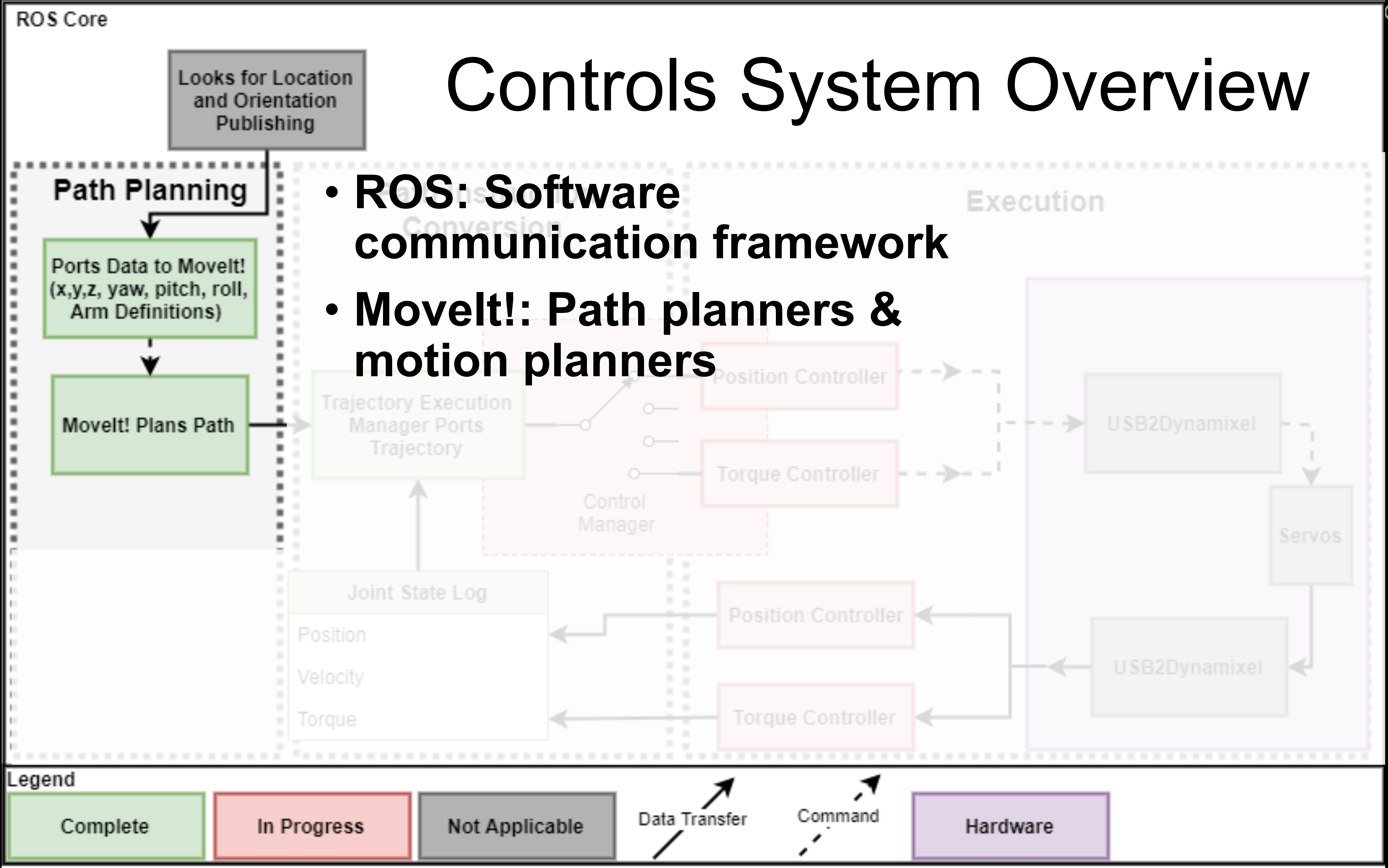
Project Overview | Schedule | Mechanical | Electrical | **Software: Controls** | Software: Visual | Budget

Controls System Overview



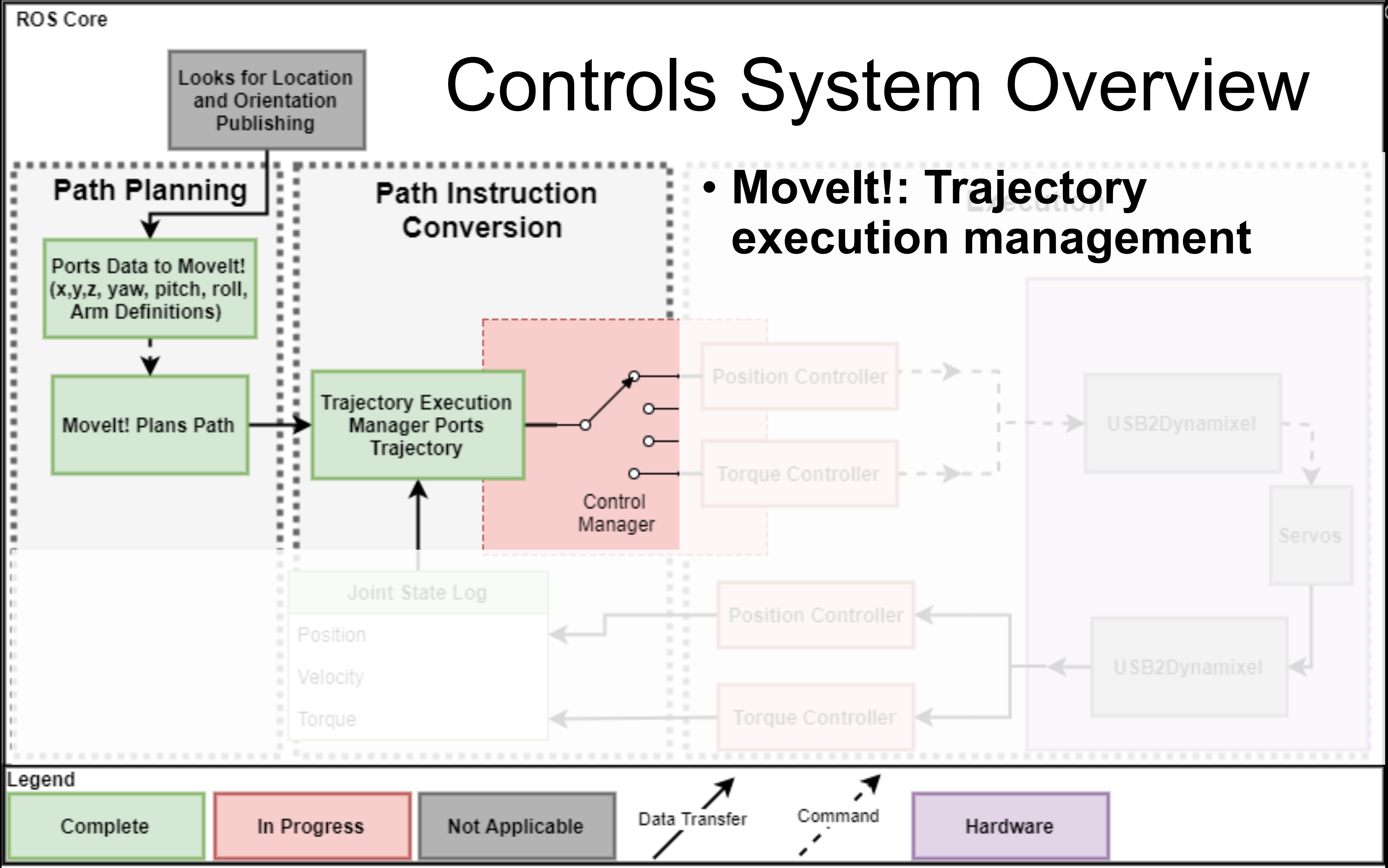
Controls System Overview

- **ROS: Software communication framework**
- **MoveIt!: Path planners & motion planners**

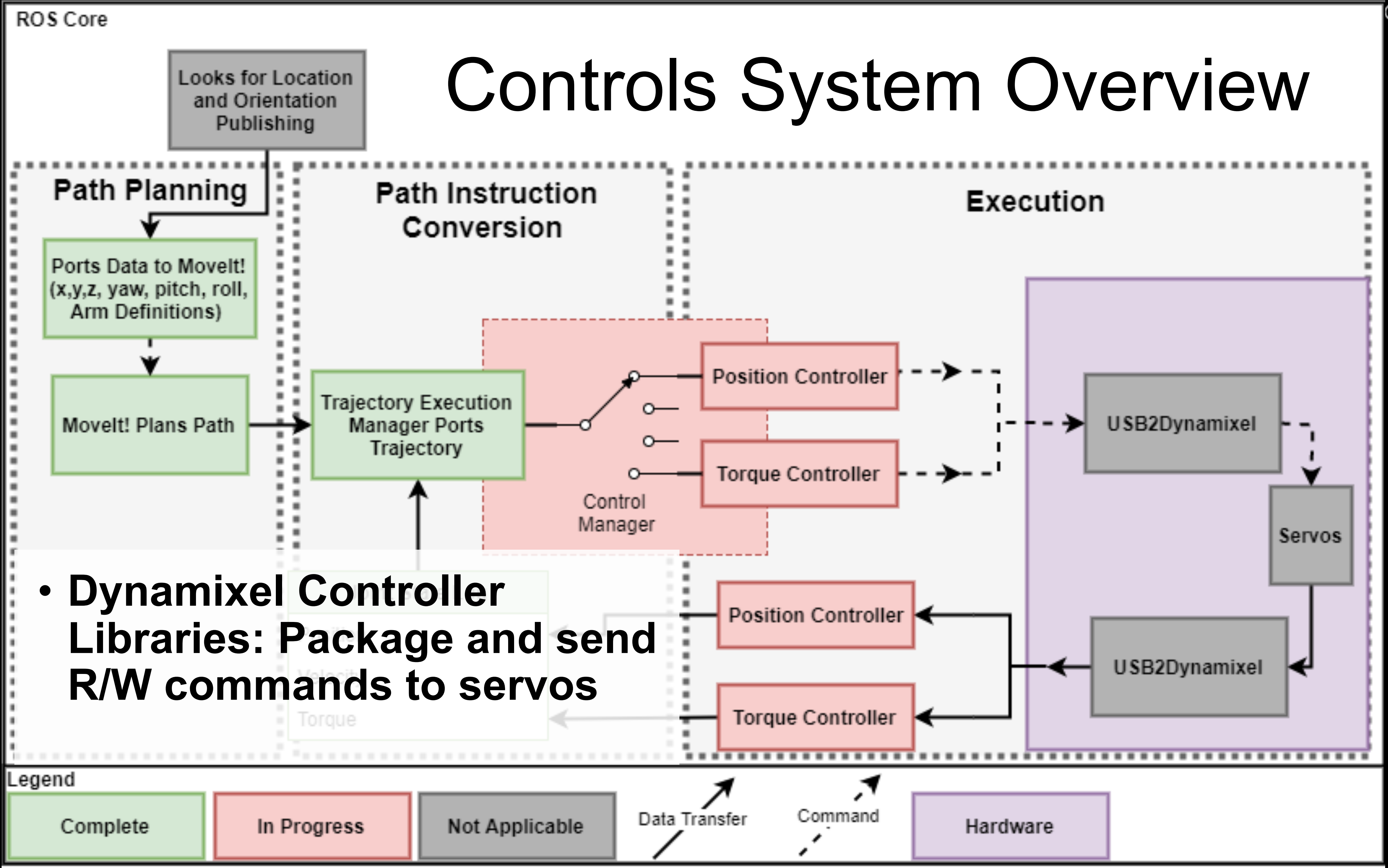


Controls System Overview

- **MoveIt!: Trajectory execution management**



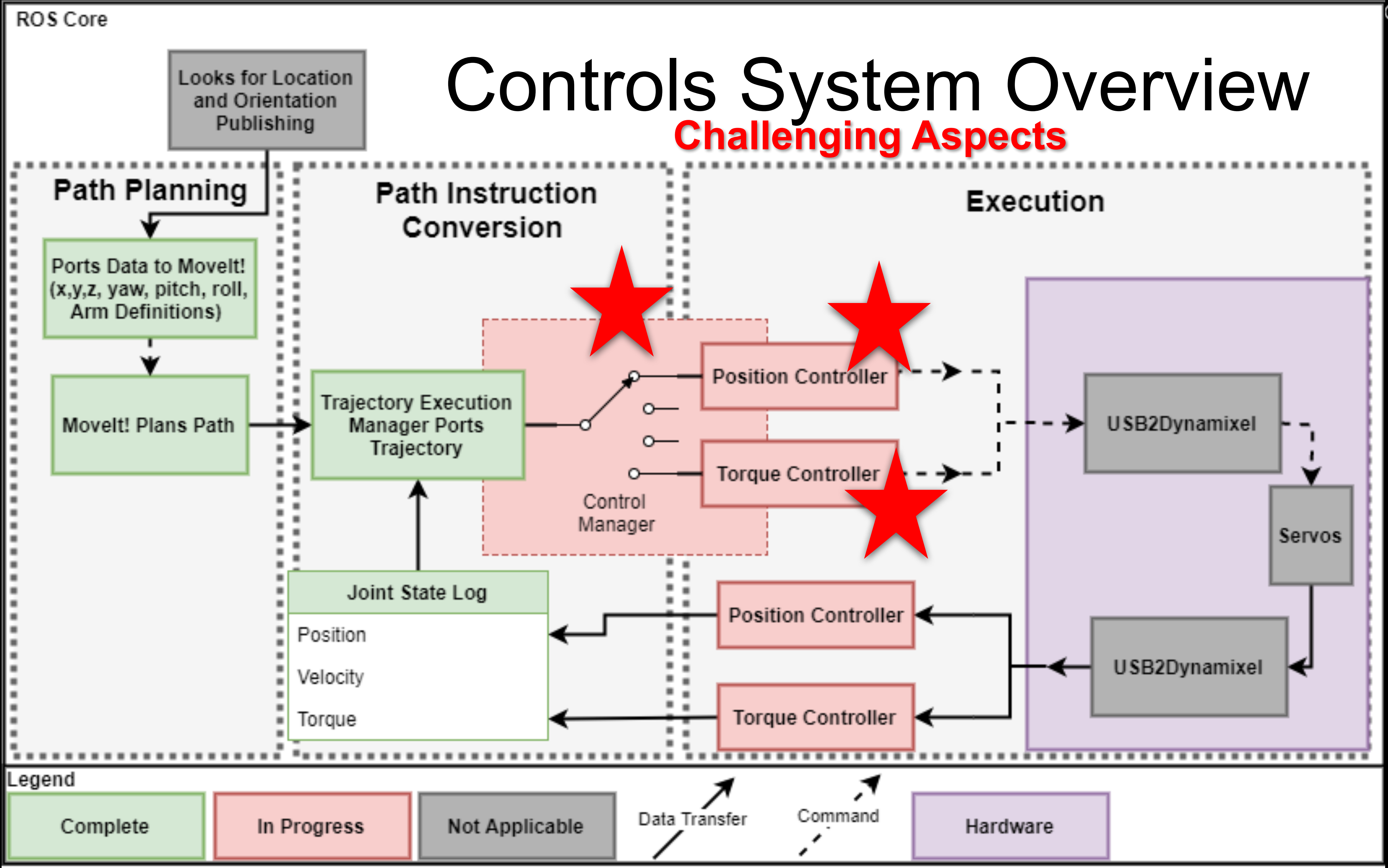
Controls System Overview



- **Dynamixel Controller Libraries: Package and send R/W commands to servos**

Controls System Overview

Challenging Aspects



Software Status

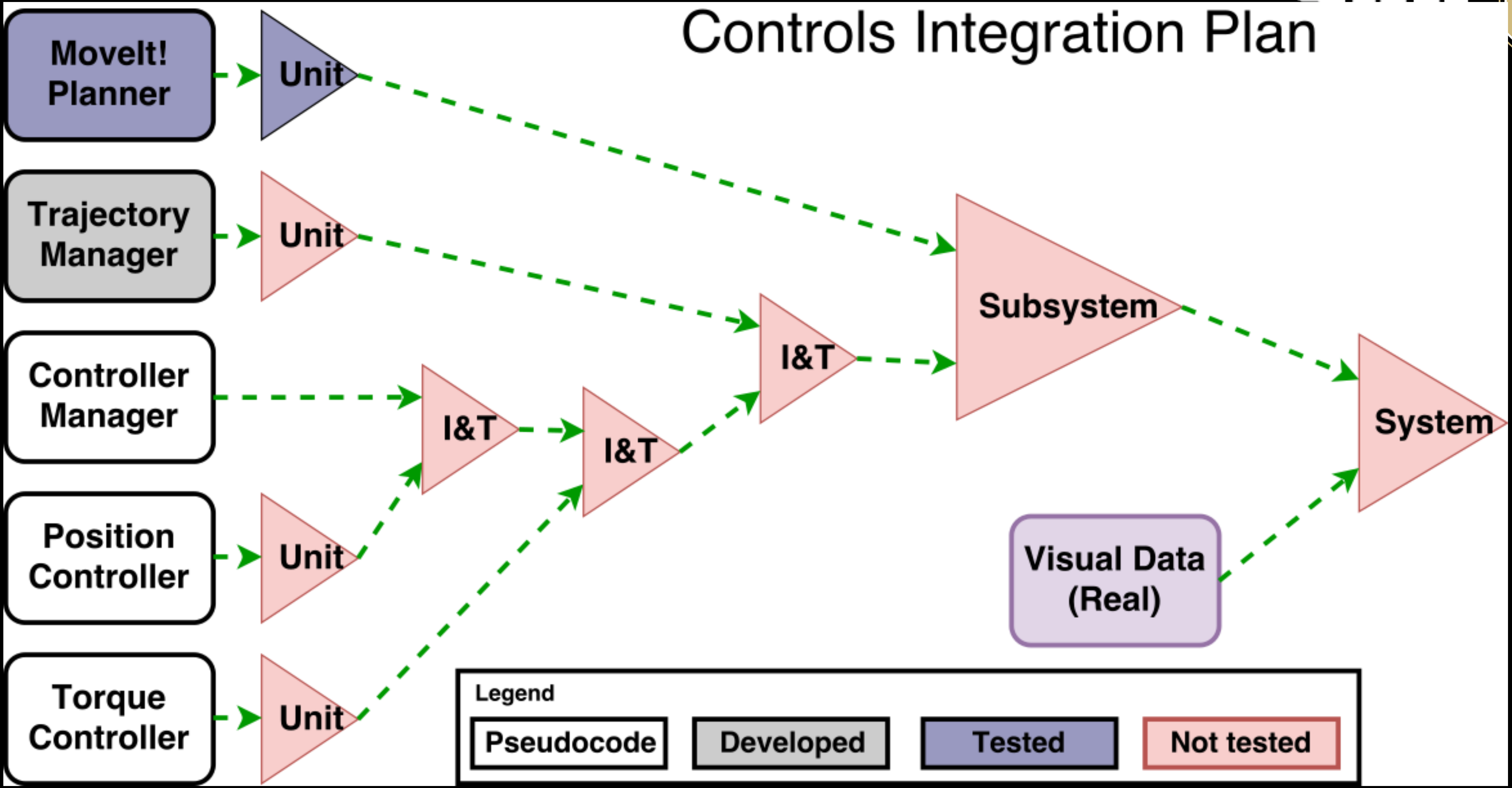
Task	Pseudocode	Development	Testing	Integration
Controller Manager				
Torque Controller				
Position Controller				
Test Framework				
ROS Data Network				
Path Planning				

Most difficult → **Least difficult**

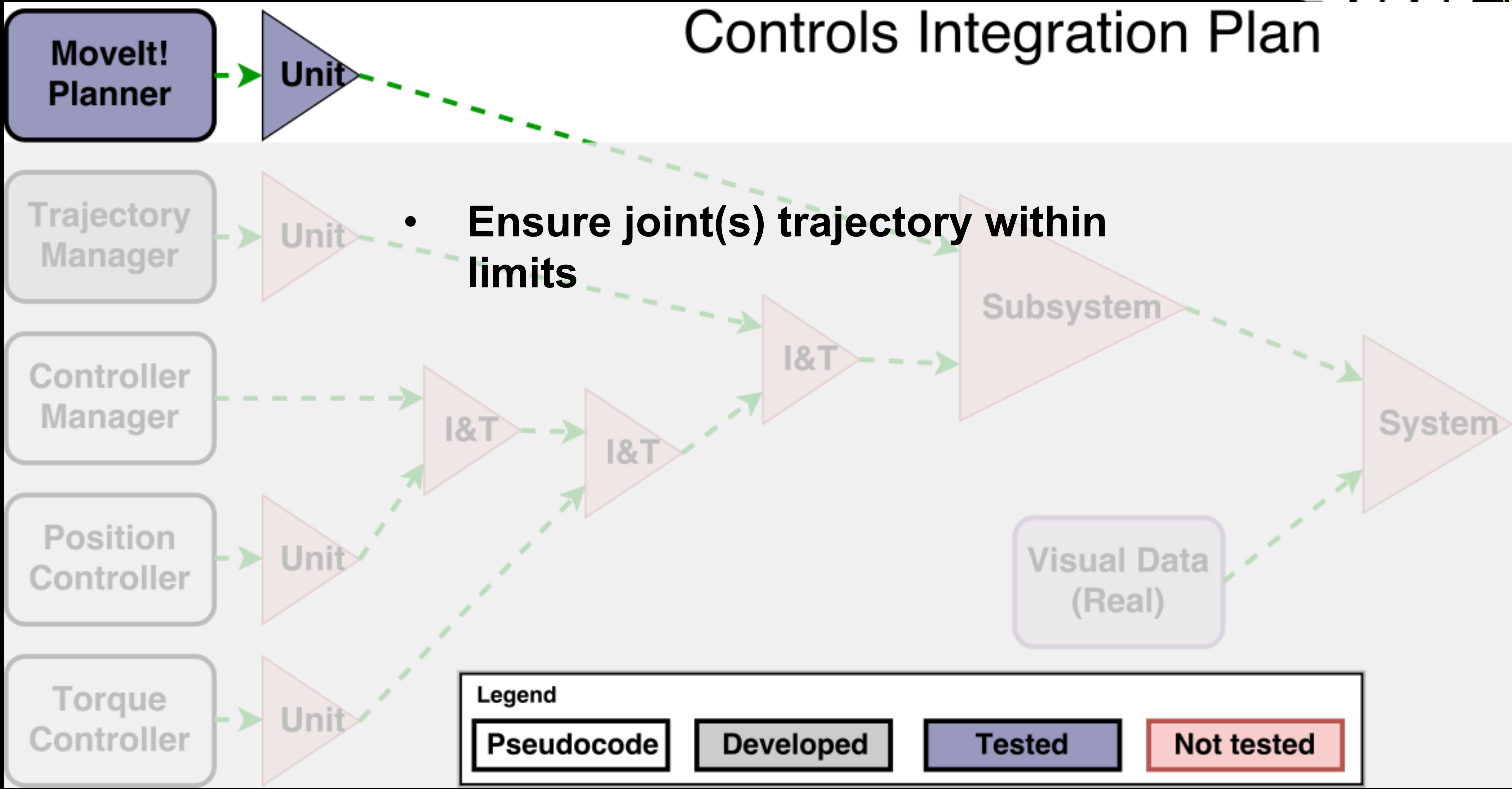
Pseudocode
Developed
Tested
Integrated
Planned 02/05

Project Overview | **Schedule** | **Mech.** | **Elec.** | **Software: Controls** | **Software: Visual** | **Budget**

Controls Integration Plan

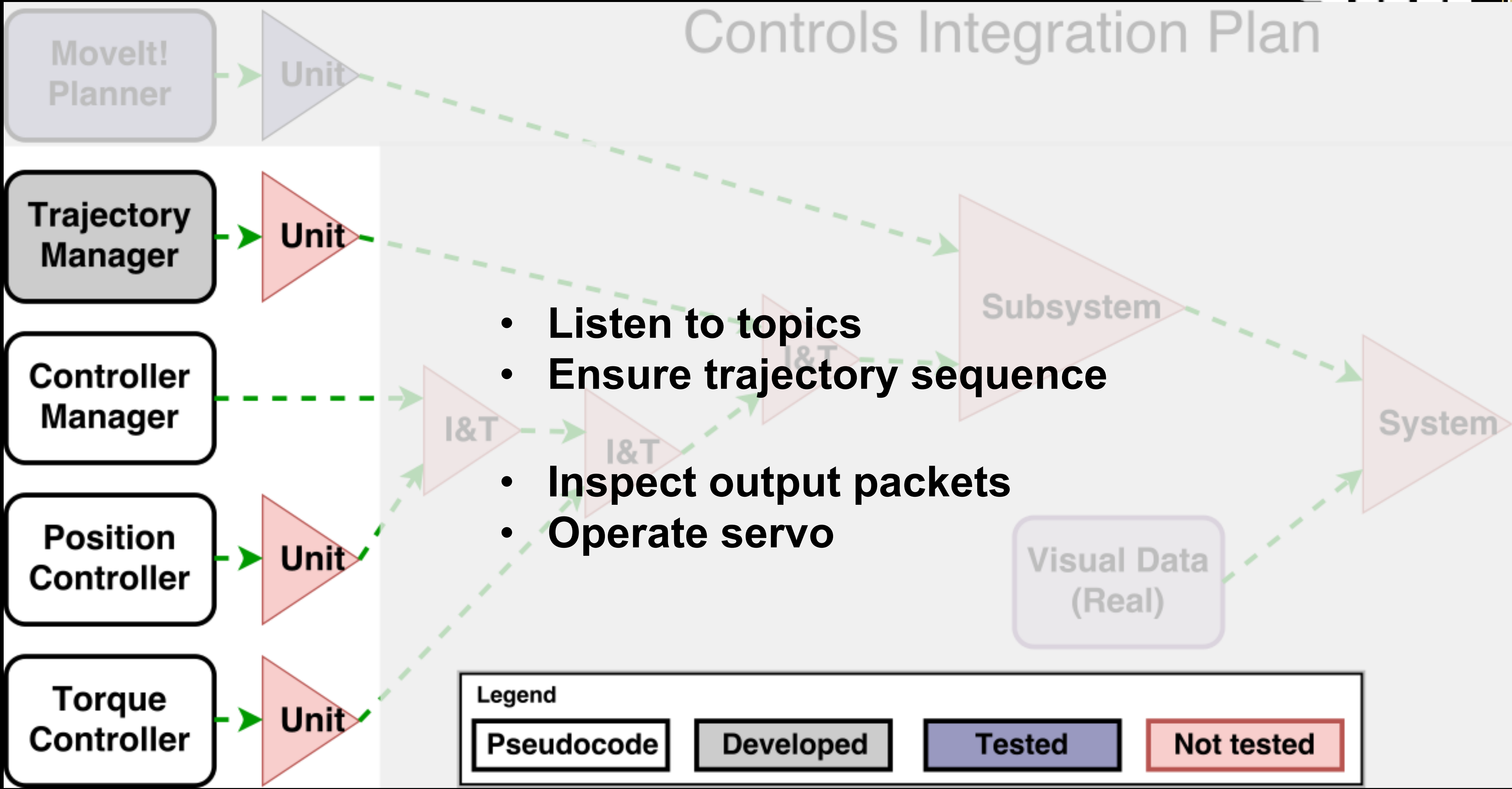


Controls Integration Plan



- **Ensure joint(s) trajectory within limits**

Controls Integration Plan

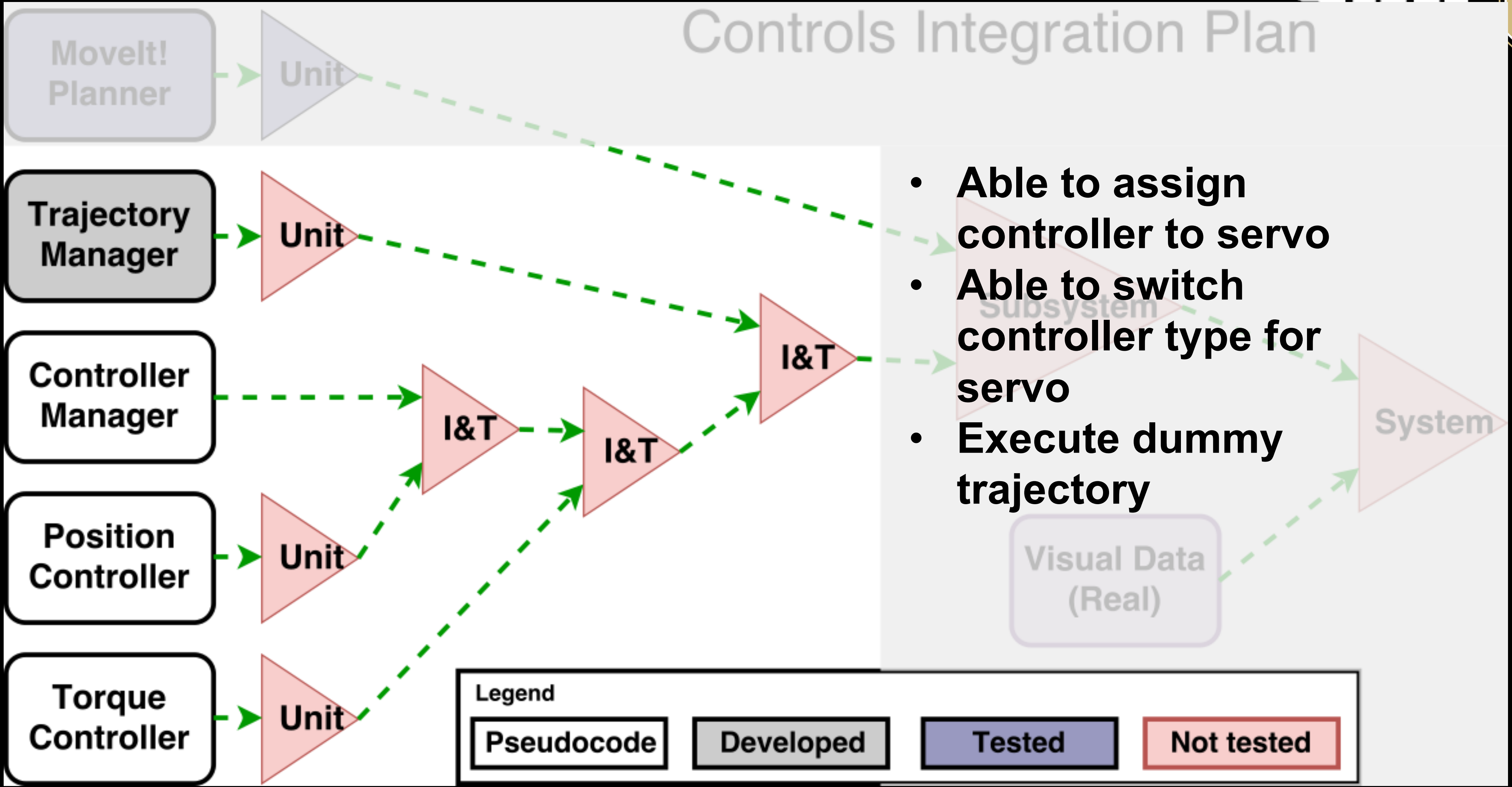


- **Listen to topics**
- **Ensure trajectory sequence**

- **Inspect output packets**
- **Operate servo**

Project Overview | Schedule | Mech. | Elec. | Software: Controls | Software: Visual | Budget

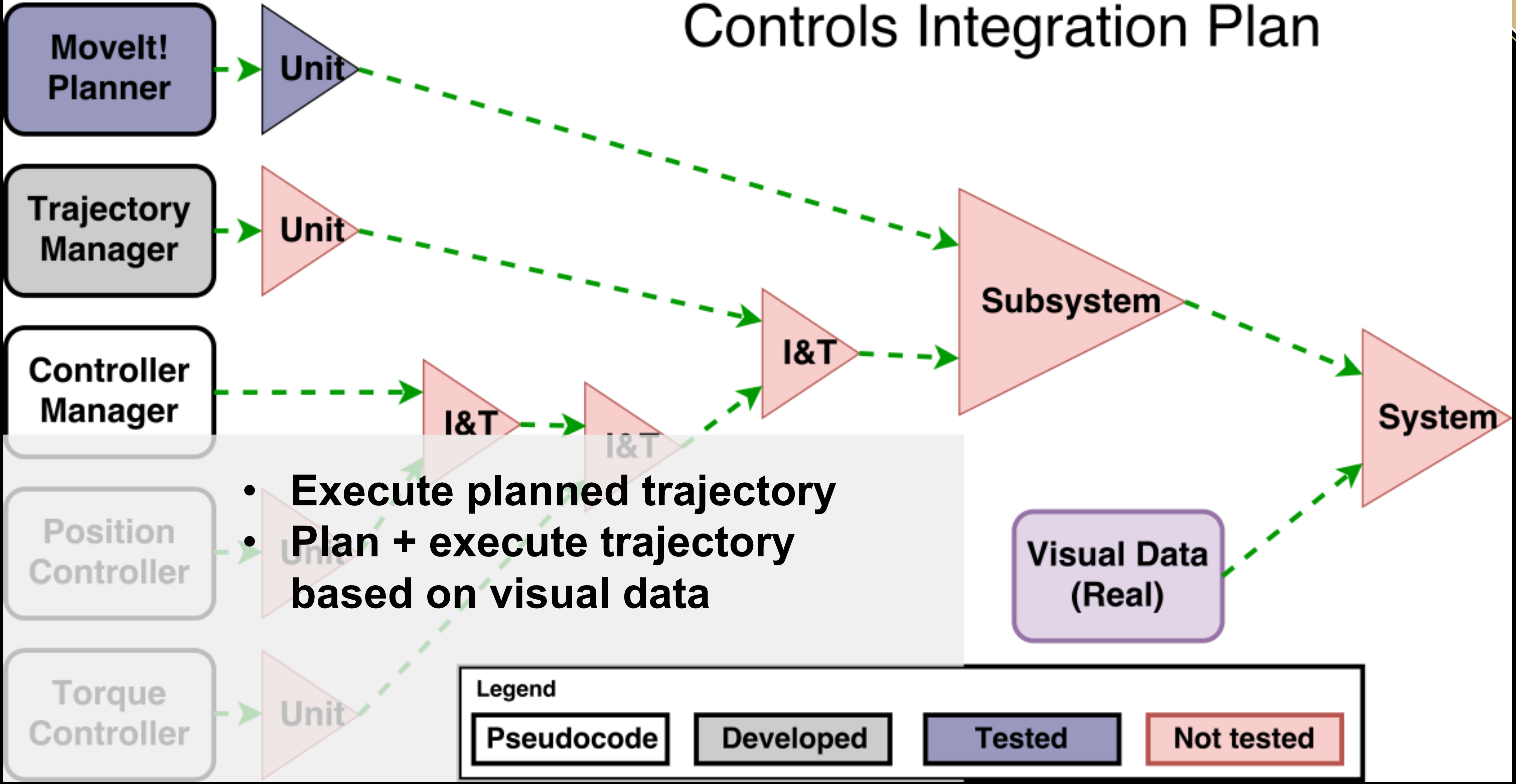
Controls Integration Plan



- Able to assign controller to servo
- Able to switch controller type for servo
- Execute dummy trajectory

Project Overview | Schedule | Mech. | Elec. | Software: Controls | Software: Visual | Budget

Controls Integration Plan



- Execute planned trajectory
- Plan + execute trajectory based on visual data

Manufacturing: Visual Processing Software

Project Overview | Schedule | Mechanical | Electrical | Software: Controls | **Software: Visual** | Budget

Previous Software Flowchart

Take image with Kinect (2D and 3D) → Identify satellite in FOV with feature matching → **Identify features by feature matching** → Find location and orientation data

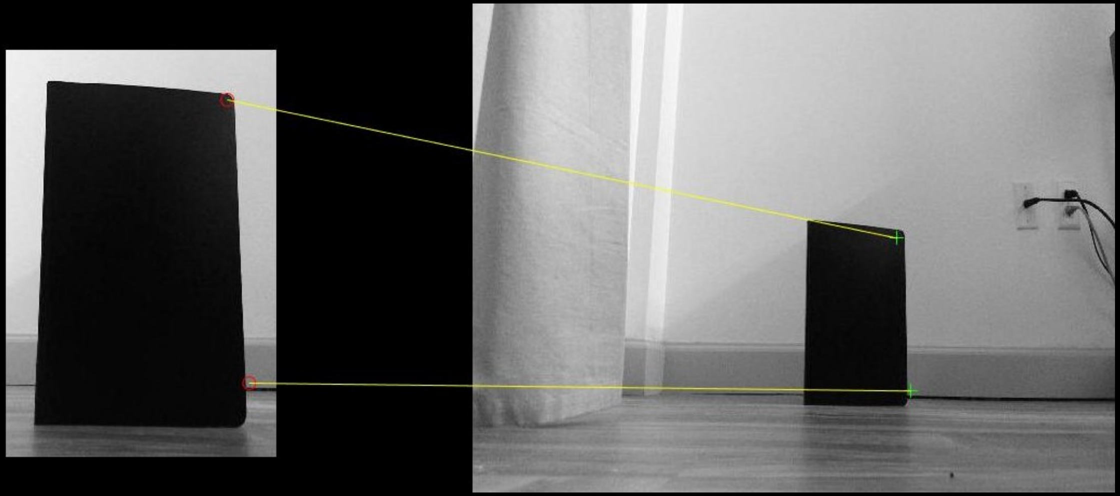


Fig. 8: Feature matching with simple shape

Reasoning for Change

- Features are too simple for feature detection
- Minimum of 3 points for match

Denotes Change (red)

Denotes No Change (yellow)

Updated Software Flowchart

1. Take image with Kinect (2D and 3D)
2. Identify satellite in FOV (using feature matching from fall 2017)
3. Identify features by color (set colors for features)
4. ★ Use geometry to find feature orientation (plane detection in MATLAB)
5. Identify closest feature (3D point cloud and found features)
6. Locate specific point to grapple (center of smallest dimension of selected feature)
7. Package location and orientation for controls (toolbox in MATLAB)

Challenging Aspect ★

Denotes Complete

Software Status

Most difficult

↓

Least difficult

Task	Pseudocode	Development	Testing	Integration
Plane detection				
Color matching				
Closest feature				
Grapple location				
Identify satellite				
Package Data				
Take image				

Pseudocode

Developed

Tested

Integrated

Planned 02/05

03/19/2018

Project Overview | **Schedule** | **Mech.** | **Elec.** | **Software: Controls** | **Software: Visual** | **Budget**

Color Matching

- Color attribute is 3 dimensional matrix (Red, Green, Blue)
- Unique combination of RGB values correlates to specific color
- Isolate certain RGB values to isolate features and recolor
  - Known colors for each feature

Solar Panels
Antennas
Bus structure

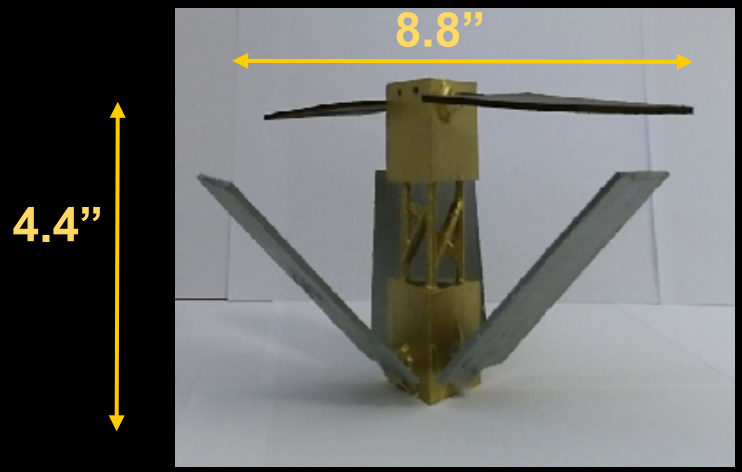


Fig. 9: Colored satellite model

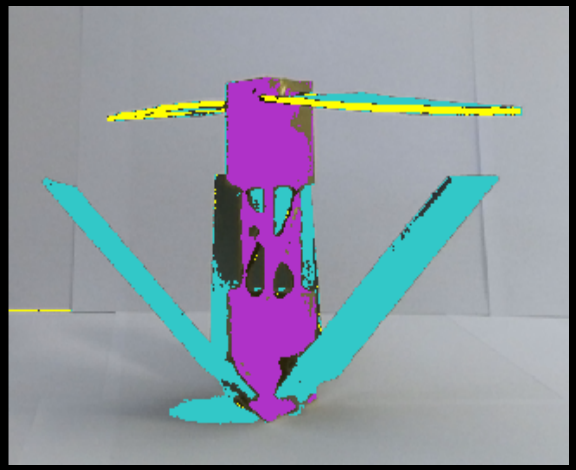


Fig. 10: Color processed satellite model

20% Scale model of satellite

3D Point Cloud Feature Identification

- Map color image to 3D point cloud
- Concern: Low density point cloud impedes detailed feature analysis
- Mitigation: Larger model to increases clarity of picture

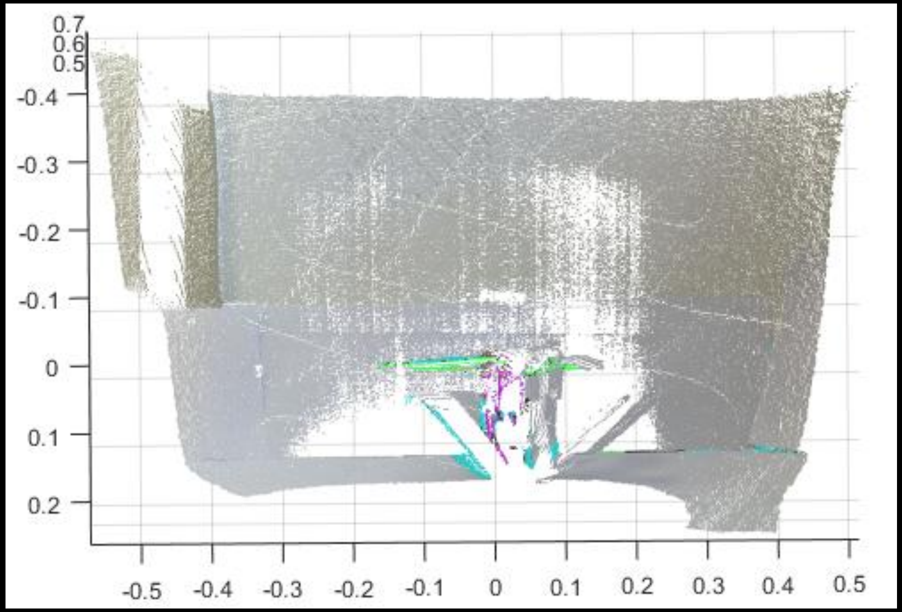


Fig. 11: Full colored point cloud with features

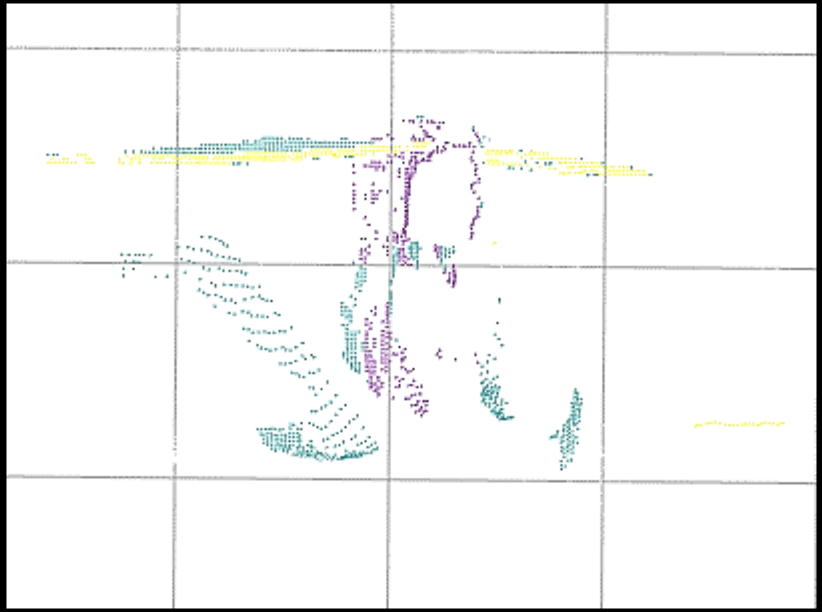


Fig. 12: Isolated satellite model point cloud

Project Overview | Schedule | Mech. | Elec. | Software: Controls | **Software: Visual** | Budget

Challenges

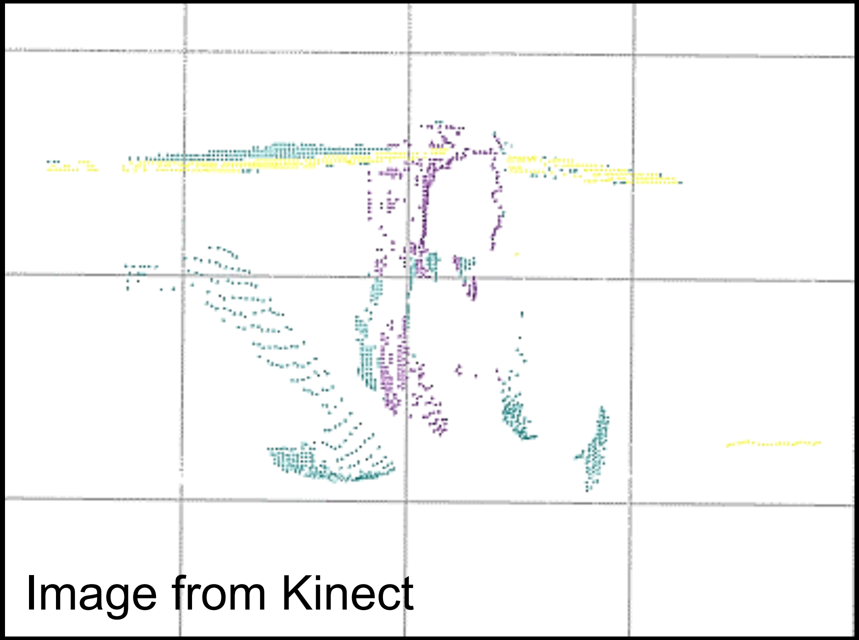


Fig. 13 : Point cloud of small satellite model

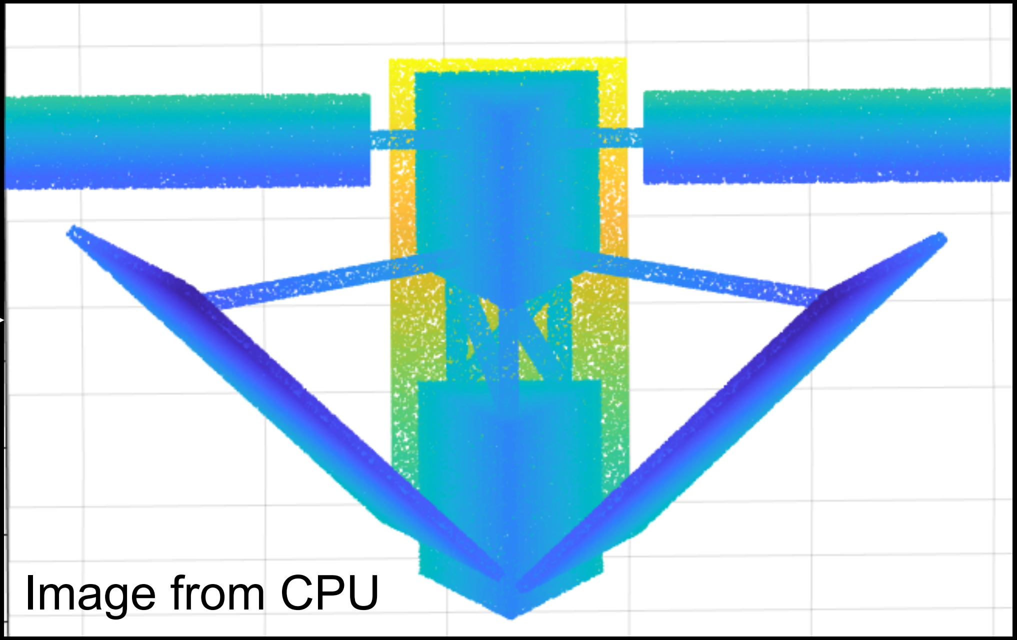


Fig. 14 : Point cloud from CAD model

- Mechanical delay postpones testing: one week delay
- Mitigation: Testing with 3D point cloud from CAD model: mitigated delay on 2/3/18, **back on schedule**

Project Overview | Schedule | Mech. | Elec. | Software: Controls | **Software: Visual** | Budget

Budget

Project Overview | Schedule | Mechanical | Software: Visual | Software: Controls | Electrical | **Budget**

Summary & Current Status

Starting Budget	$5,000.00
Subsystem Costs	
Mechanical	$1,072.10
Electrical	$23.35
Test & Safety	$742.16
Controls (Software)	$0.00
Visual Processing	$165.12
Misc.	$0.00
Total Cost	**$2002.73**
Remaining Budget	$2997.27

Updated: 2/3/2018

Subsystem	Overall Status
Mechanical	All items delivered
Electrical	Most items available, non-pivotal on order.
Test & Safety	Most items ordered, issues being resolved soon
Controls (Software)	N/A
Visual Processing	All items delivered
Misc.	N/A

Current Status: Nearly all items ordered and/or delivered.

Updated: 2/3/2018

Project Overview | Schedule | Mech. | Elec. | Software: Controls | Software: Visual | **Budget**

Updated Cost Plan

Starting Budget			$5,000.00
Subsystem Costs			
	Previously Spent	**Potential Future Expenses**	**Notes on Potential Future Expenses**
Mechanical	$1,072.10	$667.00 + $12.65 S&H	MX-64T servo, MX-28T servo, AX-12A servos (2), 5” Girder, Misc. screws
Electrical	$0.00	$350.00	3 pin DXL cable set, casing, shrink wrap, wire, harnessing
Test & Safety	$742.16	$20.00	Various fasteners
Controls (Software)	$0.00	$0.00	
Visual Processing	$165.12	$0.00	
Misc.	$0.00	$0.00	
Total Cost (Previous & Future)			**$3,029.03**
Remaining Budget			**$1,970.97**

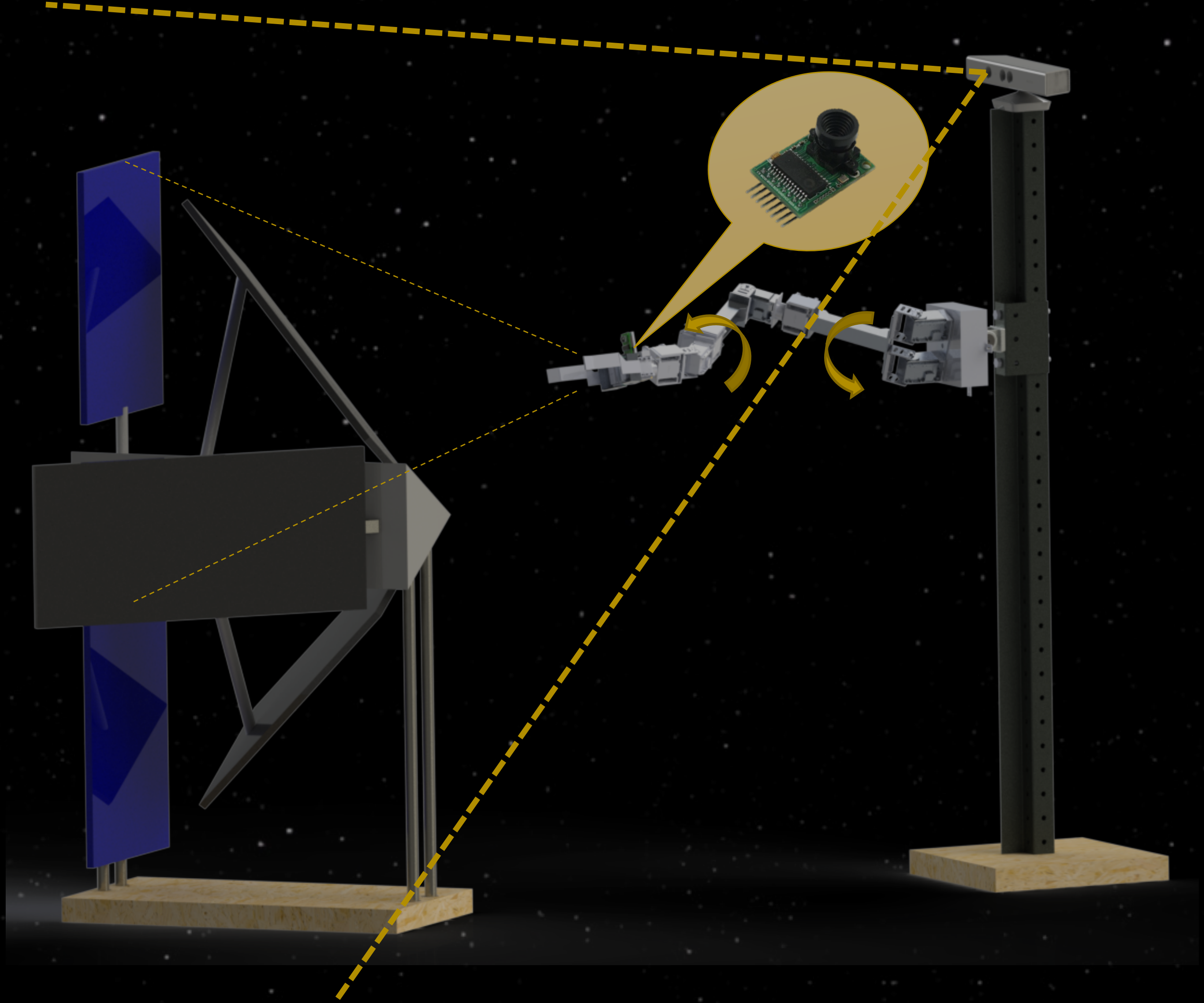
Updated: 2/3/2018

STATUS: 39% of allowed budget remaining

Project Overview | Schedule | Mech. | Elec. | Software: Controls | Software: Visual | **Budget**

Thank You!

Questions?



Backup Links

- Section 1
- Section 2
- Section 3 Mechanical
- Section 3 Electrical
- Section 3 Controls
- Section 3 Visual Processing
- Section 4

Section 1

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

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.

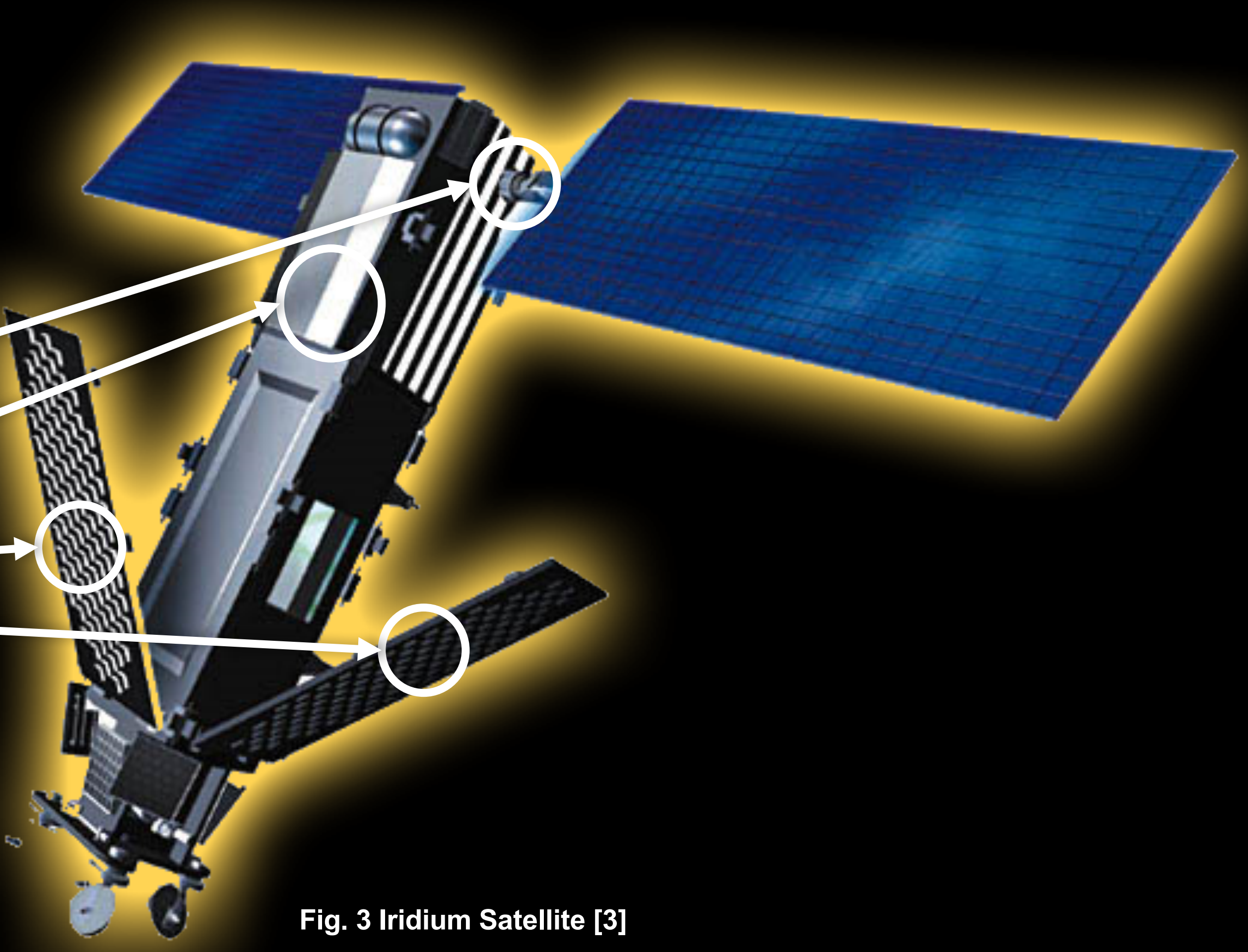


Fig. 3 Iridium Satellite [3]

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.

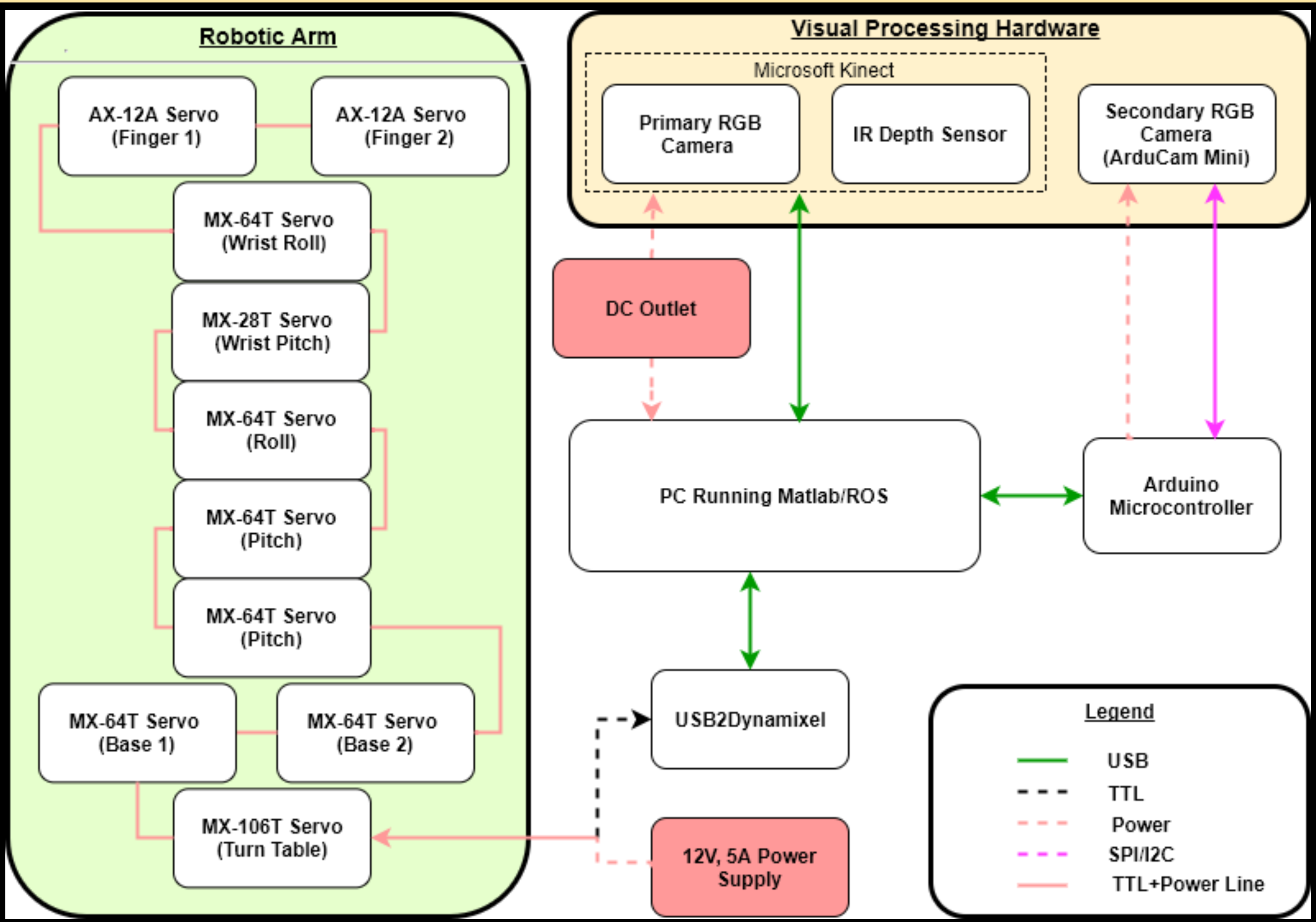
All assumptions are approved by project customer.

Proposed Design

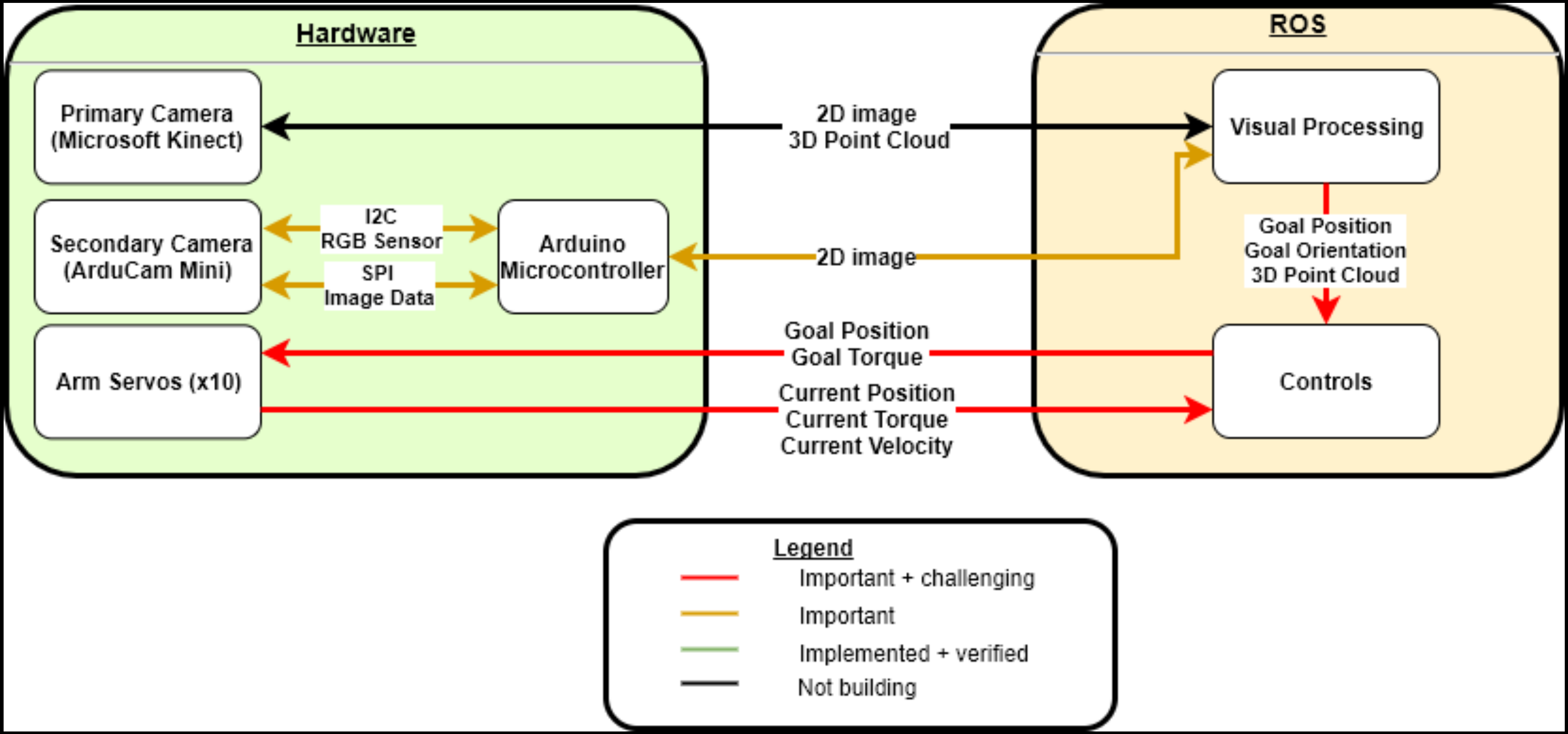
Functional Requirements

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

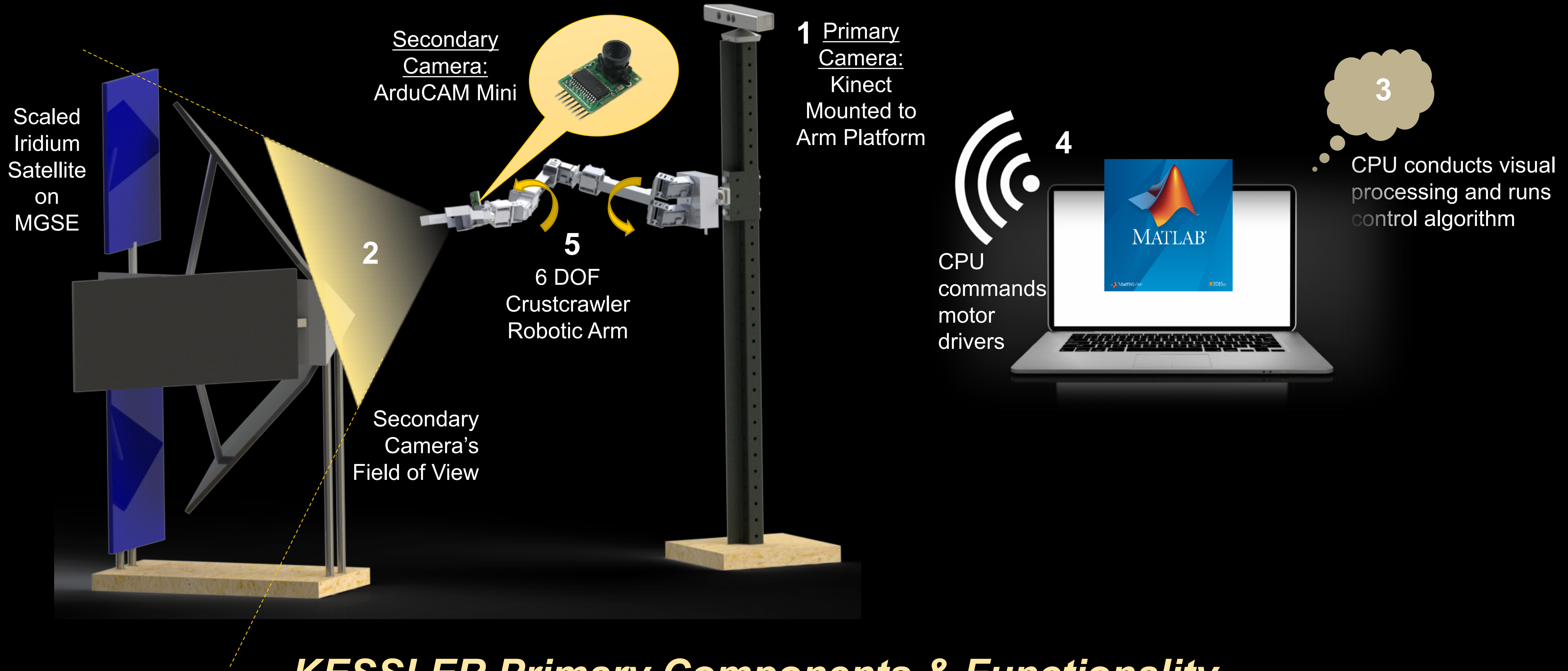
Hardware Interface



Hardware Data I/O

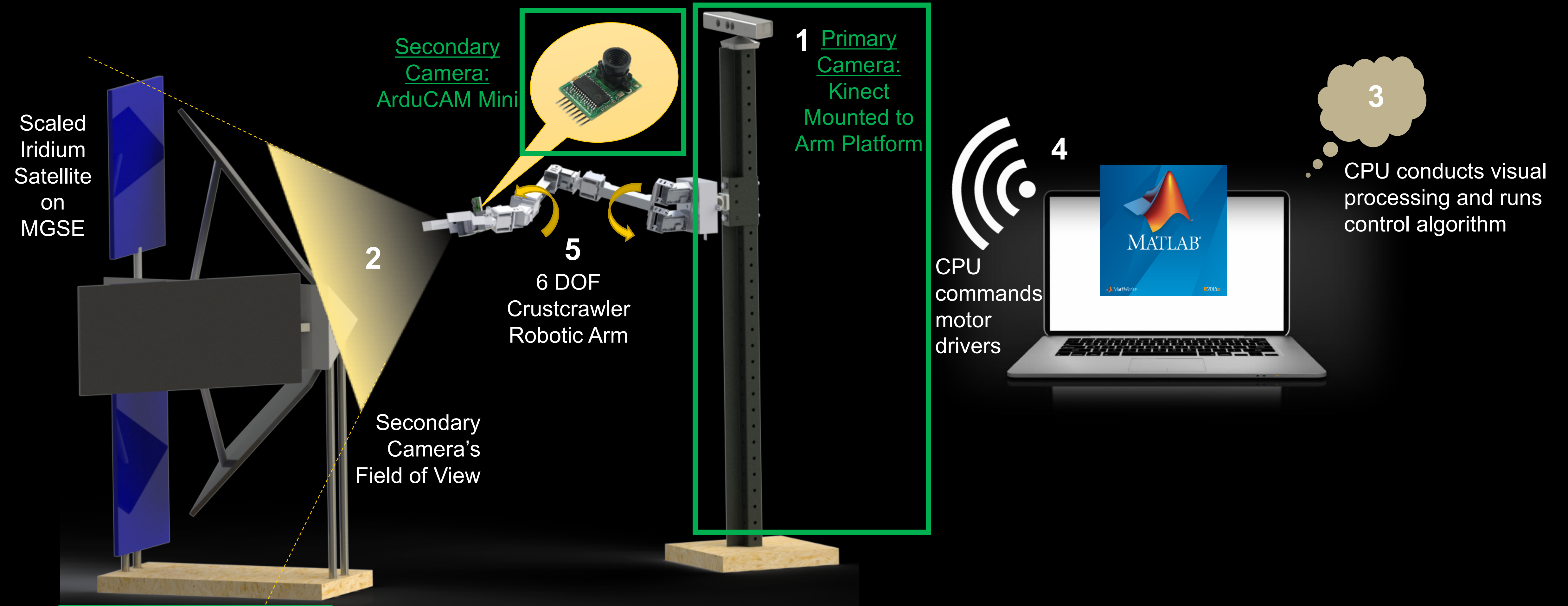


Proposed Design



KESSLER Primary Components & Functionality

Proposed Design



1. Visual system searches for grappling feature on satellite

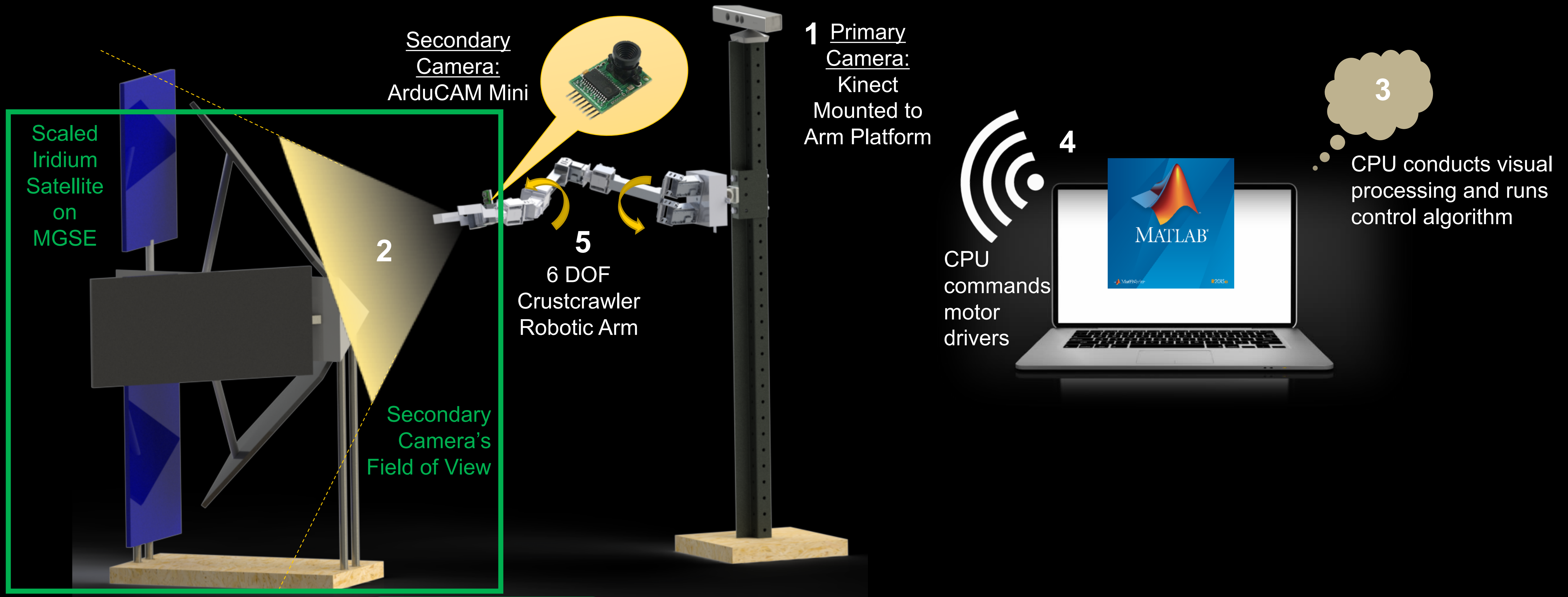
2. Algorithm identifies feature on satellite in FOV

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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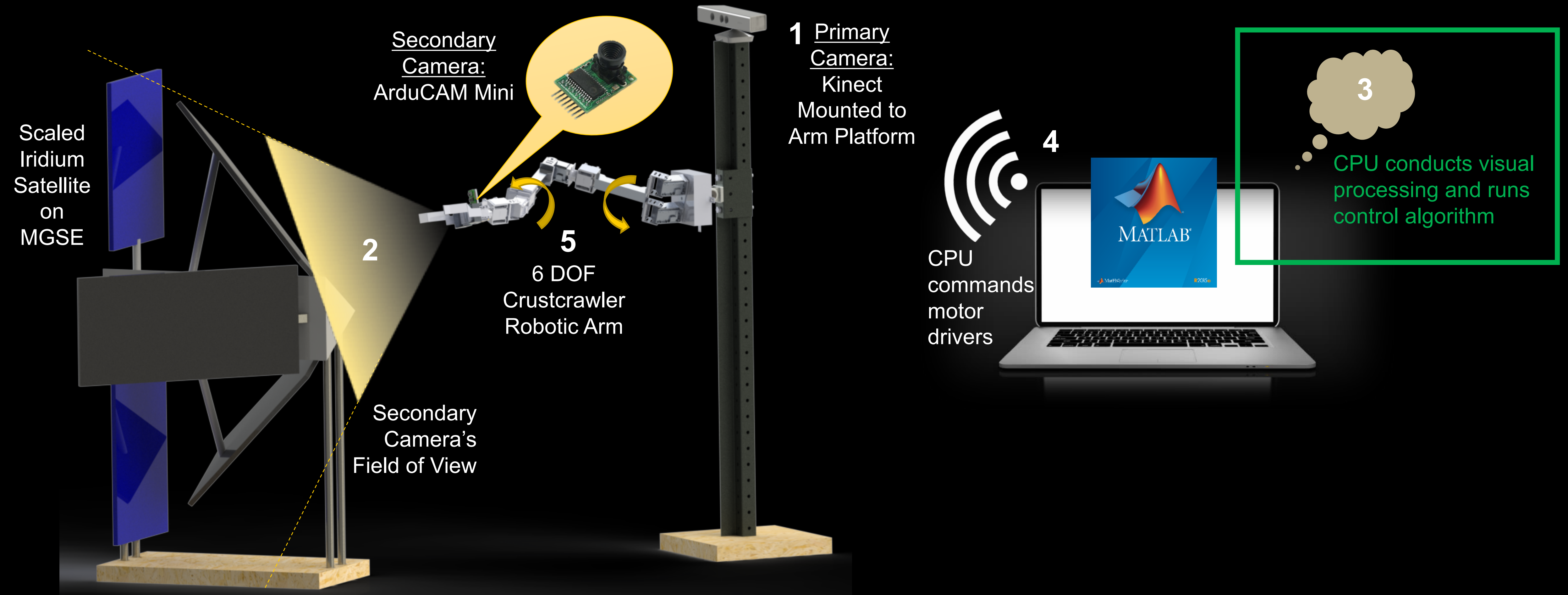
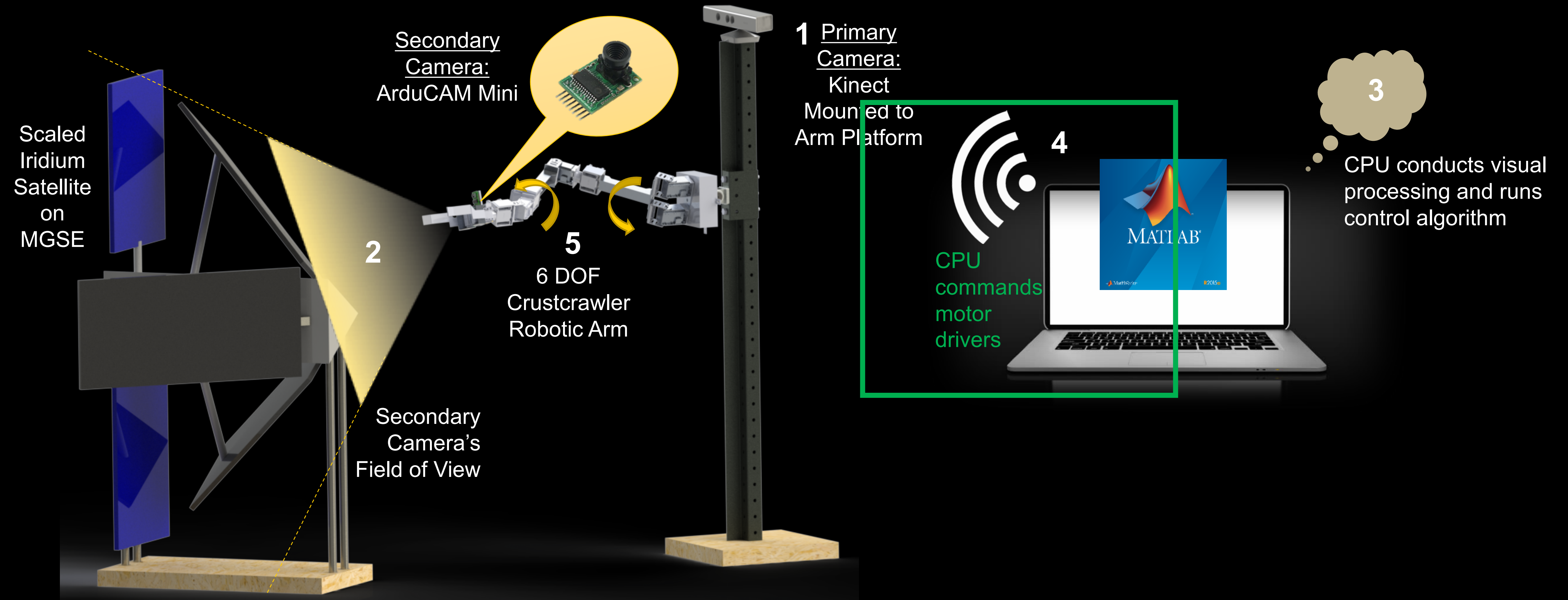
Proposed Design



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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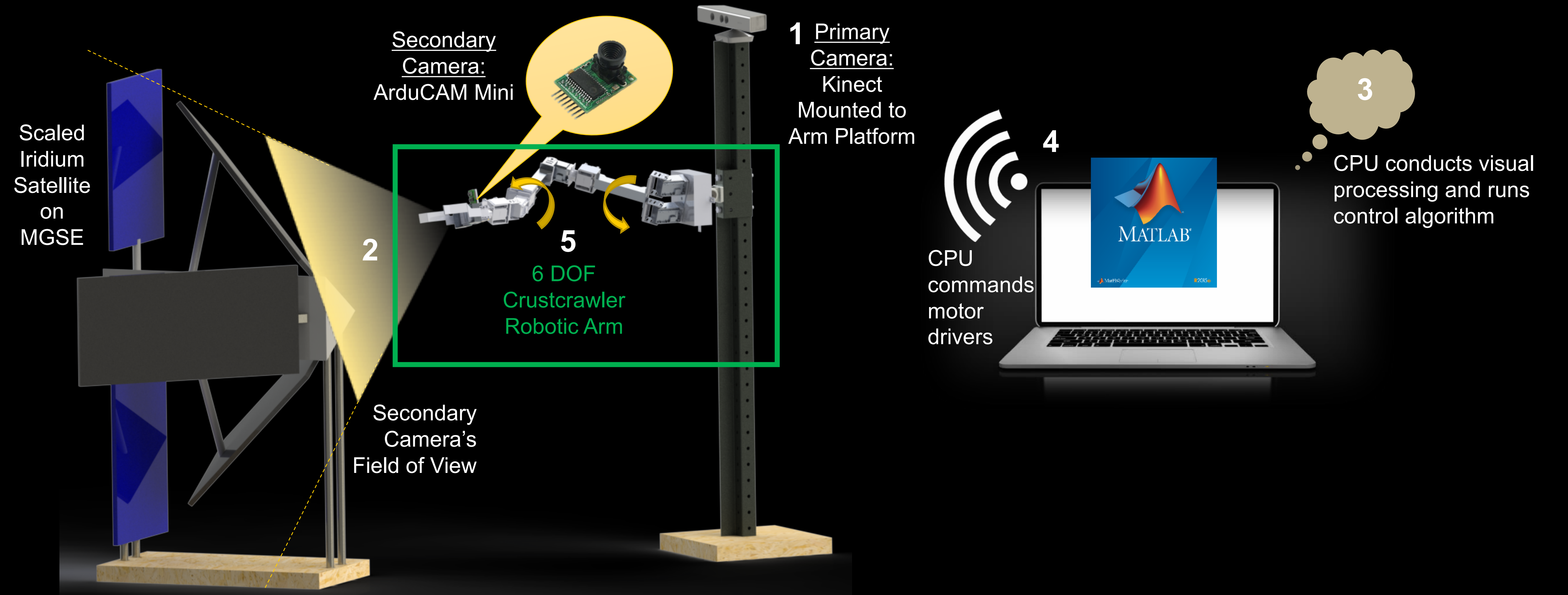
Proposed Design



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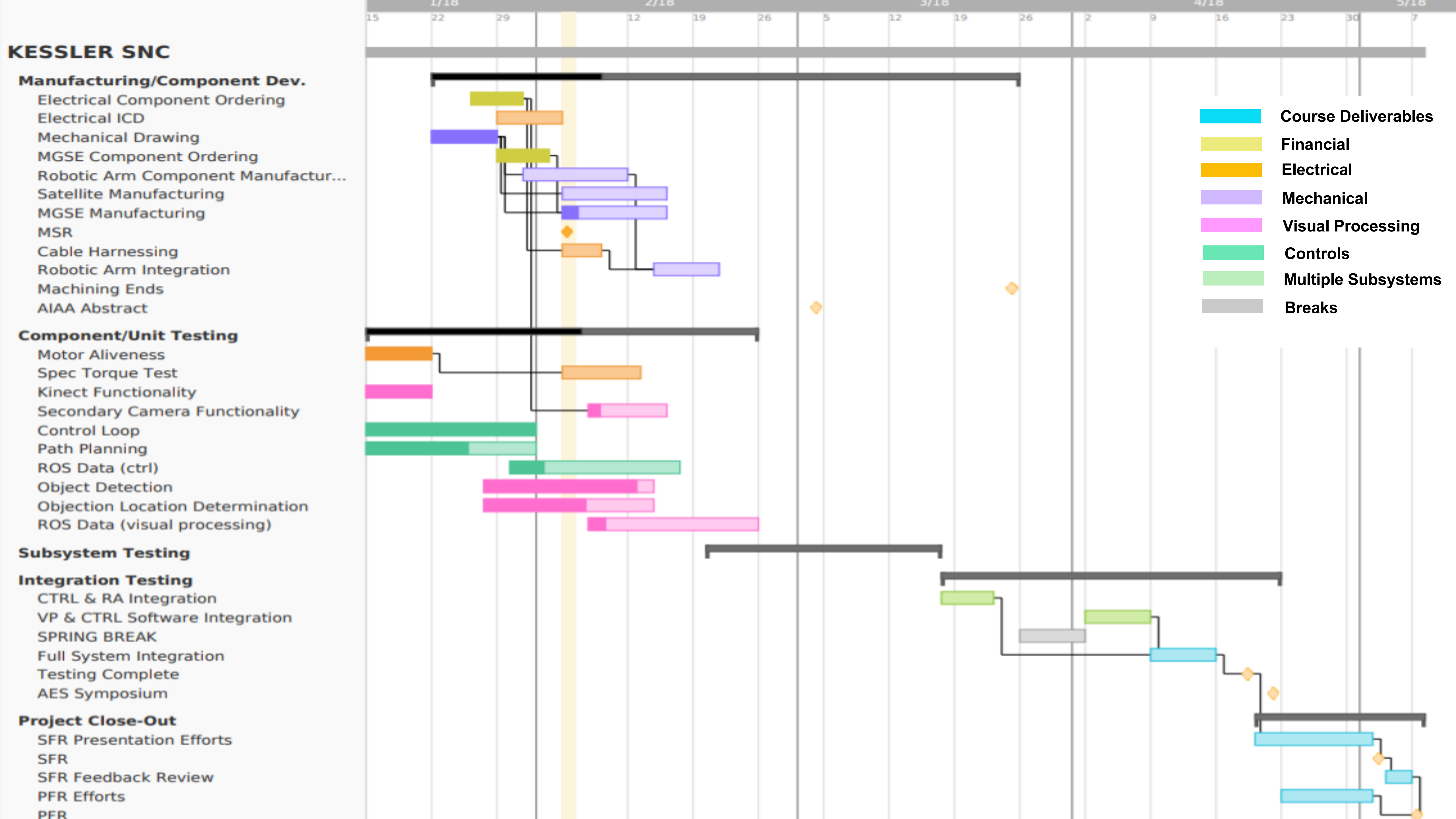
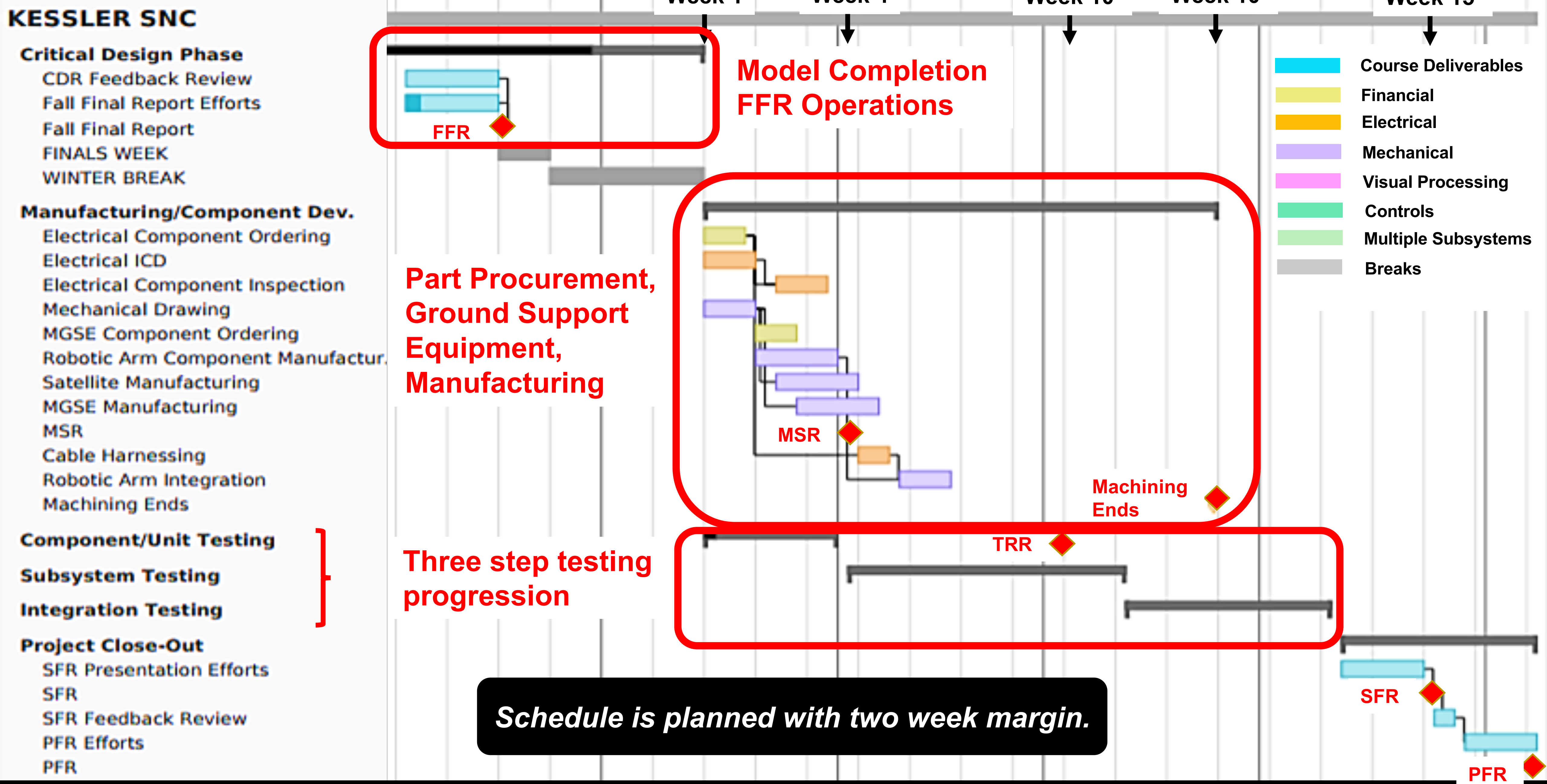
Section 2 Back-up


KESSLER SNC
Manufacturing/Component Dev.
Electrical Component Ordering
Electrical ICD
Mechanical Drawing
MGSE Component Ordering
Robotic Arm Component Manufactur...
Satellite Manufacturing
MGSE Manufacturing
MSR
Cable Harnessing
Robotic Arm Integration
Machining Ends
AIAA Abstract
Component/Unit Testing
Motor Aliveness
Spec 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
Integration Testing
CTRL & RA Integration
VP & CTRL Software Integration
SPRING BREAK
Full System Integration
Testing Complete
AES Symposium
Project Close-Out
SFR Presentation Efforts
SFR
SFR Feedback Review
PFR Efforts
PFR
1/18
2/18
3/18
4/18
5/18
15
22
29
12
19
26
5
12
19
26
2
9
16
23
30
7
Course Deliverables
Financial
Electrical
Mechanical
Visual Processing
Controls
Multiple Subsystems
Breaks

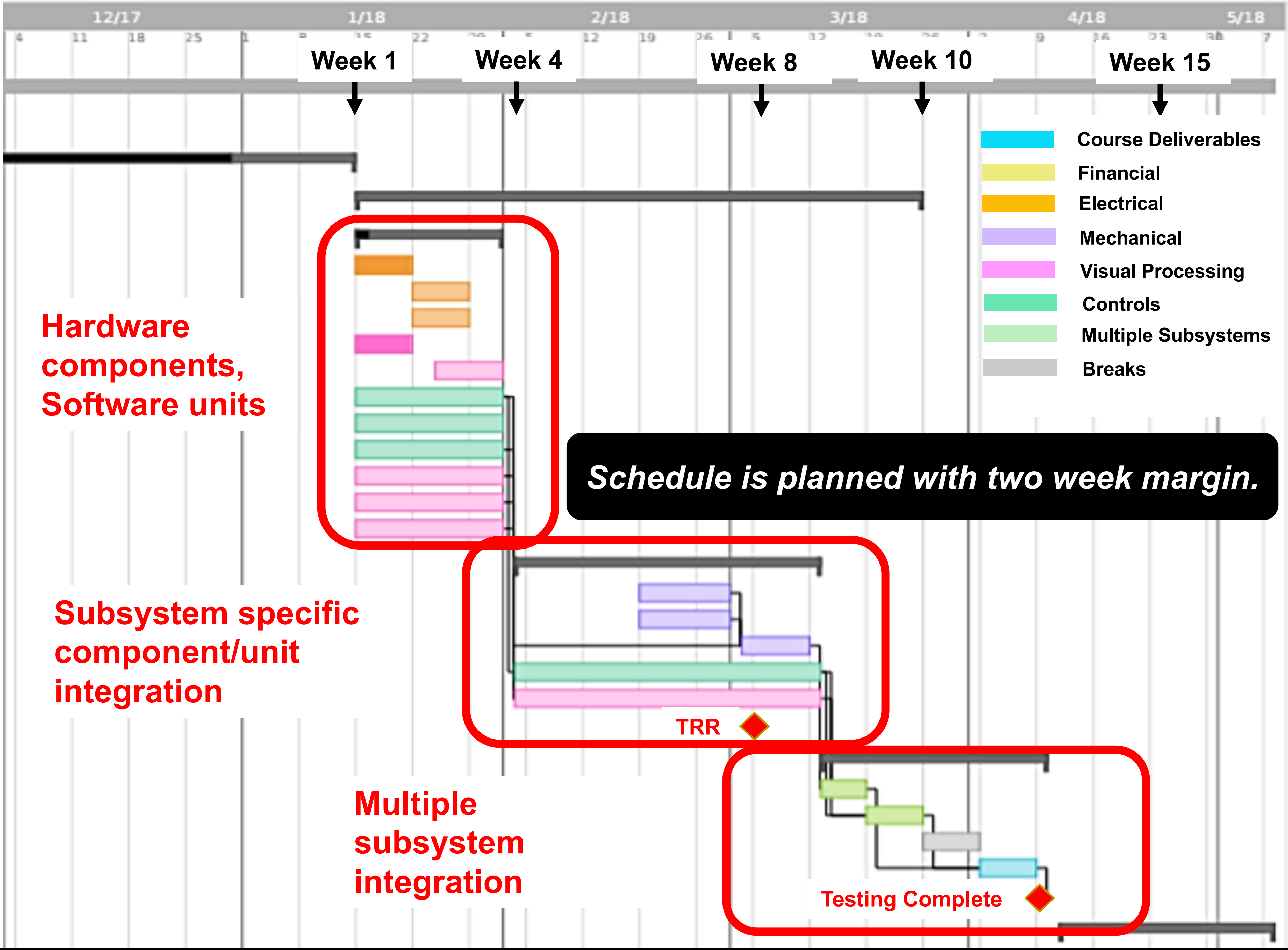
Work Plan


KESSLER SNC
Critical Design Phase
CDR Feedback Review
Fall Final Report Efforts
Fall Final Report
FINALS WEEK
WINTER BREAK
Manufacturing/Component Dev.
Electrical Component Ordering
Electrical ICD
Electrical Component Inspection
Mechanical Drawing
MGSE Component Ordering
Robotic Arm Component Manufactur.
Satellite Manufacturing
MGSE Manufacturing
MSR
Cable Harnessing
Robotic Arm Integration
Machining Ends
Component/Unit Testing
Subsystem Testing
Integration Testing
Project Close-Out
SFR Presentation Efforts
SFR
SFR Feedback Review
PFR Efforts
PFR
12/17
1/18
2/18
3/18
4/18
5/18
Week 1
Week 4
Week 10
Week 10
Week 15
FFR
Model Completion
FFR Operations
Course Deliverables
Financial
Electrical
Mechanical
Visual Processing
Controls
Multiple Subsystems
Breaks
Part Procurement,
Ground Support
Equipment,
Manufacturing
MSR
Machining
Ends
TRR
Three step testing
progression
SFR
PFR
Schedule is planned with two week margin.

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**

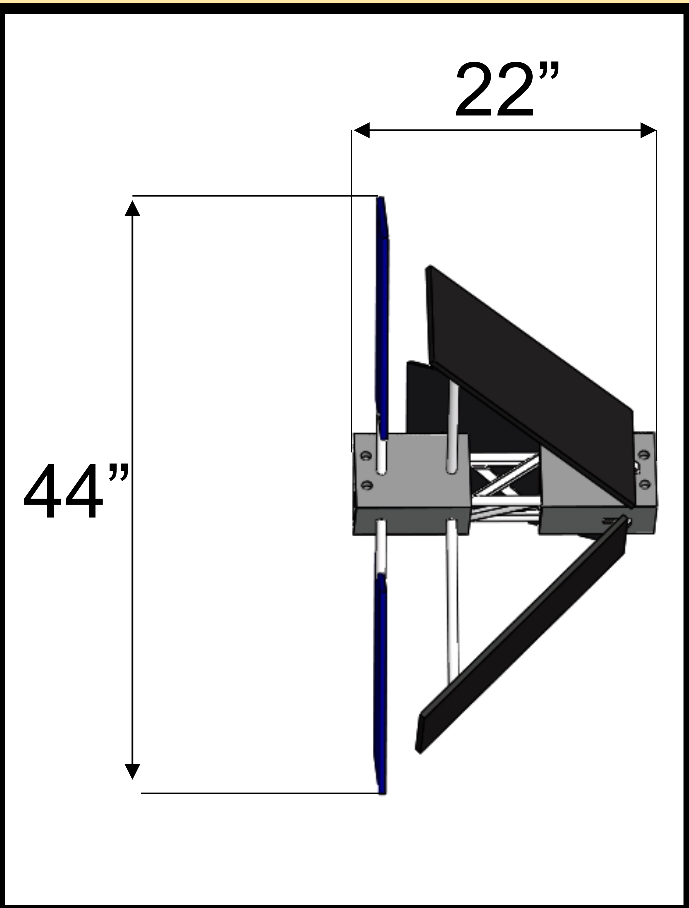


Sec 3: Mech

Subsystem: Iridium Satellite

Sub-Assemblies:

- Solar Panels x 2
- Antennas x 3
- BUS Structure x1
- Body x2

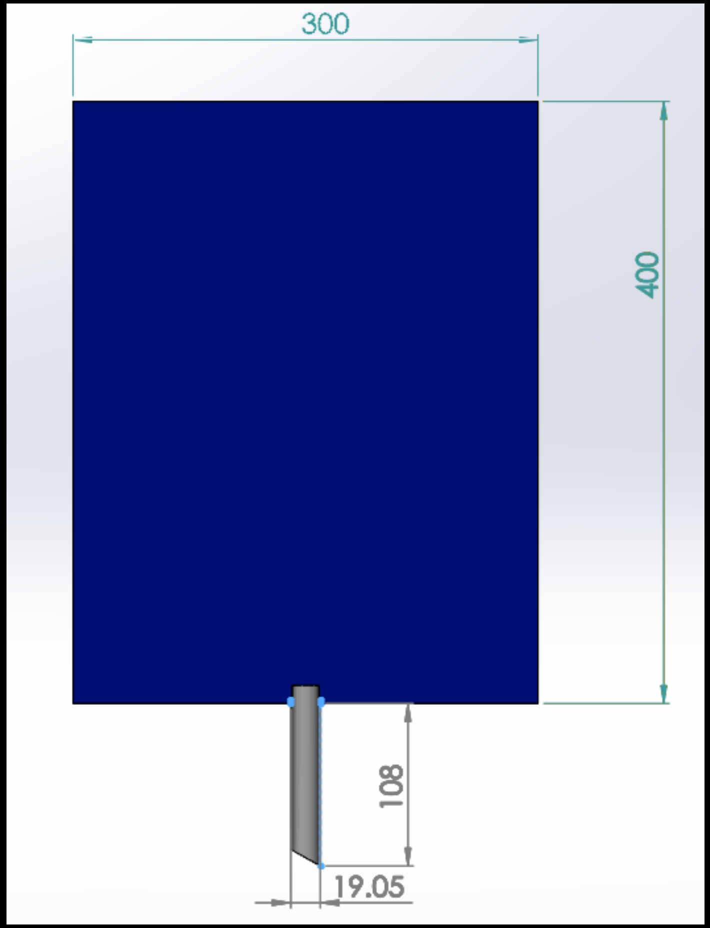


Project Purpose | Proposed Design | Critical Project Elements | **Design Reqs.** | Risks & Mitigation | Ver. & Val. | Organization

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



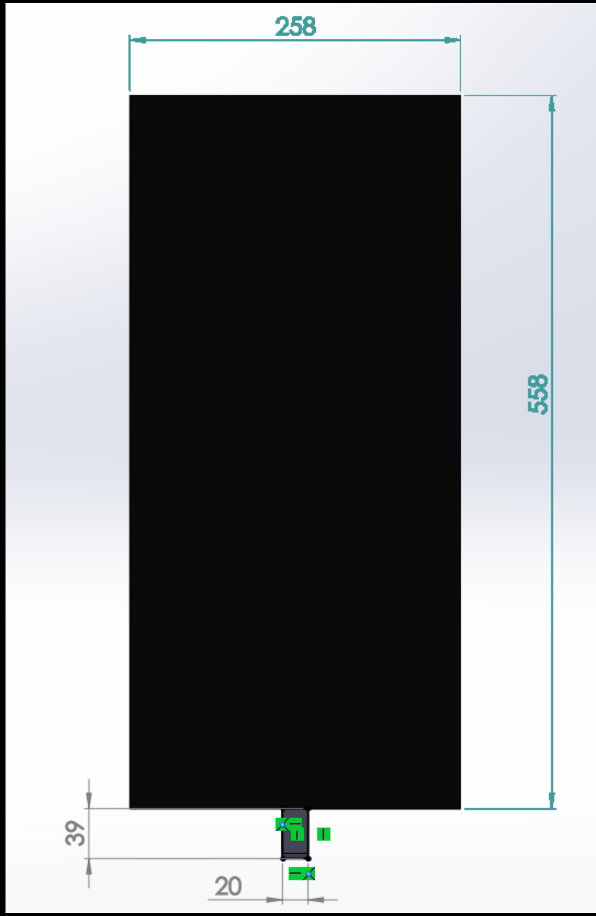
Sub-Assembly – Antenna

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

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

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

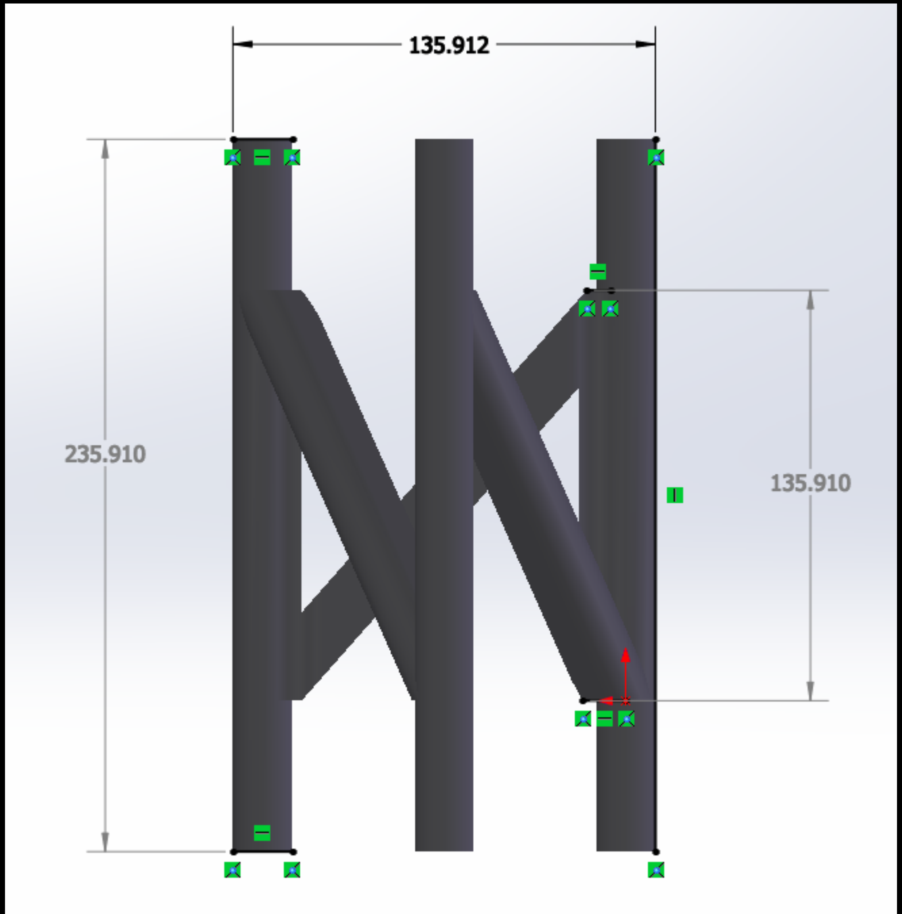
Primary Antenna from View Parallel to Surface



Sub-Assembly – Bus

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

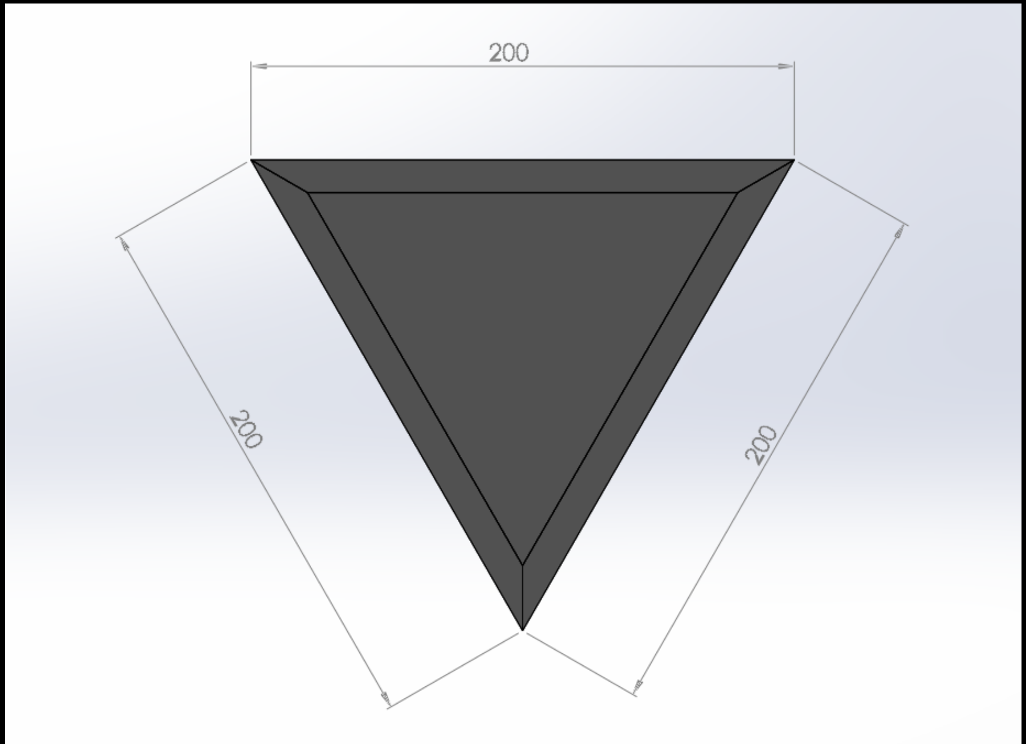
BUS Support Structure from Front View



Sub-Assembly – Body

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

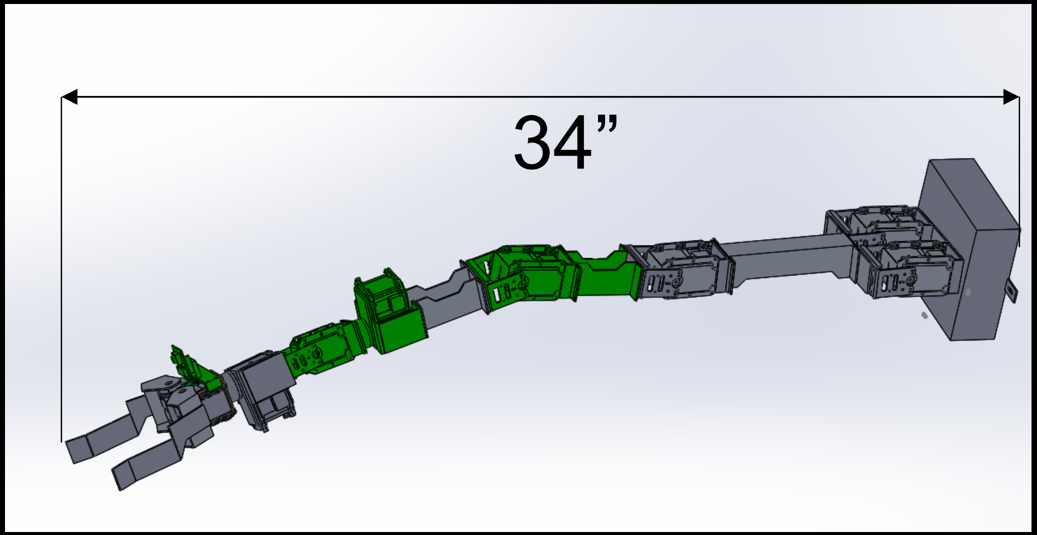
Body of the Iridium Satellite from Top View



Subsystem: Mechanical Arm

New Additions:

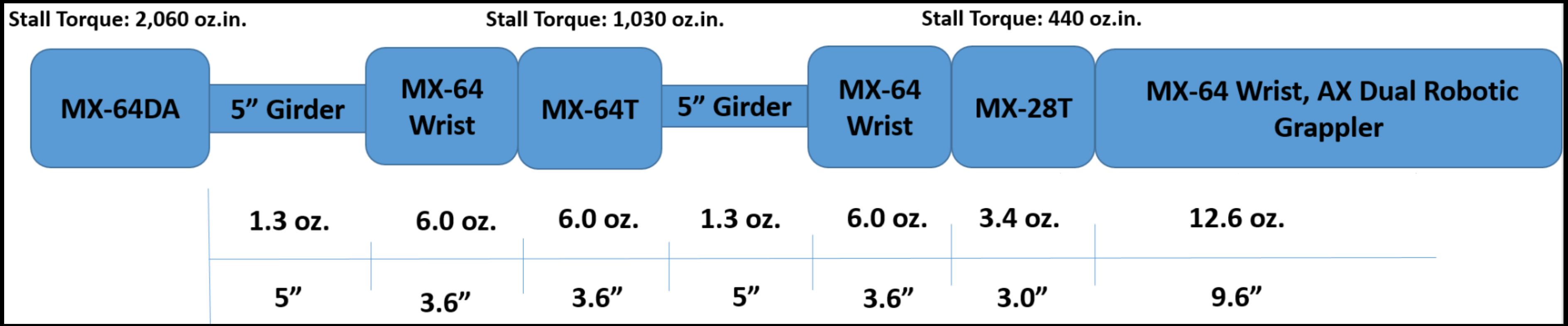
- MX-64T Wrist
- MX-64T Elbow
- MX-28 Elbow
- ArduCam
- ArduCam Mount
- Girder
- Turntable Bracket



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



Mechanical Tolerances

Governing Part(s)	Required Tolerance	Achievable Tolerance
Body Plates/Panels/Antenna	0.10”	0.00025”
Body Plates	3º	0.05º
BUS Structure	0.10”	0.001”
Support Bars	0.10”	0.001”
Stand Rods	0.5º	0.01º

***All manufacturing and integration tolerances fall within KESSLER requirements**

Sec 3: Elec

Electrical Hardware Block Diagram

ArduCam: Harnessing for communication and integration with microcontroller.

Microcontroller: USB to MicroUSB, expected location central to PC.

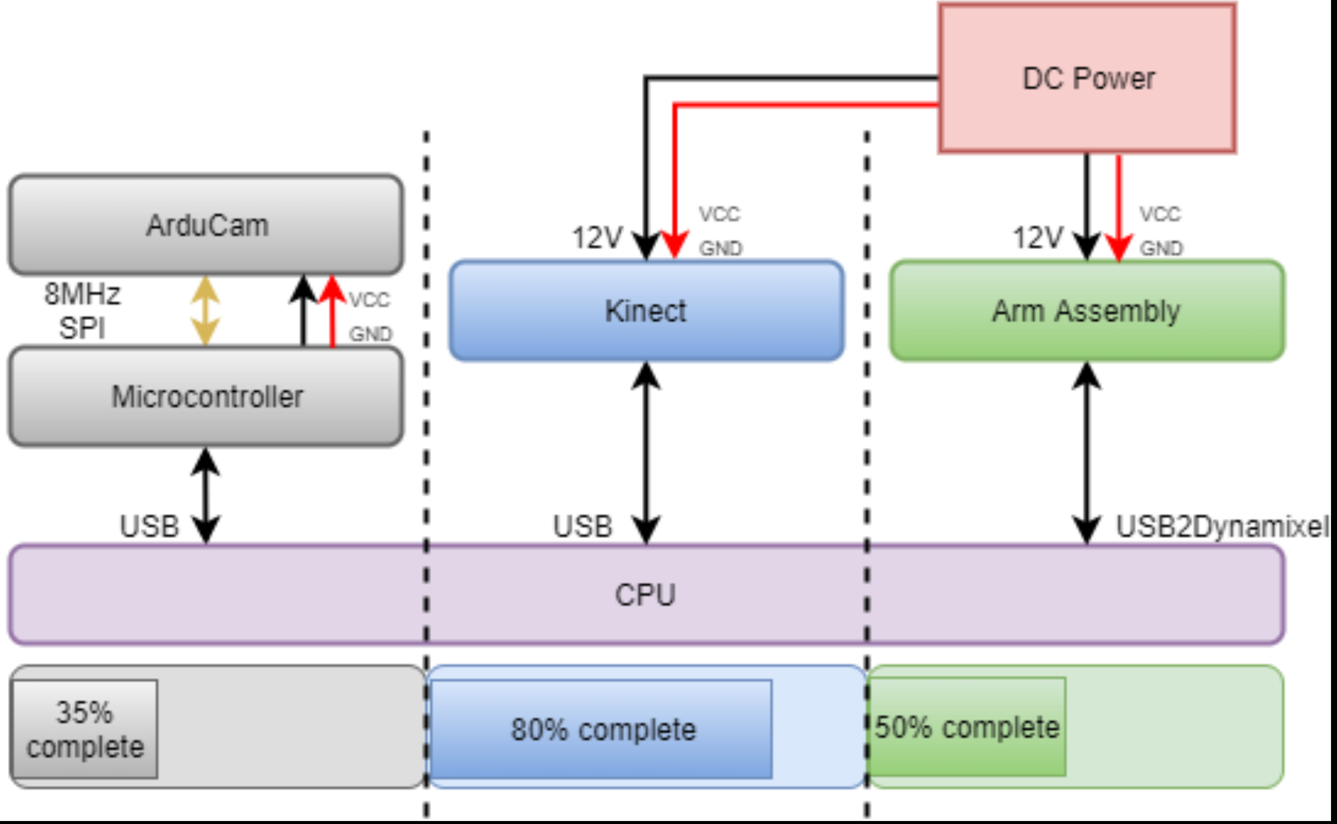
Kinect: External DC Power Supply and USB cord management

Arm Assembly: Anchors for ArduCam harnessing, removal of heritage force cells, re-harnessing of heritage Dynamixel 3-pin connectors.

<u>Expected Challenge</u>:
Verifying ArduCam harnessing provides reliable connectivity and does not impede arm execution.

Electronics Hardware Housing and Integration

- ArduCAM / Microcontroller - purchased and received
- Kinect - heritage
- Arm Assembly - heritage, purchased but not received



Electrical Tasks

Completed In Progress To Be Completed

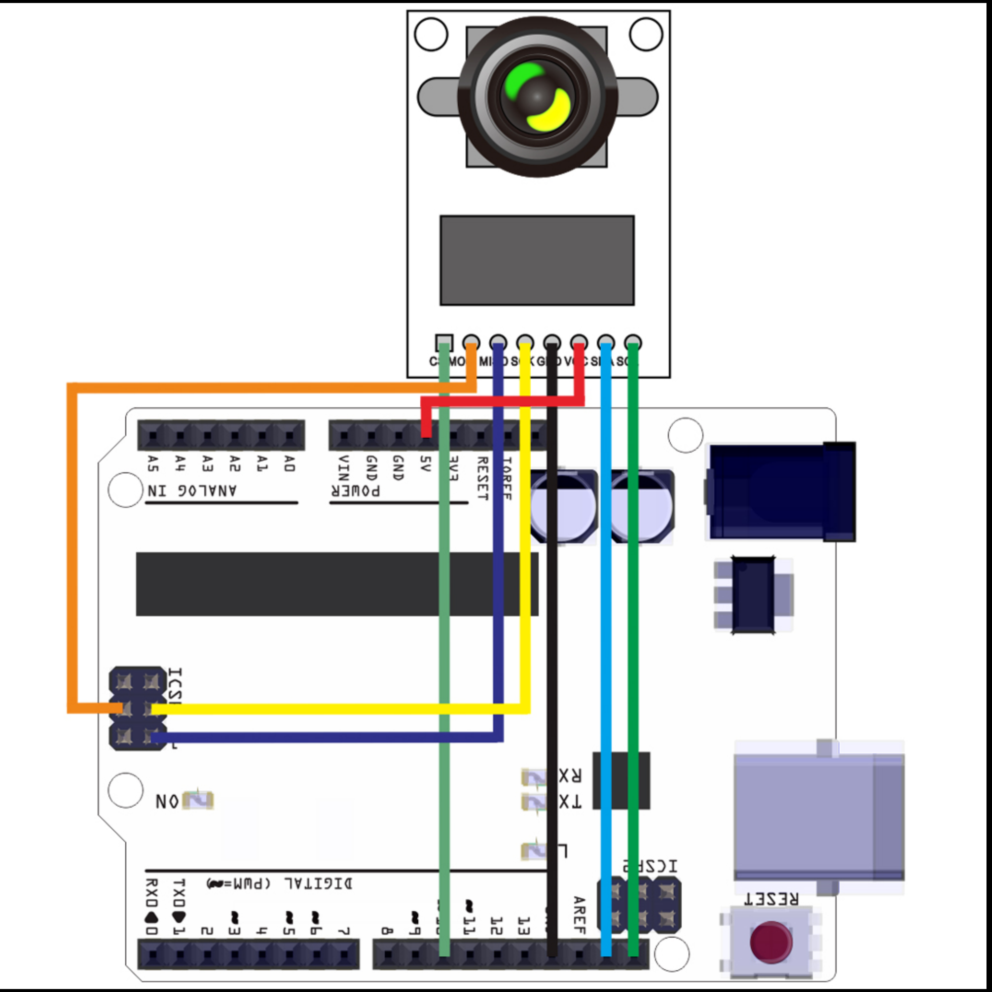
Visual System

- Microsoft Kinect USB and DC Supply verification
- Microsoft Kinect Software Recognition
- ArduCam Mini Signal Wires
- Microcontroller USB verification

Robotic Arm

- Actuator Liveliness Characterization
- Actuator Torque Analysis
- Gripper Modification
- Signal Line Verification
- DC Supply Verification
- Girder Harnessing Anchors

ArduCam Mini



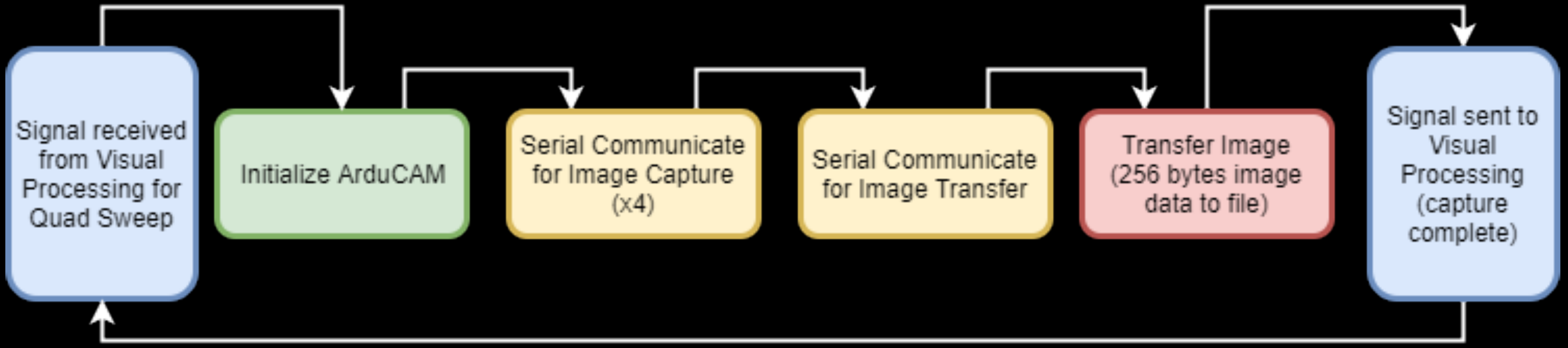
- Power
  - 3.3 to 5 VCC and GND
- SPI
  - Issues capture command; ArduCam waits for new frame and buffers the entire image data to the frame buffer, sets completion flag bit
- I2C
  - Interacts directly with the OV2640 image sensor

Secondary Visual System Software

- Green – Controller positions ArduCam to image capture location
- Yellow – Microcontroller commands image capture and transfer from camera
- Red – Transfer of Image from microcontroller to CPU
- Blue – Microcontroller communicates with Control and Visual algorithm

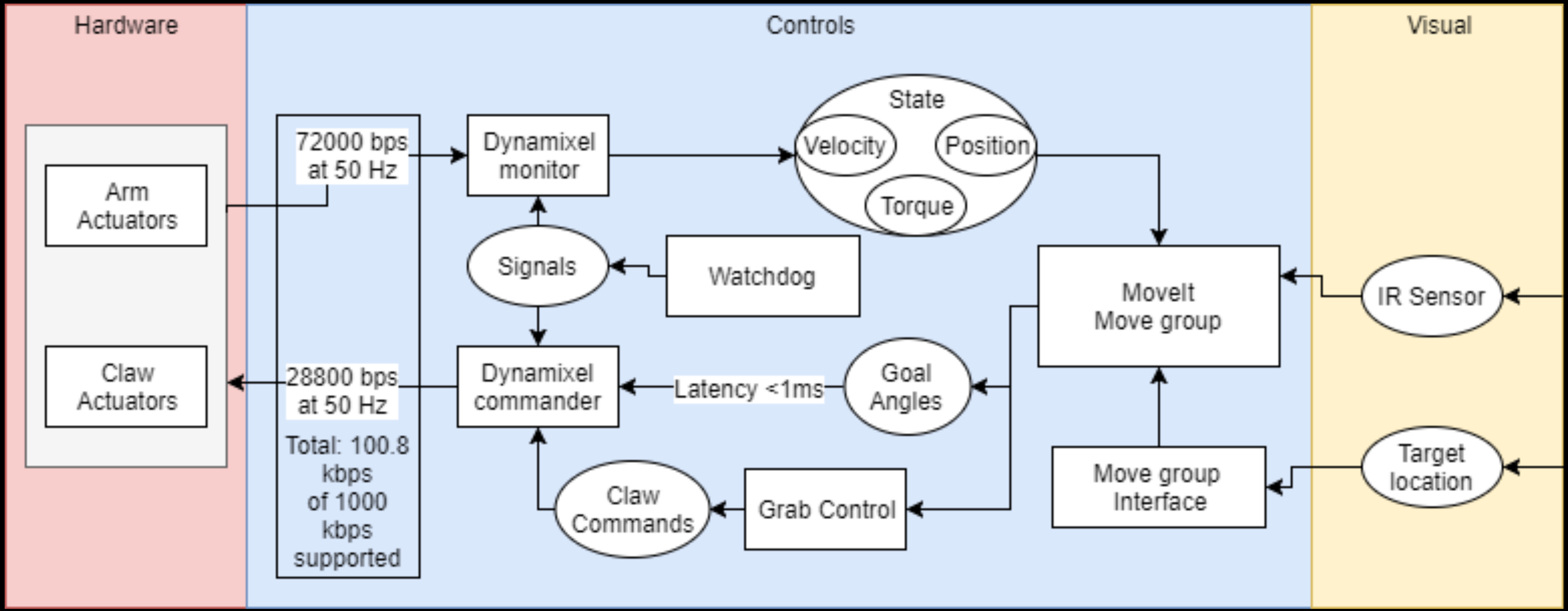
Software Completion

Cam Setup	Serial Image Capture	Image Transfer
• Extensive open source code • **60%**	• Extensive User Guide • **20%**	• Extensive implementation guide • **20%**



Sec 3: Ctrl

System


Hardware
Controls
Visual
Arm Actuators
Claw Actuators
72000 bps at 50 Hz
28800 bps at 50 Hz
Total: 100.8 kbps of 1000 kbps supported
Dynamixel monitor
Dynamixel commander
Signals
Watchdog
State
Velocity
Position
Torque
MoveIt Move group
Goal Angles
Latency <1ms
Claw Commands
Grab Control
Move group Interface
IR Sensor
Target location

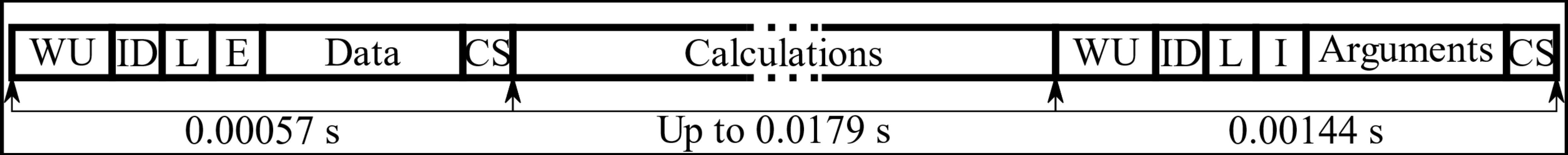
Trajectory Verification

D2.2	The robotic arm path shall be constrained by the arm's joint limitations	Demonstration/Test

Backup: Functions to Implement

- MoveIt interface
  - setPoseTarget
  - Getters: ActiveJoints, DefaultPlannerID, JointTolerance, PositionTolerance, OrientationTolerance, JointNames
- Controller Interface
  - sendTrajectory, waitForExecution, cancelExecution
- Actuator Interface
  - getState, setPosition, setTorque, initialize, detectError
- Watchdog
  - checkError, ESTOP

Backup: Timing model verification



- Calculations include:
  - Trajectory processing
  - Data packaging
  - Command packaging

Challenges

- Understanding the sample code
- Understanding MoveIt! structure

- Test safety
  - Mitigation: Limit speed, Verify path planning output
- Error bounds
  - Mitigation: Automatic adjustment

Sec 3: VP

Software Tools: MATLAB

Toolbox	Purpose	Percent written by KESSLER	Level of Difficulty (1-5)
Image Acquisition Toolbox for Kinect Sensor	Take 2D and 3D images	0%	1
Computer Vision Toolbox	Feature matching satellite	30%	2
Computer Vision Toolbox	3D point cloud processing	70%	4
Robotic System Toolbox	Data formatting for Controls System	30%	3

Table #: Visual Processing software tools

1: Requires no assistance
3: Requires individual research
5: Requires expert support

Level of Difficulty Scale

Software: Satellite in FOV

Feature Matching Results:

- Varied angles between images: 10 degrees between images is sufficient
- Tested database against satellite at random orientation not included in database
- Minimum of 3 matches needed and results are above that threshold

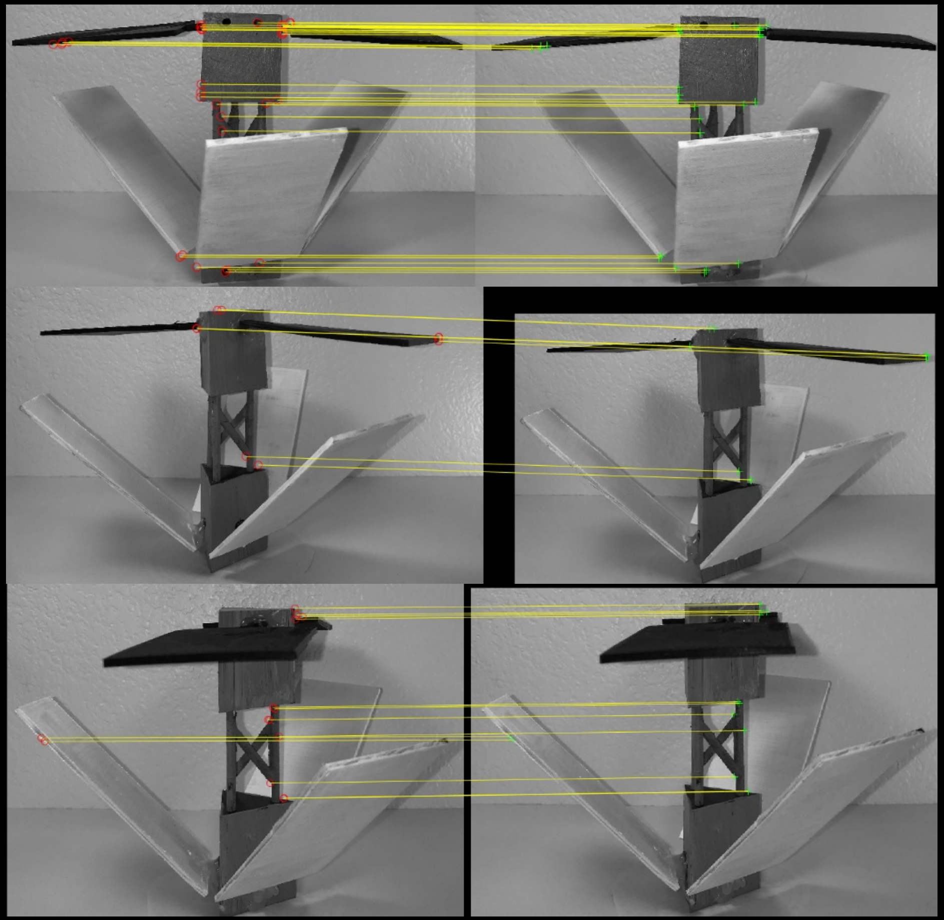
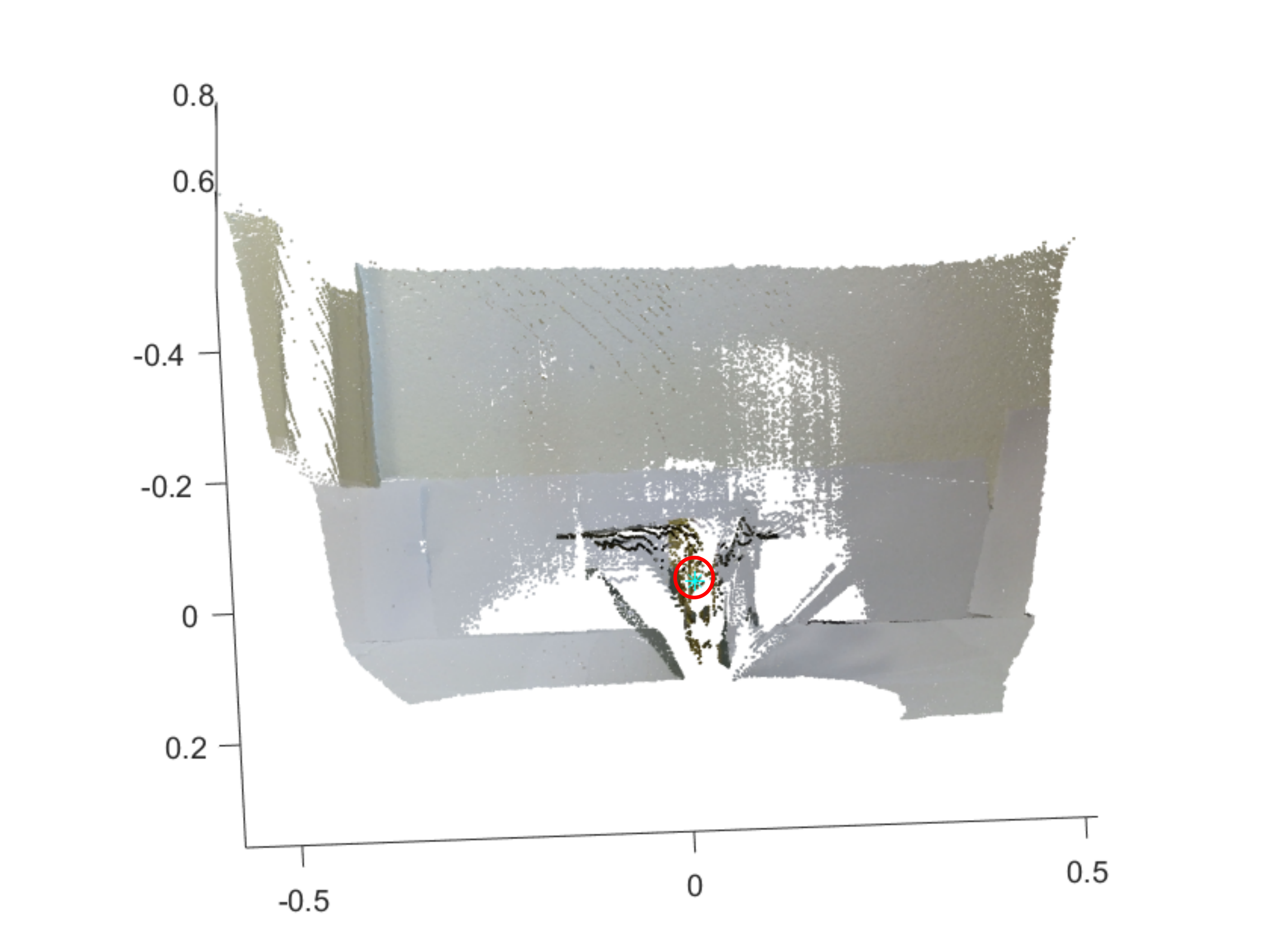
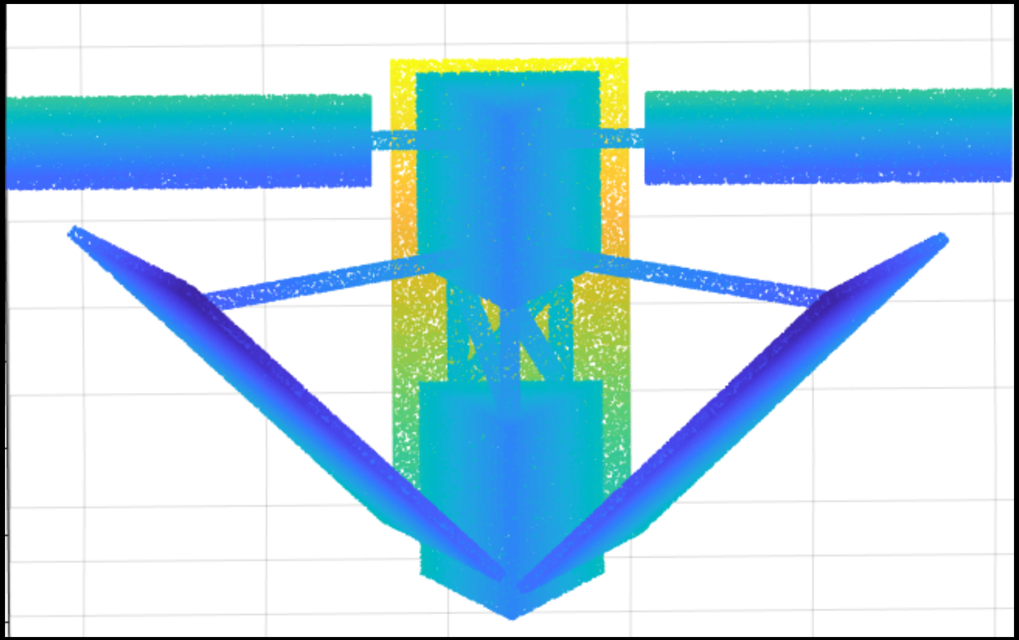


Fig. #: Visual Processing tools

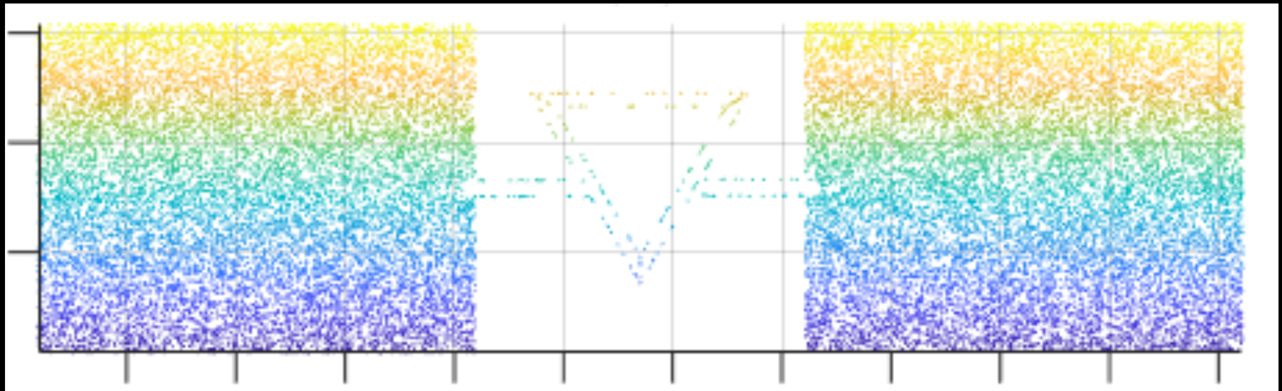
Identify Closest Point



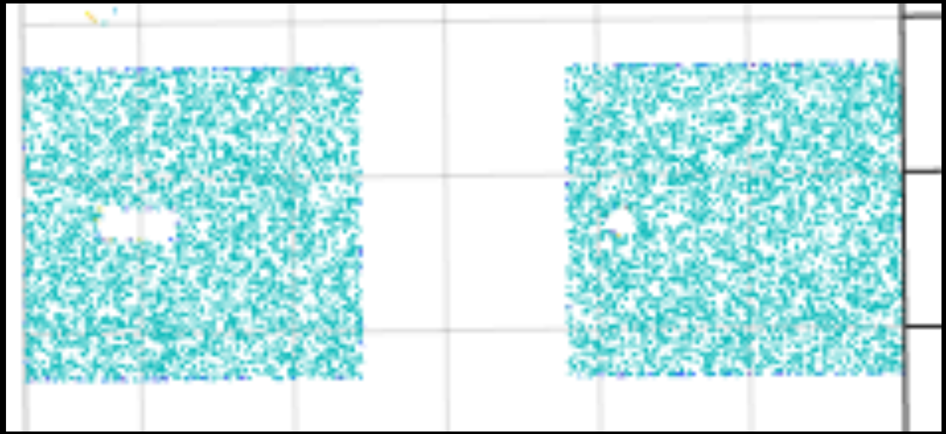
Plane Detection



Point cloud of full satellite



Planes of solar panels



Planes of bus structure

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.

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

Color Matching

- Color attribute is 3 dimensional matrix (Red, Green, Blue)
- Unique combination of RGB values correlates to specific color
- Isolate certain RGB values to isolate features and recolor
  - Known colors for each feature

Solar Panel
Antennas
Bus structure

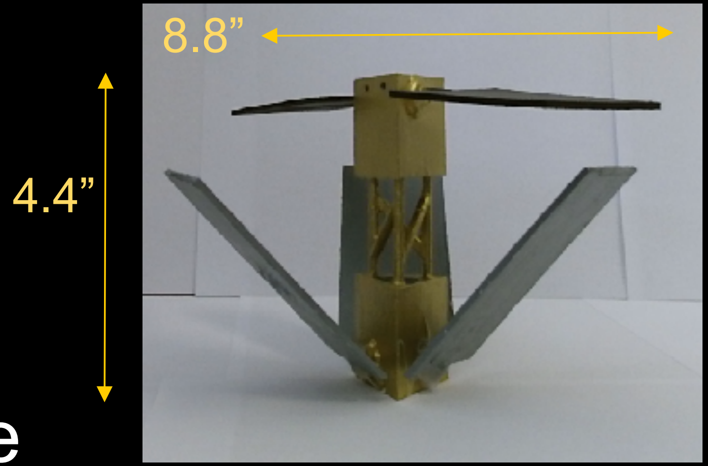


Fig. #: Colored satellite model

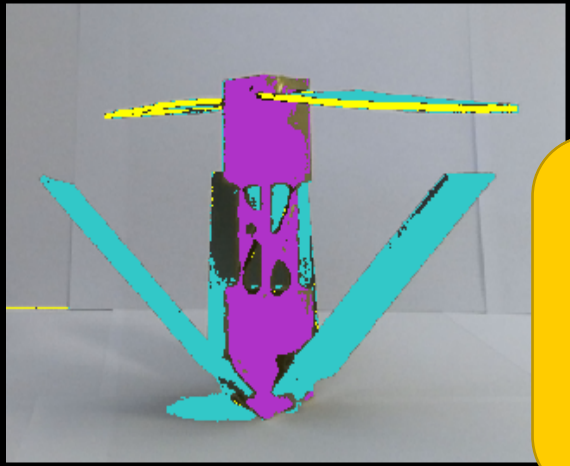


Fig. #: Color processed satellite model

Software functionality demonstrated for L2-L3 Success Criteria

20% Scale model of satellite

Project Overview | Schedule | Mech. | Elec. | Software: Controls | **Software: Visual** | Budget

3D Point Cloud Feature Identification

- Map 2D color image to 3D point cloud
  - Both 2D & 3D sensors: 1920 x 1080 pixels → *0.6mm < 4mm requirement*

4mm for Full Scale
0.8mm for 20% Scale

- Concern: <u>Low density point cloud</u> may not demonstrate 4mm requirement satisfaction capability (Pixel utilization of scale model ~ 390 x 220 pixels) → *0.6mm close to 0.8mm*

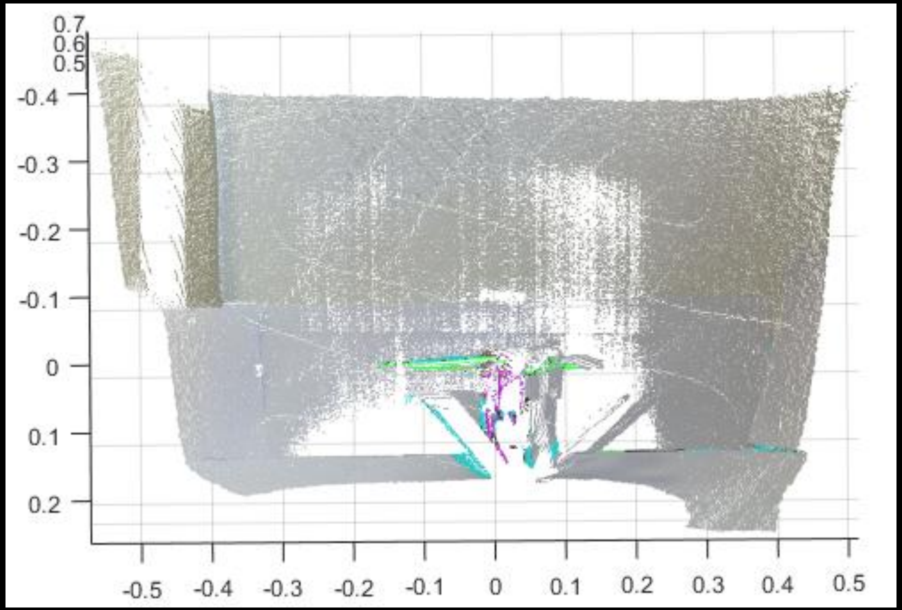


Fig. # :Full colored point cloud with features

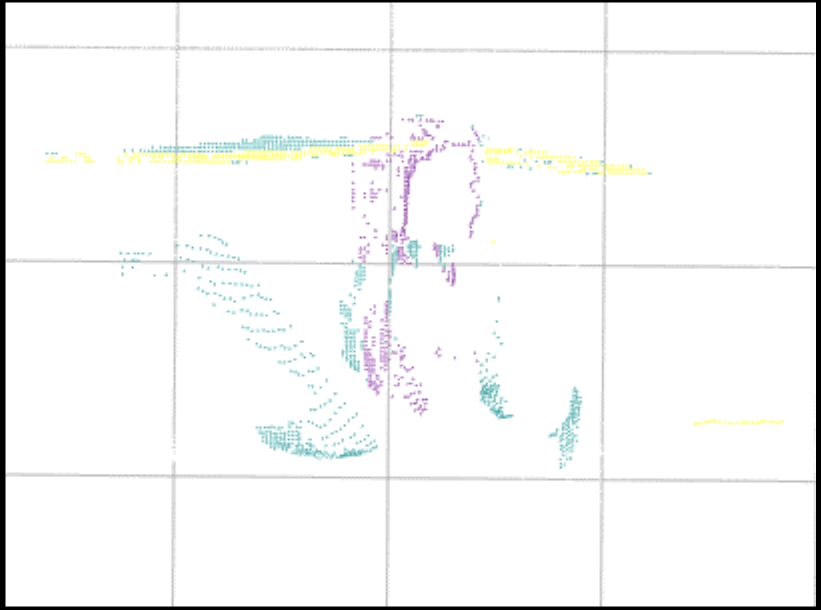
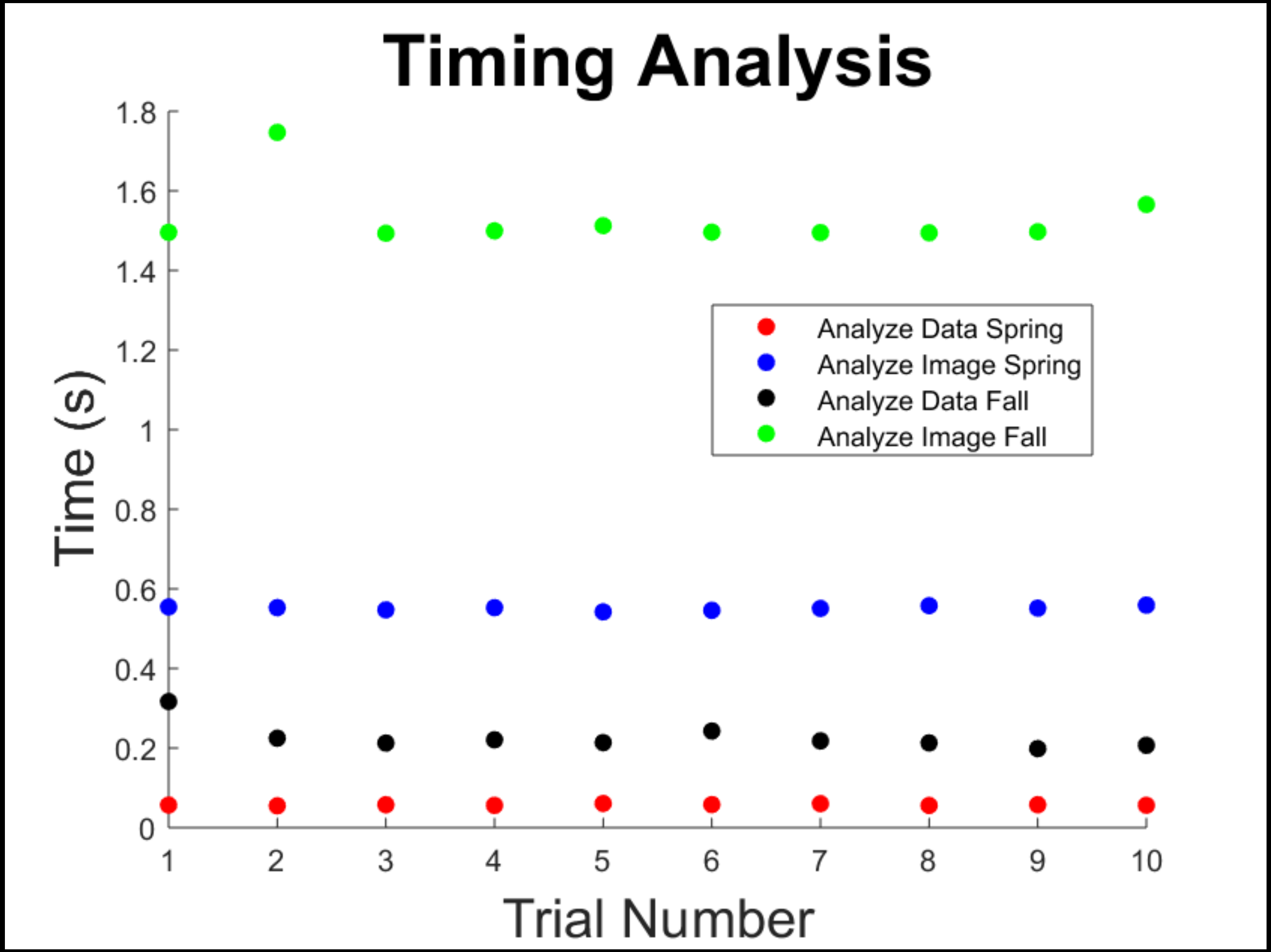


Fig. #: Isolated satellite model point cloud

Project Overview | Schedule | Mech. | Elec. | Software: Controls | **Software: Visual** | Budget

Visual Processing Timing



Section 4

Hardware Status: Mechanical

Updated: 2/2/2018

Item (Name)	Price (per unit, without tax)	Quantity	Item Total	Shipping, Handling, and any other fees	Status
MX-106T	$552.00	1	$552.00	$12.65	Delivered
MX-64T Wrist	$364.00	1	$364.00	$0.00	Delivered
2.5" Girder	$23.00	2	$46.00	$0.00	Delivered
MX-64/106 To MX-28 Adapter	$11.99	2	$23.98	$0.00	Delivered
Singleaxismount	$15.00	3	$45.00	$0.00	Delivered
12in. (30.48cm) 3-pin wire extension	$9.49	3	$28.47	$0.00	Delivered

Hardware Status: Testing

Updated: 2/3/2018

Item (Name)	Price (per unit, without tax)	Quantity	Item Total	Shipping, Handling, and any other fees	Status
Acrylic Cement	$19.17	1	$19.17	$30.97	Ordered
Acrylic Sheets (various)	$278.40	1	$278.40	$42.85	Not yet ordered
Aluminum Frame	$32.16	1	$32.16	$0.00	Ordered
Brackets (10 pk)	$14.10	1	$14.10	$5.99	Ordered
HDPE Rod	$11.98	2	$23.96	$0.00	Ordered
Locking Pin	$3.50	3	$10.50	$0.00	Ordered
Pivot Joint	$24.25	1	$24.25	$0.00	Ordered
Spray Paint	$10.13	1	$10.13	$0.00	Ordered
Tapped T-Slot Nut	$11.34	4	$45.36	$0.00	Not yet ordered
Threaded Rod	$60.00	2	$120.00	$0.00	Ordered
Plywood	$39.98	2	$79.96	$0.00	Ordered

Hardware Status: Visual Processing

Updated: 2/2/2018

Item (Name)	Price (per unit, without tax)	Quantity	Item Total	Shipping, Handling, and any other fees	Status
ArduCAM Mini	$25.99	1	$25.99	$0.00	Delivered
Arduino Zero	$39.00	1	$39.00	$3.69	Delivered
Lighting	$48.22	2	$96.44	$0.00	Delivered