Space Robotics

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- **Robotics Instructor and Flight Controller**

Outline

- Introduction
  - Types
  - Terrestrial vs. Space
- Design
  - Command
  - Thermal
  - Electrical
  - Mechanical
- Principals
  - Frames
  - Constraints
  - Kinematics
  - Modes
- Failure Response
  - Recovery
  - Procedures
  - On-Orbit Replacement
- Operational Considerations & Tools
- ISS Operations – Team Coordination
  - EVA Support
  - Visiting Vehicle Operations
- Future Operations

Mobile Servicing System

Terrestrial vs Space Robotics

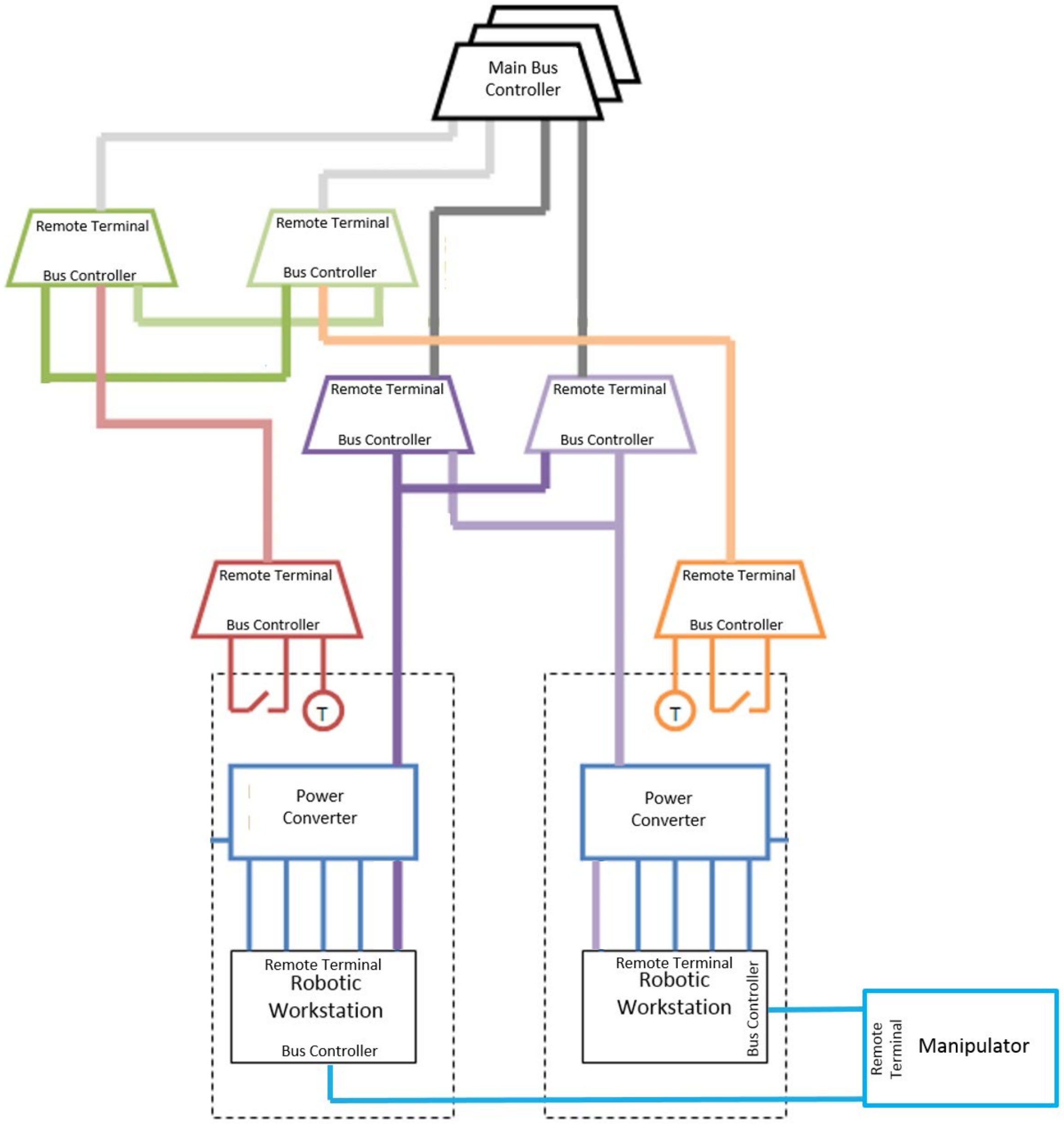
Terrestrial	Space	Design Impacts
N/A	Launch/Landing Loads	Strong Support Structure adds to launch weight
Air Particulates/ pollution/Gravity	Performance in a Vacuum (0G)	Brushless motors, lubrication, light weight materials, high torque output
	Radiation	Electronic components,
Controlled Environment	Thermal Fluxuations	Active and Passive Thermal Control
Controlled Lighting	Dynamic Lighting	Camera processing, possible delays
Instantaneous Commanding	Time Delay	Fail-safe system, autonomous control
	Remote Environment	Low maintenance equipment, Redundancy

Robotic Design

- Command Hierarchy
- Thermal Design
- Electrical
- Mechanical
- Sensors

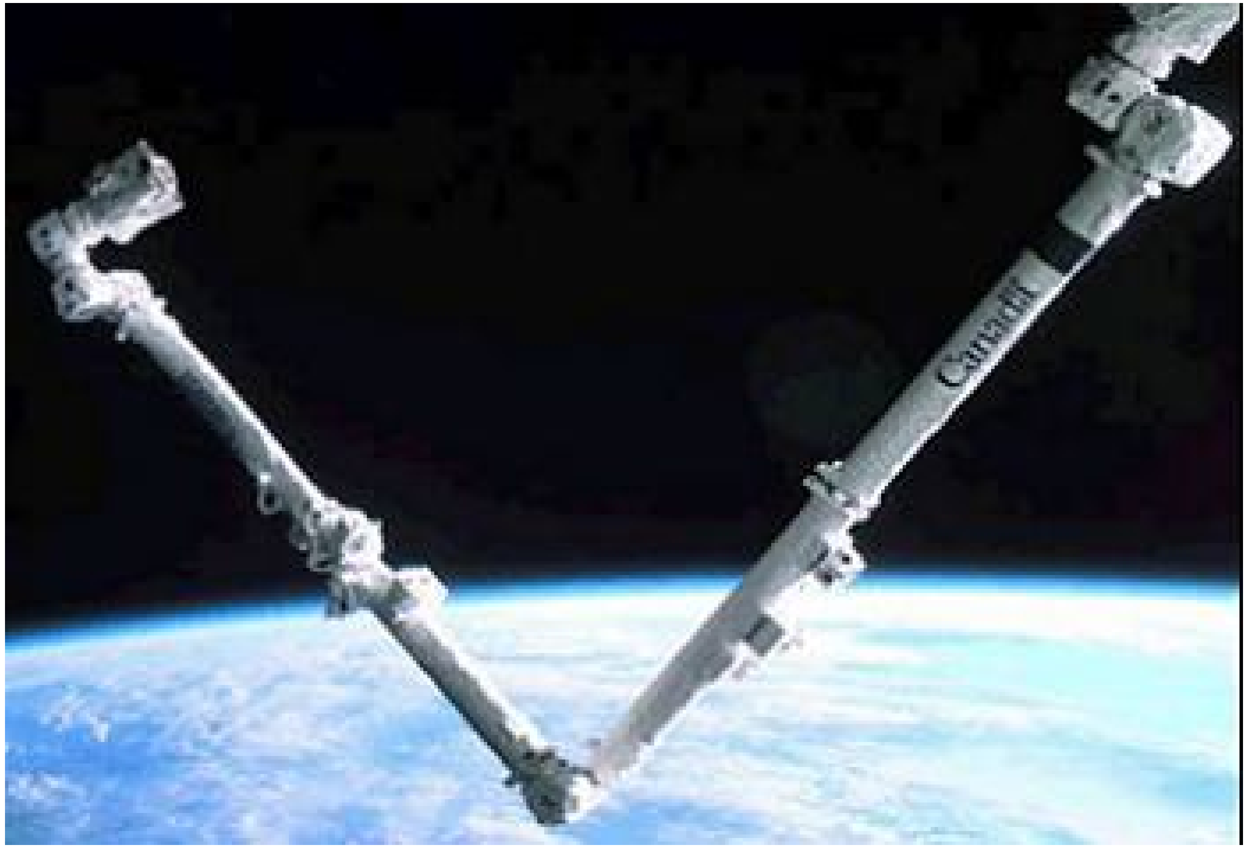
Command Hierarchy

- Bus Controller/Remote Terminal Methodology
- Importance of Communication protocol and timing
  - MBS Installation Example



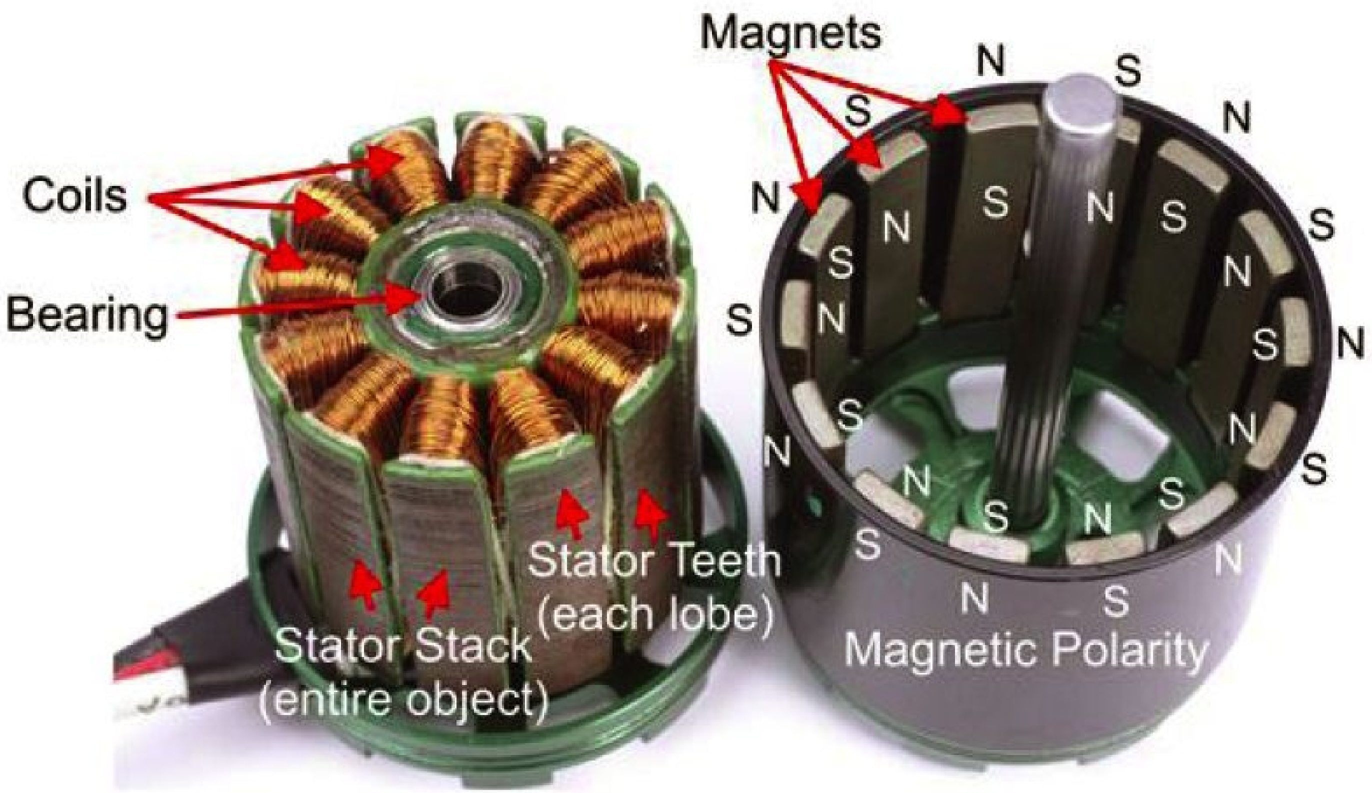
Thermal Design

- Active Thermal Control
  - Open & Closed loop control
  - Heaters
  - Thermistors
  - Command path required
- Passive Thermal Control
  - Blankets
  - Radiators
  - Paint
  - Conduction



Electrical Design

- Small motors with high ratio gearboxes
- Brushed vs. Brushless motors
- SSRMS Wrist Roll example

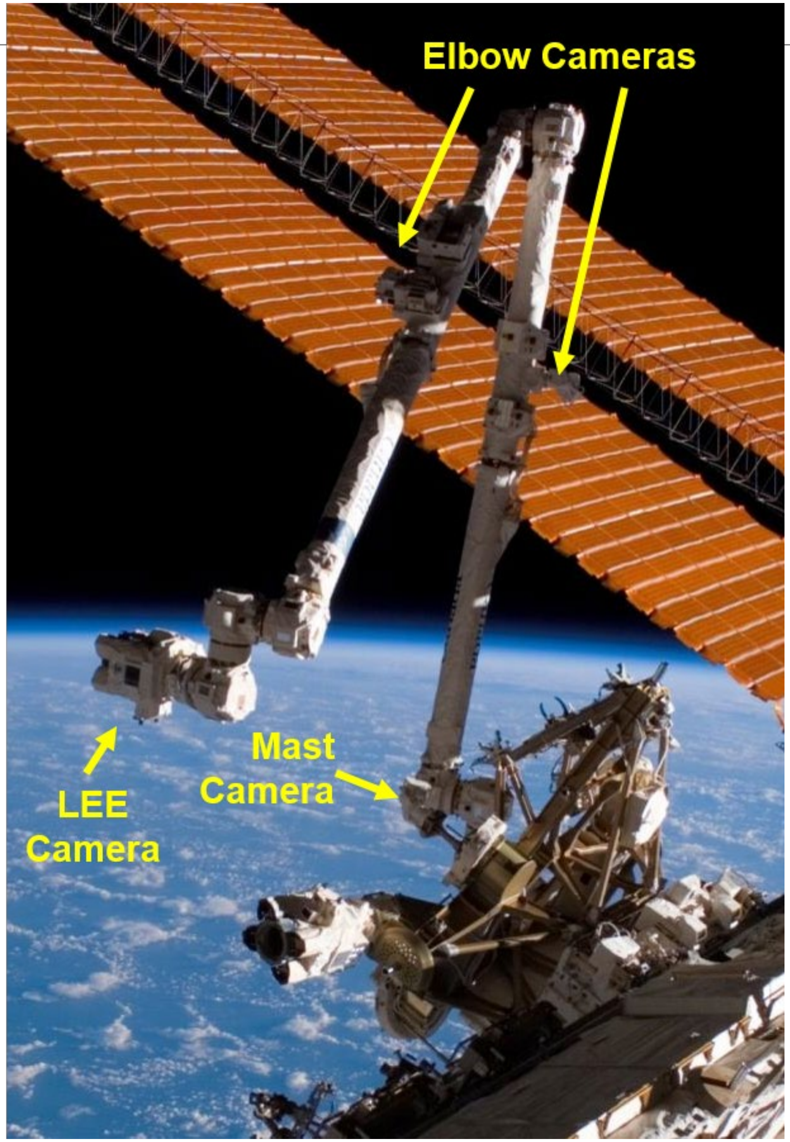


Mechanical Design

- Launch restraint
- Support Structure
  - Rigid vs. Flexible structure
- Payload interface

Sensors

- Cameras
- Temperature
- Force/moment
- Distance or Position
- Motor Current and rate
- Tactile Feedback

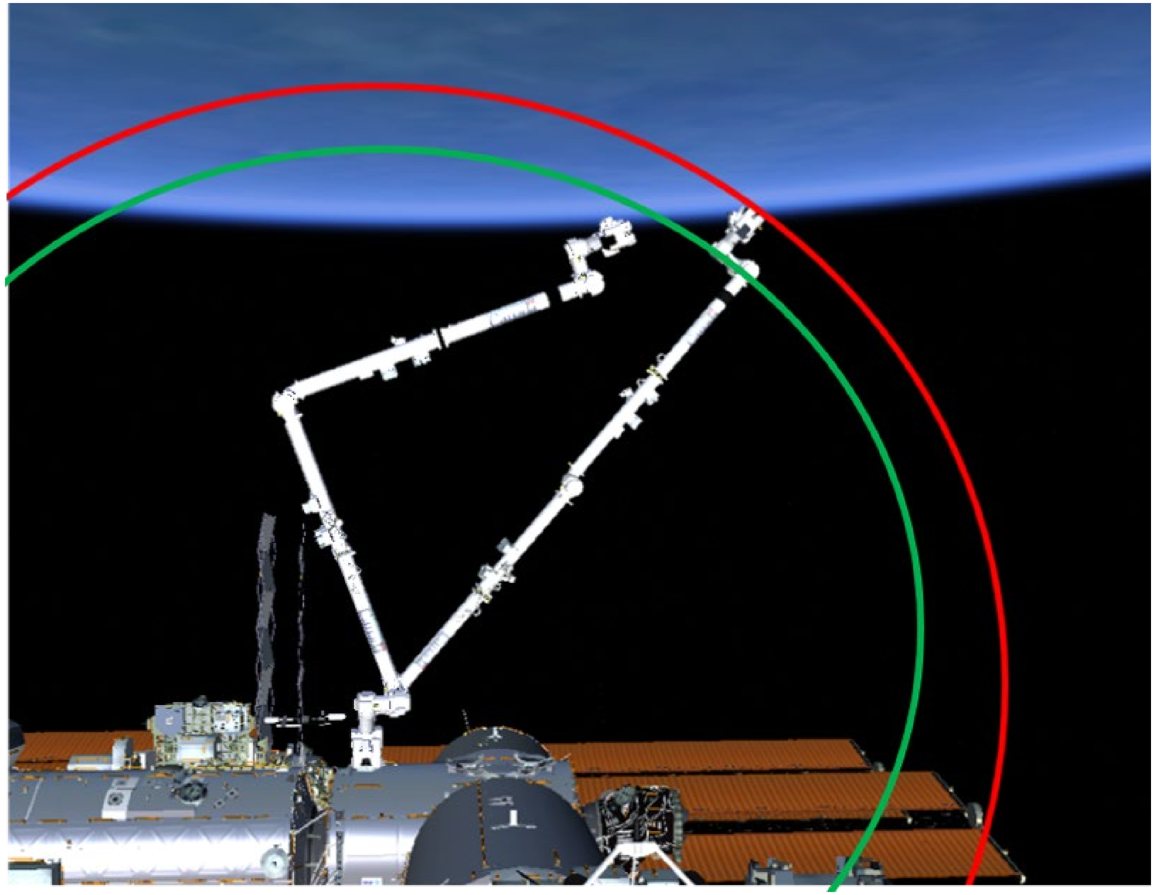


Principals

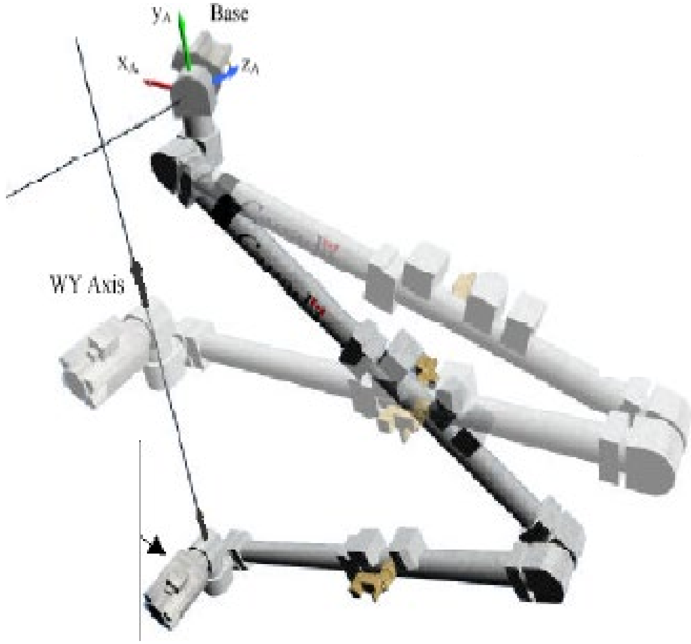
- Envelopes
  - Work Envelope
  - Operational Envelope
- Frames
  - FOR
  - Display
  - Command Hand Controller
- Modes
  - Human in the Loop
  - Automatic

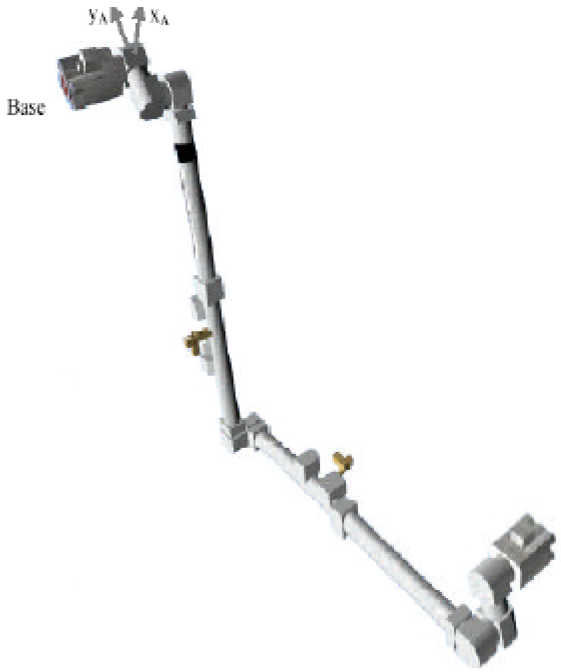
Envelopes

- Work Envelope
- Operational Envelope
  - Singularities
  - Self-Collision
  - Joint Limits
  - Structure

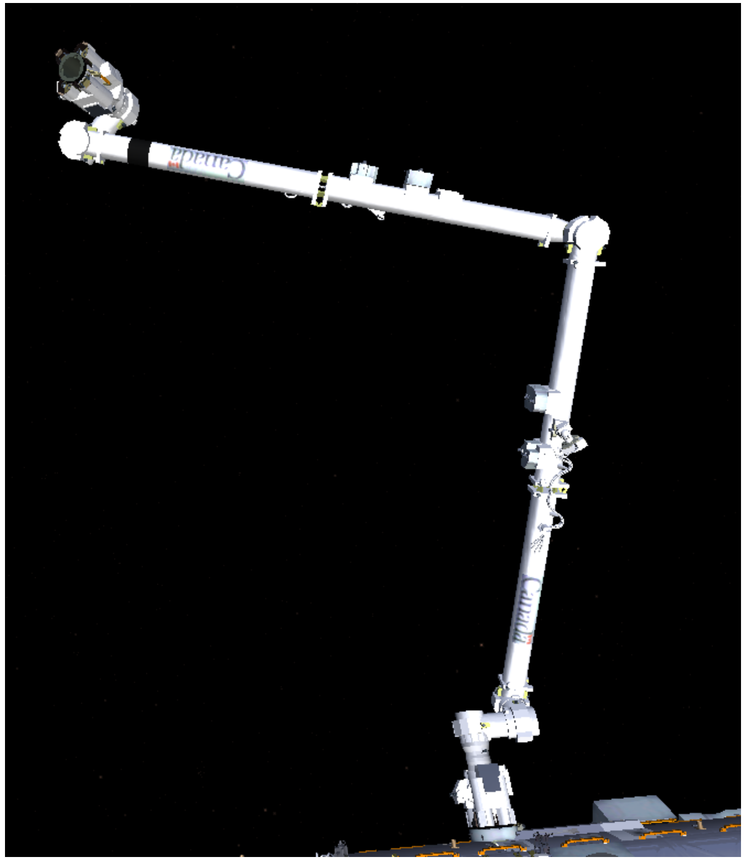


Singularities



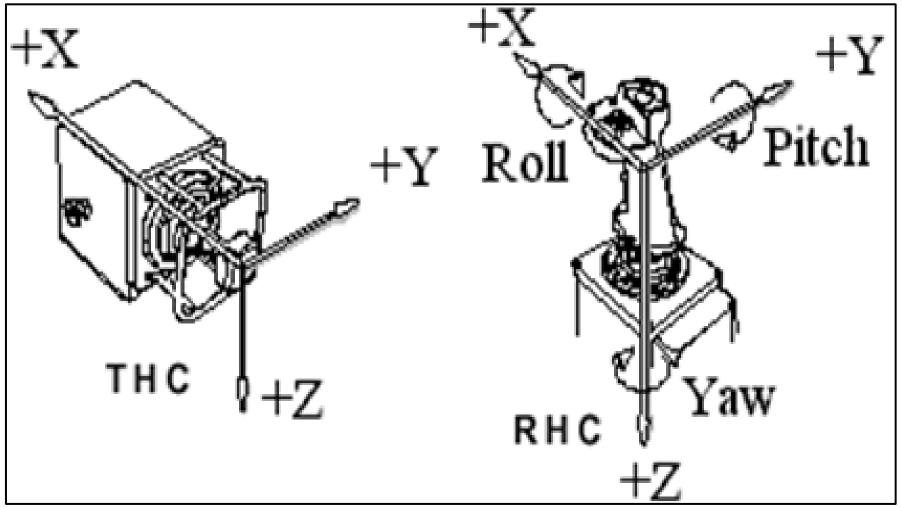


Self-Collisions & Joint Limits

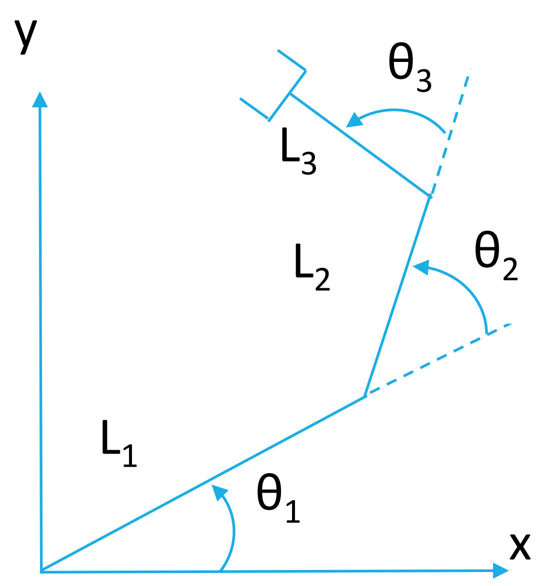


Frames

- Frame of Resolution: Defines position/orientation of manipulator/payload
- Display Frame: Reference Frame
- Command Frame: Maps inputs to motion control
- Hand Controller Frame: Maps mechanical inputs to command frame motion



Kinematics of a Three Link Manipulator



Example: Planar 3 link Manipulator with revolute joints.

Forward Kinematics: Determines the position of the end-effector in the x-y plane, given the joint angles. The solution is unique. In planar space the coordinates are determined by:

$$x = L_1\ cos\theta_1 + \ L_2 \cos(\theta_1 + \theta_2) + L_3 \cos(\theta_1 + \theta_2 + \theta_3)$$

$$y = \ L_1\ sin\theta_1 + \ L_2 \sin(\theta_1 + \theta_2) + L_3 \sin(\theta_1 + \theta_2 + \theta_3)$$

Inverse Kinematics: Determines the joint angles for the end-effector position. The solution, when it exists, is non-unique. The solution for the joint angles requires the **Jacobian** matrix (and its pseudo-inverse, Newton's method) of the nonlinear forward kinematics equations. The **Jacobian, J,** should have rank 2 for the planar manipulator. Joint angles for which J loses rank are called singularities.

$$\begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} = \begin{bmatrix} \frac{\partial x}{\partial \theta_1} & \frac{\partial x}{\partial \theta_2} & \frac{\partial x}{\partial \theta_3} \\ \frac{\partial y}{\partial \theta_1} & \frac{\partial y}{\partial \theta_2} & \frac{\partial y}{\partial \theta_3} \end{bmatrix} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix} = J \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix} \qquad \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix} = J^{\dagger} \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix}$$

Modes

	Human in the loop	Automatic
Pro	• Quick reaction time • Real time updating	• Pre-analyzed • Consistent • Predictable
Con	• Unpredictable • Operator Error	• Slow reaction time • Unable to update once started

	Joint OCAS	FOR OCAS
Pro	• 7 joint motion • Explicit Joint Control • No Singularities • Not frame dependent	• 'Straight Line' Trajectory (easy to visualize, useful for traversing tight space) • Explicit FOR control
Con	• Not 'Straight Line' motion (trajectory hard to visualize)	• Joint locking required • Subject to Singularities & Self-Collisions • Subject to 'wrong way' & display errors • Frame dependent

Failure Mitigation and Response

- Failure Recognition:
  - Internal failure detection (self Test)
  - Collision avoidance software & Operator
  - Loss of Communication Between subunits
  - Tactile Feedback
- Mitigation:
  - Redundancy
    - Trade off between cost and recovery
    - Allows the operator to swap components to recover from a failure
  - Procedures
  - Fail-Safe

Repair or Replace

- On-Orbit Replaceable Units:
  - Components that can be replaced in-orbit
  - Spares required
  - Requires EVA or robotic support to complete
- SSRMS CLPA R&R example

Repair or Replace

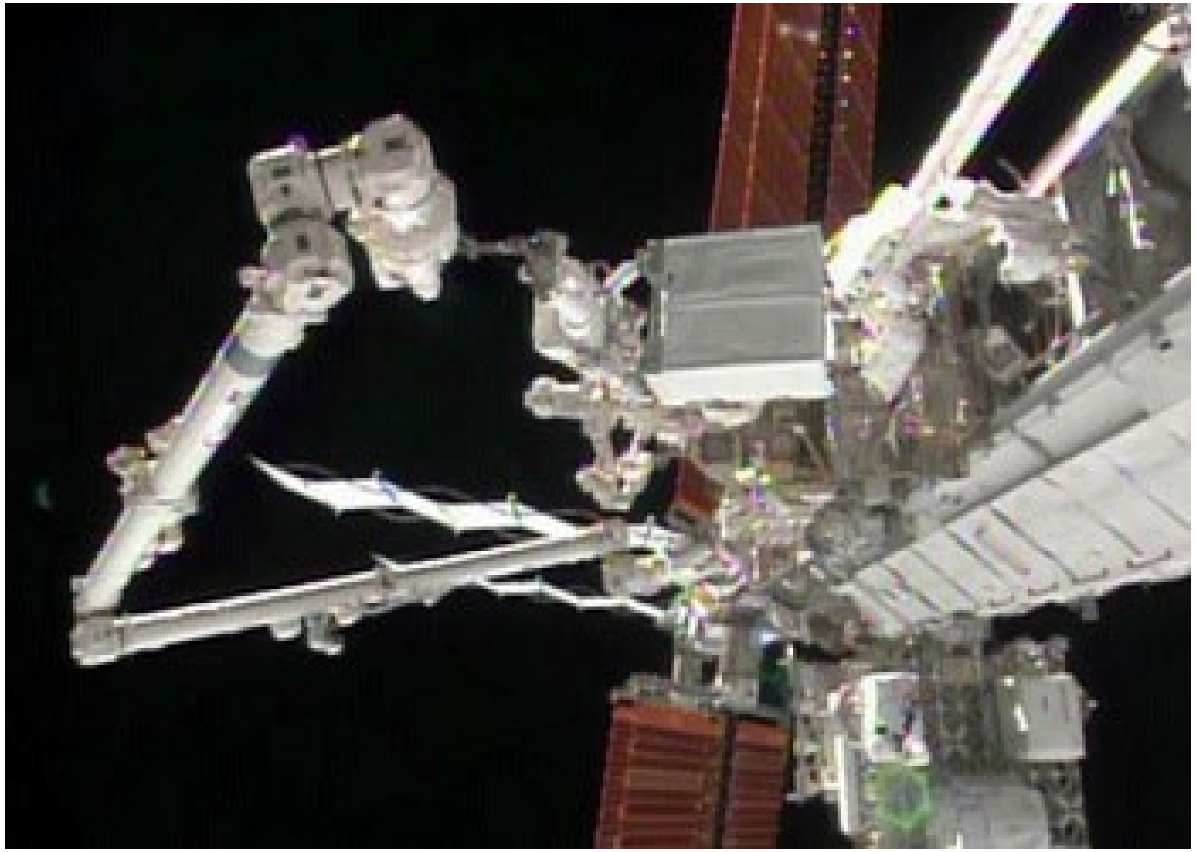
- Solar Array Repair:
  - Required EVA and robotic support to complete

SPARTAN Payload Deploy

- Operation:
  - Grapple SPARTAN Payload, configure SPARTAN for release, unberth, release
- Close Call:
  - SPARTAN did not maneuver as expected
  - Crew attempted to re-grapple the payload and mis-captured
  - EVA was required to rebirth SPARTAN
- Lessons Learned:
  - Checklist commanding required
  - Time constraint added additional pressure
  - Dynamic lighting a concern
  - End Effector overlay should be required

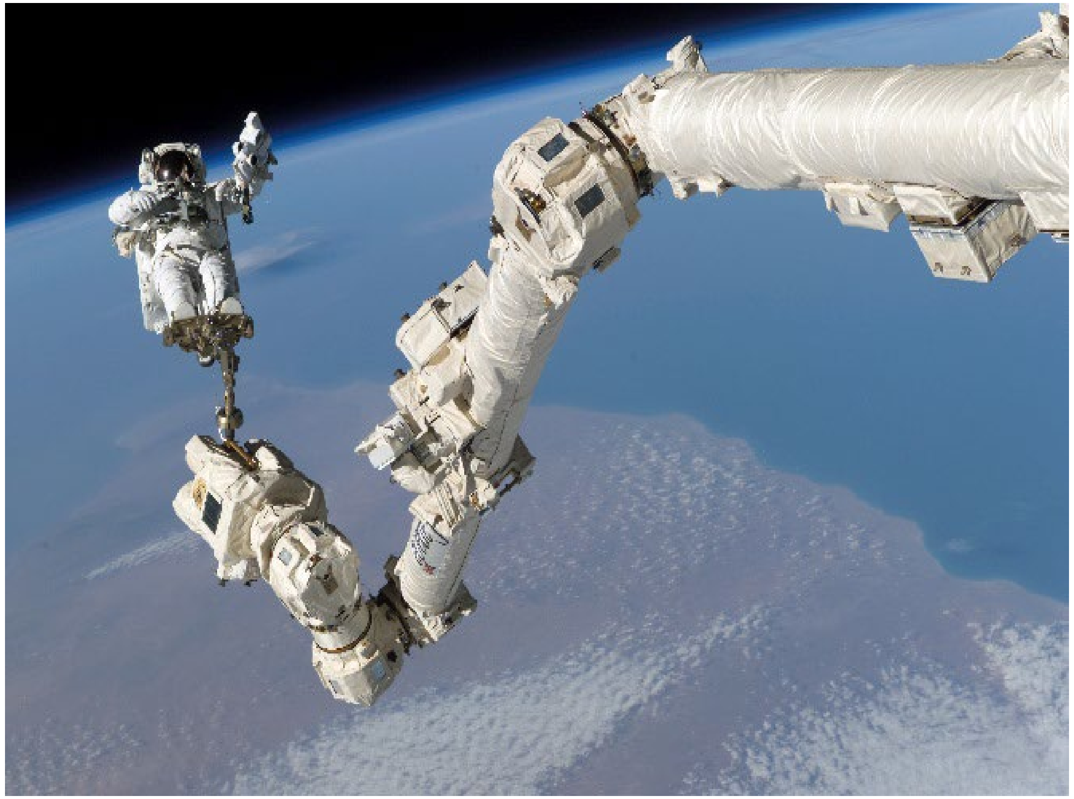
PM EVA Support Example

- December 2012 ISS Pump Module failed (required for thermal control)
  - Quick turnaround EVA required to repair Pump
- Previous EVA aborted due to water in EV's helmet
- New procedure "cue card" developed to expedite rescue of EV if required
- On-Board Training conducted to familiarize crew with procedures & GCA



EVA Support

- On- Board (two crew):
  - Two sets of eyes to avoid structure and backup commanding
  - Responsible for EV's safety & failure response
- Ground (three people):
  - Procedure/ trajectory development
  - On-board training development
  - Coordination
- Two Types of EVAs
  - Planned
  - Contingency



Visiting Vehicle Operations

- On – Board (2 crew):
  - M1: SSRMS operations & capture/release
  - M2: Clearance monitoring & Vehicle commanding

- Ground (3 person):
  - Procedure/ trajectory development
  - On-board training development
  - Coordination
  - Maneuver to and from install
  - Payload operations
  - Off-Nominal planning

Logistics – New Payload Deliveries

Increased Capability

- MISSE
- Micro Satellite Launches
- Supporting Future Science

RRM Robotic Refueling Mission

- Robotic Refueling Mission