Laboratory Validation of Vision Based Grasping, Guidance, and Control with Two Nanosatellite Models

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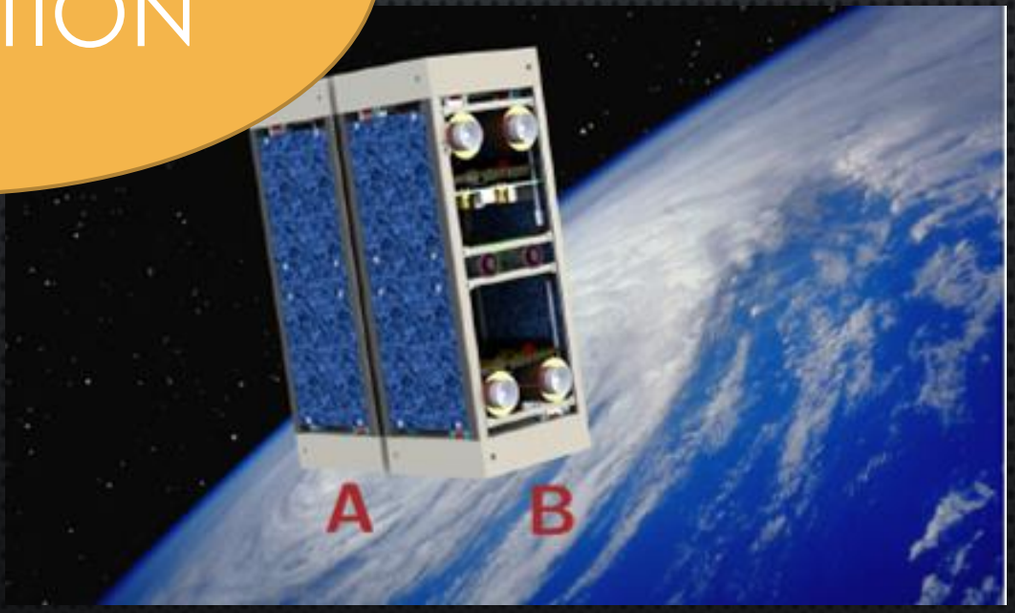
MOTIVATION

SATELLITE SER

IS REMOVAL

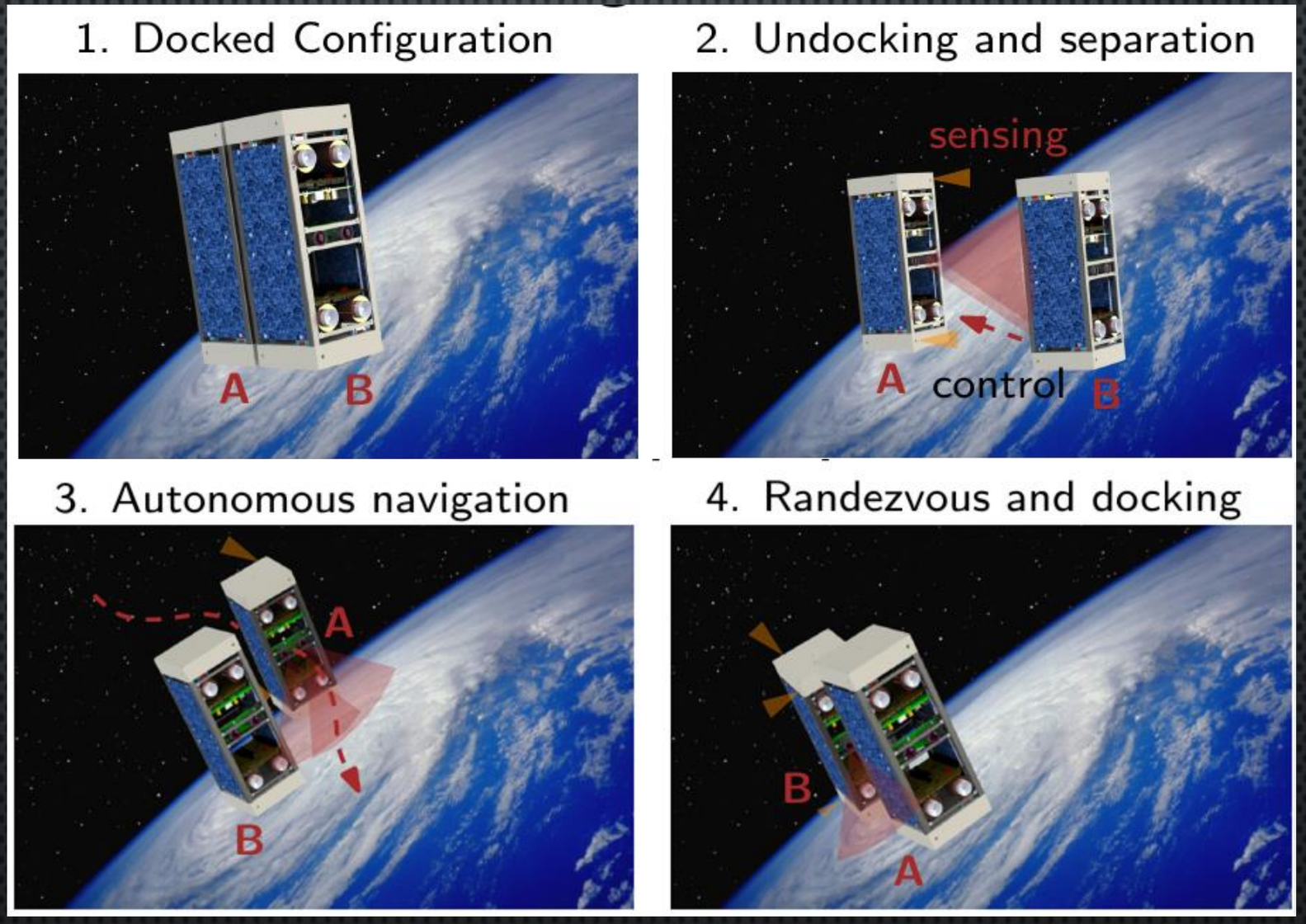
PROXIMITY OPERATION

SURFACE SAMPLING



FORMATION FLYING

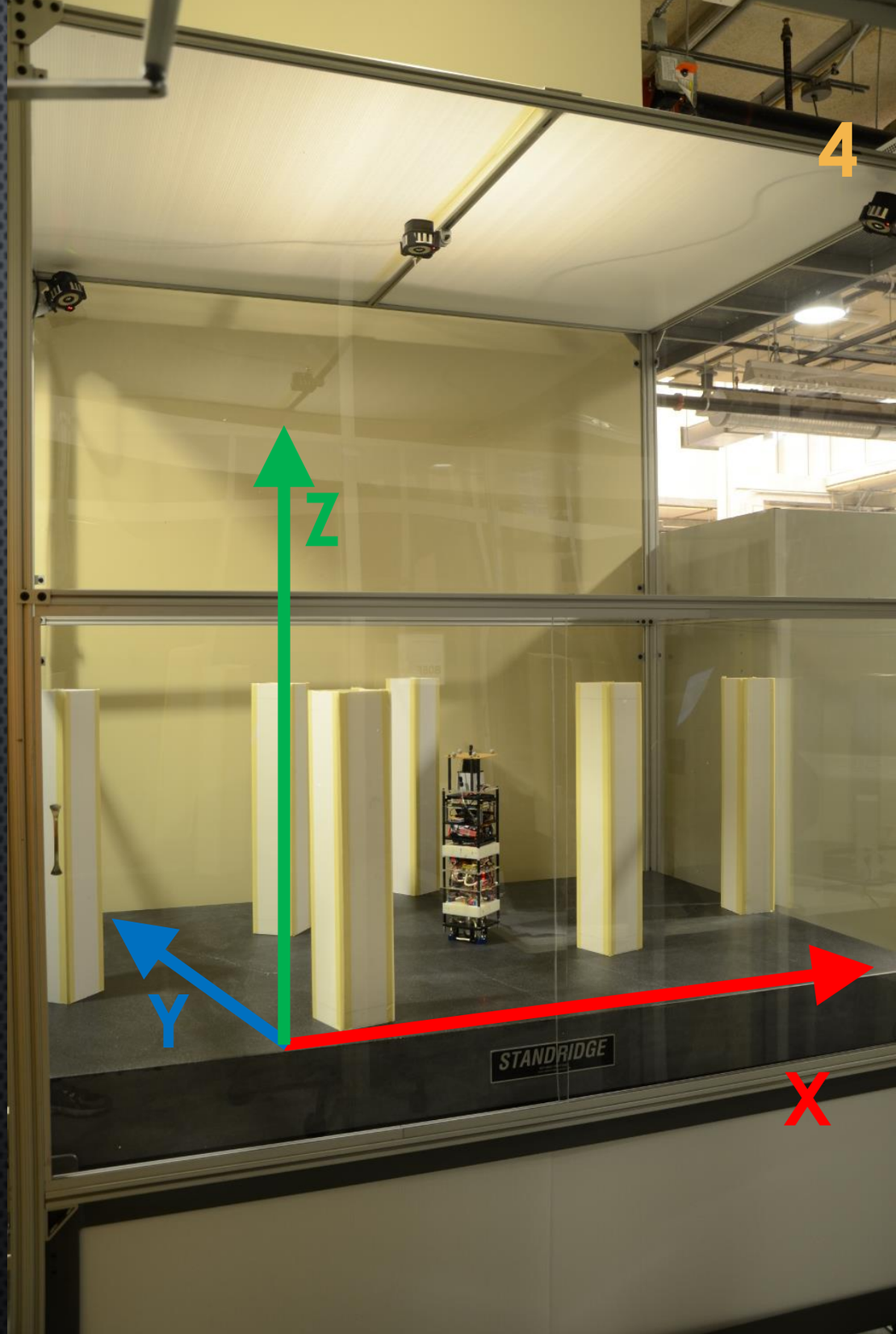
FOCUS



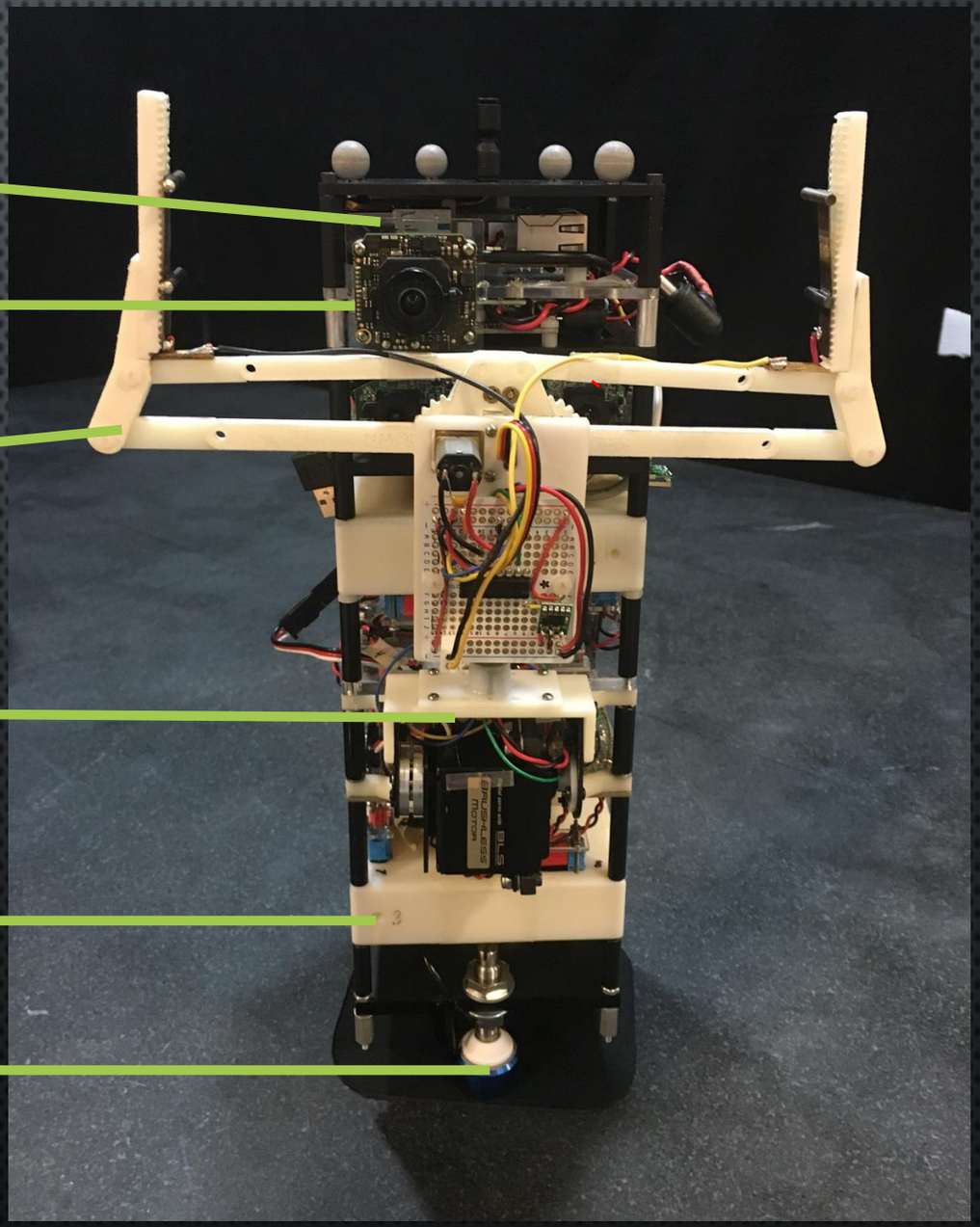
- ENABLE CLOSE PROXIMITY AUTONOMOUS NAVIGATION
- DEVELOP PERCEPTION AND CONTROL ALGORITHMS
- DESIGN CUBESAT APPENDAGE FOR GRASPING

CUBESAT TEST-BED

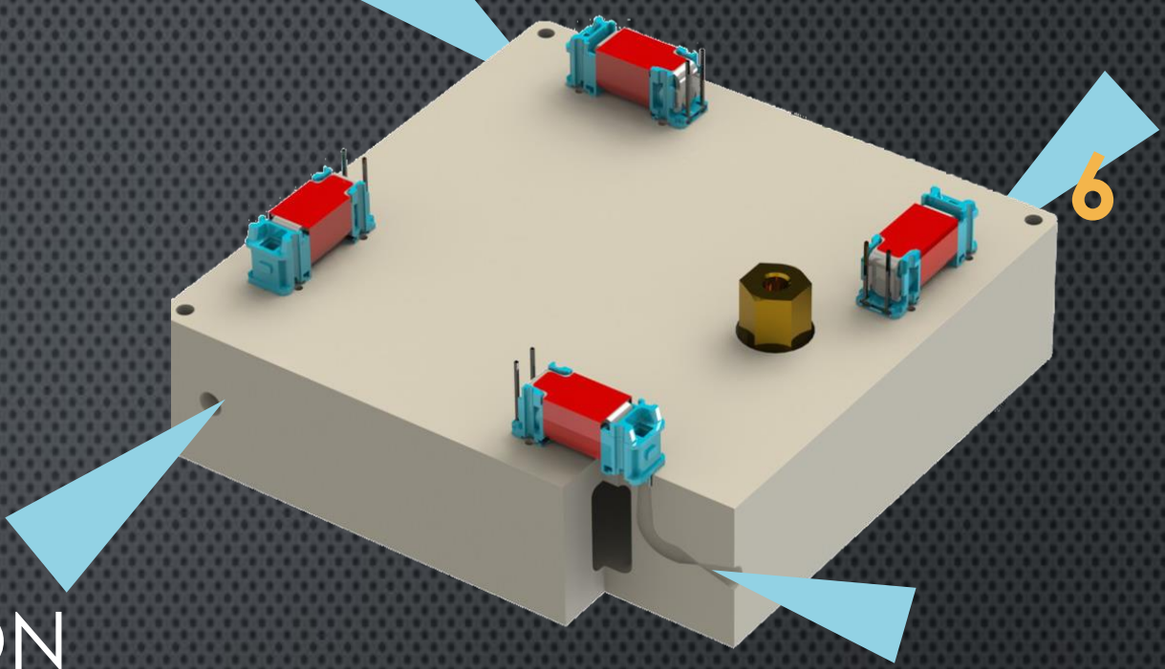
- AIR-BEARING TABLE
- CUBESAT ENGINEERING MODEL



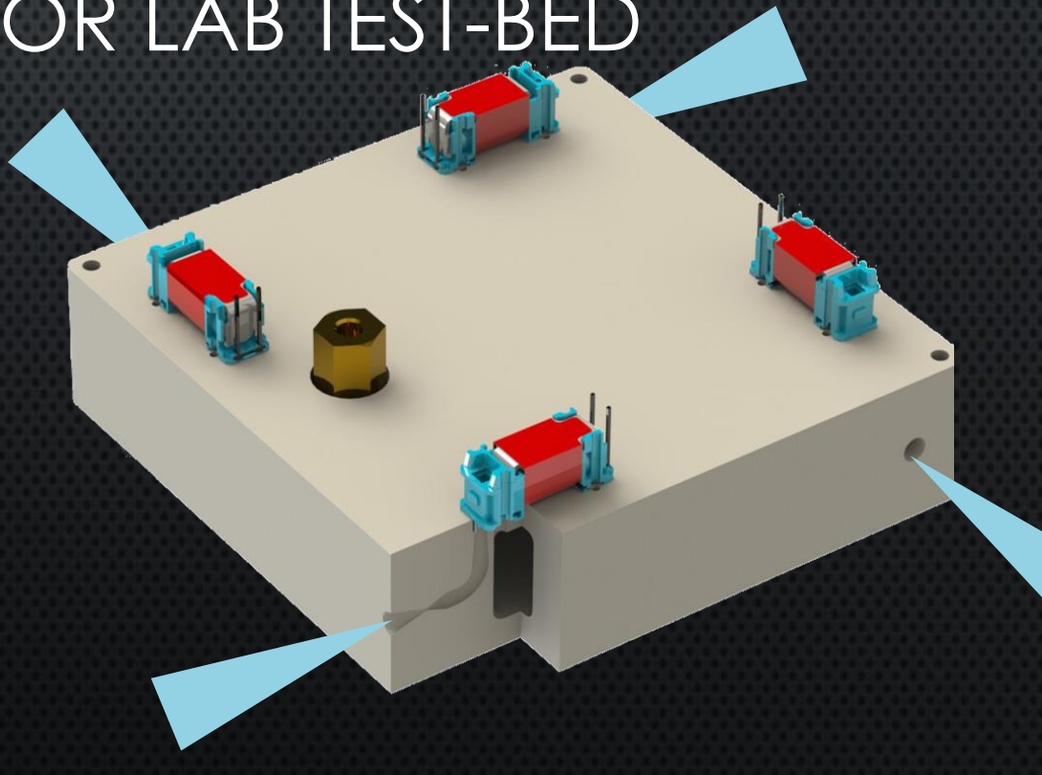
CUBESAT ENGINEERING MODEL



PROPULSION SYSTEM

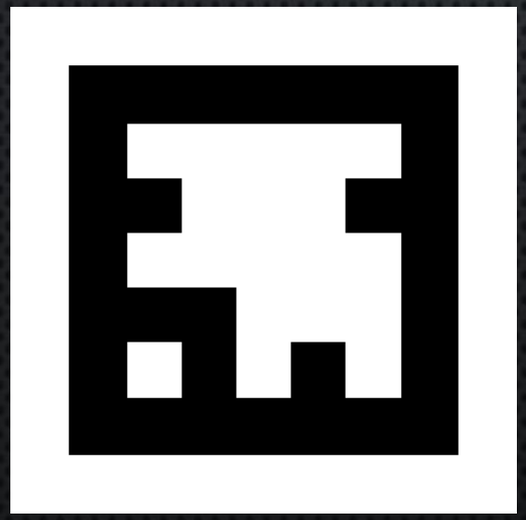


- COLD-GAS PROPULSION
- FABRICATION BY RAPID PROTOTYPING
- DESIGNED SPECIFICALLY FOR LAB TEST-BED
- DESIGN CRITERIA
  - REUSABLE
  - COMPACT
  - SAFE

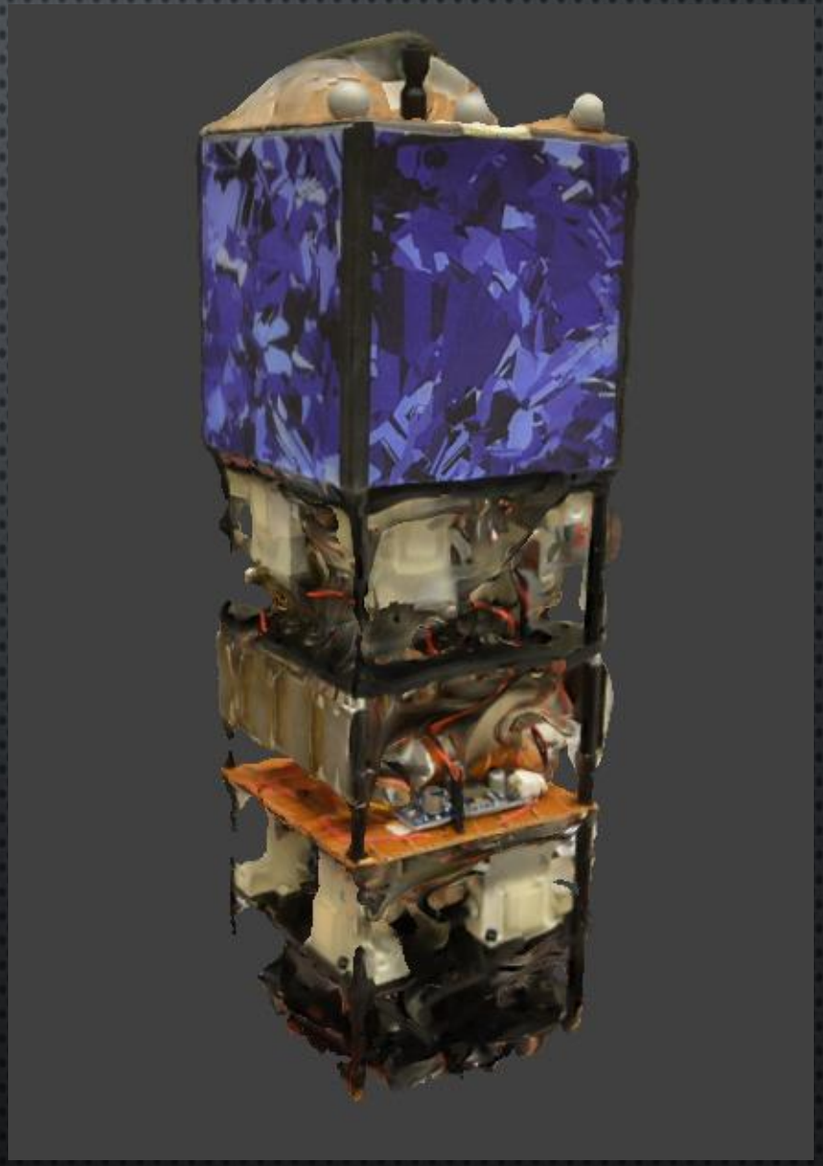


MACHINE VISION FOR PERCEPTION

CAMERA

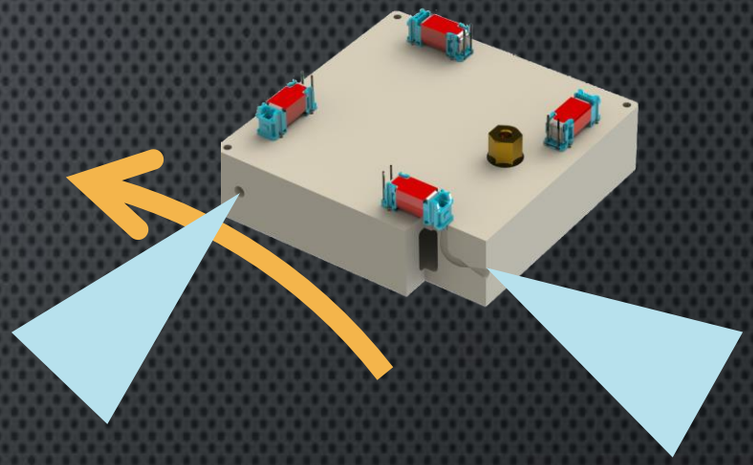


AR TAGS



3D RECONSTRUCTION

ROBOT ENVIRONMENT INTERACTION



Model

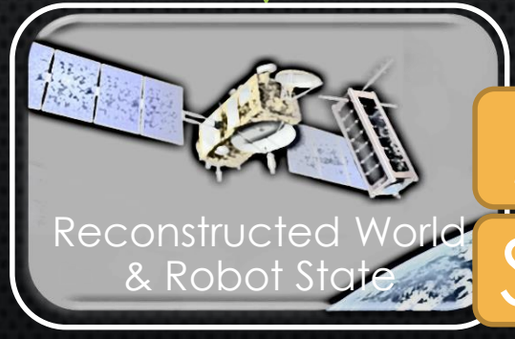
Perception Algorithms

Autono

Robot Operating System (ROS)

ithms

Control Algorithms



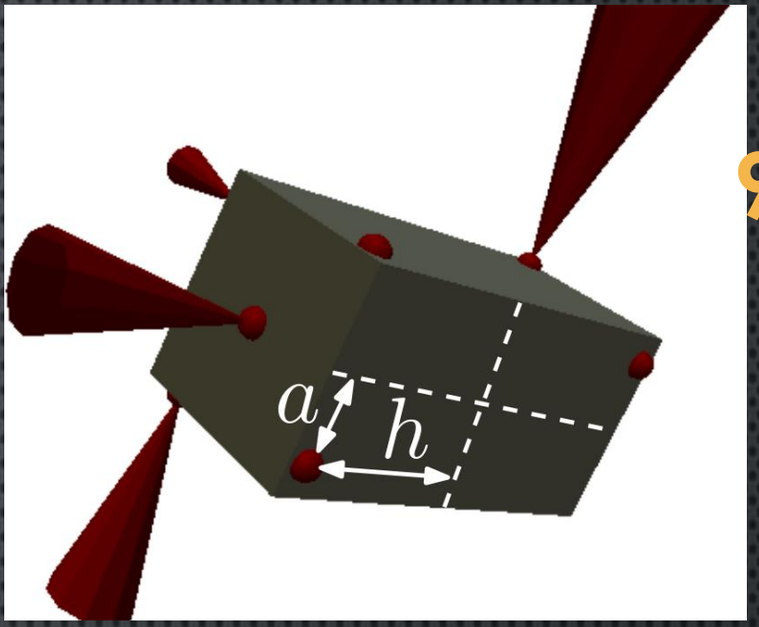
Map

State

DYNAMICAL MODEL

$$\dot{R} = R\hat{\omega},$$

$$\begin{pmatrix} \mathbb{J}\dot{\omega} \\ m\ddot{x} \end{pmatrix} = \begin{pmatrix} \mathbb{J}\omega \times \omega + \tau_{\text{ext}} \\ f_{\text{ext}} \end{pmatrix} + \begin{bmatrix} I & 0 \\ 0 & R \end{bmatrix} Bu,$$



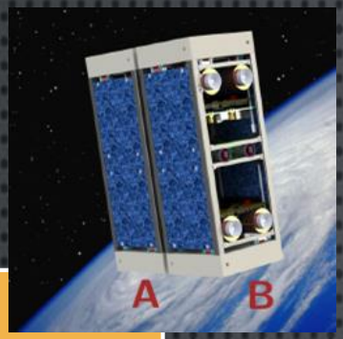
$$B = \begin{bmatrix} 0 & -h & 0 & h & h & 0 & -h & 0 & 0 & 0 \\ h & 0 & -h & 0 & 0 & h & 0 & -h & 0 & 0 \\ a & a & a & a & -a & -a & -a & -a & 0 & 0 \\ -1 & 0 & 1 & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ 0 & -1 & 0 & 1 & -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix},$$

- R: ROTATION MATRIX
- X: POSITION
- ω: ANGULAR VELOCITY
- U: THRUSTER FORCES
- B: THRUSTER ALLOCATION MATRIX
- f_{ext}: ORBITAL PERTURBATIONS
- τ_{ext}: GRAVITY GRADIENT

$$f_{\text{ext}} = m \begin{bmatrix} 2\omega_c \dot{z} \\ -\omega_c^2 y \\ -2\omega_c \dot{x} + 3\omega_c^2 z \end{bmatrix}$$

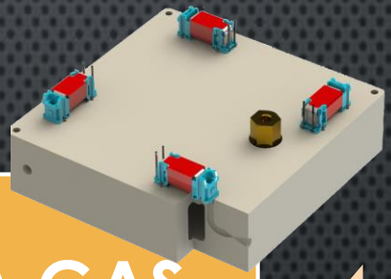
$$\tau_{\text{ext}} = 3\omega_c^2 Re_z \times \mathbb{J} Re_z$$

RECAP



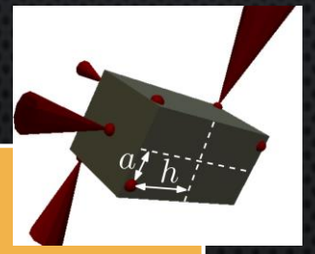
MOTIVATION → FOCUS → AIR-BEARING TEST-BED

CUBE-SAT MODEL → COLD-GAS PROPULSION → SENSING AND COMPUTING



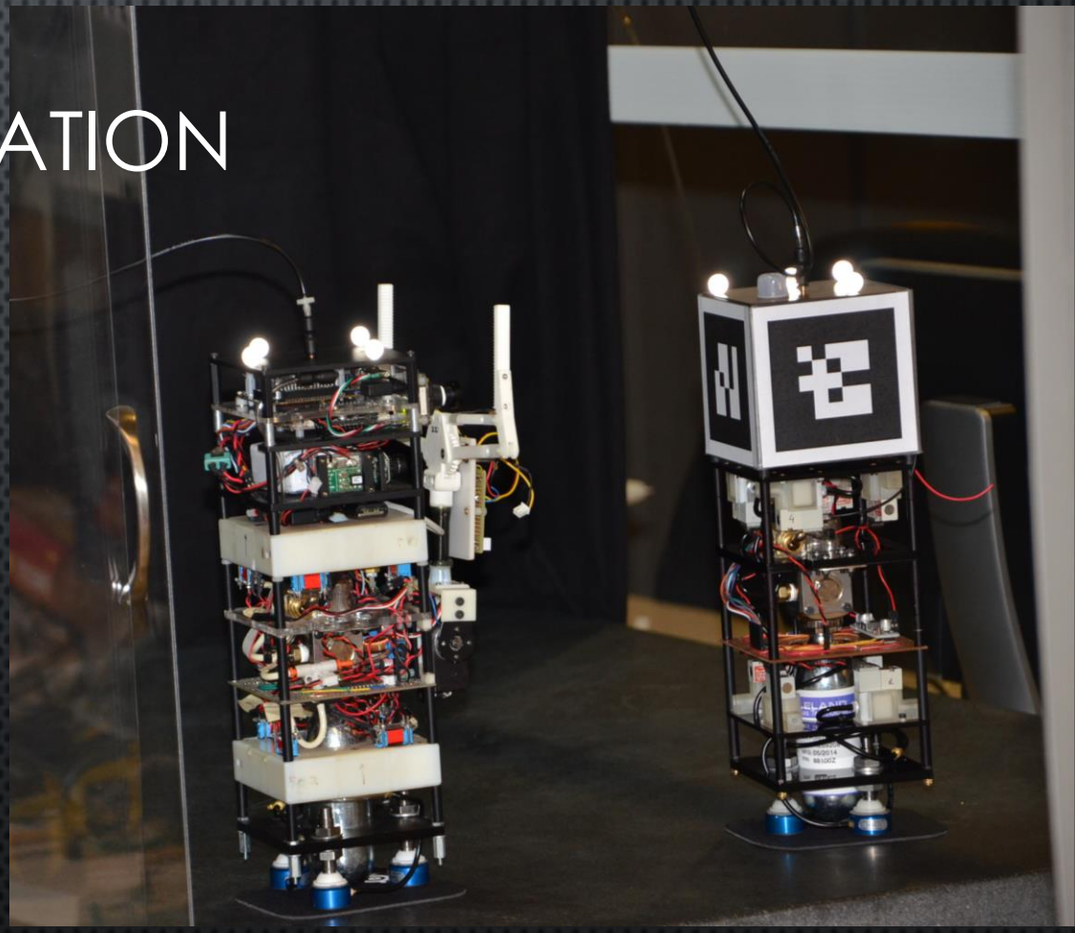
ROS

SOFTWARE FRAMEWORK → PERCEPTION ALGORITHMS → CONTROL

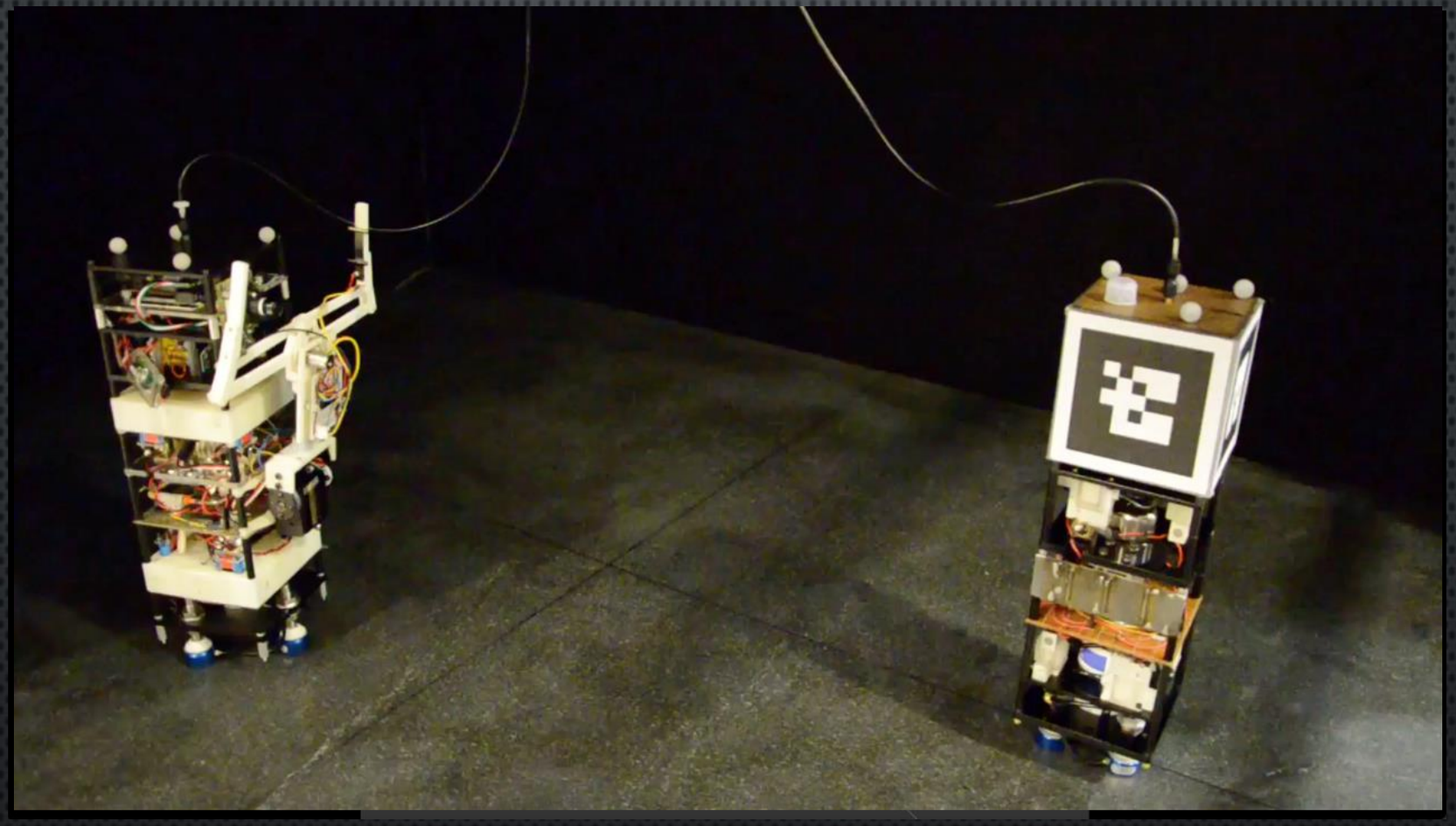


CUBESAT INTERACTION SCENARIOS

- DOCKING/RECONFIGURATION
- CHARGING
- RELATIVE NAVIGATION
- DEORBITING



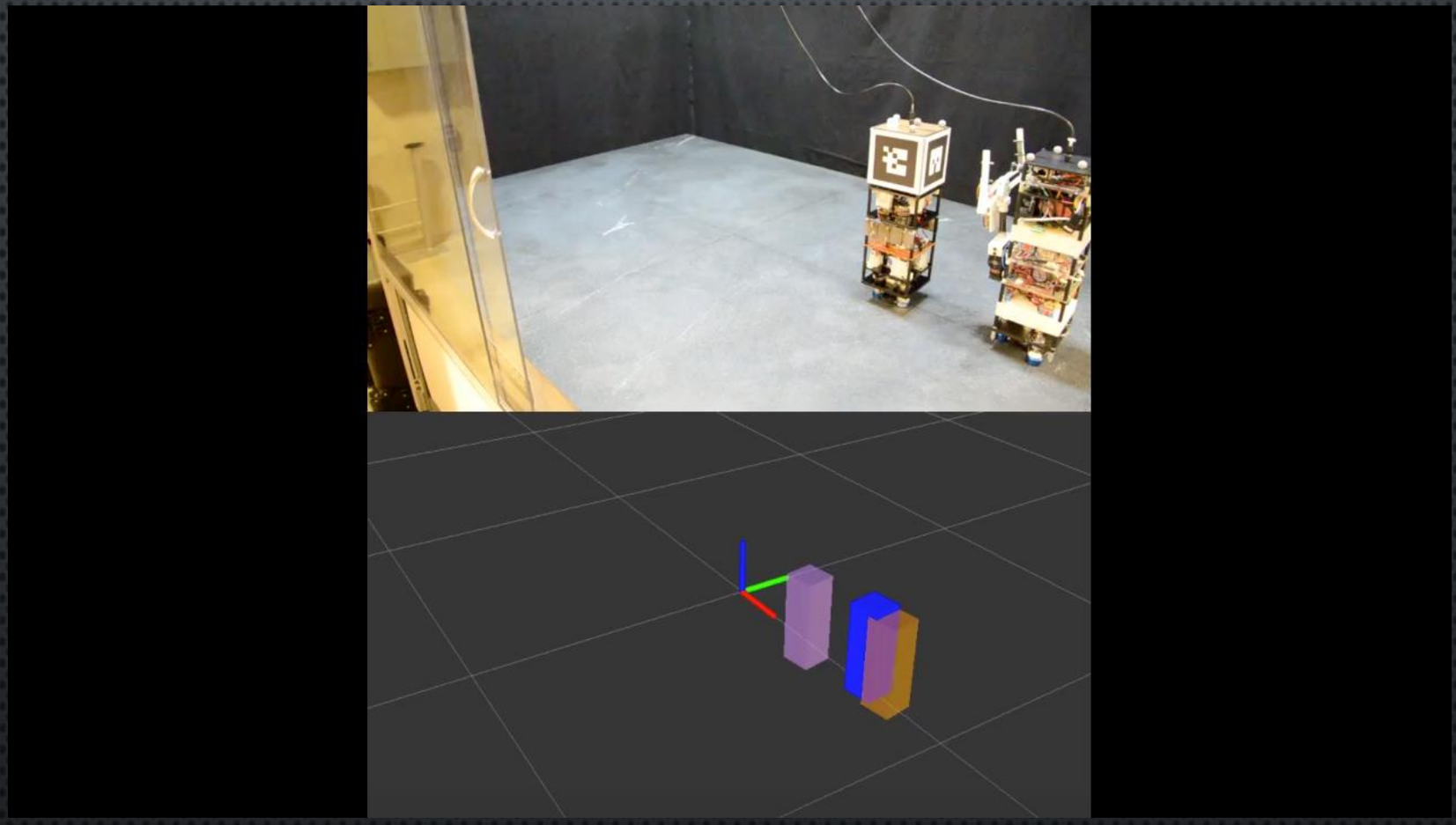
RECONFIGURATION AND CHARGING



2X

- LOCALIZATION WITH RESPECT TO SECOND CUBESAT
- NAVIGATION TO CLOSEST FACE
- GRASPING AND RECONFIGURATION
- CHARGING

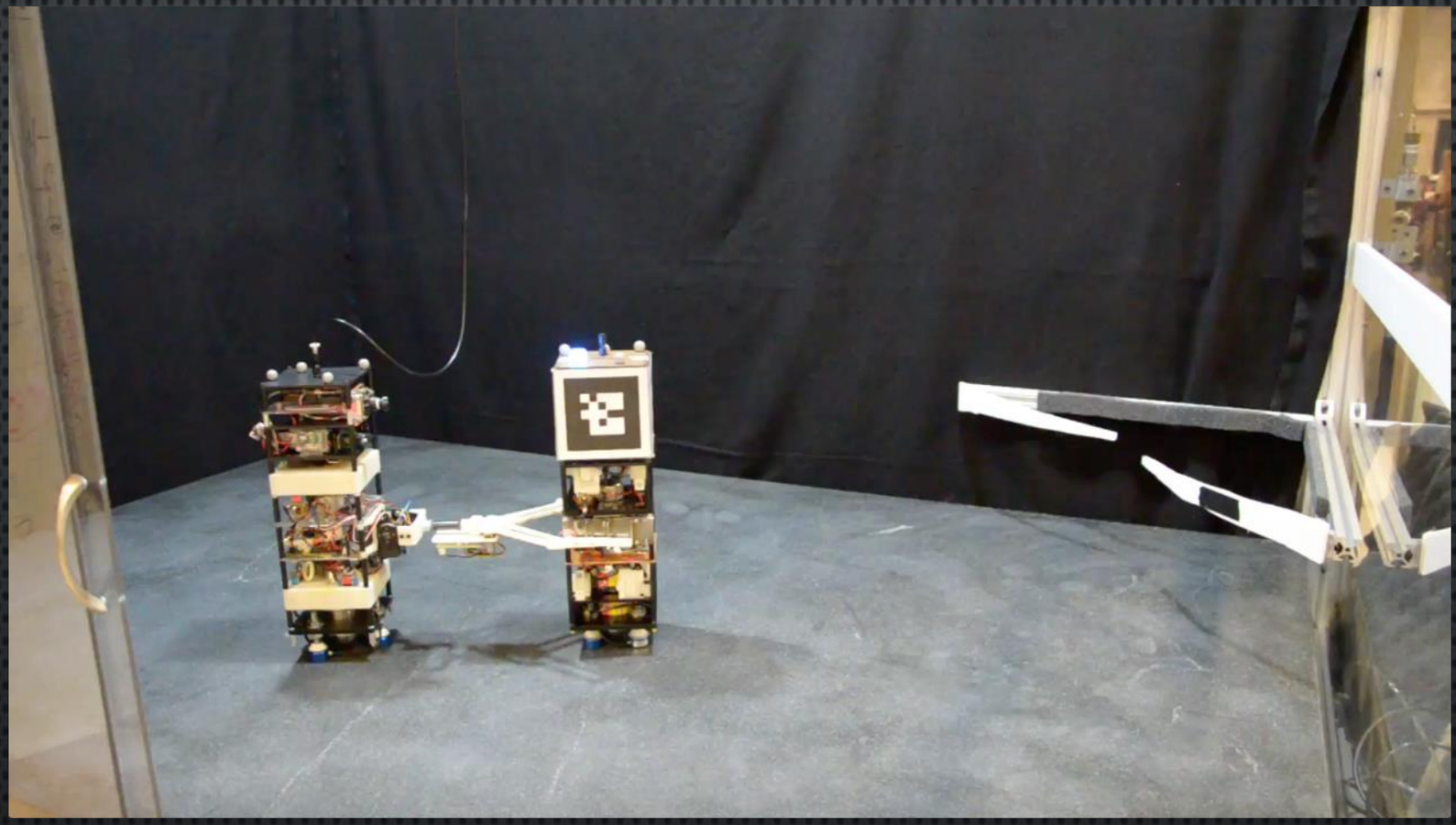
RELATIVE NAVIGATION



3X

- LOCALIZATION WITH RESPECT TO SECOND CUBESAT
- SECOND CUBESAT FOLLOWS PROGRAMMED TRAJECTORY
- NAVIGATION TO MAINTAIN FIXED OFFSET

DEORBITING MANEUVER



2X

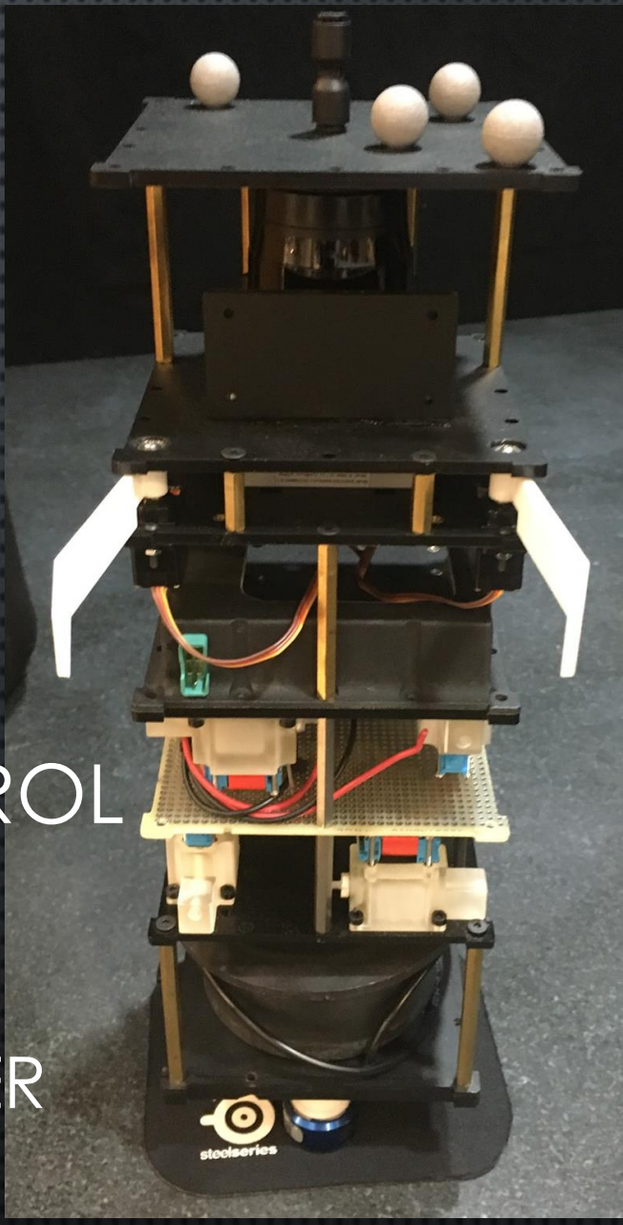
- DOCKED STATE
- NAVIGATION TO GOAL POSITION AND VELOCITY
- RELEASE OF SECOND SATELLITE
- NAVIGATION TO FINAL POSITION

SUMMARY

- CUBESAT ENGINEERING MODEL WITH PROPULSION, SENSING, COMPUTATION, MANIPULATION
- VISION BASED LOCALIZATION TECHNIQUES
- DEMONSTRATED CUBESAT INTERACTION SCENARIOS

FUTURE WORK

- IMPROVED TEST-BED
  - FULLY RETRACTABLE GRIPPER
  - REFILLABLE GAS TANK
  - 3U CUBESAT FORM FACTOR
- ADVANCED PERCEPTION AND CONTROL
  - IMPROVED PERCEPTION AND CONTROL ALGORITHMS
  - COMBINED SYSTEM IDENTIFICATION AFTER GRASPING



QUESTIONS ?

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