The Challenges of Assuring Vision Systems for Space Missions

Presented by Charley Price and Vincent Howard, with key contributions by Jeremy Yagle, NASA LaRC

September 11, 2014
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Two Advanced Robotic Missions

The two missions are:

• Asteroid Redirect Mission
  • A Robotic mission to move an asteroid to lunar orbit
  • (Followed by a Human mission to study the asteroid in lunar orbit.)
    http://www.nasa.gov/mission_pages/asteroids/initiative/

• Mars 2020
  • The next Mars surface rover mission
    http://mars.jpl.nasa.gov/mars2020/
Design Option A:

Capture an asteroid,
...and move it to lunar orbit.

Design Option B:

Pluck a boulder from the surface of an asteroid,
...and move it to lunar orbit.
Similar to Curiosity
Leaned down ~40% to accommodate caching samples for return to Earth.

Has new zoom camera on mast for longer range vision operations.

...rove, conduct science, collect rocks and other samples.
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Angles of specific stars are measured & used to update s/c attitude.

Ensures thrusters are pointed correctly

- Both Apollo spacecraft used optical alignment telescopes for ~37 star catalog.
- Shuttle steered its attitude to point star trackers at ~100 navigation stars.
  - Original Space Station used star trackers and ~100,000 stars
  - ISS currently, the Russian Segment tracks stars; the US Segment uses GPS and ring laser gyros.
NASA Missions Operate in Complex, Dynamic Environments

Objects of Interest
- Simple and complex
- Natural and fabricated
- Singular, layered, cluttered
- Varying, shifting illumination
- At varied distances
- In varied motions

Actuation Systems
- Manipulation
- Rover
- Spacecraft

So, what’s a space vision system for?
The Vision System Provides Reference Geometry for Action
Example of serial effects of vision algorithms

Vision System Algorithms

Input Image

Filtering → Feature Extraction → Object Identification → Object Location Estimation → Object Pose Estimation

Reference Information

Planning & Control
Vision Systems Significance to NASA

• Vision systems enable capabilities:
  • Autonomous control of mechanisms in complex environments.
  • Faster response time than teleoperation, i.e. ‘move and wait’
  • Autonomous, judicious, reduction of voluminous image data for downlink.

• These capabilities assure that NASA missions with long communication time delays have:
  • More efficient use of available resources such as
    • Martian daylight
    • Downlink bandwidth
    • Ground control staffing

• Better hazard avoidance & anomaly resolution
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Vision Systems Challenges

• Framing the problem space:
  • Reducing huge data sets to small essential sets
  • What is intended for the vision system to see?
  • What key features can the vision system identify?

• Robustness during lighting variability to prevent:
  • Missed feature detection
  • Mis-identification of object of interest
  • Incorrect object position and/or pose determination

• Range-dependent uncertainties:
  • Perspective geometric morphing
  • Light intensity level increase
  • Increase of details in image

• Fidelity of field testing/verification prior to operations
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The **Vision Systems Technical Reference** addresses:

- **Vision Risks**
  - Characterizes risks associated with the vision system, and associated mitigations.

- **Vision Requirements**
  - Defines the critical tasks that the vision system shall carry out, and relevant information to request from the developers.

- **Vision Design Analysis**
  - Characterizes the envelope in which the vision system is to operate with the greatest probability of mission success.

- **Vision Implementation**
  - Guidelines for implementation of computer vision systems.

- **Vision Test Analysis**
  - Addresses nominal and off nominal conditions to simulate...
The Vision Technical Reference Site Map on Confluence

Capability Development / Capability Development Home / Robotics

Computer Vision Technical Reference

Added by Vincent Howard, last edited by Vincent Howard on Aug 06, 2014 (view change)

- Site Map
- Mission Vision System Function:
  - Assumptions
  - Risks
  - Requirements
  - Design Analysis
  - Test Analysis
  - Implementation
  - Test Questions
  - Vision Algorithm Information
  - Analyst's Reference Table
Mitigations for VS IV&V: A Vision System Testbed for the Analyst

• Vision System Purpose
  • To test operating envelope of a vision system’s object identification, position, and attitude estimation algorithm by comparing it against an independent truth measurement system.

• Testing of a vision system’s algorithm components:
  • Vision algorithms can be deconstructed into constituent parts, which can then generate outputs specific to each individual filter or technique.
  • Attitude and position estimate algorithms can be tested to ensure and quantify the vision system's accuracy.

• Simulating the mission environment:
  • Using the satellite drawings and diagrams, analysts can create a 3D-printed scale model with appropriate details.
  • The test bed can simulate lighting conditions during mission operations.
Mitigations for VS IV&V: The Vision System Testbed Architecture

- ITX Laptop
- ITX Main
- Inverse Kinematics
- TPC/IP Sockets
- RoBoard Main
- (Servo Outputs)
- Physical Scale Target Model
- Truth System Cameras
- Video Feed
- Arm Commands
- Robotic Arm
- Rigid Frame
- Target Satellite
- Vision System Camera
- Vision Processing

Inversed Kinematics

ITX

Laptop
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Wrap Up and Take Aways

- NASA continues to push the envelope in space exploration.

- Complex robotic operations are part of the planned Asteroid Redirect and Mars 2020 missions.

- The vision systems included in these missions offer new challenges for the developers and for the IV&V analysts.

- Mediations for the IV&V challenges have been presented as a Vision System Technical Reference and a Vision System Testbed for use by IV&V analysts.
• Questions?
  • Missions?
  • Robotics?
  • Vision systems?

• Thank you for your time and interest!