Application of CFS to a Lunar Rover: Resource Prospector (RP)

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The Hunt for Lunar Volatiles

**Clementine (1994):**
Curious bi-static radar findings at the poles...
*Water-ice?*

**Lunar Prospector (1998):**
Shadowed craters contain elevated Hydrogen levels...
*Water-ice?*

**LCROSS/LRO (2009):**
Yes! Water-ice. *How is it distributed?*

**RP (2022):**
Prospect for water-ice on human scales and demo ISRU processing.
• Mission to Lunar Pole to search for and characterize the water ice
  – What form (eg. Snow or Ice lens?)
  – How much water is there?
  – How deep is it?
• Lunar Rover with:
  – Prospecting instruments to search for ice deposits
  – Drill to extract samples from the subsurface
  – Oven to bake the samples and scientific instruments to study its contents
• Developed and demonstrated a first prototype in 2015
• Currently scheduled to launch in 2022
RP Storyboard
Software Process

• Guiding documents:
  – NASA Software Engineering Handbook
  – 7150.2B NASA Software Engineering Requirements
  – NASA-STD-8739.8 NASA Software Assurance Standard
  – APR8070.2 Class D Spacecraft Design & Environmental Test

• Processes based on LADEE experience
  – Incremental Development Process
  – FSW Model based development technique

• Leverage Heritage Software
  – VxWorks, CFE/CFS, & LADEE C&DH Software
  – JSC Rover Control Software
  – Ames Rover Software (VERVE, Mapping, Path Planning, Hazard Detection, etc).

• Incremental Development:
  – 6 Builds, 2 releases
    • Each build has “theme of development” for focusing activities
    • First release fully functional – occurs prior to start of Rover I&T
    • Second release for bug fixes and late changes to requirements – occurs during Rover I&T
  – Test Early, Test Often
RFSW Model Based Development

- Requirements
- Design/Algorithm Development
- Heritage Models
  - Flight Software Modeling
  - Vehicle & Environment Modeling
  - Workstation Simulations (eg. Simulink)
    - Hand Developed Apps
    - Code Generation
    - Unit Tests
    - Integrated Tests
- Processor-in-the-Loop
- Hardware-in-the-Loop
- Analysis
- Automated Reporting
- Verification
RFSW Modules

Mobility  Rover Kinematics  Rover Mode Manager  Pose Estimation  IMU Filter  HGA Pointing  Camera Pointing  Virtual Bumper

Power I/O  BMS I/O  Thermal I/O  NSS I/O  Camera I/O  Gimbal I/O  Wheel Module I/O  IMU I/O

Software Bus  Time Services  Executive Services  Event Services  Table Services

Telemetry Output (TO)  Command Ingest (CI)  House Keeping (HK)  File Manager (FM)  Checksum (CK)  Scheduler (SCH)  Limit Checker (LC)  Health and Safety (HS)  Stored Command (SC)  Data Storage (DS)

Legacy

OSAL  VxWorks  Drivers

I/O Module  Hand Written Application  Simulink Application  CFS Application  CFE Modules
Rover Software Operation

- Rover Kinematics
- Mobility
- Rover Mode Manager
- Wheel Module I/O
- Pose Estimation
- IMU I/O
- Cam/HGA Gimbal Pointing
- Gimbal I/O
- Virtual Bumper
- Camera I/O
- Software component
- Talks to external elements
- Operator Interface
- Simulator
- Planning
- Hazard Detection
- Offboard Localization
- Mapping
- Stereo Reconstruction
- RP FSW
- Link to Earth
- RP GSW
Results

• RP15 mission in a year met all objectives
  – Rover (and Software) developed on time and within cost constraints
  – Successful demonstration of remote operations
  – Demonstrated effective use of heritage software (CFE/CFS, JSC Controls) and processes (LADEE).
• CFE/CFS architecture did not impose significant limitations
  – Distributed control system allowed reasonable control loop frequencies
  – Event based sequences not necessary with human-in-the-loop decision making and limited autonomy
  – Limit Checker sufficient for “phone home” fault management approach
Future Software Challenges

• Impact of limited visibility, shadows, and occlusions
  – Stereo and Localization studies using Lunar Lab Environment

• Communication Delays and Limited Bandwidth
  – Studying impact of onboard compression algorithms

• Impact of Excessive Slip and Embedding
  – Ongoing analysis and testing

• Multi-path effects and potential loss of Comm
  – Fault Management discussions ongoing

• How to drive effectively given constraints
  – Development of high fidelity driving conops simulator