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
Resource Prospector

• 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
RP15 Distributed Operations Test testing

NASA-ARC Mission Control room driving RP15 rover

RP15 rover @ NASA-JSC Rock Yard

NIRVSS Payload Operations

NASA-KSC Payload Control room
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
  - Flight Software Modeling
  - Vehicle & Environment Modeling
  - Workstation Simulations (e.g., Simulink)
  - Hand Developed Apps
  - Code Generation
  - Integrated Tests
    - Processor-in-the-Loop
    - Hardware-in-the-Loop

Verification

Analysis
  - Unit Tests
  - Automated Reporting
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)

OSAL
VxWorks
Drivers

I/O Module
Hand Written Application
Simulink Application
CFE Modules

Legacy
Rover Software Operation

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

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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