Software Engineering for Human Spaceflight

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Spacecraft Software Engineering Branch / ER6
NASA Johnson Space Center

The Spacecraft Software Engineering Branch of NASA Johnson Space Center (JSC) provides world-class products, leadership, and technical expertise in software engineering, processes, technology, and systems management for human spaceflight. The branch contributes to major NASA programs (e.g. ISS, MPCV/Orion) with in-house software development and prime contractor oversight, and maintains the JSC Engineering Directorate CMMI rating for flight software development. Software engineering teams work with hardware developers, mission planners, and system operators to integrate flight vehicles, habitats, robotics, and other spacecraft elements. They seek to infuse automation and autonomy into missions, and apply new technologies to flight processor and computational architectures. This presentation will provide an overview of key software-related projects, software methodologies and tools, and technology pursuits of interest to the JSC Spacecraft Software Engineering Branch.
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NASA Johnson Space Center
JSC is the heart of the operations, scientific, and engineering community that leads at the frontier of human space exploration, where technical challenges are most daunting and risks are highest.

Main Site: Houston, TX
Civil Servants ~3100
On/near site ~11,000
JSC Engineering Directorate
Software, Robotics and Simulation Division (ER)
ER6 Responsibilities:

– “GFE” Software for ISS and Other Customers
– MPCV/Orion Software System Management and in-line software development
– Software technology development and software for advanced projects
JSC ER6 Expertise Overview

• Spacecraft Software Engineering Branch/ER6 is the Engineering Directorate’s organization for:
  – Flight software systems engineering and integration (SE&I)
    • Full spectrum of spacecraft software functions, e.g., Vehicle Systems Management (VSM), Command and Data Handling, Communications and Tracking, etc.
    – Software advanced technology development

• Flight software SE&I accomplished via three organizing principles and related technologies
  – Robust, proven software architecture base
  – Detailed process definition and management
    • CMMI Maturity Level 3 Organization
  – Tools and technologies for reliable software implementation
JSC ER6 Software Expertise

- Software Development
  - Flight and ground systems
  - Real-time, mission-critical, embedded software development
  - Software integration and hardware in-the-loop testing
  - Vehicle systems management
    - Fault detection, isolation and recovery software
    - Automation for human workload reduction
    - Flight safety enhancement
    - Resource management
- Automation and Robotics
  - Hardware/software integration for human robotic systems
  - Teleoperation and autonomous system control
  - Automation for operations
Software Testing and Simulation in conjunction with ER7
  • Advanced simulation environments allowing integration of software developed for many different platforms
  • Integration of multiple models into a single simulation
    • Real-time analysis
    • High-accuracy analysis
Software Project Management and Consulting
  • Experience on multiple complex spacecraft programs
  • Proven experience integrating across NASA organizations
  • CMMI compliant processes
  • Systems analysis
  • Software architecture for spacecraft within a larger system
JSC ER Software Expertise (Continued)

- Spacecraft Software Development

- Automation and Robotics
JSC ER Software Expertise (Continued)

• Software Simulation and Testing

• Software Project Management and Consulting Services
Spacecraft Software Engineering Branch (ER6)
Current Projects and Activities

• Software Engineering Leadership
  – EA SEPG Chair
  – JSC SEPG Chair and rep to NASA software working group
  – JSC rep to NASA Mission Software Steering committee
  – EA SSET – CMMI Level 3

• MPCV/Orion System Management
  – Flight software
  – Software T&V / Kedalion
  – Vehicle System Management
  – Data integration & software tools and Processes
  – Simulation Software

• GFE Software
  – ISS Simplified Aid for EVA Rescue (SAFER)
  – ISS Advanced Resistive Exercise Device (ARED)
  – ISS Countermeasures System Software (CMSS)
  – ISS LIDS/NDS (Low Impact Docking System / NASA Docking System)
  – ISS C2V2 formulation and oversight
  – ISS Tissue Equivalent Proportional Counter / Advanced Radiation Instrument (TPEC/ARI)

• AES Software
  – Morpheus VTB
  – AEMU (Advanced Extravehicular Mobility Unit)
  – Deep Space Habitat
  – AMO (Advanced Mission Operations)
  – RadWorks/REM
  – RPM Lander
  – CATALYST
  – Core Flight Software

• STMD IR&D/Advanced Development
  – STMD Autonomous systems
  – Augmented Reality IR&D
  – Ontologies / Semantic search
  – E-Procedures
  – Intelligent system SE&I
  – MED prototype software
  – JSC institutional support software applications
Core Flight Software (CFS) Architecture

Typical CFS Application Software Architecture

Inter-task Message Router  
(Software Bus – Publish/Subscribe)

- Scheduler
- Telemetry Output
- Command Ingest
- CFDP
- File Manager
- Mass Storage Device
- Data Storage
- Limit Checker
- Health & Safety Manager
- Software Bus
- Time Services
- Executive Services
- Event Services
- Table Services

Core Services
Example CFS Reuse Apps
Mission Specific Apps

Core Flight Software System Architectural Layers

- Mission Specific CFS Apps
- CFS Reusable Apps
- cFE (core Flight Executive) API
- Operating System Abstraction Layer (OSAL) API
- Platform Specific Package (PSP)
Software Development Triad – Built upon Reuse

Flight Software

- CFS Core Apps
- Mission Specific Applications
- Custom Sensor/Effector Apps
- CFS Infrastructure (Goddard)
  - Operating System (Several)
  - Processing Hardware (Many)
  - I/O Devices (Many Sensors/Effectors)

Simulation Software

- Mission Specific System & I/O Models
- Dynamics, Time, Environment Models
- Generic Systems Models
- Trick Simulation Core (JSC)
- Linux OS

Ground Software

- Displays & Controls
- Command & Data Dictionary
  - ITOS Infrastructure (Goddard)
    - Data Com/Decom, Recon, Distribution, Display, Scripting, Recording, Post processing
- Database (postgresql)

Tool Chain

- VMWare (local PC/Mac)
- Eclipse (local IDE)
- CentOS/Linux (local VM OS)
- GNU C/C++, Java (compile/Xlate)
- Subversion (CM)
- Redmine (change tracker)
- Hudson (build checker)
- UCC (code count metrics)
- Windriver Workbench (target IDE/OS)
- Parasoft C++test (standards checker)
Procedure Background

- **Mission Operations: Overview**
  - Crew operate equipment using *procedures*
  - Mission Control staff operate equipment remotely using procedures
  - Mission Control staff maintain operations *schedules and plans*
  - Staffing, equipment configuration and manifests also require scheduling and planning
• Procedures are critical to conduct any complex operation

• Procedures contain knowledge about how to operate systems to achieve mission goals

• Procedures are the approved means by which a user operates a system

• Users of procedures include crew, flight controllers, instructors, mission designers, payload community, etc.
Evolution of Procedures

Johnson Space Center
Engineering Directorate
Software, Robotics and Simulation Division

Apollo & Space Shuttle—Paper

Early ISS—PDF

Current ISS—IPV/XML
- No Automation or Computer Oversight

Orion; Enhanced XML (PRL)
- Computer Oversight
- Automation

Deep Space Exploration- AR-eProc;
- PRL Extension
- Machine Vision and Marker-less Registration
Procedure Requirements

• Need support for automating procedure execution
  – Commands and telemetry
  – Safety conditions/context
  – Explicit control structures

• Don’t want to lose human readability
  – Capturing “look-and-feel” of current procedures
  – Presentation of procedure content in a human-friendly way

• Improve quality of execution
  – Improved ease of use
  – Reduction of human error
  – Improved situational awareness

• Interleave human actions with automated scripts

• Use Procedure Representation Language
  – Capture and formalized the above stated requirements
  – Started from NASA ODF standards and construct support automation
Uses of PRL

Procedure Authoring Tool (PAT)

Procedure Representation Language (PRL) file

Procedure Verification Tools

Translator

Paper Procedure

Ground Control Tools (e.g., Thin Layer)

Procedure Displays

Orion eProc (RPL XML)

Automated Scripts (e.g., SCL)

Send Command foo
Command bar
Wait 10 secs
Command foo2

SCL
Execute foo
Verify bar
Wait 10 secs
Execute foo2
End
Advanced Procedure Authoring Tool

- Full PRL features
- Full PRL compliant
- Drag-n-drop user interface
- Leverage on web based & html5 technologies
- Benefits
  - No executable download or plug-in installation require
  - Centralized application deployment
  - More robust media support from html5 better integration editing, viewing and execution
Procedure Viewer & Executor

**Orion eProc–Flight Deck** – focus on Edge Keys Display & Keyboard-less interaction

**Google Glass** – Focus on Mobility & mobile interactions

**WebPD** – Focus on C&W Integration

**AR-eProc**– Focus on mixed reality interaction with tablet device

**AR-eProc**– Focus on mixed reality interaction hands-free operation

*Capture Rich Procedure Content Once and Use It Everywhere*
Augmented Reality Training Assistance

Technology Infusion
- JSC IR&D
- AES/AMO, OCT/AS
- ISS DTO

Technology Collaboration
- Google / Glass Project
- Methodist Hospital

The AR-eProc Vision

AR ARED – Augmented reality Advanced Resistive Exercise Device Cylinder Evac. Procedure

AR DSH Locator – Deep Space Hab augmented reality assets monitoring

AR Ultrasound – Autonomous guidance

AR TOCA – Augmented reality Total Organic Carbon Analyzer Buffer Change Out Procedure

Autonomous Operation
Future Direction: Autonomous Operations

1. Image detection software depiction of anatomical landmarks which define an adequate carotid image superimposed over an actual carotid artery ultrasound image

2. Robonaut 2 being remotely guided through carotid artery ultrasound imaging technique
Miniature Exercise Device (MED):
a. Equipment Assembly Task
b. Equipment Dis-Assembly Task

Just-in-time (JIT) training of a Sani-tank purge

After the task was completed using the Google Glass – the same JITT material was viewed on an iPad
Augmented Reality to Enhance Crew Medical Training

Adjust the transducer according to the liver’s short axis by translating the probe towards the chest.
Augmented Reality (AR-eProc ARED)
Augmented Reality (AR-eProc TOCA)
Other Projects
SAFER

SIMPLIFIED AID FOR EVA RESCUE (SAFER)

SAFER On-Board Trainer (SOT)
Robonaut 2 on Centaur 2
R-2A at launch of R2-B
Systems Engineering Simulator

SES On-orbit Simulation in the “Dome”
MPCV/Orion Testing

Kedalion Lab
Miniature Exercise Device

- Miniature Exercise Device (MED) is a small, compact, lightweight exercise device that is capable of supporting high-intensity exercise for deep space missions
- Based on R2 joint technology
- Utilizes torque control to manage cable resistance
- System capable of greater than 300 lbs of resistive force
- MED actuation system ~10 kg
- Proof-of-Concept testing successfully completed
- Supports customized exercise protocols
- Future work will incorporate EMG sensing to close exercise control loop around muscle activity
X1 Exoskeleton

- The X1 is designed as an assistive walking aid for astronauts re-acclimating to gravity environment after long duration spaceflight
  - Post ISS long duration
  - Mars transit
- X1 capabilities have been expanded to provide exercise to crew during the mission
- X1 also functions as a dynamometer to assess changes in strength during spaceflight
- X1 is currently being expanded to include an upper body exoskeleton for similar benefits
ARGOS

Active Response Gravity Offload System Specs

• Dimensions of Structure 41 ft x 24 ft x 18.5 ft
• Horizontal Travel 37 ft x 17 ft
• Vertical Travel 15 ft
• Offload Force [Max Payload Weight?] 750 lbs
• Vertical Velocity of a 750 lbs load 4 ft/s
• Vertical Acceleration of a 750 lbs load 29 ft/s²
• Vertical Velocity of a 250 lbs load 10 ft/s
• Vertical Acceleration of a 250 lbs load 88 ft/s²
• Horizontal Velocity 9.8 ft/s
• Horizontal Acceleration 13 ft/s²

Active Response Gravity Offload System Applications

• Micro G (ISS, L1, L2, Asteroids, HEO, Martian Moons)
• Lunar G (Lunar Surface)
• Mars G (Martian Surface)
• Terrestrial Rehabilitation
Spidernaut
AERCam

Automated Extravehicular Robotic Camera (AERCam)
Rovers

Lunar Rover Prototype - “Chariot”
Space Exploration Vehicle
Interest in Joining Us?

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pathways.jsc.nasa.gov

Current application period closes 26. September 2014
Backup