NASA Satellite Servicing

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Satellite Servicing Capabilities

Servicing provides capabilities for resilient architectures

Remote Inspection
  Relocate
  Replace
  Repair

Refuel
Replenish
Assemble
How We Do Business

Stakeholders
- Commercial Owners, Operators, Insurers
- Department of Interior USGS
- NASA Science
- NASA Exploration
- Department of Commerce NOAA
- Other Government Agencies

Continuous Needs Assessment

Satellite Servicing Projects Division

Projects
- Robotic Refueling Mission 1, 2, 3
- Raven Project
- Near Earth Object Detector
- Restore-L Servicing Mission
- Asteroid Redirect Mission
- Cooperative Servicing Aids

Technologies
- Relative Navigation System
- Servicing Avionics
- Fluid Transfer System
- Robot Arm and Software
- Tool and Tool Drive System

Studies
- WFIRST
- LUVOIR
- FarIR
- 20-Meter
- Landers
- EMC - tug
- EMC - MAV
Projects on ISS or in Development

RRM3
- Launching in 2018
- Developing technologies for cryogen and xenon transfer

External Leak Locator
- Quadrupole mass spectrometer
- Species identification and concentration
- Expected capability: plume source to within 1 m²

Raven
- Launching in Jan 2017
- Testbed for autonomous rendezvous algorithms and sensors

VIPIR / VIPIR2
- Fixed camera
- Motorized zoom lens camera
- 30” deployable articulating camera

ISS Technology Development is cost-effective and highly visible
RRM Phase 1
- **Storable propellants: steps required to refuel a legacy spacecraft**
  A. Take apart components (cut wire, manipulate thermal blankets and fasteners, remove caps)
  B. Connect refueling hardware and transfer fluid
  C. Reseal fuel port
- **Cryogen fluid: initial steps required to replenish cryogens in zero-g**
  1. Take apart components

RRM Phase 2
- **Cryogen fluid: intermediate steps required to replenish cryogens**
  2. Connect replenishment hardware

RRM Phase 3
- **Cryogen fluid: final steps required to replenish cryogens**
  3. Transfer and freeze cryogenic fluids in 0-g, maintain fluid mass for six months via zero boil-off
  - Share technology data with Space Launch System (SLS), ISRU, Advanced ECLSS
- **Cooperative recharge of xenon propellant**

### Timeline
- **RRM Phase 1**
  - 2011: Machine Vision Task
  - 2012: Cryogen Step 1 complete
  - 2013: Propellant Steps A, B, C complete
  - 2014: Cryogen Step 2 Complete
- **RRM Phase 2**
  - 2015: Cryogen Step 3 & Xenon planned
- **RRM Phase 3**
  - 2016: 2017: 2018:

**RRM is a joint demonstration with the Canadian Space Agency that is advancing technologies required for future exploration missions beyond low earth orbit as well as demonstrating on-orbit servicing techniques for legacy and cooperative spacecraft.**
The Robotic Refueling Mission tested tools, technologies and techniques to refuel and repair satellites in orbit – especially satellites not designed to be serviced.

On-Orbit robotic demonstrations included:
- Lockwire cutting and removal of fill/drain valve and cap components
- Tape cutting and MLI manipulation
- Fluid transfer through an on-orbit mated nozzle-to-valve connection
In Phase 2, NASA tested a new inspection tool, practiced intermediary steps leading up to cryogen replenishment, tested electrical connections for "plug-and-play" space instruments, and worked with decals and a vision system to guide ground operators.

Task Board 4 (TB4) returned to Earth on SpX-8, Currently evaluating solar cell and material exposure data to compare to pre-flight measurements.
Advanced Robotic Tools - Phases 1 and 2

Multiple tools and adapters were developed

Visual Inspection Poseable Invertebrate Robot (VIPIR)

MLI/Wire Cutter Tool (WCT)

EVR Nozzle Tool (ENT)

Safety Cap Tool (SCT)

Adapter Suite

Multi-Function Tool

The MFT provides an interface with several adapters
VIPIR is a robotic, teleoperated inspection tool equipped with an articulating, deployable borescope and a motorized zoom-lens camera.

- Provides close- and mid-range inspection capabilities
- Video Borescope Assembly (VBA)
  - Nearly three feet of deployable tube
  - Final 2.5 inches rotate up to 90 degrees in four opposing directions
  - Ideal for inspection at 1-2 inches from subject
- Motorized Zoom Lens (MZL)
  - 8-24mm optical zoom lens
  - Can resolve worksite details as tiny as 0.02 inch while tool stays 2 feet from spacecraft
- Situational camera (fixed)
  - Helps control tool during operations
VIPIR Design Overview - Vision

**Fixed Camera Assembly**

**Primary Tool Vision Camera**

NTSC, Color, VGA (640 x 480)

This camera, with a fixed 6mm focal length has full view of Reel Position visual indicators and is used as the primary camera for tele-operation, tool positioning, and VBA deployment.

**Video Borescope Assembly (VBA)**

**Miniaturized Close-range Inspection Camera**

NTSC, Color, (224 x 224)

- This camera, with miniaturized optics and sensor is designed to be deployed into an open orifice, tube, or cavity with ~1-inch diameter cross-section
- The VBA camera is used to deploy into close-quarters worksites, and provide views of hard-to-reach targets using its miniaturized optics and integrated lighting.

**Motorized Zoom Lens Camera**

**Mid-range Inspection Camera**

NTSC, Color, VGA (640 x 480)

- This camera, with miniature motorized 8-24mm optical zoom and focus capability, is used for worksite inspection and tool positioning at 8mm focal length.
- At 24mm focal length, this camera serves as an excellent mid-range detailed inspection camera.
VIPIR – VBA Articulation Video

Visual Inspection Poseable Invertebrate Robot (VIPIR)
Video Borescope Articulation
Robotic Refueling Mission (RRM) Phase-2B
NASA Goddard Satellite Servicing Capabilities Office
RRM2 – Task Board 4
VIPIR Inspection Path

- Inlet Port
- Decision Box
- Optical Target
- VBA Camera
- VBA
- VIPIR
VIPIR On-Orbit Inspection Video

VISUAL INSPECTION POSEABLE INVERTEBRATE ROBOT (VIPIR)

On-Orbit Footage - May 4, 2015 (2x speed)

Robotic Refueling Mission (RRM)
- Phase 2 -
Taskboard 4 Inspection Task
VIPIR’s Inspection of SSRMS Boom
Motorized Zoom Lens Camera

- VIPIR was used by the ISS Program to examine an unexplained discoloration on the SSRMS, the Space Station Remote Manipulator System in Oct 2015
- VIPIR captured imagery that confirmed that there was a raised mass (center) on the SSRMS
- The lighting conditions cast a shadow (extending to right of the mass site) that showed the presence of the object

3D Animated .gif processed by the JSC Image Science and Analysis Group

VIPIR Imagery (~8” from MZL)
• Tool Suite for RRM3 is being updated based on lessons learned from previous missions
  • Improved Hose manipulation
  • More compliance between tools and interfaces
  • Enhance cameras and positioning systems

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VIPIR2:  
Similar to VIPIR – situational awareness and close-range inspection

Cryogen Servicing Tool:  
Transfers cryogen fluid from source dewar to receiver dewar

Multi-Function Tool-2:  
Technology pathfinder for Restore-L tool development
• The Visual Inspection Poseable Invertebrate Robot 2 (VIPIR2) is a robotic inspection tool that builds upon the success of its predecessor, the RRM Phase 2 VIPIR

• VIPIR achieved all of its mission objectives during RRM Phase 2 operations in May 2015
VIPIR2 Design Overview – Vision

**Fixed Camera Assembly (FCA)**
*Situation Awareness Camera*
NTSC, Color, VGA (640 x 480)
Provides view of the front end of the tool and various visual indicators in order to position the tool to the worksite and deploy the VBA

**Video Borescope Assembly (VBA)**
*Miniaturized Close-Range Inspection Camera*
Digital, Color (1280 × 720)
Deploys into close-quarters worksite, provides view of hard-to-reach target using miniaturized optics, sensor, and integrated lighting

**Enhanced Motorized Zoom Lens (EMZL)**
*Mid-Range Inspection Camera*
NTSC, Color, VGA (640 x 480)
Provides view of target using motorized 12-36 mm optical zoom and focus capabilities
Updated Camera effectively doubles pixel sampling
RRM Summary

• RRM is a highly successful on-orbit demonstration series
• Awarded the Top Exploration Technology Application from the International Space Station in 2012
  - All objectives to date have been achieved
  - Advanced the TRL for in-space servicing, space robotics and ground control
  - Team gained significant knowledge with respect to the robotics alignment, tool markings, interfaces and loads
• RRM is a great teaming model of inner agency and multi-national partnerships
• The International Space Station has been a cost effective platform for rapid technology development
Raven Overview

During its two-year lifespan on ISS, NASA operators on the ground will be evaluating how Raven’s technologies are working as a system and making adjustments to increase Raven’s tracking performance. Contains three sensors (visible, infrared, lidar), a high-speed processor (SpaceCube) and advanced algorithms.

- Technology demonstration launching to ISS on Space Test Program-Houston 5 on the SpaceX CRS-10 mission
- Raven will track visiting vehicles to ISS, developing a “off-the-shelf” relative navigation capability for NASA
- Raven technologies apply to:
  - Restore-L servicing mission
  - Asteroid Redirect Mission
  - Orion
  - Journey to Mars
  - ISS
Objective:

To advance the state-of-the-art in rendezvous and proximity operations (RPO) hardware and software by demonstrating:

• Accurate relative navigation to visiting vehicles:
  - Progress
  - Soyuz
  - Cygnus
  - HTV
  - Dragon

• Autonomous operations during visiting vehicle approach

• Both non-cooperative and cooperative relative navigation using a single sensor suite
Raven Science Objectives

• Collect sensor data (visible, infrared, lidar) over various ranges
  - Critical for post-processing rendezvous for a best-estimated trajectory

• Collect imagery for unique visiting vehicles
  - Useful to verify and develop on-orbit modeling techniques; compare to accurate CAD models

• Collect imagery over multiple rendezvous per vehicle
  - Rendezvous is more valuable science-wise due to expected vehicle dispersions and durations

• Demonstrate real-time Pose estimation for several visiting vehicles
  - Critical, final validation of relative navigation components
  - Proves flexibility for multi-client servicing vehicle

• Demonstrate multi-sensor filtered solution tracking of visiting vehicles
  - Non-cooperative and cooperative pose measurements
Pose Overview
Goddard Nature Feature Image Recognition (GNFIR)

• Estimates 3D pose (position & orientation) from a 2D image
• Detects edges in images, compares with a-priori object model
• Capable of initialization and tracking
• Raven will fly two variants
  - GNFIR-IR – Infrared
  - GNFIR-Vis – Visible
• Sample from STS-125 HST SM4, image from camera that will re-fly on Raven
Sample GNFIR Tracking

GNFIR-IR

GNFIR-Vis
Pose Overview
Flash POSE (FPose)

Flash LIDAR Basics

Flash LIDARs
At each measurement time, Flash LIDARs create both an intensity image and a range image. The range image may be reinterpreted as a 3D point cloud.

Example: STORRM VNS Image from STS-134

Transforming 3D point cloud into Pose

Model of object overlaid in point cloud at Pose solution position and orientation