NASA's R2
Vision Software Controls a Space-Robot

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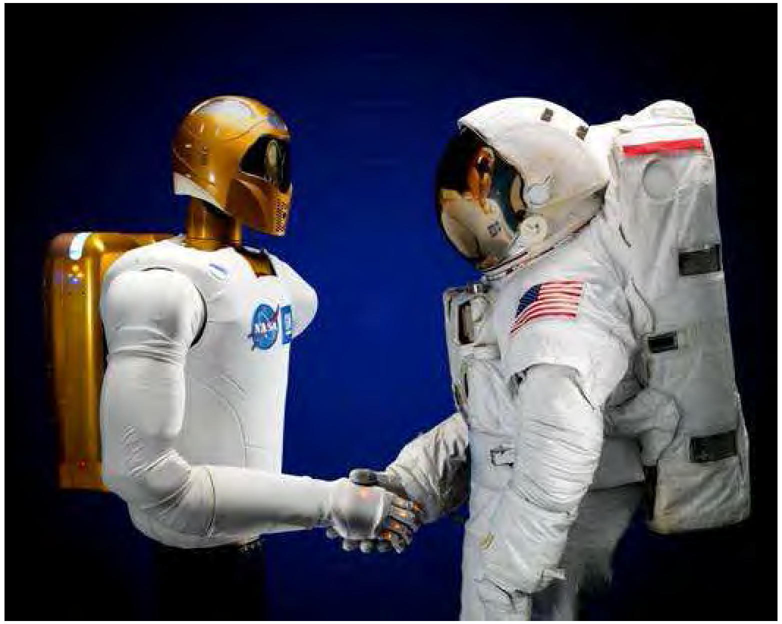
Overview of the presentation

- What is a Robonaut?
- Challenges
- Special robot features
- Used machine vision components
- What makes the design special?
- Sensor integration and development
- 3D camera calibration
- Object recognition
- 3D alignment and pose estimation
- Stepwise implementation



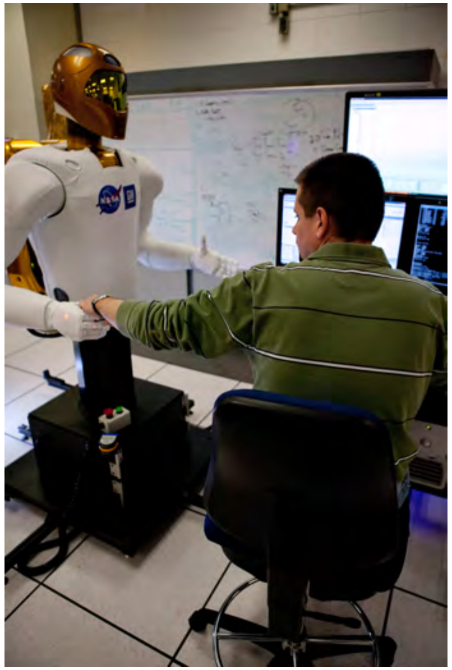
MVTec Software GmbH - A company snapshot

What is a Robonaut?

A Robonaut is a dexterous humanoid robot built and designed at NASA Johnson Space Center in Houston, Texas. Our challenge is to build machines that can help humans work and explore in space. Working side by side with humans, or going where the risks are too great for people, Robonauts will expand our ability for construction and discovery.

In the current iteration of Robonaut, R2, NASA and General Motors are working together to accelerate development of the next generation of robots and related technologies.

R2 is capable of handling a wide range of EVA tools and interfaces. R2 is capable of speeds more than four times faster than R1, is more compact, is more dexterous, and includes a deeper and wider range of sensing. Advanced technology spans the entire R2 system and includes: optimized overlapping dual arm dexterous workspace, series elastic joint technology, extended finger and thumb travel, miniaturized 6-axis load cells, redundant force sensing, ultra-high speed joint controllers, extreme neck travel, and high resolution camera and IR systems. The dexterity of R2 allows it to use the same tools that astronauts currently use and removes the need for specialized tools just for robots.



Challenges

R2 will be confined to operations in the station's Destiny laboratory. However, future enhancements and modifications may allow it to move more freely around the station's interior or outside the complex.
R2 has to handle station's radiation and electromagnetic interference environments.
Vibration, vacuum and radiation testing along with other procedures being conducted on R2.
In the future, the greatest benefits of humanoid robots in space may be as assistants or stand-in for astronauts during spacewalks or for tasks too difficult or dangerous for humans.

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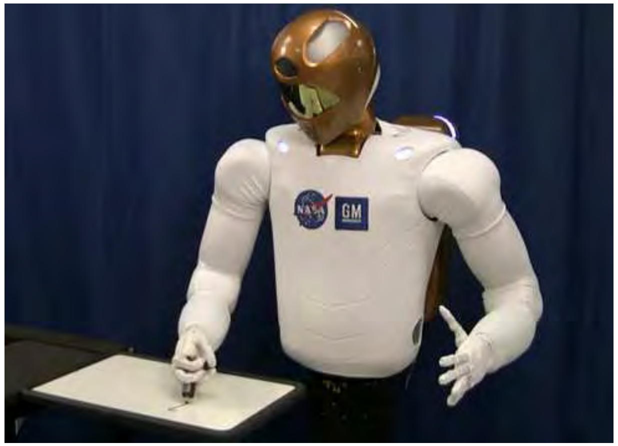
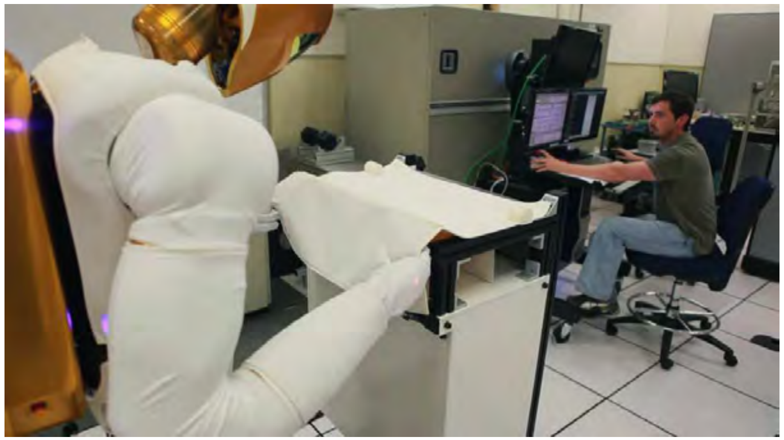
Basic facts

- Materials: Primarily aluminum with steel
- Weight: 330 pounds
- Height: 3 feet, 4 inches (from waist to head)
- Shoulder Width: 2 feet, 7 inches
- Sensors: 350+
- Processors: 38 power PC processors
- Degrees of freedom: 42
- Speed: Up to 7 feet per second

Special robot features

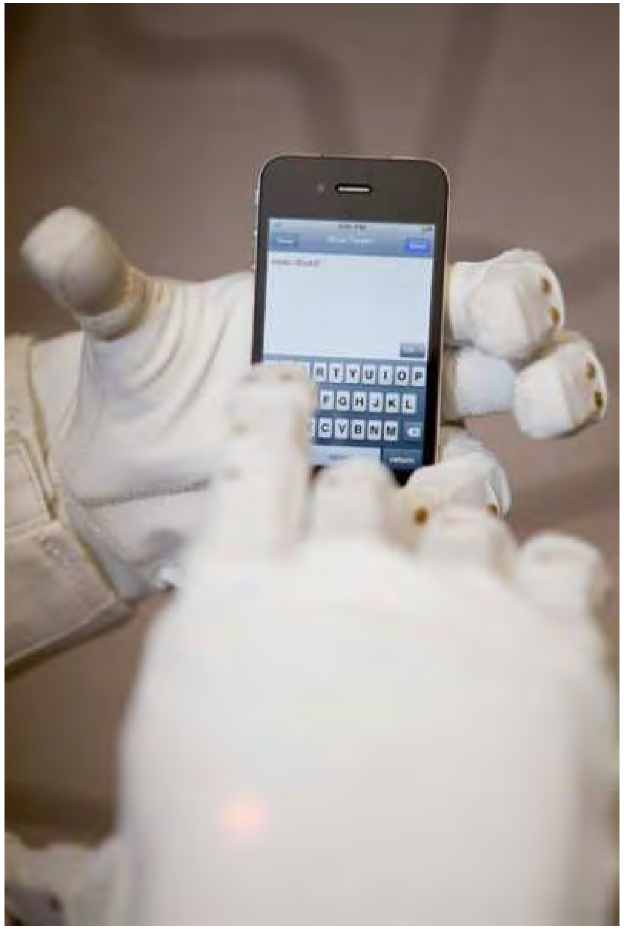
NASA: “Among the many planned ISS tasks for R2, sensing and manipulation of softgoods material is among the most challenging. It generally requires a very high degree of coordinated sensing and actuation.
For example, a soft-goods box made of a flexible ortho fabric is used to hold a set of EVA tools. To remove an EVA tool, the box must be identified, opened, and closed again. The challenge lies in the tendency of the fabric lid to float around in zero-g, despite the base being secured.”



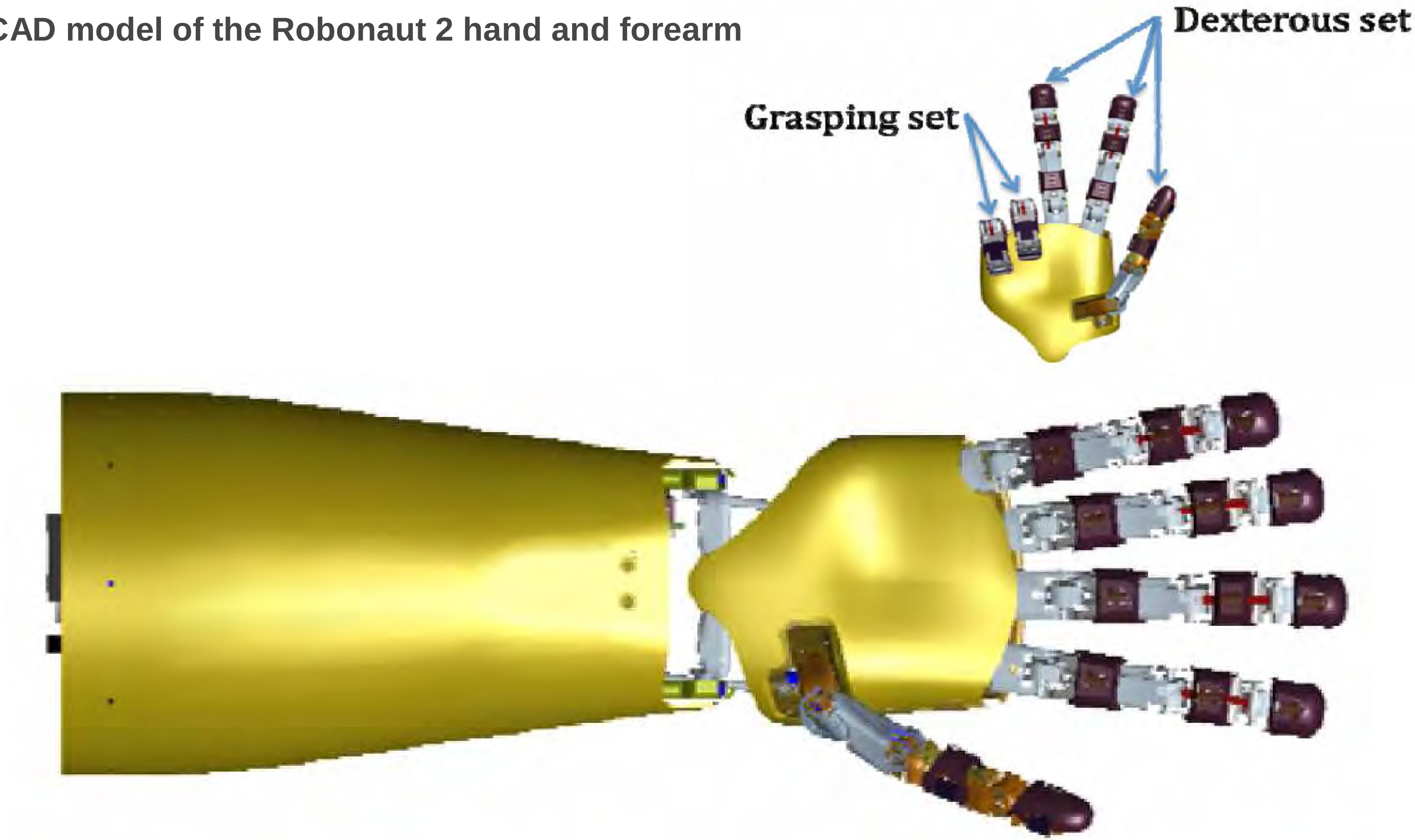


Advanced hand design

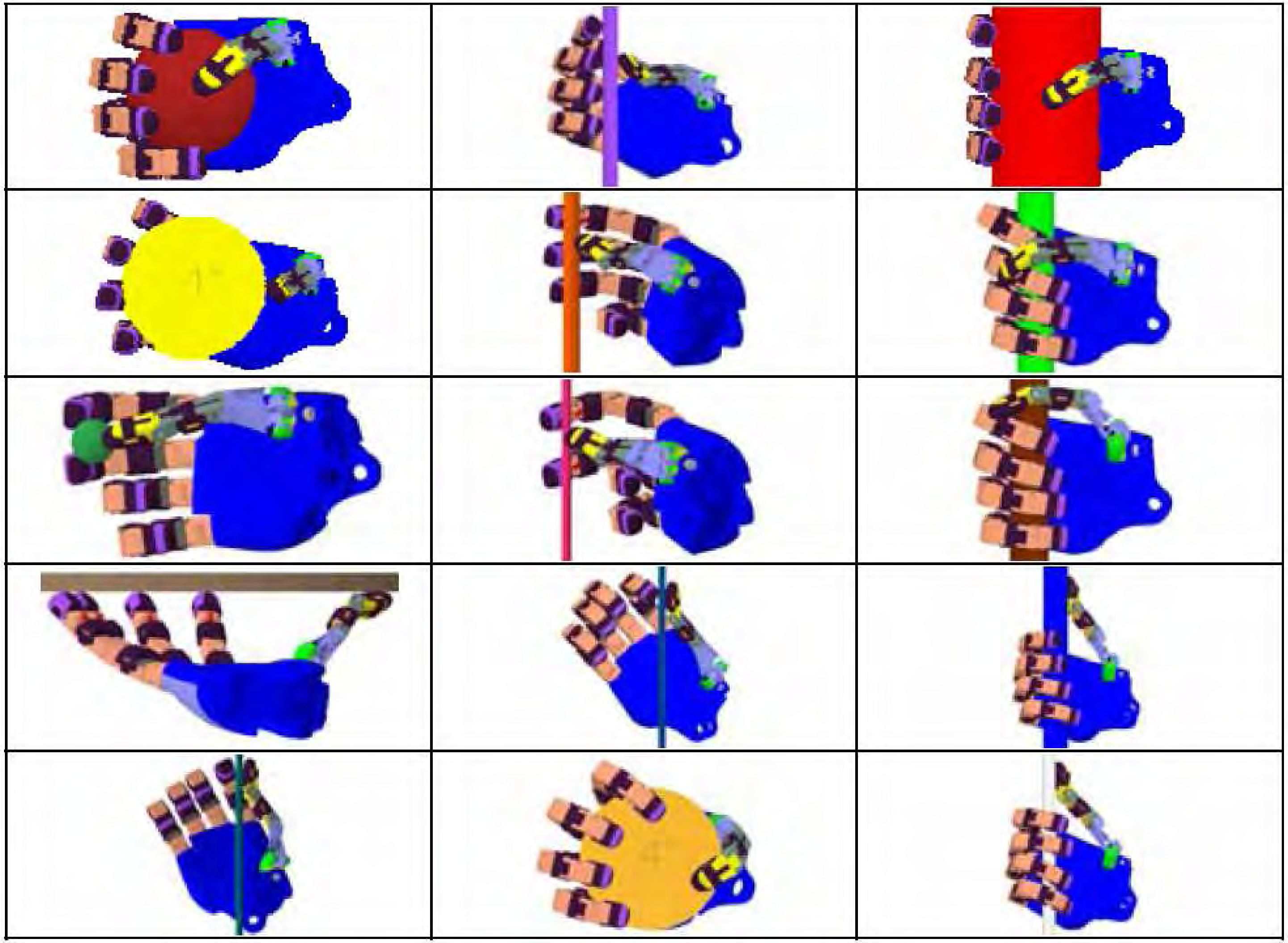
The hands have 12 degrees of freedom – 4 degrees of freedom in the thumb, 3 degrees of freedom each in the index and middle fingers, and 1 each in the ring and pinky fingers. Each finger has a grasping force of 5 pounds.
NASA: “In degrees of freedom it still falls short of a human being, particularly in the thumb. It is as close to human hand as we could (get) with the packaging limitations."
The finger are employing “the equivalent of tendons” to operate the fingers, rather than using direct-controlled motors in the hands.



CAD model of the Robonaut 2 hand and forearm

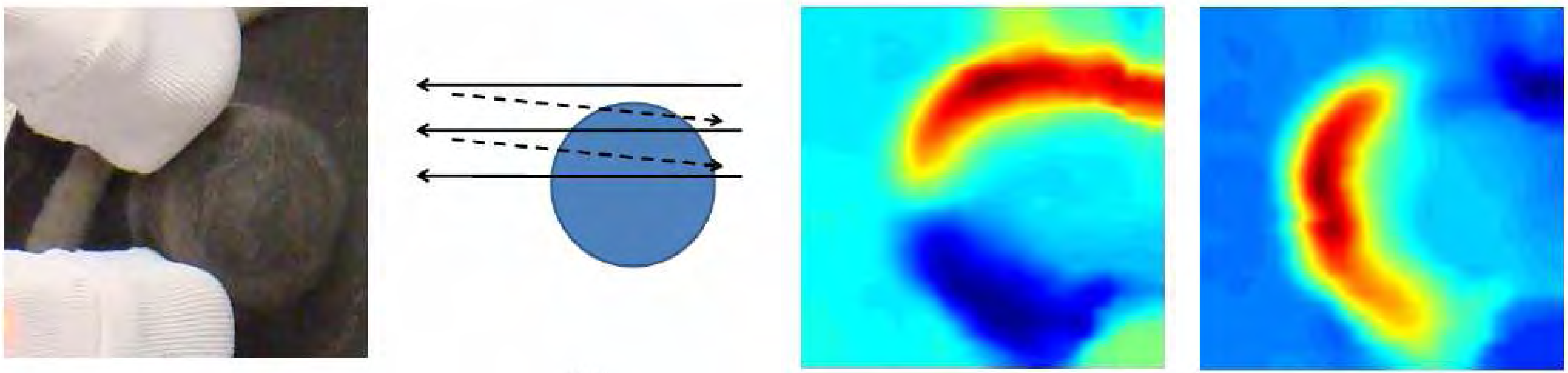


Robonaut 2's emulation of Cutkosky's Grasp Taxonomy



Creation of a “tactile map”

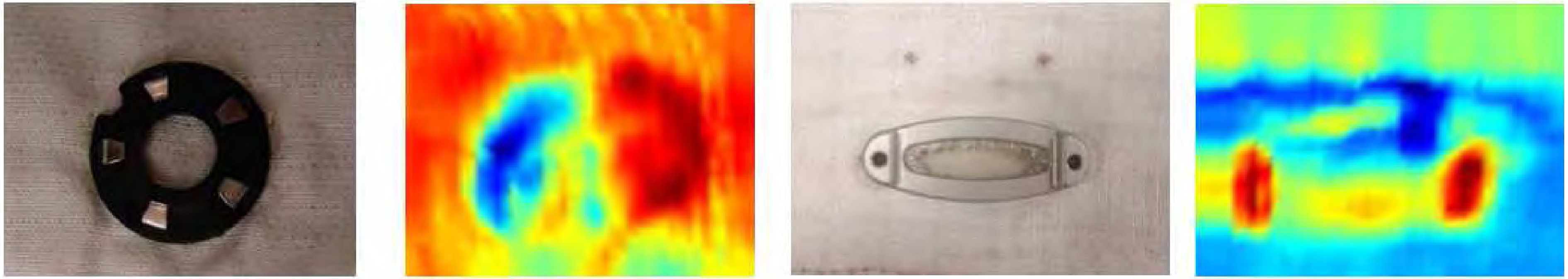
The fingers make a series of lateral sweeps from right to left. (a) shows the fingers making such a sweep over a bump in flexible plastic. (b) shows the path of these sweeps. (c) and (d) show two elements (out of a total of eight per sensor) of the haptic map for the bump. Notice that the two elements of the sensor signal respond differently to the interaction.



(a) (b) (c) (d)

Tactile maps are used to identify objects

The models are created from a training data set rather than building a geometric model of the manipulation interaction, the approach works well localizing difficult-to-model objects such as flexible materials or fabrics.
The approach can localize a haptic feature in a piece of flexible plastic to within 2.5mm.



Tactile maps for a snap and a grommet

Used machine vision components

Hardware

- Stereo cameras: Prosilica GC2450
- Infrared range finder (TOF): Swiss Ranger SR4000

Software

- Library: HALCON 9.0
- Development Environment: HDevelop
- Image acquisition: GigEVision
- Sensor integration: C/C++ HALCON extension packages

What makes the selected design special?

Important design criteria for outer space projects

- Solution according to the requirement
- Error freeness
- Overall cost

Consequences for former projects

An outer space project demands the optimal solution.
Therefore, components have to be developed specifically for this project.

Consequences for new projects

The cost for developing everything from scratch is extremely high.
A complete testing of newly developed components and software is extremely difficult – if not impossible.
Therefore, high end standard components are used.

- They are flexible enough to be optimally adapted
- Extensive testing has already been performed
- Dramatic reduction of development cost

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Sensor integration and development

NASA’s comment on the development scheme:
“The Swiss Ranger, tactile, and finger position sensors use custom C/C++ code to perform depth measurements and tactile object recognition.
HALCON’s Extension Package Programming feature allow us to import all custom code in to a single development environment, such as HDevelop used for rapid prototyping of our applications.”

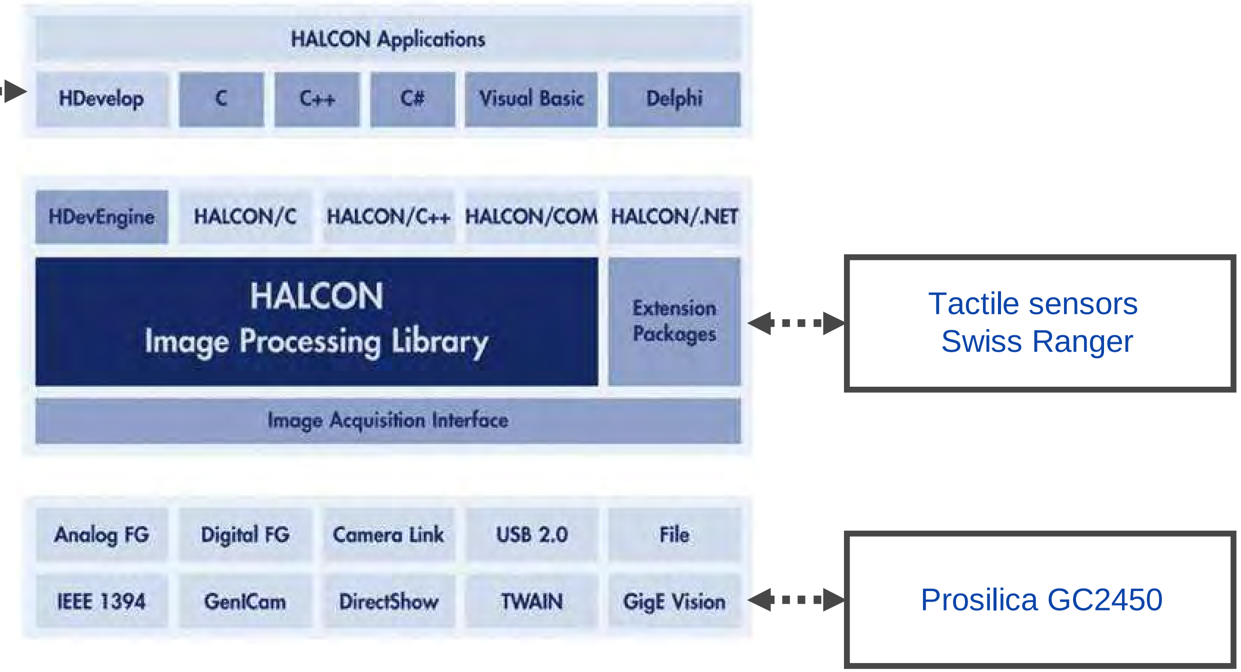
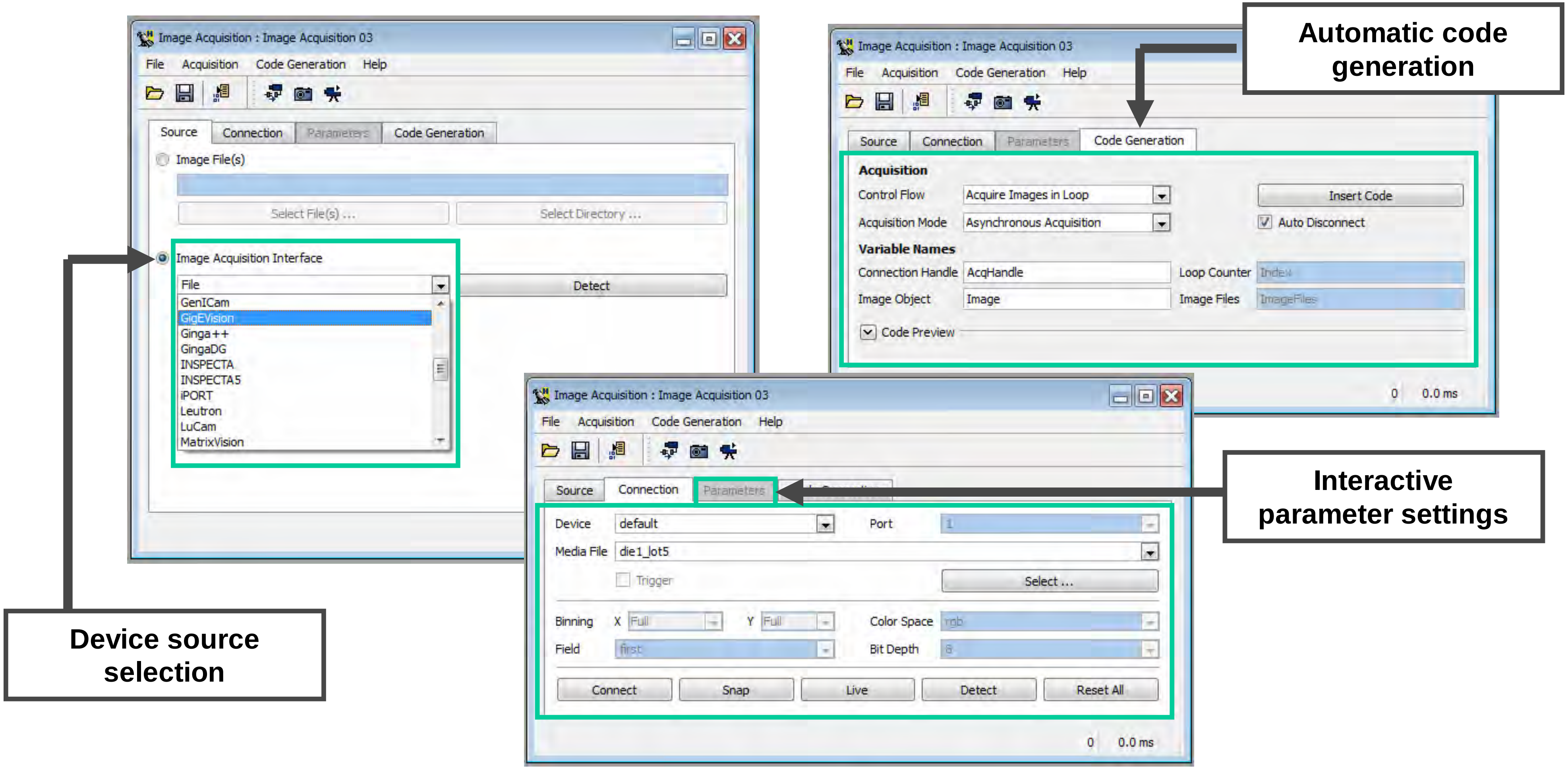


Image acquisition integration

NASA’s comment on the selected software: “HALCON supports GigEVision and allows for a quick setup of each camera in software via its automatic code generation feature.”



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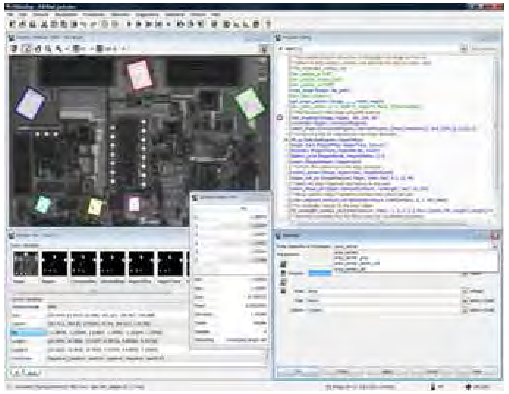
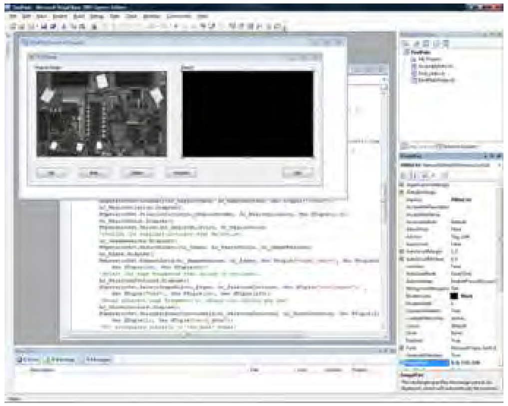


Prototyping
Vision development



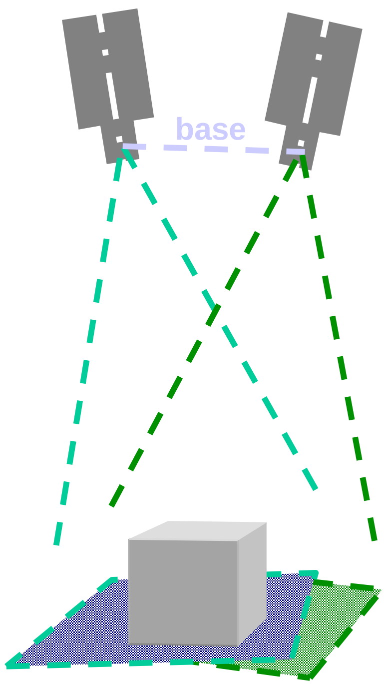
User interface
Further tools

HALCON library

3D camera calibration

Calibration consists of multiple steps

- Internal camera parameters
- Relative poses of the stereo cameras
- Depth calibration of the range sensor
- Relative poses between cameras and range sensor
- Hand-eye calibration



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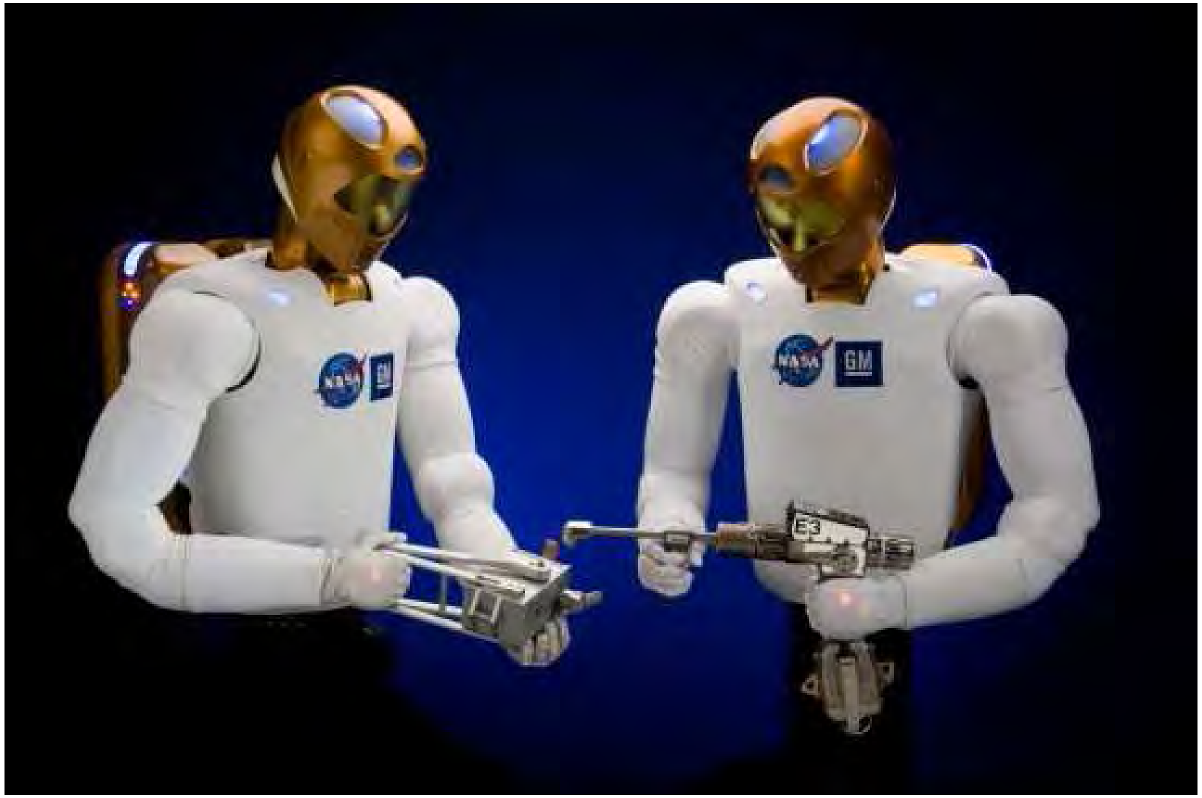
Object recognition

NASA: “Robust object recognition requires the use of complex patterns measured from the environment using multiple sensor types.
Complex pattern recognition of entire scenes can be computationally prohibitive.
Our solution to the problem is to apply complex pattern recognition to small segmented regions of the scene.
Information within the image

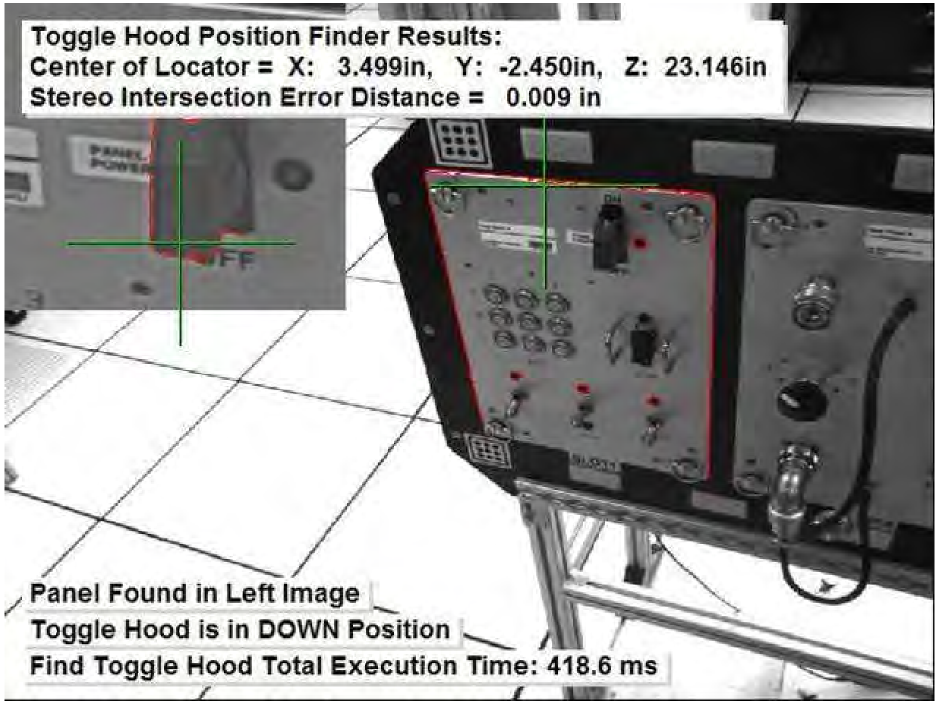
- color,
- intensity, or
- texture

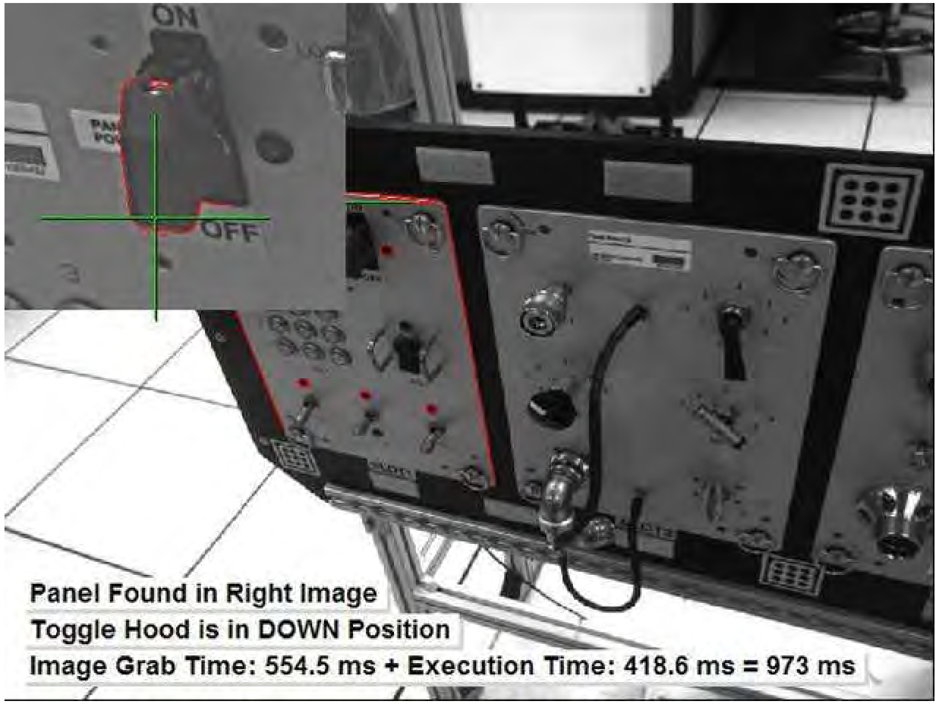
are used to segment the regions.”



3D alignment and pose estimation

NASA: “The elements will be identified in the stereo images by using HALCON’s shape-based matching techniques. Point based stereo vision will be used for fast computation of the lid fastener poses. HALCON’s intersect lines of sight function will use the stereo-pair calibration information and the location of the fastener components in each image to compute the 6D pose of each component.”





Stepwise implementation

Like all programs with NASA, R2 will not undergo full implementation once it arrives on the ISS via Space Shuttle Discovery. Instead, a three step, phased approach will be used.

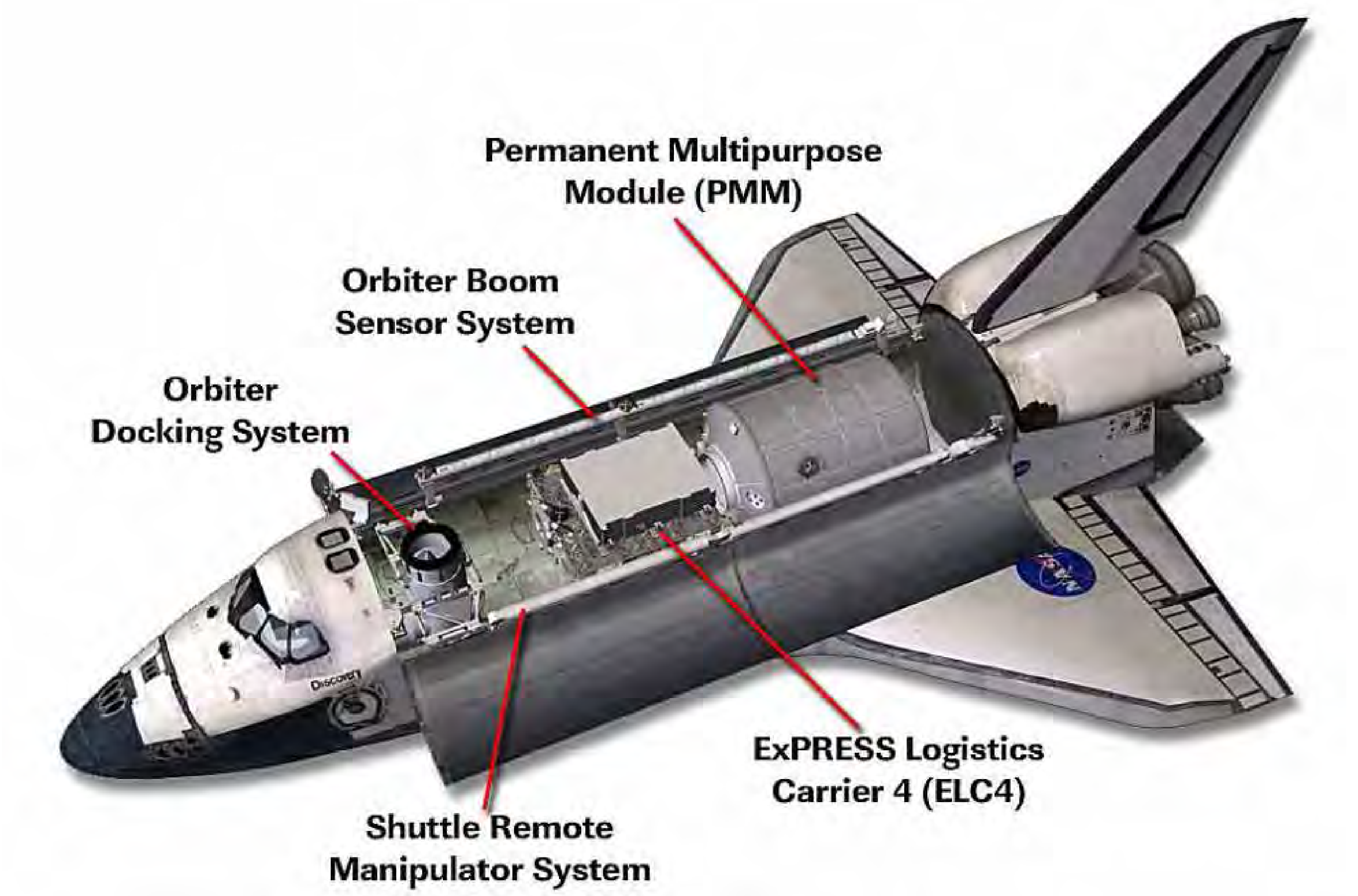
During phase I, R2 will only operate from “scripts” or programs sent to the robot “from a remote computer.” Control of Robonaut 2 by the ISS crew will be enabled by a GUI on the local ISS laptop with ground operation enabled via a remote desktop.
Robonaut 2 operations, will involve commanding the robot to perform increasingly complex tasks on its task board using its limbs and articulating fingers and thumbs, the incorporation of tools into the task board ops (permitting R2 to grab and manipulate tools with its hands), the performance of tasks cooperatively with the ISS crew, and the engagement of Robonaut in educational and Public Relations tasks.

In phase II, R2 will be given more freedom on the ISS. This will involve mounting a structural appendage to Robonaut that will allow it to anchor to handrails or other structural interfaces inside the ISS, thus permitting “mobile IVA operations.”

Phase III will involve upgrading Robonaut with the ability to perform EVA tasks.

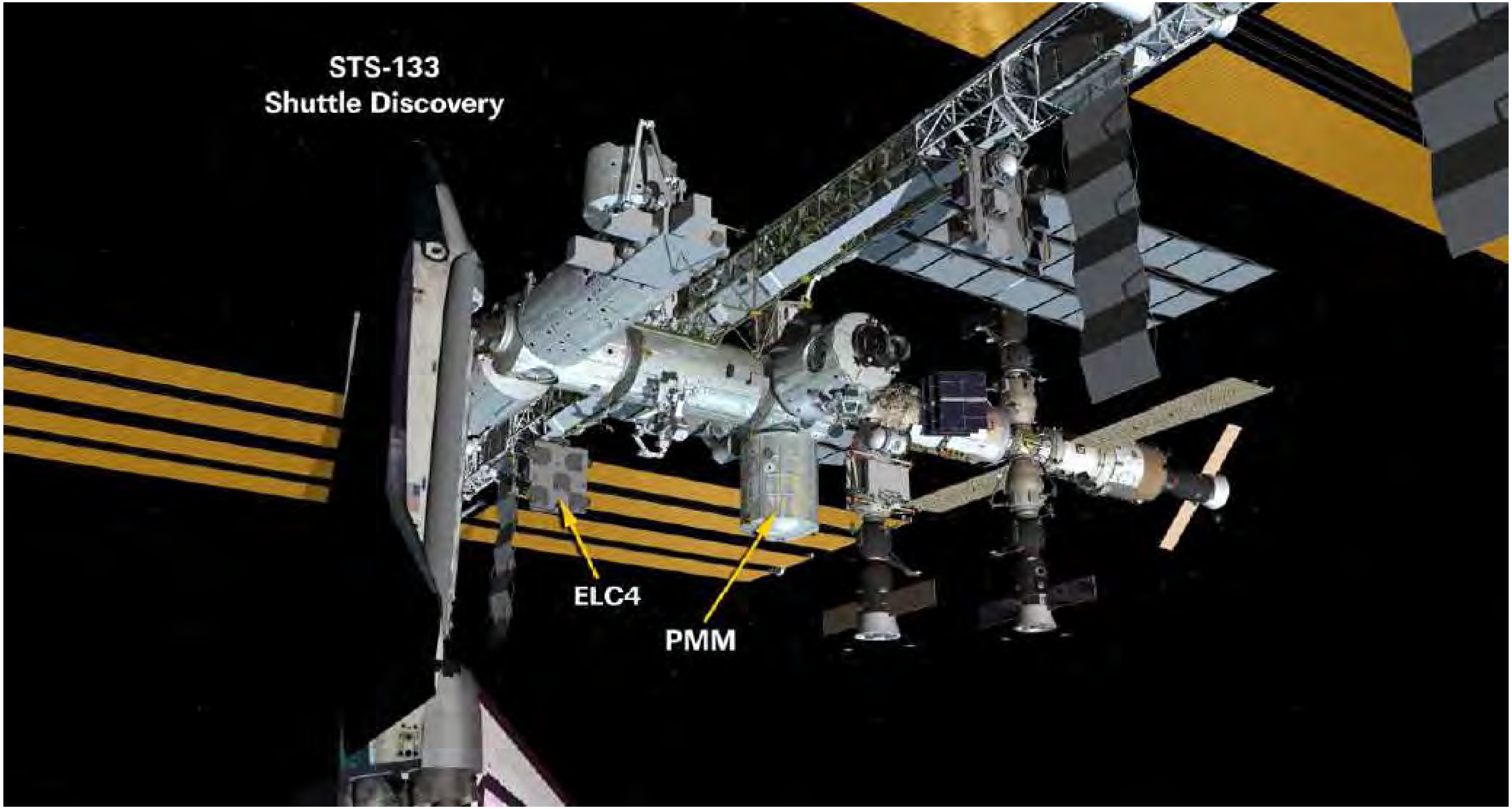
Stepwise implementation

Space Shuttle payload overview

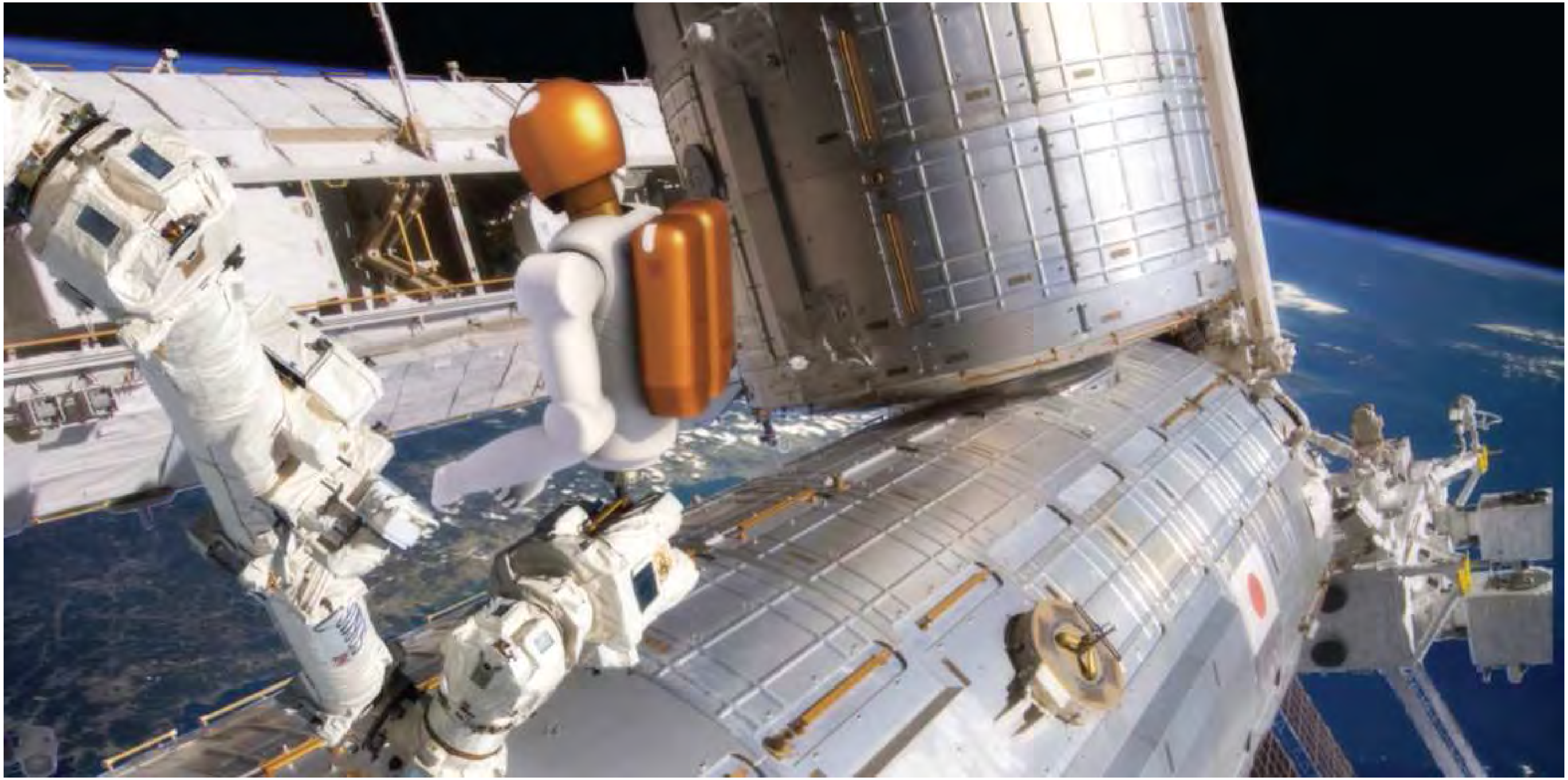


The inner of the Permanent Multipurpose Module (PMM)

The Permanent Multipurpose Module mounted at the Space Station



The future



Summary of the vision tasks

- Combination of stereo vision and TOF
- Object recognition of ISS objects
- Fusion of multiple sensor types
- Pattern recognition in segmented regions
- Segmentation using color, intensity, texture
- Shape-based matching combined with stereo

R2 and the STS-133 Crew