WHITING SCHOOL OF ENGINEERING
JOHNS HOPKINS UNIVERSITY

Enabling Technologies for Remote Robotic Manipulation With Time Delay

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LABORATORY FOR Computational Sensing + Robotics
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JHU Laboratory for Computational Sensing and Robotics

The **Laboratory for Computational Sensing and Robotics (LCSR)** was founded by the School of Engineering in 2007 as the center for robotics research at the Johns Hopkins University

Research grants : $15M active, $43M pending.

Over 100 researchers:

- 10 engineering faculty
- 15+ postdocs
- 60+ M.S. and Ph.D. students
- 5 admin staff
- 5 engineering staff

Active collaborations worldwide:

- JHU School of Medicine (SOM)
- JHU Applied Physics Laboratory (APL)
- JHU I4M Initiative: Integrating Imaging, Intervention, and Informatics in Medicine
- Penn, CMU, MIT, Columbia, U Washington, Harvard, Berkeley, Morgan State University, TU Munich, Fraunhofer-Gesellschaft. University of Toronto, Queens University, Oregon Health and Science University.
- Siemens, Phillips, Intuitive Surgical, Medtronic, Sentinelle Medical, Hologic, Ikona. Robodoc/Curexo, Hologic.
- Extensive patents, industrial partnership, and commercialization.

Computational Science and Engineering Building

Robotics Research Extending Human Reach into Extreme Environments

JHU has the Leading Medical Robotics Research Program Worldwide

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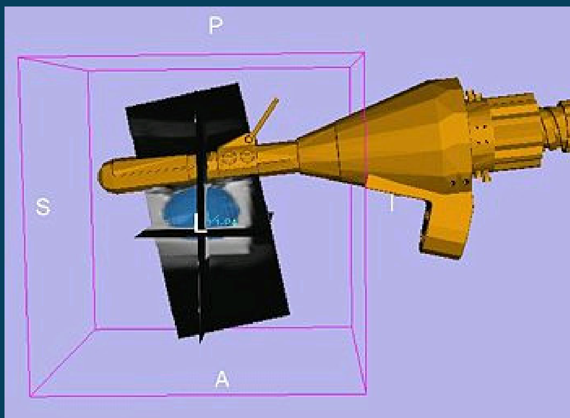
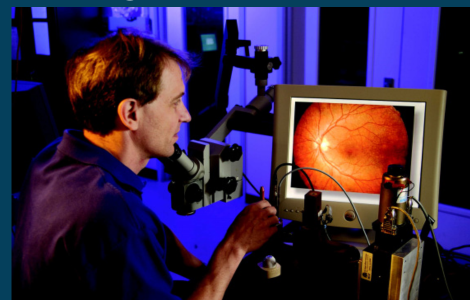
Design and Control

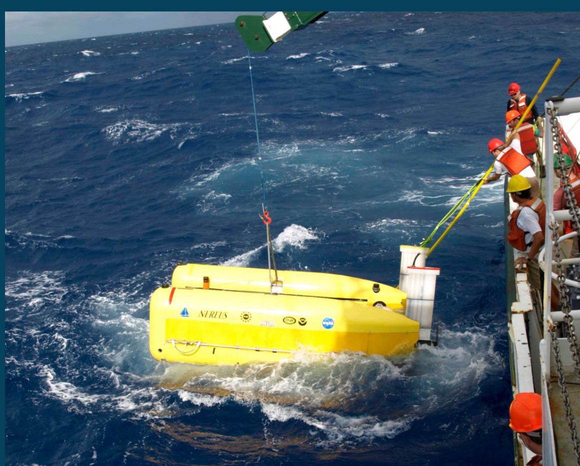


Sensing and Interpretation



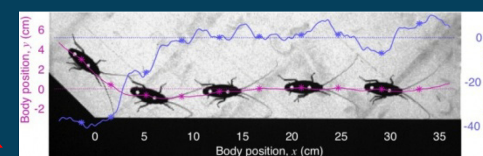
Human-Machine Interaction

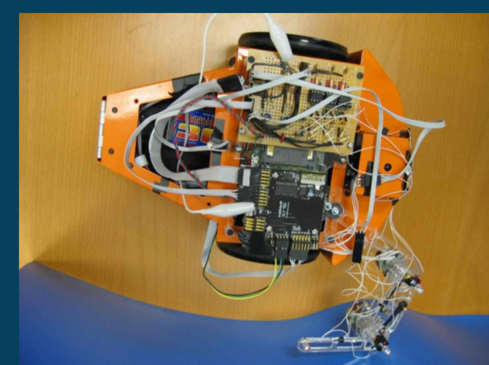
Basic Engineering Science



Robotics in Extreme Environments

Robotics in Medicine





Bio-Engineering

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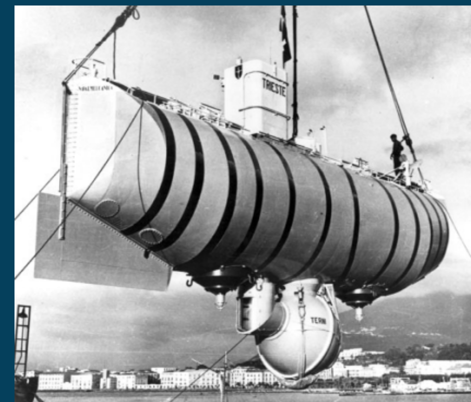
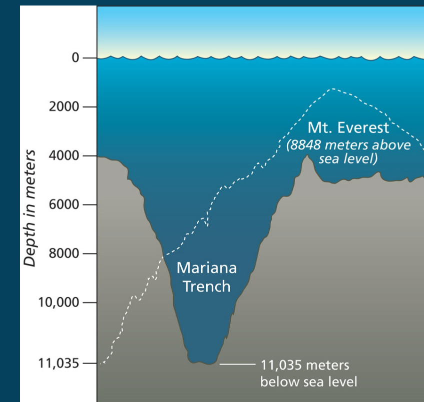
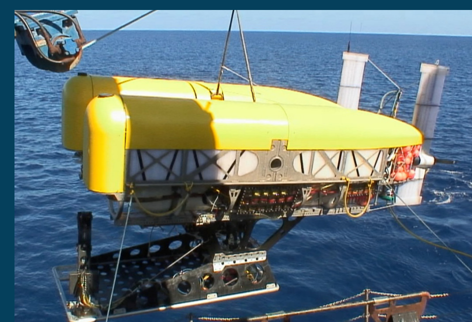
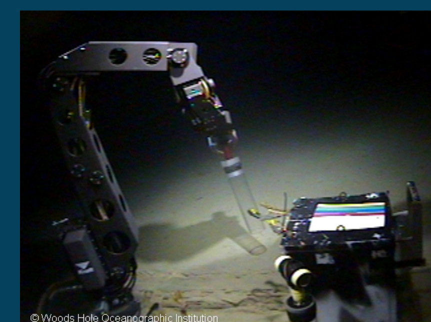
Teleorobotic Intervention in Extreme Environments: Some Food for Thought

- 12 Humans have explored the moon 1969-1972.
- Only 2 Humans have explored the deepest place in the ocean – the Mariana Trench – once in 1960, 15 minutes bottom time.
- 2009 U.S. telerobotic *Nereus* mission to the Mariana Trench, over 13 hours bottom time.
- Over 1,000 *da Vinci*® telerobotic surgical systems are operational worldwide.









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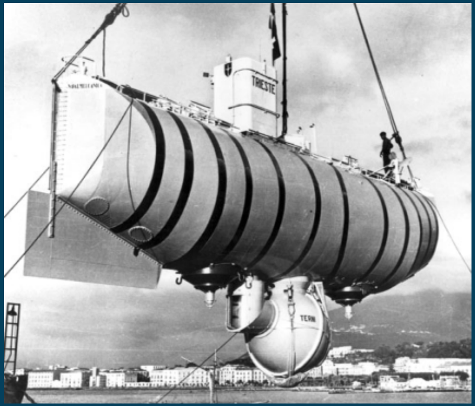
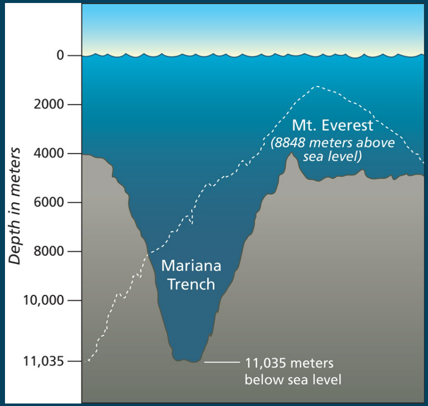
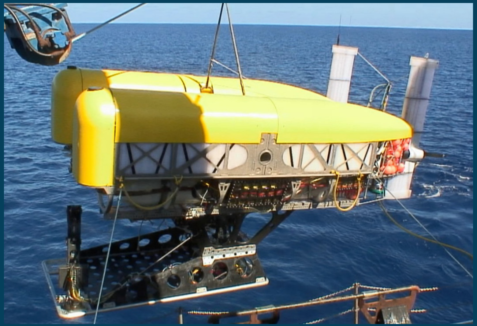
Teleorobotic Intervention in Extreme Environments: Some Food for Thought

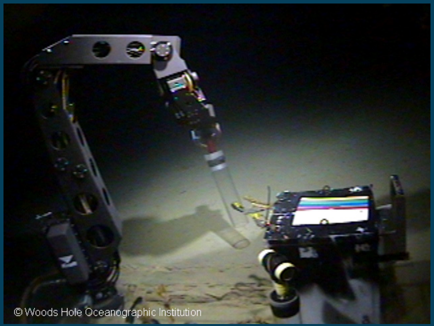
- The fields of Ocean Science and Medicine routinely employ teleoperated robots for complex remote intervention.

- The human operator controls the remote intervention, the robot is a tool to extend human reach into extreme environments.







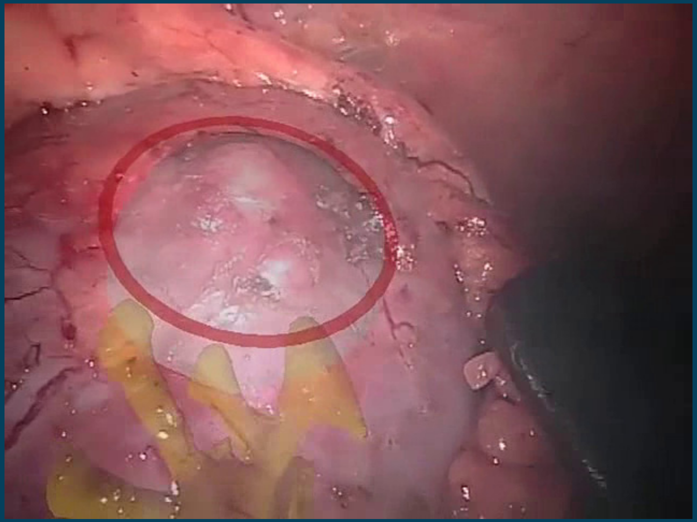


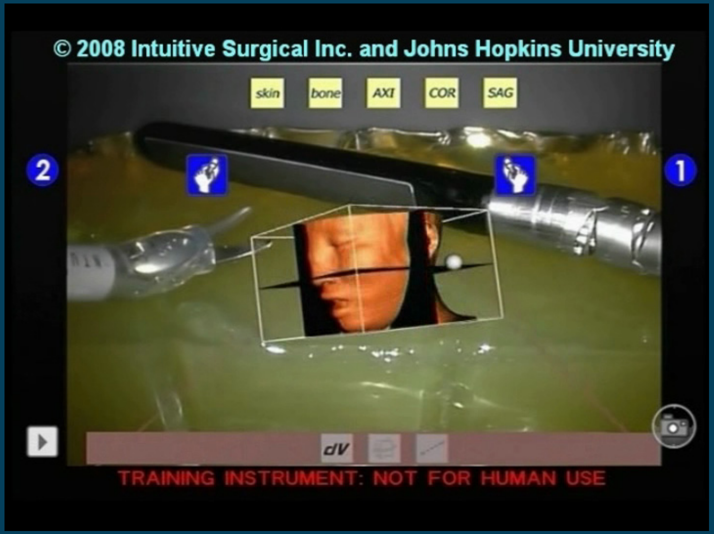
Enabling Technologies for Remote Robotic Manipulation With Time Delay

1. Information-rich immersive software environment for planning and executing remote fine telemanipulation tasks
2. Fine telemanipulation with time delay through predictive model-based telemanipulation
3. Semi-automated manipulation "macro" behaviors for safe remote manipulation in the presence of time delay
4. Real-time computer vision scene understanding and tracking of complex telemanipulation environments
5. Virtual and physical simulation environments for servicing telemanipulation operational plan development, training, and execution

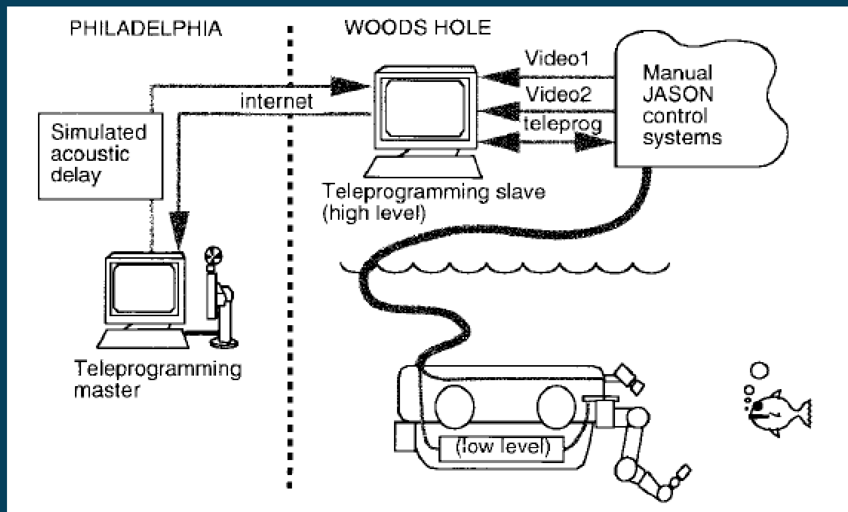
Information-rich immersive software environment for planning and executing remote fine telemanipulation tasks

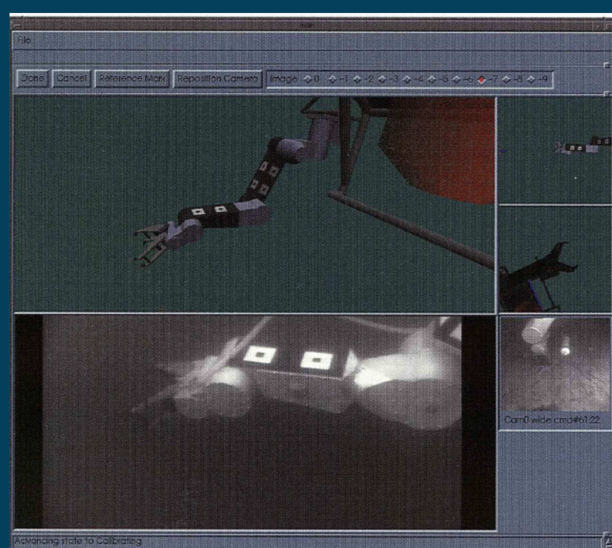
- Leverage telesurgery framework
  - Overlay CT/MR images → overlay CAD models
  - Interact with patient data → interact with system data
  - Initiate autonomous “macros”
  - Define virtual fixtures

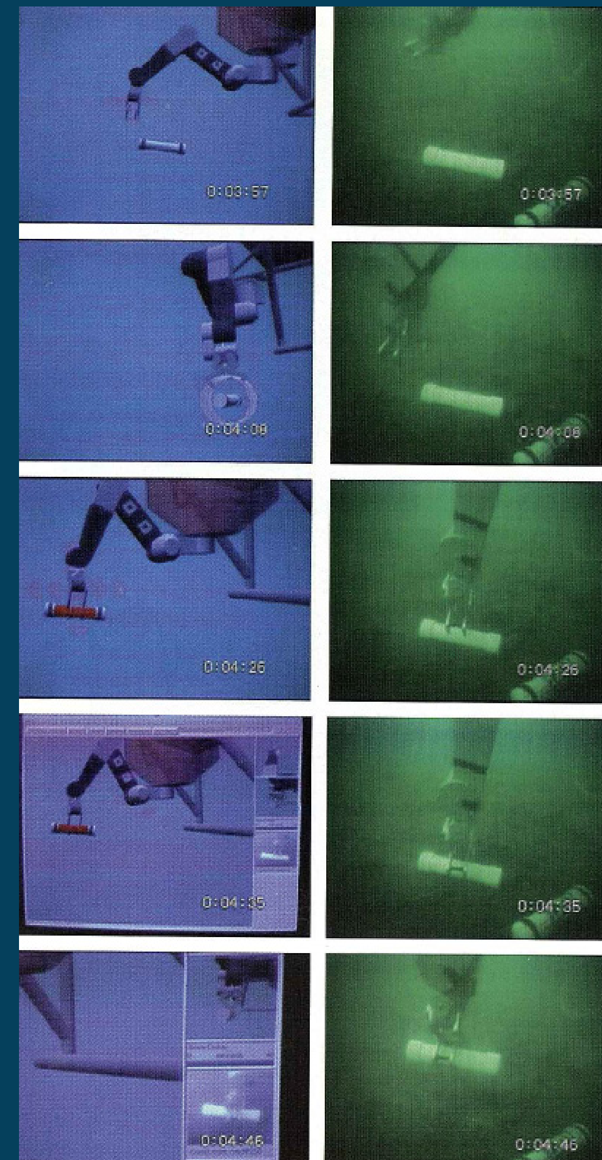




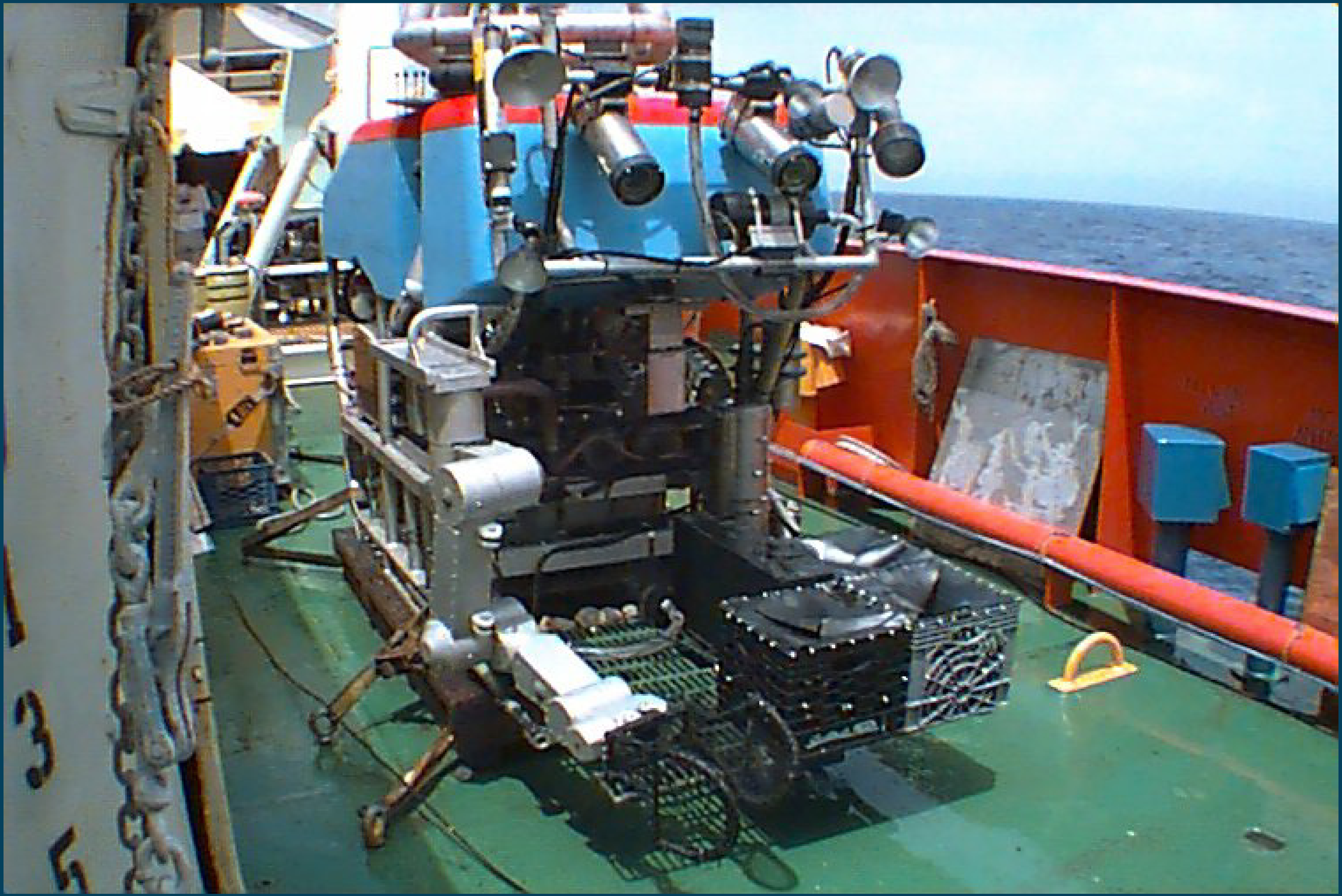
Fine telemanipulation with time delay through predictive model-based telemanipulation







Fine telemanipulation with time delay through predictive model-based telemanipulation

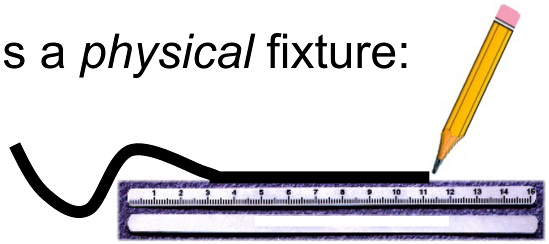


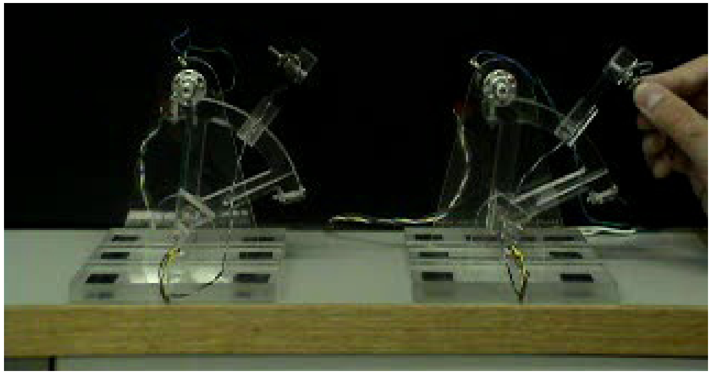
The Jason I Remotely Operated Underwater Vehicle (ROV):
A 6,000 m (depth) ROV developed and operated by the Woods Hole Oceanographic Institution

Semi-automated manipulation “macro” behaviors for safe remote manipulation in the presence of time delay

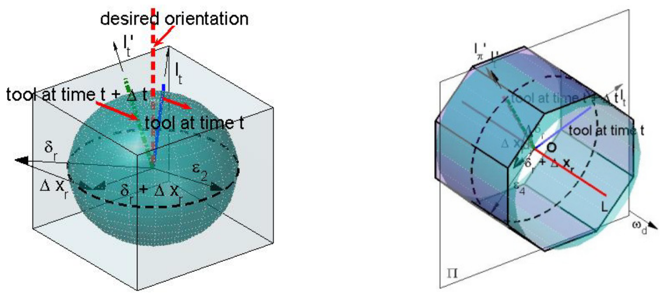
- Virtual fixtures
  - Are force and motion constraints
  - Allow high-level human decision-making and low-level robotic accuracy and precision
  - Use task and environment models to improve safety
- Active behaviors
  - Extend virtual fixtures to define desired motion derivatives

A ruler is a *physical* fixture:





Examples from virtual fixture library:



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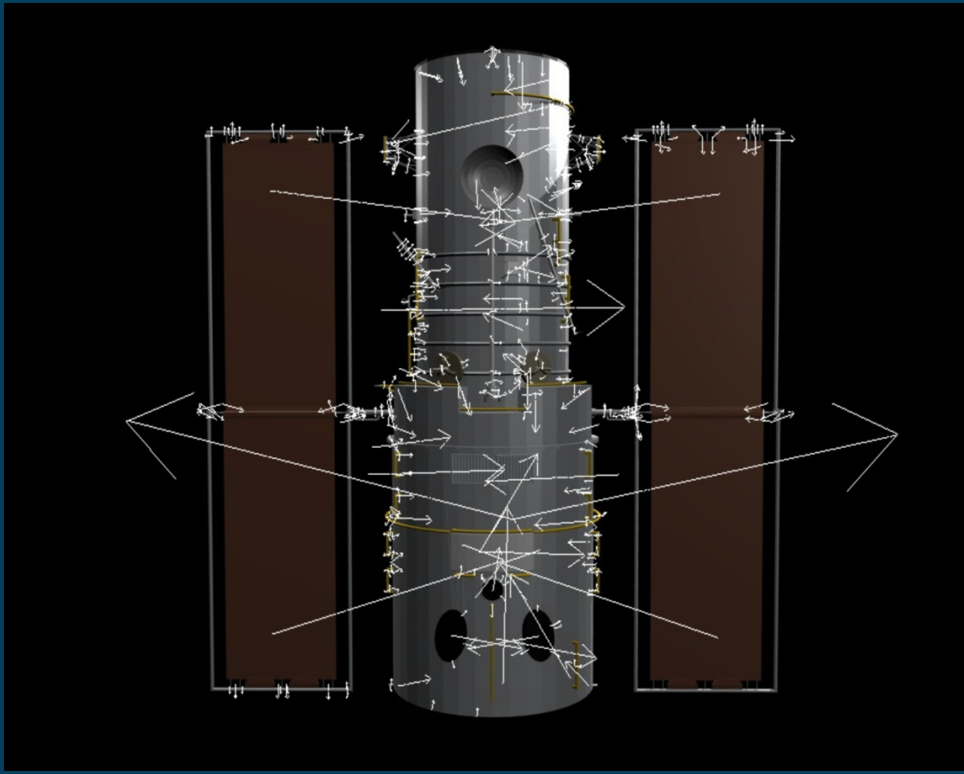
Real-time computer vision scene understanding and tracking of complex telemanipulation environments

- Create a relationship between images and a 3D model
  - **Survey the spacecraft with a camera and extract features from images**



Real-time computer vision scene understanding and tracking of complex telemanipulation environments

- Create a relationship between images and a 3D model
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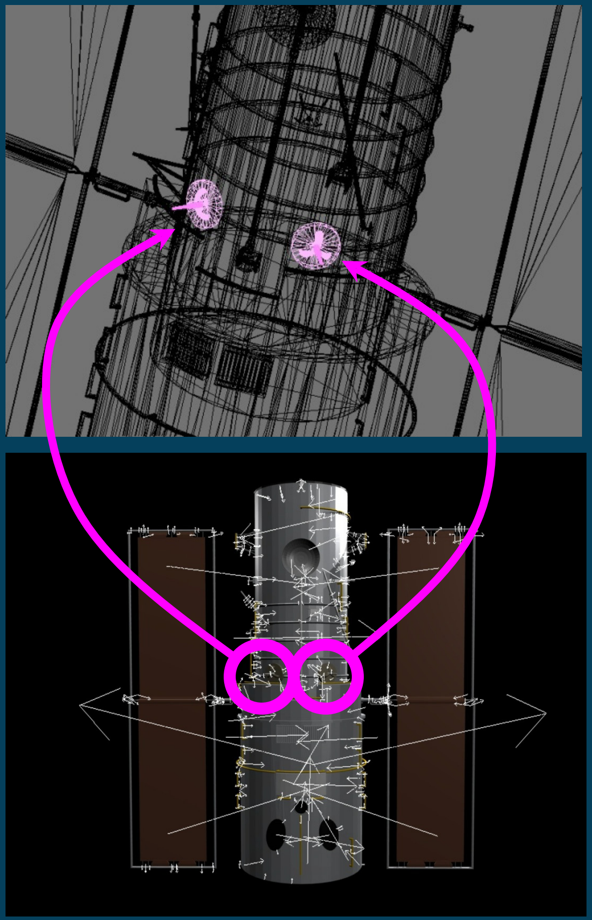
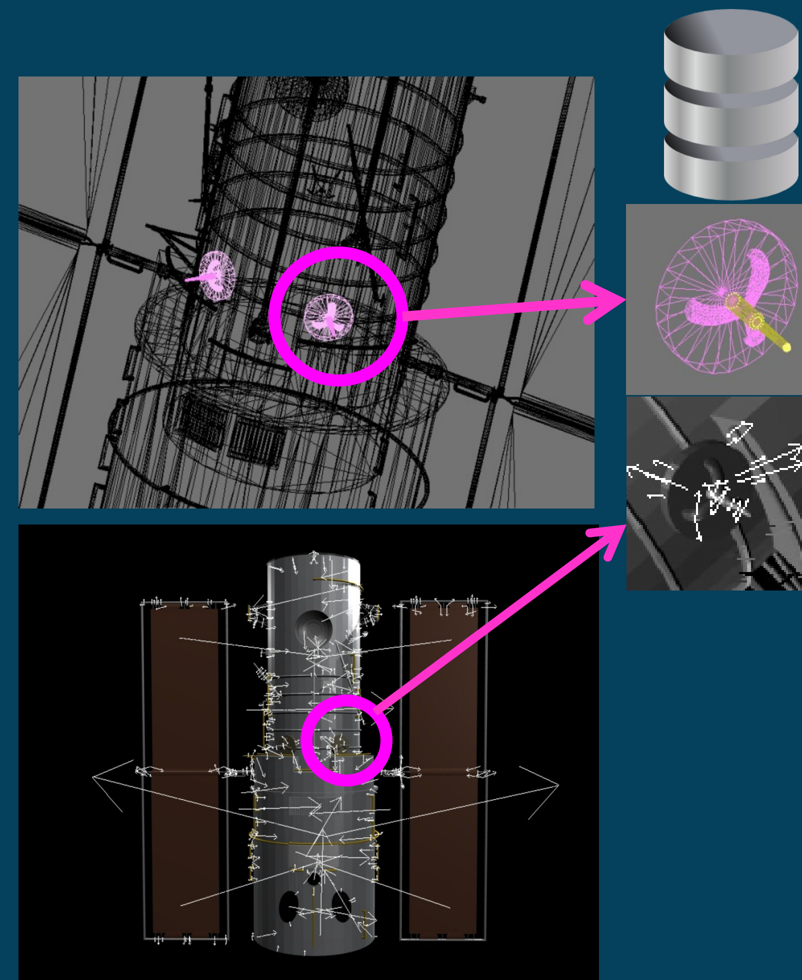
  - **Relate the features to the geometry of the spacecraft manually**



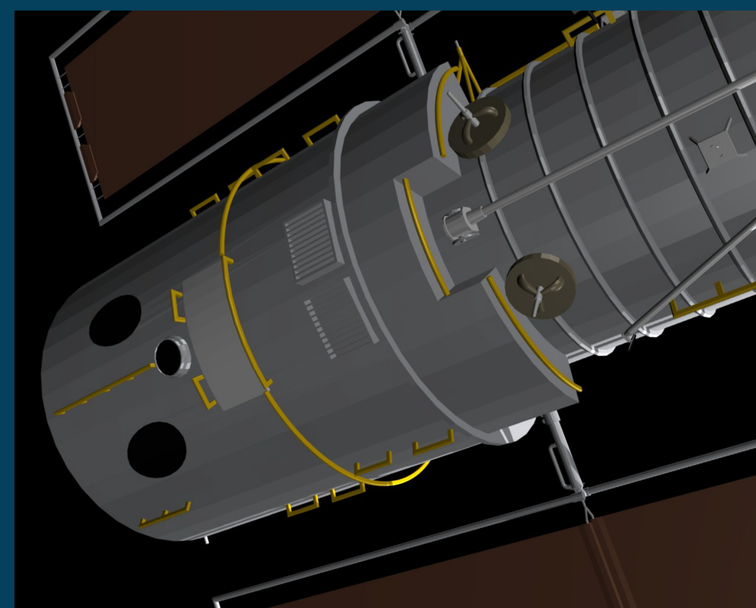
Real-time computer vision scene understanding and tracking of complex telemanipulation environments

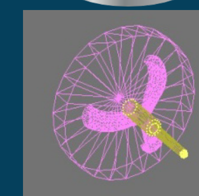
- Create a relationship between images and a 3D model
  - Survey the spacecraft with a camera and extract features from images
  - Relate the features to the geometry of the spacecraft manually
  - **Store the each relationship in a database**



Real-time computer vision scene understanding and tracking of complex telemanipulation environments

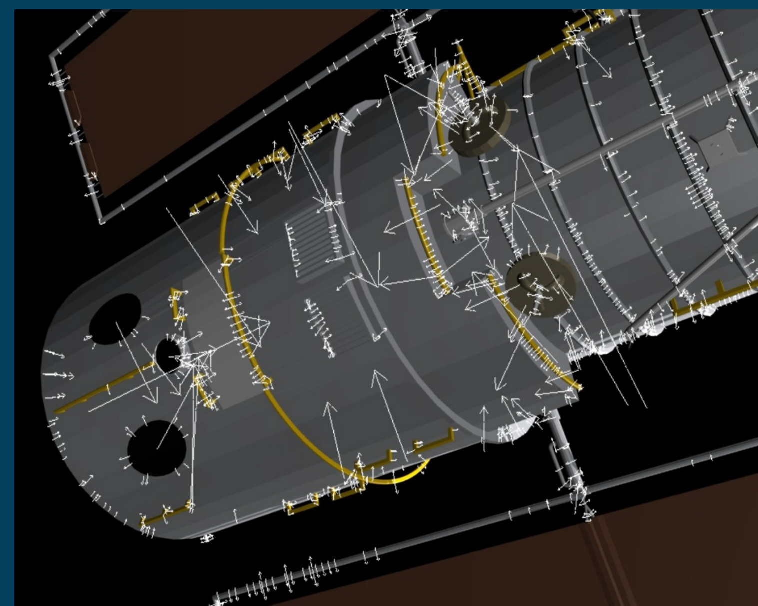
- During operation, use the relationships to estimate the pose
  - **–Obtain an image from the spacecraft**

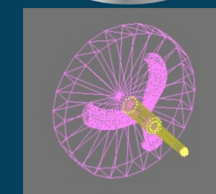




Real-time computer vision scene understanding and tracking of complex telemanipulation environments

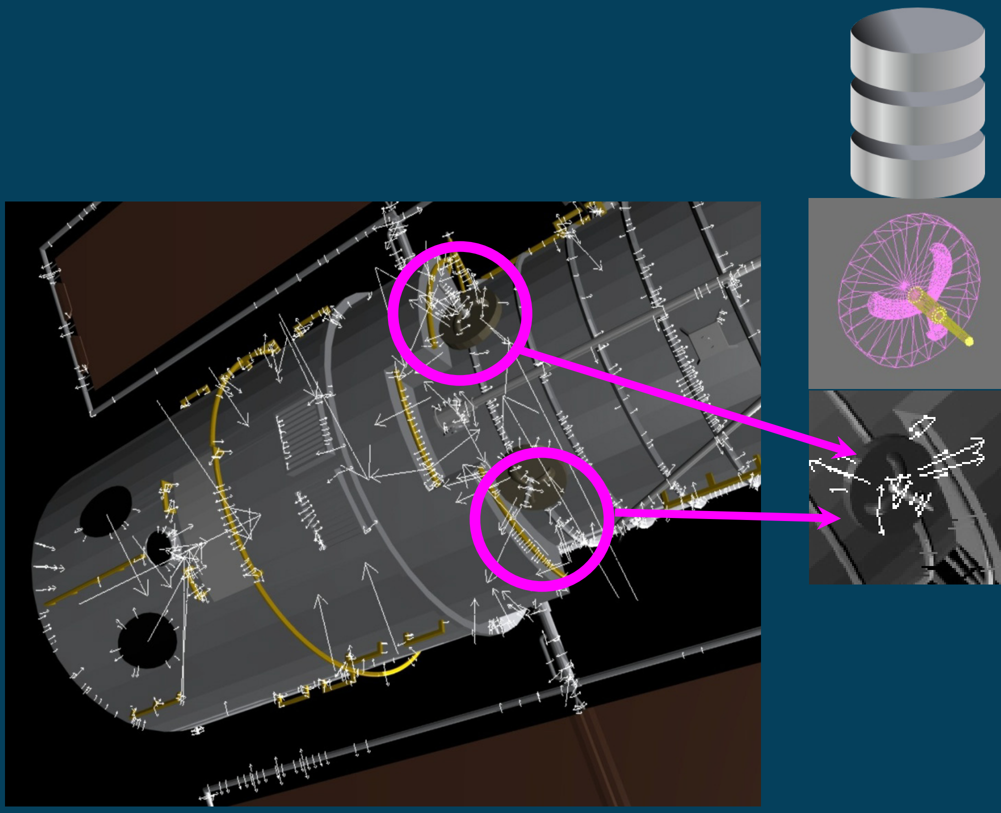
- During operation, use the relationships to estimate the pose
  - –Obtain an image from the spacecraft
  - –**Extract features**





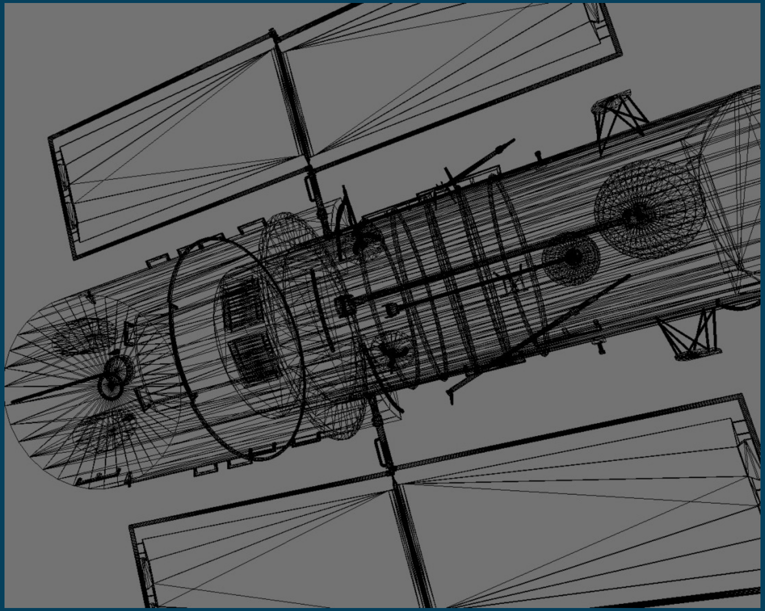
Real-time computer vision scene understanding and tracking of complex telemanipulation environments

- During operation, use the relationships to estimate the pose
  - –Obtain an image from the spacecraft
  - –Extract features
  - –**Match features to the database**



Real-time computer vision scene understanding and tracking of complex telemanipulation environments

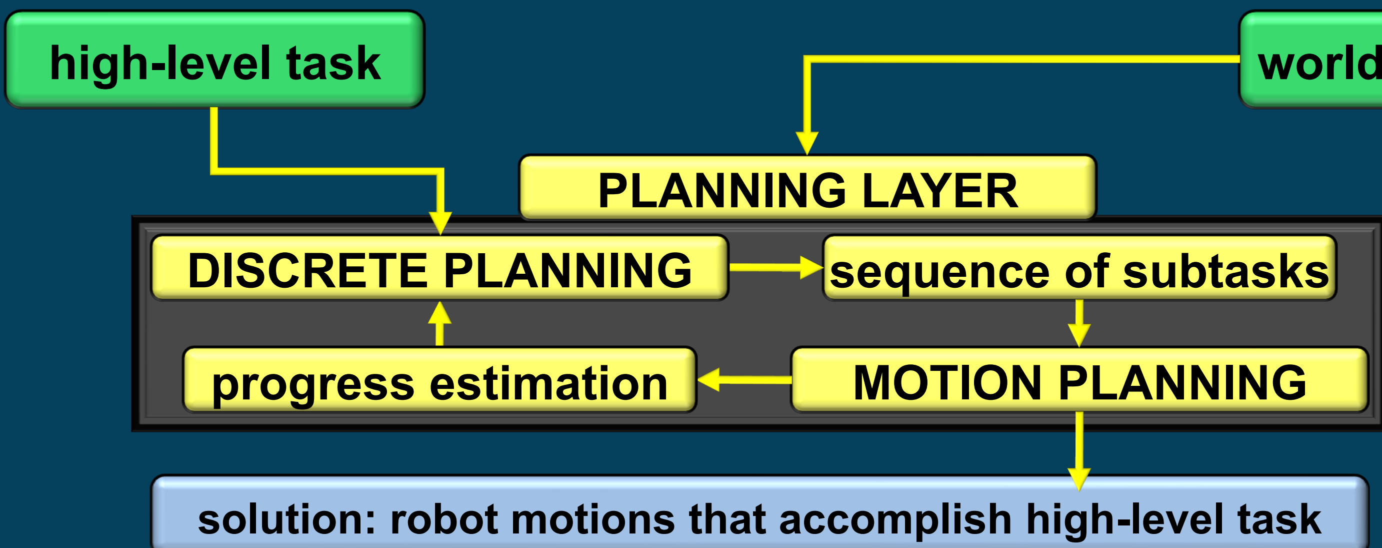
- During operation, use the relationships to estimate the pose
  - –Obtain an image from the spacecraft
  - –Extract features
  - –Match features to the database
  - –**Robust regression to estimate the pose of the spacecraft**

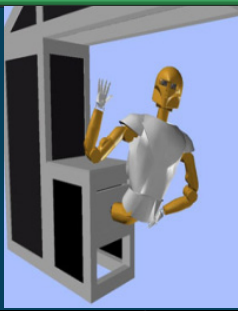


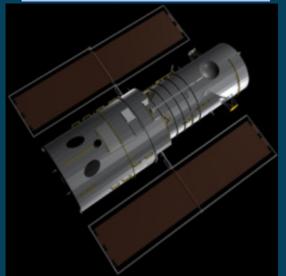
Virtual and physical simulation environments for servicing telemanipulation operational plan development, training, and execution

- Physics-based simulations to accurately model robot dynamics and interactions with the environment (e.g., ODE, Bullet, Vortex)

- High-level planning and motion planning to compute collision-free and dynamically feasible motions that enable the robot to accomplish high-level task (Plaku, Hager '10)

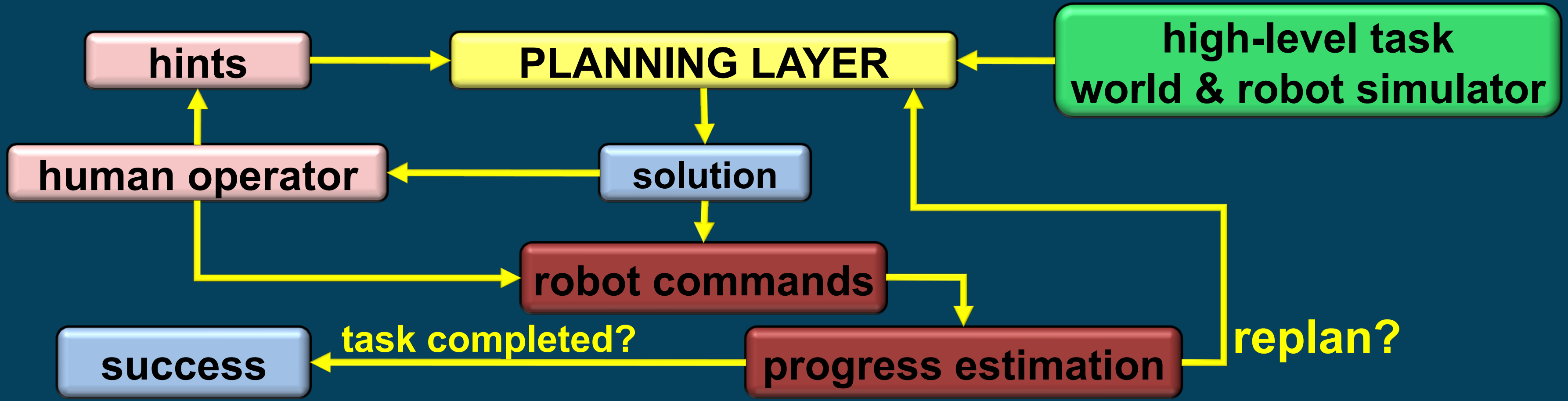




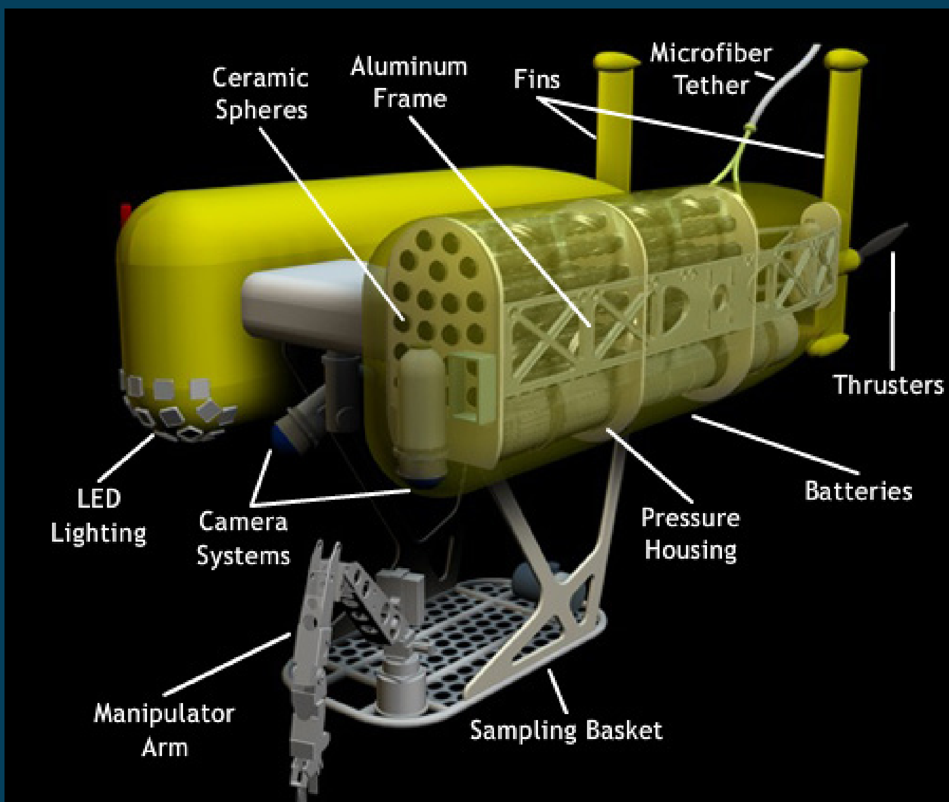


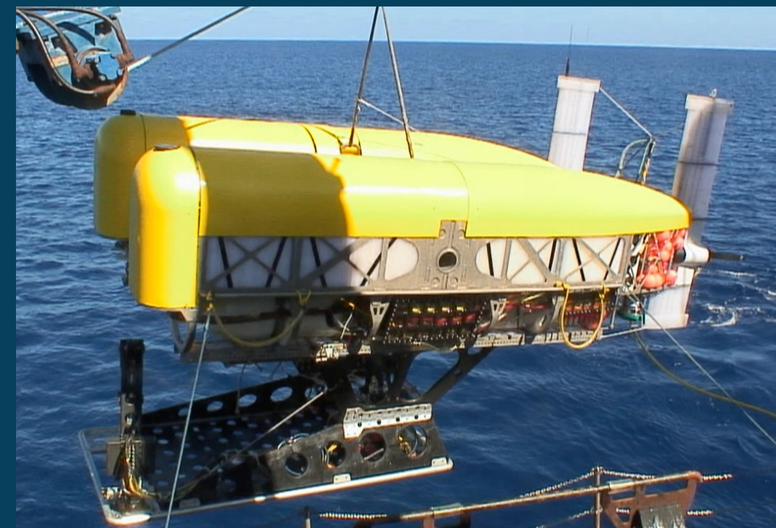
Virtual and physical simulation environments for servicing telemanipulation operational plan development, training, and execution

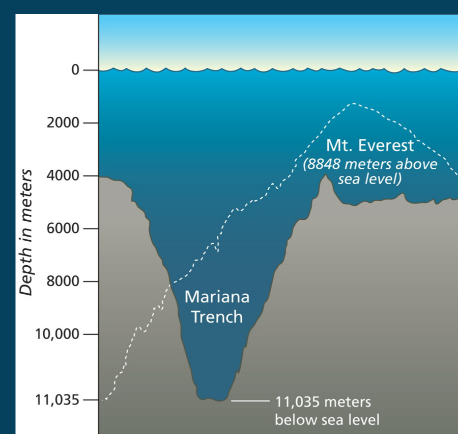
- Human operator interacts with planning layer at two levels:
  - Planning layer suggests solutions to human operator
    - Solutions can serve to correct/guide human operator during plan development, training, and execution
  - Human operator provides hints to guide planning layer
    - Hints can take the form of subtasks planning layer needs to solve or possible motions of how to accomplish certain subtasks
    - Hints can also be constructed from prior solutions to similar tasks

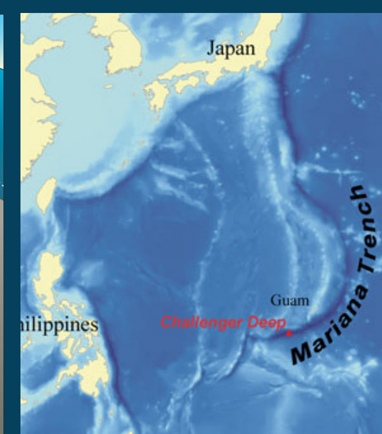


Remote telemanipulation in extreme environments: The *Nereus* Underwater Vehicle









Remote telemanipulation in extreme environments: The *Nereus* Underwater Vehicle

Summary

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