Enabling Technologies for Remote Robotic Manipulation With Time Delay

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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.
- Extensive patents, industrial partnership, and commercialization.

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Robotics in Extreme Environments

Robotics in Medicine

Bio-Engineering

Design and Control

Sensing and Interpretation

Human-Machine Interaction

Basic Engineering Science

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• 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.
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 \(\rightarrow\) overlay CAD models
  - Interact with patient data \(\rightarrow\) 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

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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:
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
  – Survey the spacecraft with a camera and extract features from images
  – 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

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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

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Remote telemanipulation in extreme environments: 

The Nereus Underwater Vehicle
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Summary

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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