Enabling Technologies for Remote Robotic Telemanipulation with Time Delay

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Hackerman Hall

Swirnow Mock Operating Room

Robotorium (shared lab)
Outline

• Telerobotic surgery
• From surgery to satellite servicing
  – Control architecture
  – System overview
  – Teleoperation experiments
• Current and future work
Intuitive Surgical da Vinci® surgical robot

Photo: © 2012 Intuitive Surgical, Inc.
Robotic Surgery Research

• Augmented reality
  – View and interact with data
  – Overlay information
• Virtual fixtures
Integration of Preoperative Information

Current state of the art

Better integration is possible!
Integration of Preoperative Information

Credit: Intuitive Surgical, Inc. & JHU
Support: NSF EEC 9731748, 0646678
Surgical Assistant Workstation (SAW)

teleoperation

(clutch)

“masters as mice”
Overlay of Preoperative Information

Stereo surface tracking

Video/CT registration

Information Fusion with daVinci Display

Preoperative Images

Credit: Vagvolgyi, Hager, Taylor, Su
Overlay of intraoperative data

Camera LEFT

Camera RIGHT

Ultrasound System

Video Capture → Video Processing Pipeline → 3-D User Interface Environment (UI3) → Video Overlay

Surgical Assistant Workstation

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Surgery vs. Satellite servicing

• Similarities:
  – Target is not designed for servicing
  – Prior data is often available
  – Cutting MLI is similar to cutting tissue

• Differences:
  – Large time delay (2-7 seconds)
  – Bandwidth constraints
  – Stereo vs. mono video
Satellite Servicing

• Perform “image-guided surgery” on satellites
  – CT/MRI Image $\rightarrow$ CAD Model
  – Virtual fixtures to provide guidance

• Collaboration with West Virginia Research Technology Center (WVRTC) and Goddard Space Flight Center (GSFC)

• JHU Team
  – P. Kazanzides, G. Hager, L. Whitcomb
  – S. Leonard, A. Deguet
  – T. Xia, J. Bohren, K. Guerin, I. Kandaswamy
Position Available

The Johns Hopkins Laboratory for Computational Sensing and Robotics (http://www.lcsr.jhu.edu) seeks to hire a Postdoc or Research staff member to support our work in perception-augmented telemanipulation. The successful candidate will support ongoing projects that involve the development and testing of new paradigms for remote manipulation for both terrestrial and space applications. Ideal qualifications include a strong background in robot manipulation, computer vision, and software engineering. Day to day duties will include participation in multiple research projects in this area, contributions to the development of software systems for telemanipulation, and an active role in the development of scientific papers and proposals.
JHU Project Goals

- Develop telerobotic system to assist with removal of insulating blanket flap that covers spacecraft’s fuel access port
- Use JHU da Vinci console to teleoperate Motoman robot at WVRTC or GSFC
- Simulate round-trip time delay of 2-7 seconds
Control Architecture

Constrained optimization

\[
\begin{align*}
\min_{\Delta x_c} & \quad \|\Delta x_c - \Delta x\|^2 \\
\text{s.t.} & \quad h_1(\Delta x) < 0 \\
& \quad \ldots \\
& \quad h_N(\Delta x) < 0
\end{align*}
\]

Currently implemented
Teleoperation Setup (JHU ↔ WVU)
Teleoperation Experiments at JHU
Software Block Diagram

Master Controller → Virtual Fixture Controller → Telemetry Delay Component → Remote Slave Controller

Operator's Display

3D Visualization → Virtual Fixtures Models → Remote Scene Models

Remote Side

Video Delay Component → Video Capture
Teleoperation Experiments

• Following scenarios:
  – Unaided teleoperation
  – Teleoperation with boundary plane virtual fixtures
  – Teleoperation with line virtual fixture

• Two conditions:
  – No added delay
  – 4 second delay
Demonstration of MLI cutting at JHU (da Vinci console ↔ WAM robot)

(unaided teleoperation, no time delay)

Credit: T. Xia, S. Leonard
Virtual Fixture Example

Augmented reality environment for defining/adjusting virtual fixtures:

- Delayed video overlayed on top of registered model
- 3D interactive manipulators (green arrows) to adjust virtual fixtures
# Results

**Unaided teleoperation**
- Time $\approx 30$ min (4s delay)
- Time $\approx 8$ min (no delay)

**Two plane virtual fixture**
- Time $\approx 9$ min (4s delay)
- Time $\approx 7.5$ min (no delay)

**Line virtual fixture**
- Time $\approx 4$ min (4s delay)
- Time $\approx 4$ min (no delay)
Current and Future Work

- Use remote sensing (force) to update virtual fixture models
- Collect force data to develop models
- Compensate for motion between satellite and robot


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