Open-Architecture 5DOF Telepresence System

Quanser Consulting, Inc., a developer of real-time hardware and software, is known for its numerous experimental testbeds for control engineering education and research. Quanser also provides hardware and software solutions for the industrial environment. This spotlight article focuses on Quanser’s turnkey robotic telepresence system, which provides an open-architecture testbed for developing and investigating telehaptics as applied to telepresence and teleoperation. IEEE Control Systems Magazine (CSM) thanks Jacob Apkarian, Quanser founder and CTO, and Paul Karam, a design engineer at Quanser, for speaking with us.

Q. What is the 5-degree-of-freedom (5DOF) telepresence system?
Jacob: The 5DOF telepresence system is an integrated suite of products consisting of a haptic interface, which is offered as a choice between either the 5DOF Haptic Wand shown in Figure 1 or the F3D-35 Mirage (not shown), a 5DOF robot with a force-torque sensor, and open-architecture hardware and software. The standard system configuration allows the user to remotely perform operations such as writing, moving objects, or carving, all with high-fidelity haptic feedback. Several configurations are offered with the main option being the choice between two haptic interface devices, one delivering a higher stiffness (5DOF Haptic Wand) and the other for higher force (F3D-35 Mirage).

Q. What motivated the development of the 5DOF telepresence system?
Paul: Haptics and teleoperation are emerging fields where considerable research is yet to be performed to attain optimal performance. Quanser’s real-time, open-architecture solutions offer tools for investigating and exploring solutions to the relevant control issues. Quanser has been offering an open-architecture robot since 1998 and recently developed a complementary suite of haptic devices that can be combined into a telepresence system. One of these devices, the 5DOF Haptic Wand, was originally developed by a group led by Tim Salcudean from the University of British Columbia. Quanser’s rapid prototyping tools, specifically, WinCon and the Q8 interface board, facilitated the integration of the 5DOF Haptic Wand to achieve a 5DOF telepresence system, which is now part of our emerging biomedical engineering product line.

Q. How does the 5DOF telepresence system advance technology?
Jacob: One of the deficiencies in previously developed telepresence systems was poor transparency. Haptic transparency can be defined as the measure of distortion of the tactile signals as transmitted to the operator through the haptic interface and hence similar distortion of the operator’s input back into the interface. A key factor of transparency is the range of renderable stiffness, which can be quantified as a combination of the mechanical stiffness and actuated stiffness of the device. While mechanical stiffness refers to the natural (nonactuated) level of rigidity of the mechanical components, the actuated stiffness refers to the stiffness created by the transmission of force through the system, which depends on the control loop frequency, as well as the A/D and encoder resolutions as defined within the deliverable force range of the device. Hence, while any given haptic system may have a high mechanical stiffness, it may still have a resulting low renderable stiffness if the accompanying power and control hardware and software is deficient and cannot deliver adequate force control. The 5DOF telepresence system reduces the barriers to haptic research by providing a high level of haptic transparency. Moreover, the open architecture implementation provides the ability to investigate control and communication problems that arise in robotic telepresence systems. For example, application areas such as telesurgery and nanomanipulation impose stringent positioning and stability requirements, which can

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be compromised by time delays, sensor resolution, and jitter.

**Q.** What are some of the innovations in the 5DOF telepresence system?

**Jacob:** The haptic interfaces use several technologies to enable a previously unreachable level of renderable stiffness while maintaining a high-bandwidth response with minimum inertia. Specifically, the use of direct-drive, low-friction, low-inertia components, and linear current amplification for driving motion (as opposed to voltage and PWM amplification), and a low latency and jitter real-time open-architecture development environment all contribute to enhancing the performance of the haptic interfaces. Moreover, the use of a dual-pantograph configuration in the 5DOF Haptic Wand (see Figure 1) increases the stiffness of the haptic interface with respect to a serial link system. Likewise, the 5DOF ThermoCRS Robot, for which Quanser provides an open-architecture control format, has a high payload-to-accuracy ratio. Finally, as a turnkey system, the 5DOF telepresence system provides an out-of-the-box haptic-enabled telepresence system.

**Q.** Who are the end users of the 5DOF telepresence system and how will they use it?

**Paul:** Researchers requiring an open-architecture turnkey testbed to develop control algorithms and communication protocols for real-time control or to test new teleoperation equipment will find the 5DOF telepresence system useful. Biomedical laboratories based at universities, companies, and teaching hospitals will also find this system useful for research and teaching advanced topics in telerobotics.

**Q.** What are the implications of the 5DOF telepresence system for control engineers?

**Jacob:** The 5DOF telepresence system was designed to allow researchers an open and versatile platform to design and validate various teleoperation control architectures. Using Quanser’s 5DOF Telepresence System Specifications

**GENERAL**
- Approximate mass of entire system as delivered: 100 kg
- Example control loop rate of telepresence system: 5 kHz
- Maximum distance between haptic input and robot: unlimited, with the addition of a second PC

**OPTION 1: 5DOF HAPTIC WAND**
- 5-axis position sensing
- Maximum closed-loop renderable stiffness: 6000 N/m
- Maximum peak force: 9.0 N

**OPTION 2: F3D-35 MIRAGE**
- 3-axis force feedback, 6-axis position sensing
- Maximum closed-loop renderable stiffness: 2000 N/m
- Maximum peak force: 100 N

**5DOF OPEN ARCHITECTURE ROBOT**
- Rated payload: 1 kg
- Reach (standard gripper): 660 mm

<table>
<thead>
<tr>
<th>Q8 PCI OPEN-ARCHITECTURE CONTROLS BOARD</th>
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<tbody>
<tr>
<td>8 × 14-bit programmable analog inputs</td>
</tr>
<tr>
<td>8 × 12-bit D/A voltage outputs</td>
</tr>
<tr>
<td>8 quadrature encoder inputs</td>
</tr>
<tr>
<td>Simultaneous sampling of both analog and encoder sections</td>
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<tr>
<td>8 × 24-bit reconfigurable encoder counter/timers</td>
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<tr>
<td>Easy synchronization of multiple Q8 boards</td>
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**WINCON/QUARC REAL-TIME CONTROLS SOFTWARE**
- Interfaces seamlessly with The Mathworks’ MATLAB/Simulink software
- Supports all regular controls blocks as well as several new communications and processing functions from Quanser
- WinCon: Windows Real-Time target RTX
- QuaRC: QNX Neutrino 6.3

![Network block diagram of an impedance-impedance-type haptic interface controlled by a four-channel bilateral controller.](image-url)

(continued on page 140)
Report of the Vice President, Publication Activities

Following are the highlights from Y. Yamamoto’s report to the BoG:

» All publications are operating smoothly with minor or no backlog. Some publications have a minor increase compared to last year, but this should be taken care of by the recently approved page budget increase.

» CSS editorial policy has been clarified for a double submission for an IEEE conference and our Transactions, and the new policy discouraging such practice is already posted http://control.bu.edu/ieee/information.html.

» A major upgrade was completed to the Web-based editorial system used by TAC in the fall of 2005. This upgrade provides extended functionalities in the handling system. However, this system cannot be maintained and upgraded in the same way in the future. Thus, the CSS has committed to develop a new system. This is currently being designed by H. Kwakernaak and P. Misra.

» Submissions to TAC in 2006 recorded 472 regular-paper manuscripts, slightly less than in 2005, but still a high number. This has led to a slight increase of backlog, which will be resolved by our page budget increase.

» 614 papers were submitted as Technical Notes in 2006, as compared to 635 in 2005. Among them, the corresponding author of 23% of the submitted papers is from China. Virtually no backlogs for Technical Notes in the past few years.

» IEEE Transactions on Control System Technology (TCST) set a new record in 2006 for submissions with 596 manuscripts, almost a 200 increase from 2005. Submissions this year (2007) are on a similar pace.

» The average submission-first decision periods are approximately six months for TAC and three-four months for TCST.

Bernstein (IEEE Control Systems Magazine Editor) informed the BoG that the CSM has a new “Ask the Experts” column and requested BoG members to actively contribute to it.

Report of the Secretary-Administrator

Bushnell noted that the next BoG meeting will be held on Tuesday, December 11, 2007, at 1:00 p.m. in New Orleans, Louisiana at the 46th CDC.

ADJOURNMENT

Djaferis thanked the BoG members and visitors for attending the meeting. The meeting was adjourned at 5:33 p.m.

PRODUCT SPOTLIGHT (continued from page 131)

tools that allow for both master and slave controllers to run within the same control loop, a variety of teleoperation schemes and limitations can be implemented and investigated.

For instance, while controller design is simplified by eliminating the need to compensate for flexure, friction, backlash, and other nonlinearities, further challenges come into play. These challenges include the complex kinematics and dynamics of the system, operating under the teleoperation model (as shown in Figure 2), and exploring the effects of time delays. In addition, the ability to implement more demanding control architectures on presents new control challenges such as the requirement for adaptive damping.

As a further example, a researcher could implement standard teleoperation schemes such as impedance control and admittance control, as well as three-channel and four-channel teleoperation architectures. The three-channel impedance control system implemented in WinCon is shown in the Simulink diagram in Figure 3.

Q. What is the cost of the 5DOF telepresence system?

Jacob: The cost of the entire system, including computer, Q8 PCI control boards, QuaRC or WinCon rapid control development software, controllers, amplifiers, manuals, examples, and free technical support is approximately US$150,000. An additional force torque sensor integrated into the wand’s handle (for four-channel operation) and controller design software such as Matlab/Simulink/RTW and Maple from Maplesoft can be included at an additional cost.

FIGURE 3 WinCon implementation of the impedance-impedance haptic interface for the Quanser 5DOF telepresence system as shown in Simulink.