Raven II™: Open Platform for Surgical Robotics Research

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INTRODUCTION

In this paper we present a new platform for surgical robotics research: the Raven II™. The goal of this work is to provide a robot with which researchers can explore new techniques in telerobotic surgery by modifying the hardware and software to meet their needs.

The first generation RAVEN[1] was designed for experiments in long distance, Internet based telepresence surgery. Several studies using RAVEN by our team, demonstrated feasibility of Internet based teleoperation to remote and extreme environments [2]. Investigations using the Raven also measured the impact of common Internet latencies on surgical performance and explored interoperability among a wide range of telesurgery master/slave robots [3,4].

Raven II is a second-generation system that includes all the same Internet telepresence capabilities, and features many improvements that make it better suited for a wide range of telesurgery research.

With support from the US National Science Foundation Computing Research Infrastructure program, seven Raven II systems were built, and in February 2012 they were distributed to US based researchers at Harvard University, Johns Hopkins University, University of Nebraska, University of California (UC) Los Angeles, UC Berkeley, UC Santa Cruz, and University of Washington. Having the Raven II hardware creates a new opportunity for groups to share design improvements, replicate results, and collaborate on research. Having a common open-source code base allows new developments to be shared among multiple institutions. The authors believe this is the best route to continued innovation in telerobotic surgery.

Design of the Raven II is described in Materials and Methods below. Project completion is described in the Results section, and the significance of this new platform is treated in the Discussion.

MATERIALS AND METHODS

Raven II evolved from the original RAVEN surgical system. Mechanically Raven II differs from the RAVEN in several significant respects. The system inertia, especially due to reduced mass of a linear-actuation guide rail, was significantly reduced from RAVEN to Raven II for improved control performance. Link mass of RAVEN was 4.6 kg, compared to 2.0 kg for Raven II. In addition, the Raven II mechanism was designed to accommodate either two or four arms. Optimization was performed for mechanism isotropy over the ranges of motion in laparoscopy, as well as maximizing common workspace among the four maniplators. (For complete details see [5].) A new, patented tool design provides six degrees of Cartesian motion and grasping [6]. A unique feature of the tool is a wrist design that eliminates cable coupling between degrees of wrist actuation.

The RAVEN used Maxon EC40 with 12.25:1 gear reduction and EC32 DC brushless motors. Brushless motors such as these provided better torque-to-weight ratio than brushed motors. However, they require significant additional cabling and complex expensive motor controllers. Raven II uses Maxon RE40 and RE30 brushed DC motors with a 12:1 and 3.7:1 gear ratio respectively. This has not made noticeable difference in performance, and has reduced cabling and electronics complexity.

Raven II electronics have many of the same features as RAVEN, but in a compact form factor more easily situated in a laboratory environment or carried to the field (Figure 1). A single nineteen-inch desktop rack holds the robot power supply, motor controllers and I/O for the two arms and a Linux PC. As in RAVEN, a key hardware safety feature is a DL05 programmable logic controller that monitors the robot inputs and outputs and has the capability to trigger fail-safe brakes on the frist three (gross positioning) mechanism joints. Z6A6 and Z12A8 servo amplifiers (Advanced Motor Control, Camarillo, CA) drive the robot's smaller and larger motors at six and twelve amps respectively. I/O with the computer is via a custom designed eight channel USB

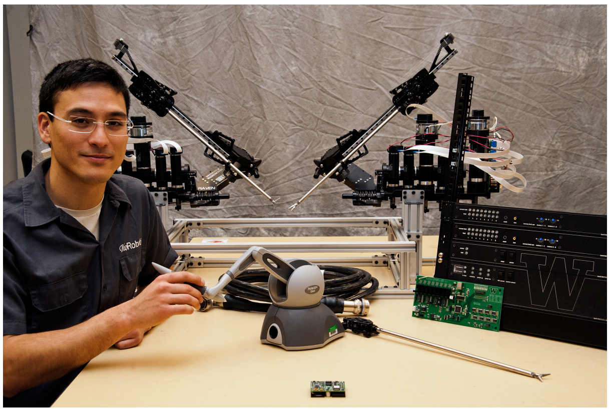

Fig. 1 Raven II: a second-generation surgical robotics research platform.

I/O board. This board can read 8 encoder signals and write 8 analog motor outputs in less than 125 μs.

Raven II software has been dramatically revised from RAVEN. As with RAVEN, the basic sensor-actuator control loop is closed through the Linux PC at one thousand hertz. To achieve the necessary speed and determinism RAVEN used an RTAI Linux kernel module. Now, Raven II uses CONFIG_PREEMPT_RT, a hard real-time patch for the Linux Kernel. The patch satisfies all timing requirements, providing an accurate 1kHz control loop. It also allows real-time software to execute in user space with minimal modification, thus simplifying the software development environment.

In addition the Raven II software has been integrated with Robot Operating System (ROS) [5]. ROS is a modular, open source robotics middleware package that makes it very easy to combine the Raven II software with other robotics software libraries. For example, Raven II state information is output using ROS message passing mechanisms, and can be plotted in real time using "rosbag" or used by a teleoperation system to calculate force-feedback. In addition a robot visualization tool (shown in Figure 2) was developed using the "rviz" ros module. The ROS parameter server is used for initial gains configuration of the robot. Despite integration with ROS raw UDP sockets are also supported for teleoperation control, since our research has shown slightly better performance this way.

The Raven II control software was rewritten in C++, with the goal of making it easy for collaborators to implement new controllers and features. At the same time, much of the modularity of the original RAVEN code was maintained. All Raven II partners have access to a common source code repository that will include future contributions from all sites.

Several Internet-based collaboration tools foster communication among research peers and provide peer-to-peer support for the new systems. A wiki has been created to hold documentation and keep it up to date. An online discussion forum, integrated with the wiki is also in place, and has proven crucial to supporting the deployed systems and sharing information. Finally a blog kept participants up-to date as the robots were developed, and is now used for periodic news updates.

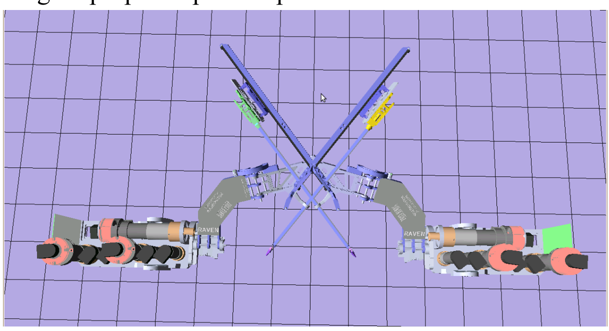

Fig. 2 Integration with Robot Operating System makes the software compatible with many off-the-shelf robotics packages. This figure shows the use of the "rviz"package for visualization of the robot.

RESULTS

Dual-arm Raven II systems were completed in February 2012 and provided to seven institutions around the United States. One robot suffered damaged to two motor encoder shafts which were replaced. In all partner locations, the robots are set up and running and new research is being devised and implemented.

Community participation via dedicated Internet forums has been active with over one hundred posts in February and March. This hints strongly at further collaboration among groups.

DISCUSSION

Raven II is a major improvement over the original RAVEN system and is a robust platform for MIS robotics research. Open-source control software simplifies development of new modules, and ROS integration means it's easy to directly interface with many existing robotics packages.

In the future, revisions are planned to fix some minor hardware anomalies. Also, many new avenues of research are being pursued on this platform involving haptic feedback for improved control, machine learning, image guidance and more.

Raven II is now a common surgical robotics research platform in use by seven leading U.S. based research groups with more to follow. This forms the basis of a promising new research network.

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