Control of Surgical Robots: Network Layer to Tissue Contact

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Abstract

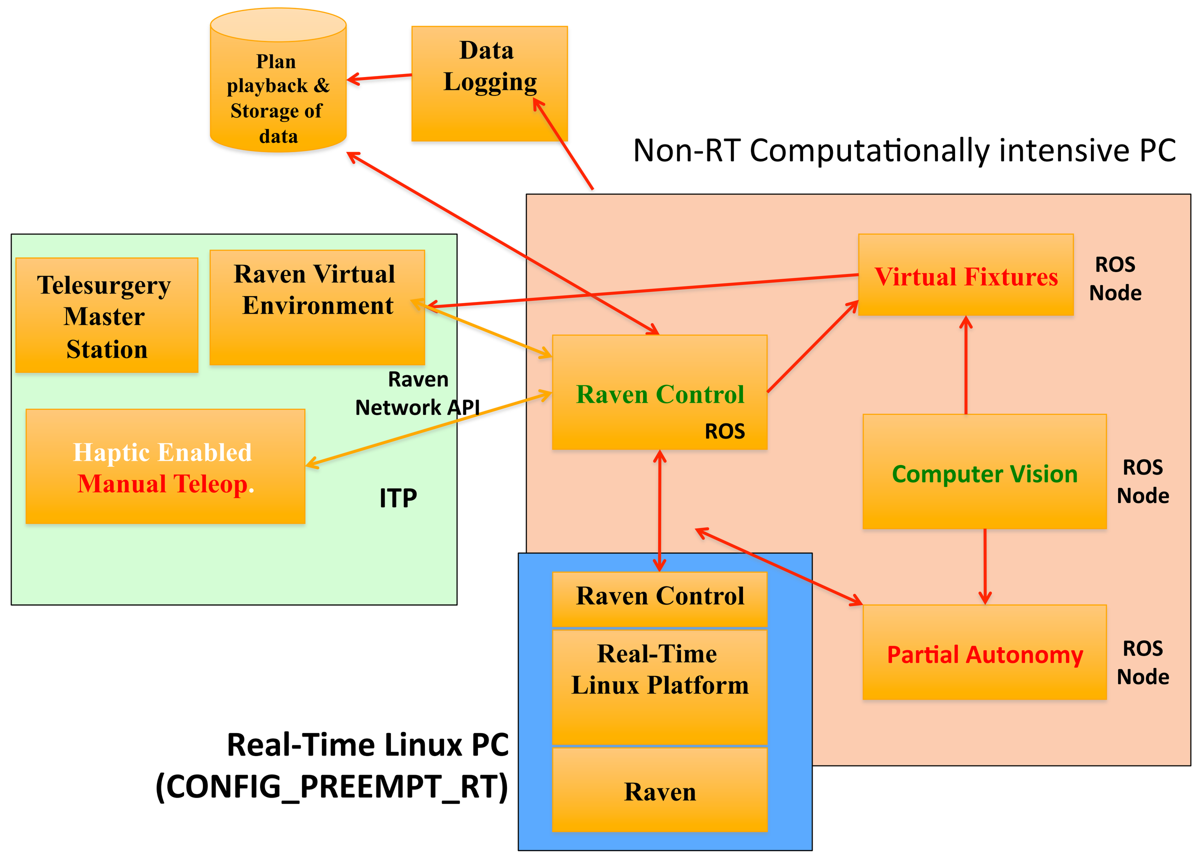
The BioRobotics Laboratory at the University of Washington is working to improve robotic surgery by augmenting surgeons with advanced cyber-physical capabilities. Our work comprises four objectives: (1) open network interface providing interoperability among tele-surgical systems; (2) methodology for flexibly connecting tele-surgical robots to assistive agents like automation or virtual fixtures; (3) developing safe feedback control algorithms that use online tissue modeling to minimize unnecessary damage during robotic surgery; and (4) a consideration of security issues in remote teleoperation.

Research leverages the Raven surgical system and several recently developed technologies to create breakthroughs in Cyber-Physical Surgical Systems.

Open Interfaces

Objectives:

- Develop an open-source platform for surgical robotics research.
- Develop common protocols for collaborative research in Telerobotic Surgery.
- Incorporate cutting-edge robotics research to improve surgical robotics outcomes.



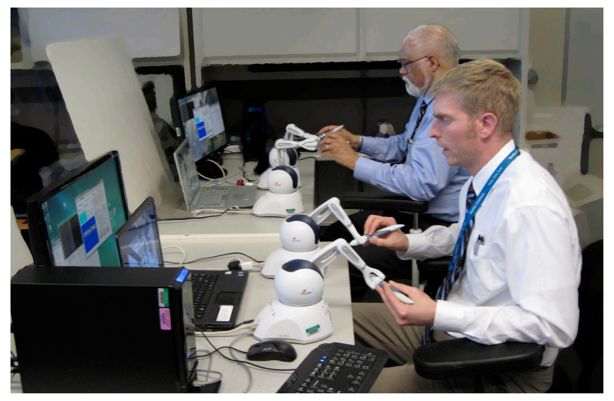
The Robot Operating System (ROS) provides a flexible architecture for developing robot software and provides many robotics services like computer vision and motion planning.

Our "**I**nteroperable **T**elesurgery **P**rotocol is a data specification for communicating motion data between master and slave robots over the Internet. The ITP has been used by research groups around the world.

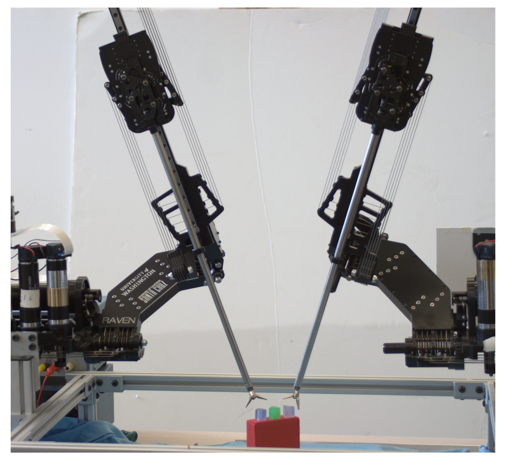
```
#pragma pack
struct u_struct {
        unsigned int sequence;
        unsigned int pactyp;
        unsigned int version;

        int delx[2];
        int dely[2];
        int delz[2];
        int delyaw[2];
        int delpitch[2];
        int delroll[2];
        int buttonstate[2];
        int grasp[2];
        int surgeon_mode;
        int checksum;
};
```

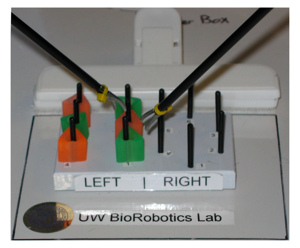
Raven Surgical System: CPS Surgery Testbed



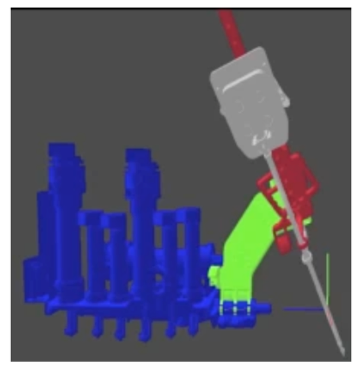
Surgeons Thomas Lendvay (front) and Mika Sinanan of Seattle Children's Hospital and UW Medicine at dual surgical master stations.



Two arms of the RAVEN, developed at the BioRobotics lab for telesurgery research.

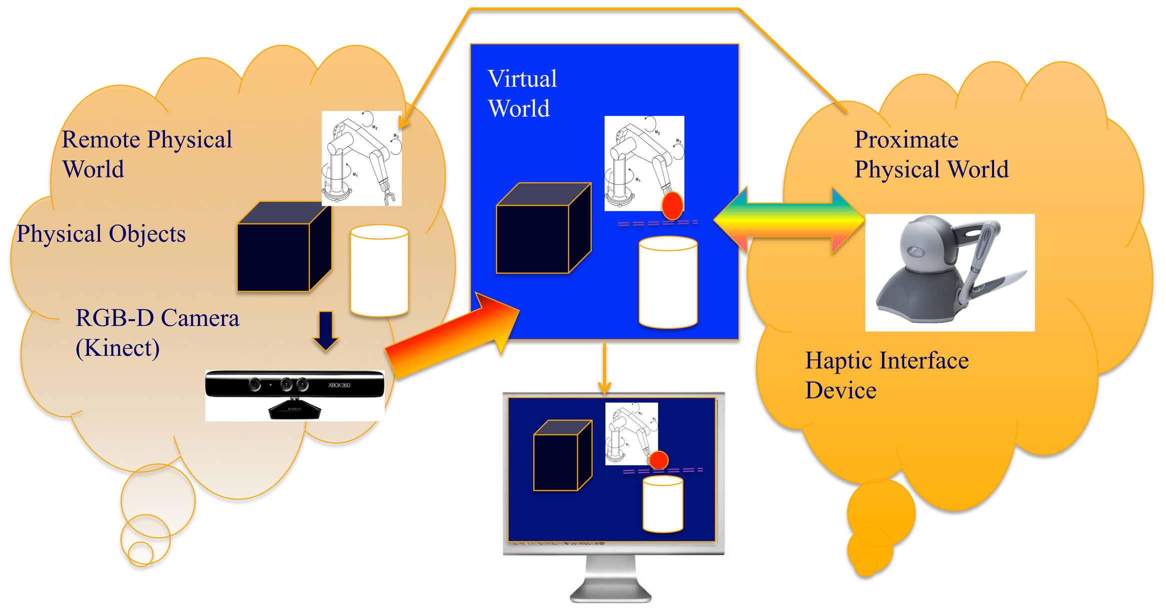


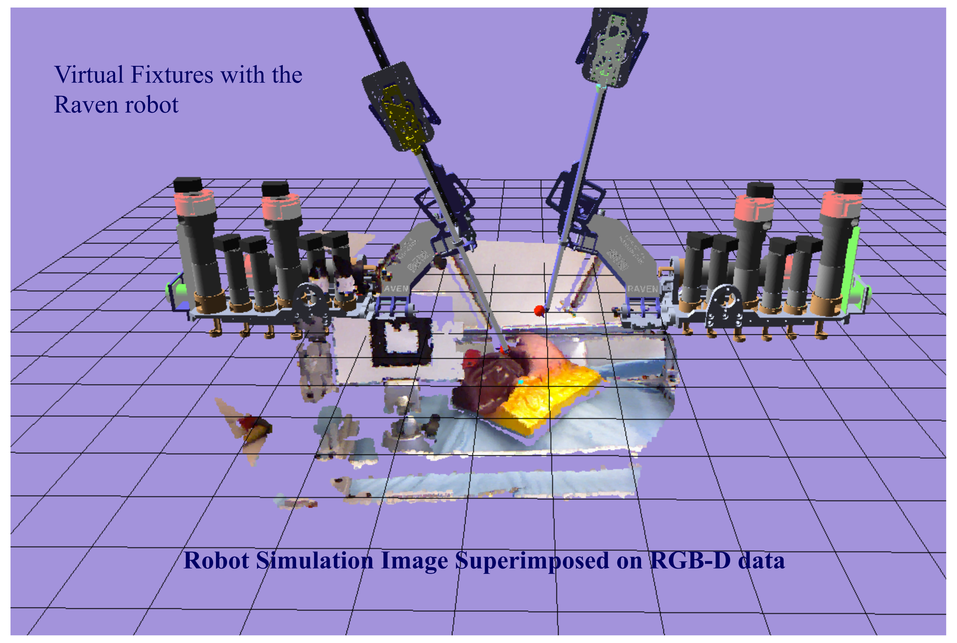
"Fundamentals of Laparoscopic Surgery" is a standard test of surgical skill we've adapted for Telerobotic Surgery.



Raven visualization with full dynamic and kinematic simulation, allows offline software and controller testing.

Virtual Fixtures: Augmented Reality Surgery

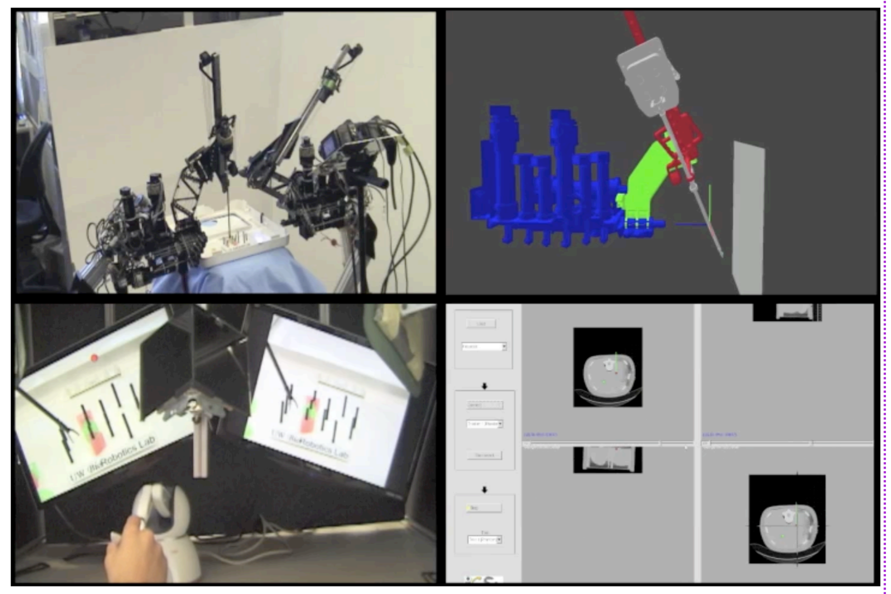




"Virtual fixtures" are augmented reality features; artificial force-fields superimposed on a user's workspace.

- Can improve safety by keeping the surgeon out of dangerous areas, or constrain her motion to an area of interest.
- Virtual fixtures derived from streaming point clouds, as generated by depth cameras (such as the Kinect) can be combined with haptic rendering to restore a sense of touch without force sensors.
- Our novel algorithms use streaming point cloud data for fast update rates that can track moving views and anatomical structures. Recent results permit 6 DOF haptic rendering, using depth clouds obtained simultaneously from multiple depth cameras

At right is a demonstrator system using the Raven I master-slave telesurgery system, and incorporating static haptic virtual fixtures and an "in-body navigation system" implemented using the open-source "Image Guided Surgery Toolkit".



Tissue Aware Control

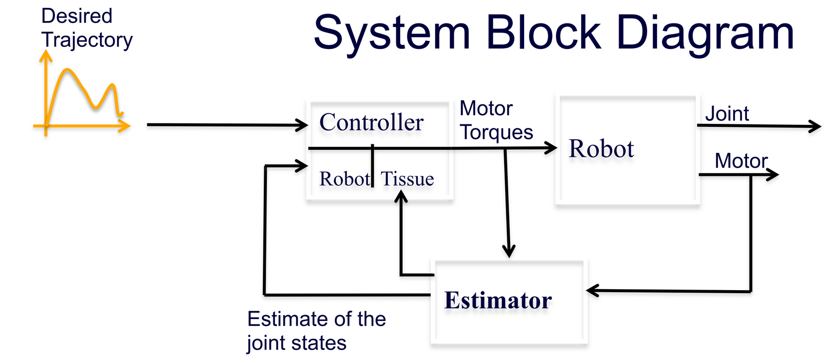
Challenges:

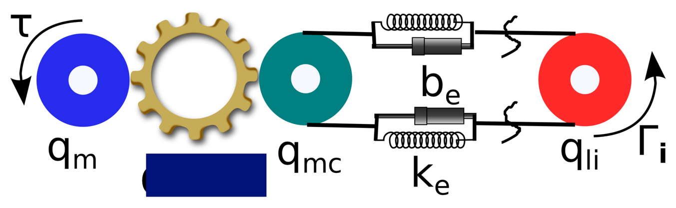
- Dynamics of tissue
  - Nonlinear tissue parameters
  - Different from organ to organ and patient to patient
- Lack of sensory information. Sensors are:
  - Noisy
  - Often expensive
  - Require additional wiring
  - Small enough?
  - Sterilizable?

Can we control the position of the end effector when we don't know

- Where the end effector is AND
- Whether it is in contact with tissue or not AND
- With what type of tissue it is in contact.

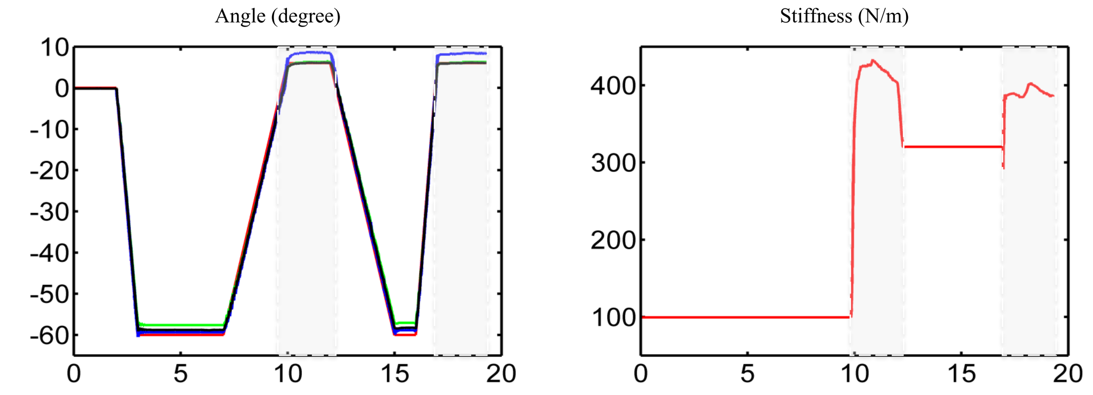
System Block Diagram





Schematic diagram of Raven's cable actuation system.

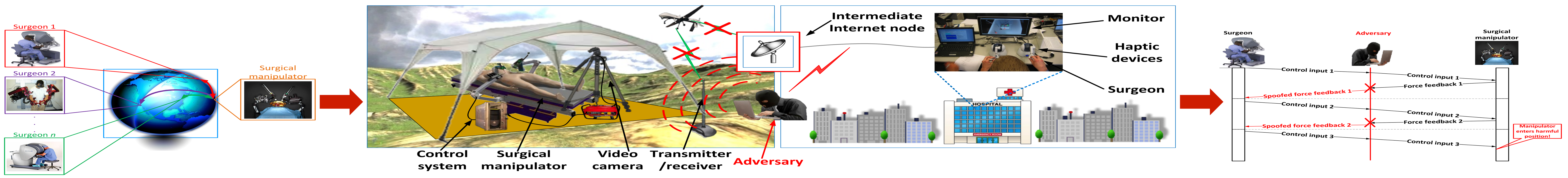
Below: Robot and tissue parameter estimation results (using an Unscented Kalman Filter). Estimator accurately reports the robot state, and the stiffness of the contact surface.



Telerobotic Security

In hostile environments, an adversary can target wireless and/or Internet-enabled communication between surgeons and surgical manipulator to disrupt remote operation.

An example of possible attack: an adversary spoofs force feedback, causing the surgeon to issue incorrect movements. As a result, the manipulator's end effectors enter a harmful position.



Acknowledgments

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