Suture knot manipulation with a robot

Tian Xia

Ph.D Advisor: Peter Kazanzides

Project Advisor: Russell Taylor, Rajesh Kumar

Johns Hopkins University

Baltimore, Maryland, USA

LABORATORY FOR Computational Sensing + Robotics

THE JOHNS HOPKINS UNIVERSITY

Knot Tying Video

Some Approaches to Knot tying and placement

- Mayer et al @ TUM
  - Knot tying using supervised machine learning algorithms on trajectories recordings of surgeons, then intelligent playback.
  - **Autonomous.**
- Our approach: "surgeon-in-the-loop"
  - Controller that reduces the cognitive load of the surgeons
  - Leaves surgeons in command at all times
  - **Semi-autonomous**

Currently only concerned with **knot placement!**

A constrained optimization approach to virtual fixtures

- Virtual fixtures are task-dependent computer-generated constraints, which help a robotic manipulator perform a task by limiting its movement into restricted regions and/or influencing its movement along desired paths.

- We can implement virtual fixtures using instantaneous kinematics (e.g. Jacobian) of the manipulator and the geometric constraints

- **Approach**: For a given geometric constraints, generate virtual fixtures in the form of a quadratic optimization problem with linear constraints

- Compute output incremental joint motion given input desired motion using the formulation:

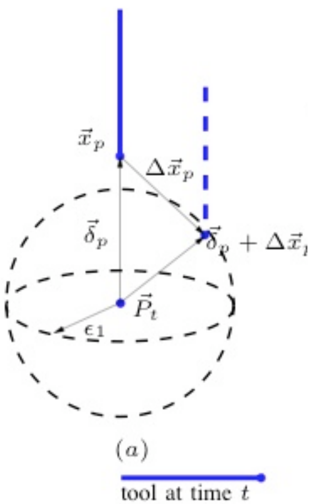
$$\Delta \boldsymbol{q}_{cmd} = \arg\min_{\Delta \boldsymbol{q}} C(\boldsymbol{x}(\boldsymbol{q} + \Delta \boldsymbol{q}), \boldsymbol{s}, \boldsymbol{x}^d)$$

$$\text{s.t.} \quad A(\boldsymbol{x}(\boldsymbol{q} + \Delta \boldsymbol{q}), \boldsymbol{s}) \le \boldsymbol{b},$$

$$\boldsymbol{s}_{up} \ge s \ge \boldsymbol{s}_{low} \ge 0; \qquad \Delta \boldsymbol{q}_{up} \ge \Delta \boldsymbol{q} \ge \Delta \boldsymbol{q}_{low}$$

A constrained optimization approach to virtual fixtures

- Abstract aspects of the surgical procedures into assistive motion primitives:
  - rotate around a fixed point, move toward a point
  - following a line, rotate around a line
  - stay above a plane …



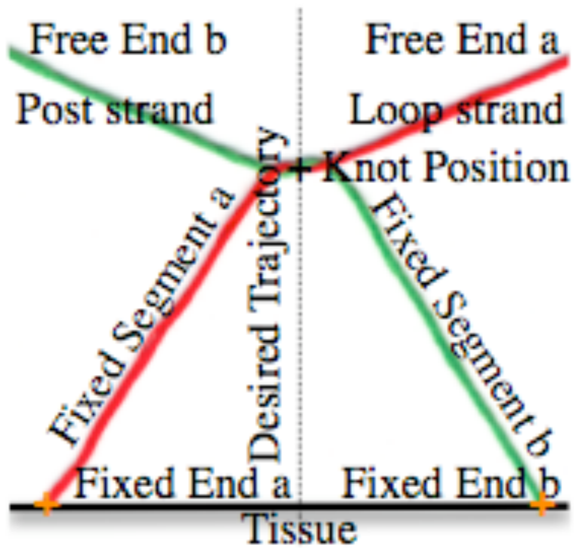
$$\vec{\delta}_p = \vec{x}_p - \vec{P}_t,$$

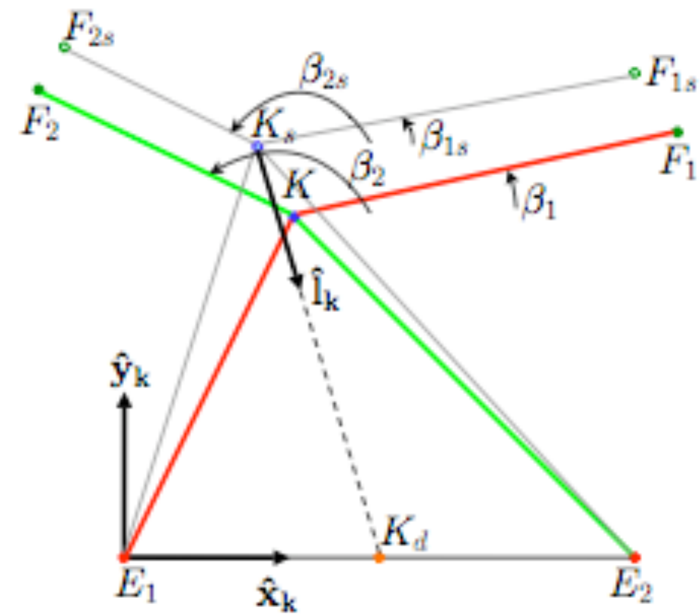
$$\|\vec{\delta}_p + \Delta\vec{x}_p\| \le \epsilon_1$$

Fig. 1. Geometric relation for (a) Mo to a direction

M. Li, et al, 2008

Knot Placement: Task Analysis





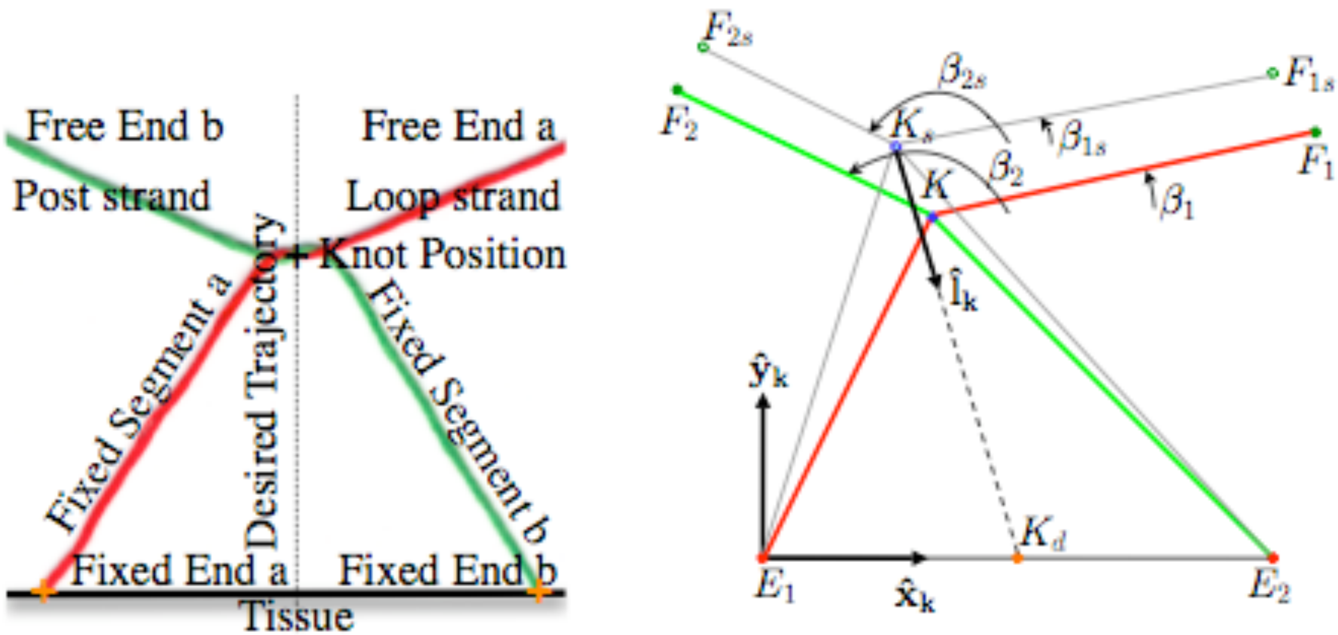
A. Kapoor et al, 2008

Desired behaviors
- move knot along desired direction
- maintain sliding condition (friction)

→

Instantaneous Kinematics relationship
- relates motion of free ends *and* knot
- free ends *and* of rate of change of angles β

Knot Placement: Task Analysis



A. Kapoor et al, 2008

Formula … control!

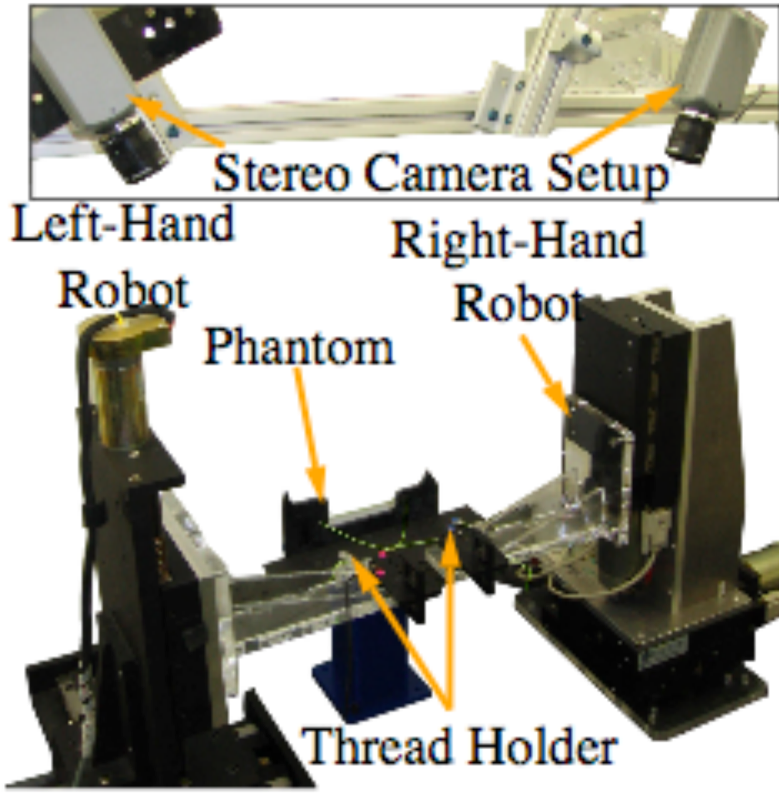
Using the i … to formulate c … **al input motion** of

Maintain sliding condition of the thread

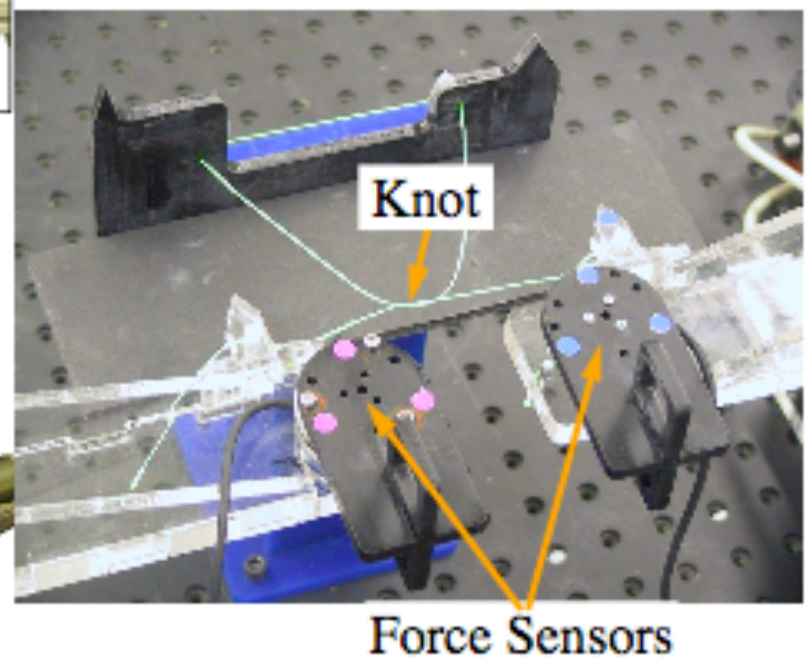
$$\beta_L \le J'_{\beta f} \cdot \Delta\mathbf{F} + \beta \le \beta_U;\; J'_{\beta f} \in \Re^{2\times 6}$$

Prior Work @ JHU: dual robot test bed

A Kapoor, R. Taylor 2008.



Admittance type robots consist of three translational stages per robot.



Use color markers and bright colored threads to simplify tracking of knot and robot end-effector.

Prior Work @ JHU: dual robot test bed

Assistance Modes

In Human Subject Experiment

- No Assistance
- Dual Hand Assistance
- Follower Assistance

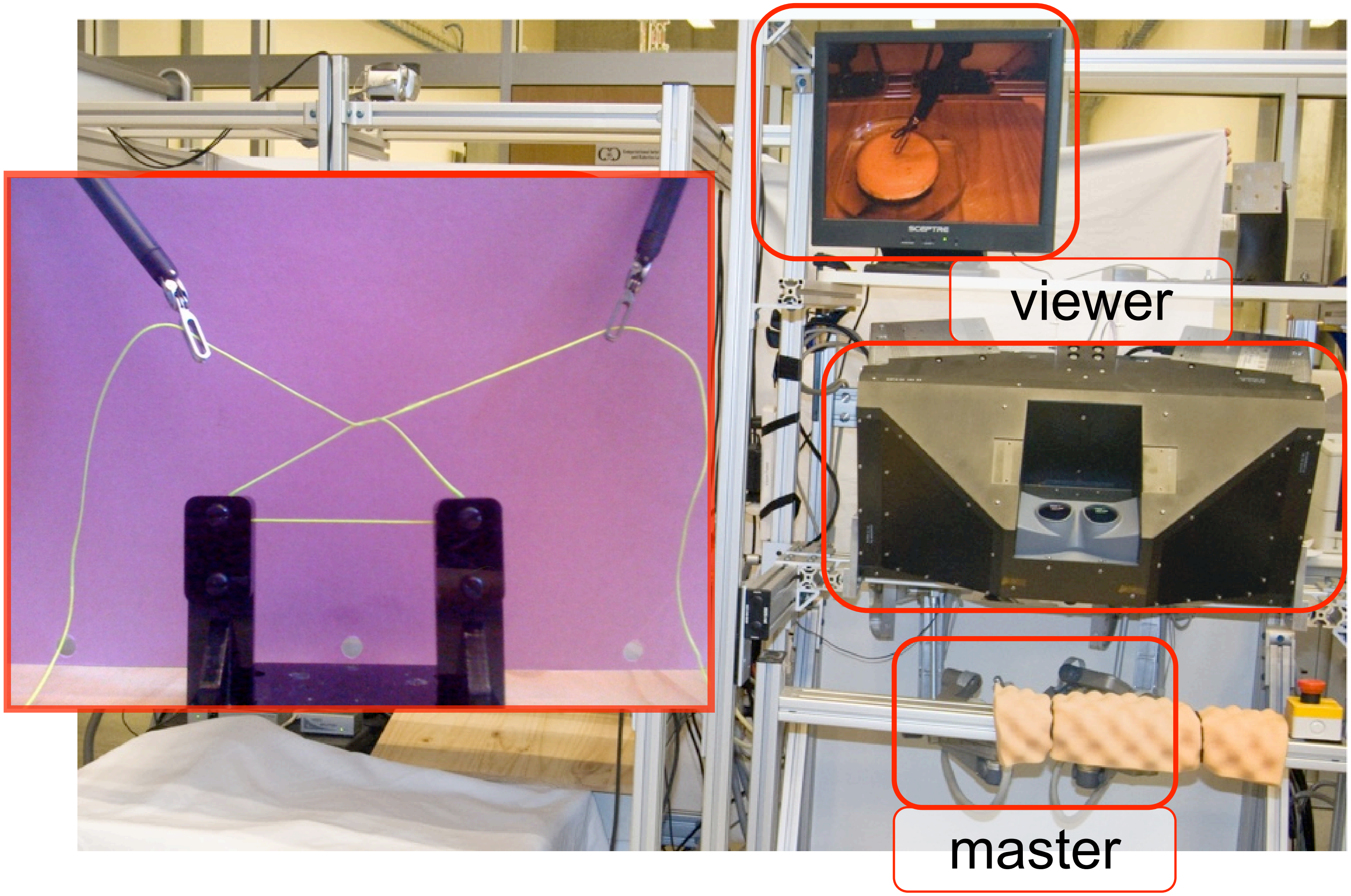
A Constrained Optimization Approach to Virtual Fixtures for Multi-Handed Tasks

Application Example: Knot Positioning

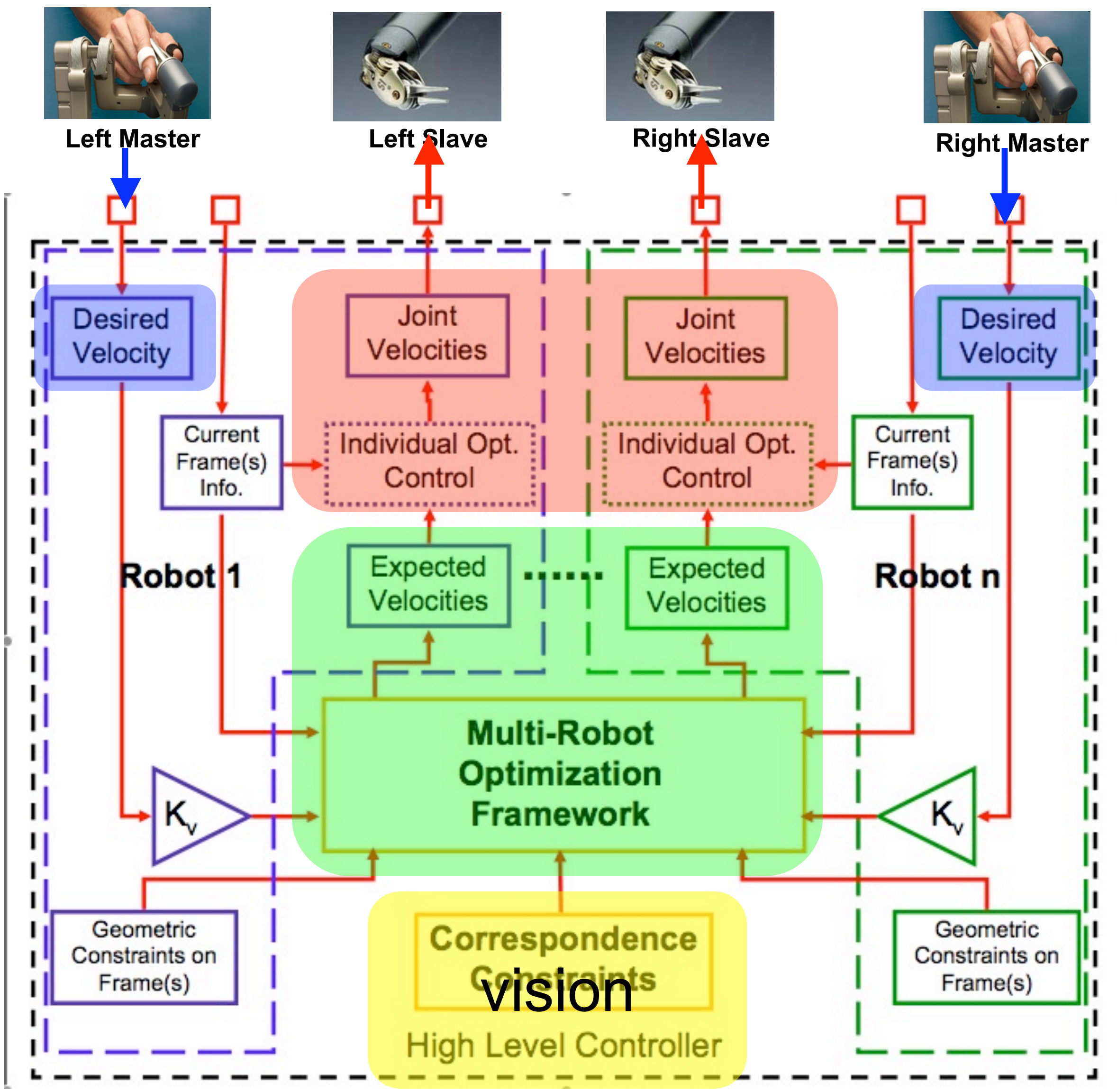
Ankur Kapoor and Russell H. Taylor

NSF Engineering Research Center for
Computer Integrated Surgical Systems and Technology
The Johns Hopkins University

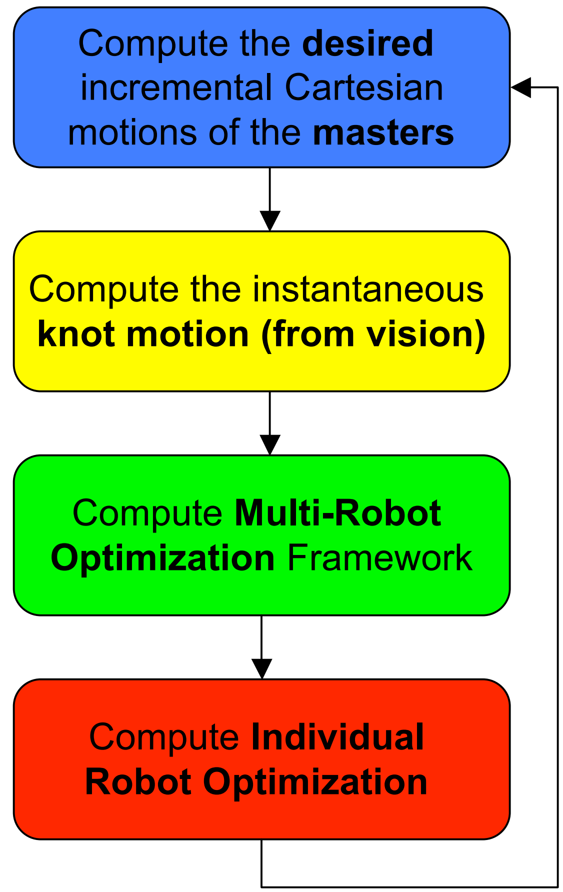
Now: The JHU ***custom*** da Vinci robotic system



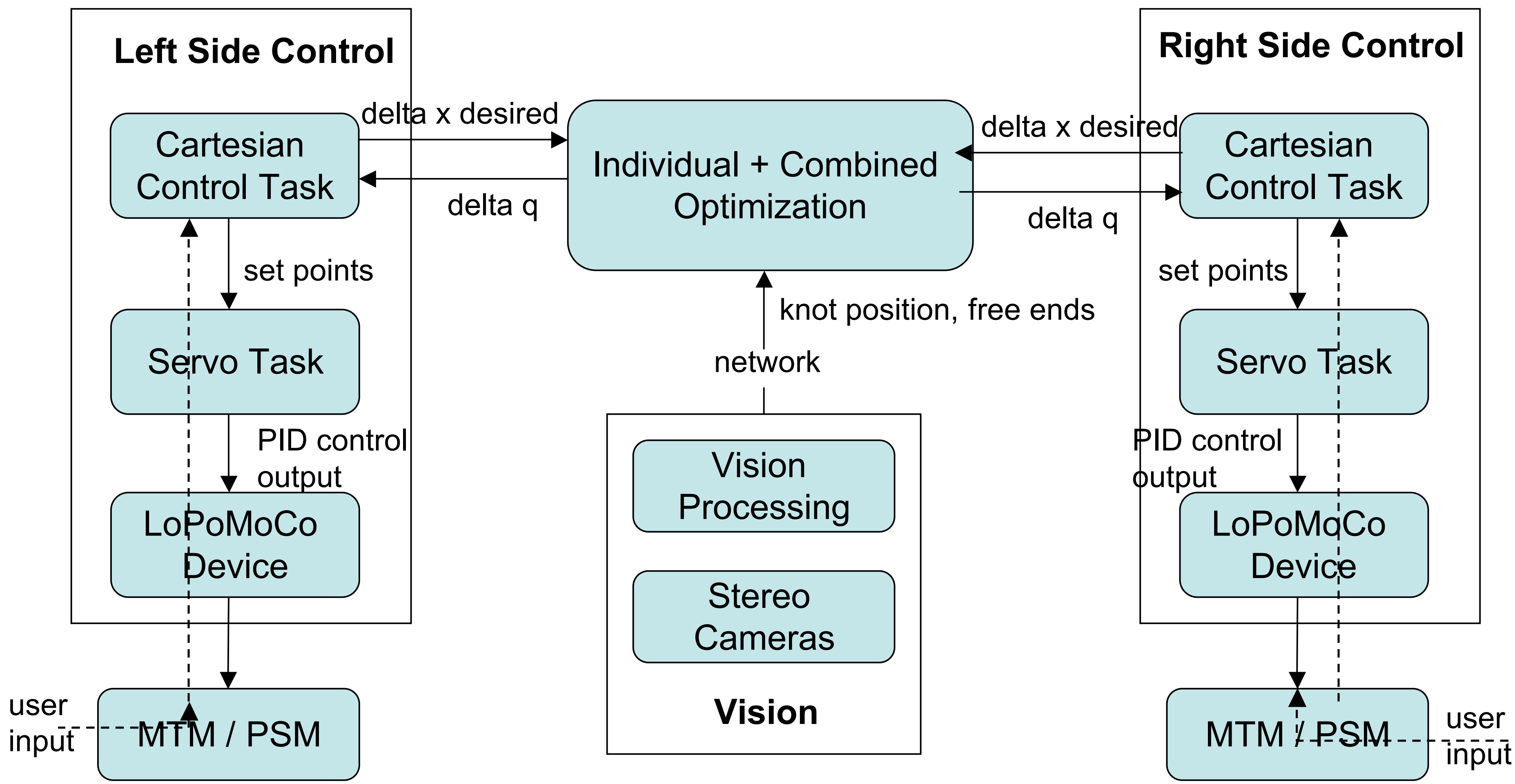
Constrained Optimization for Multiple Robots



Computation loop



Software Architecture



Contributions

- Implement system component on the da Vinci robot
  - Robot control, teleoperation, vision, optimization algorithms
  - * Impedance vs. Admittance control. Consider **Pseudo-admittance Bilateral Telemanipulation** approach by Abbott, IJRR 2007
- Perform complete experiments for knot placement
  - Human subjects experiments

now

- Other possible tasks (two-handed?)
  - Motion overlays: palpation/elastography
  - Integrating real-time sensor information
  - Dynamic or deformable constraints generation

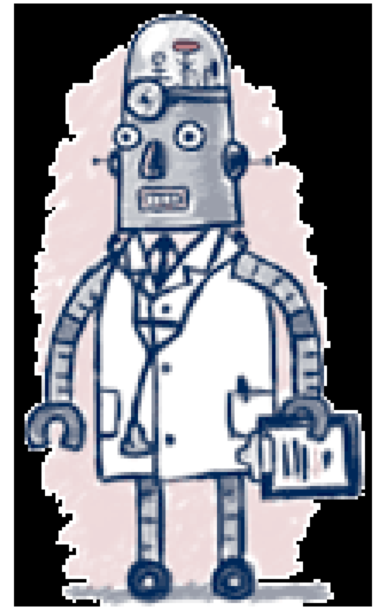
future


First 1885 Brewed
NATIONAL
BOHEMIAN
BEER
From the Land
of Pleasant Living
G. HEILEMAN BREWING CO., INC.



www.lcsr.jhu.edu

Questions ?



Coming soon...

Many thanks to:

Ankur Kapoor, Rajesh Kumar, Russell Taylor, Peter Kazanzides, Iulian Iorchita, Anton Deguet, Marcin Balicki and others …

Many thanks to:

Robotics Summer School

Etienne DOMBRE

Philippe POIGNET

And others…

Relevant Publications:

Kapoor and **Taylor**. A Constrained Optimization Approach to Virtual Fixtures for Multi-Handed Tasks. **ICRA 2008.**

Abbott and **Okamura**. Pseudo-admittance Bilateral Telemanipulation with Guidance Virtual Fixtures. **IJRR 2007.**

Funda and **Taylor**, et al. Constrained Cartesian Motion Control for Teleoperated Surgical Robots. IEEE Trans. Robotics and Automation, Vol 12, No. 3. **June 1996.**