Intuitive Human-in-the-Loop Control for Medical Cyber-Physical Systems

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Human-in-the-Loop Control Can Be Difficult

https://www.youtube.com/watch?v=bsK5C8m44JY

Non-holonomic systems can be hard to control.

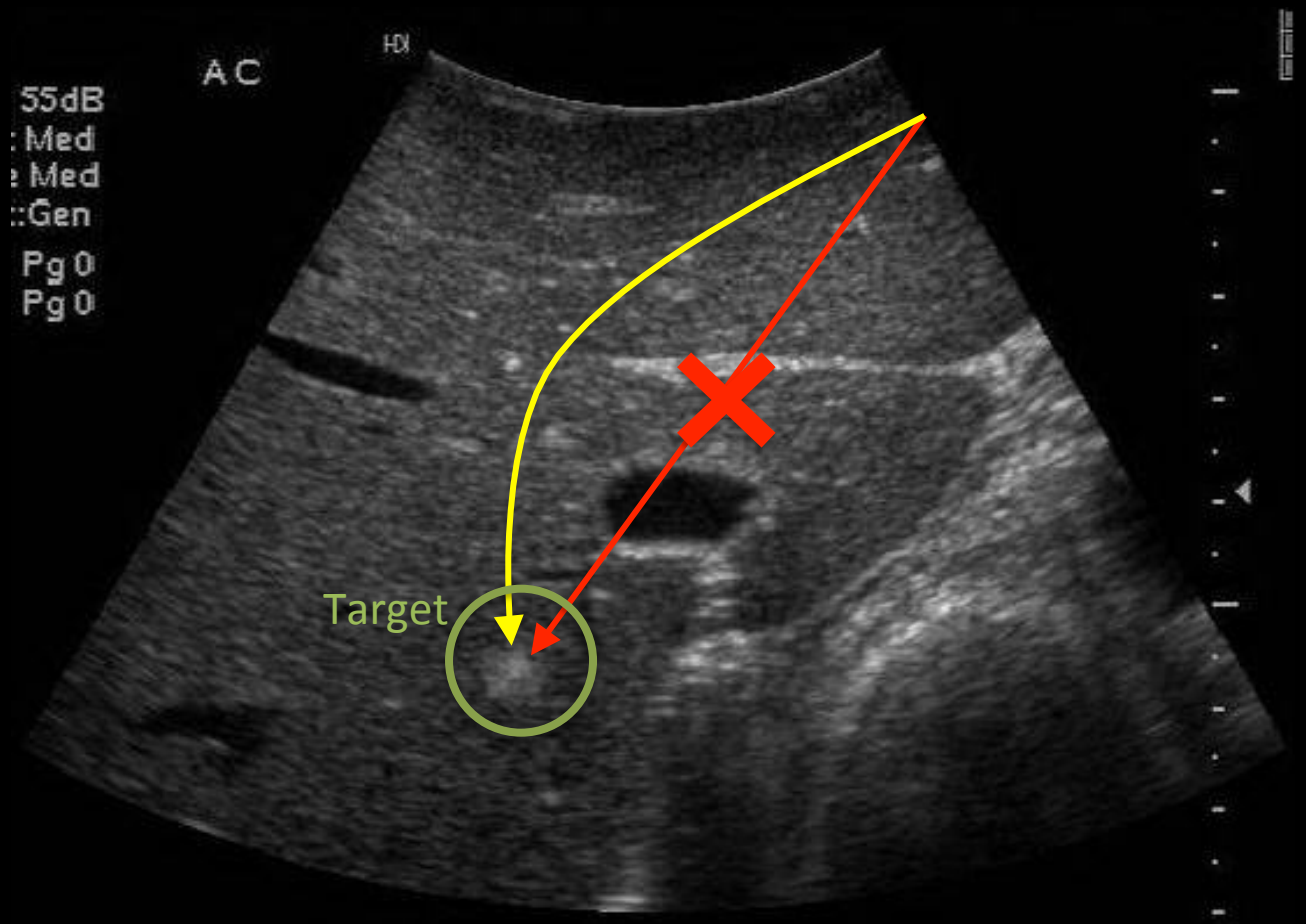
Motion constraints
Environmental constraints
Dynamic properties
Location and type of user input.

https://www.youtube.com/watch?v=XKRy9hQShwQ

Holonomic systems can be hard to control too.

Robotic Needle Steering: A Case Study

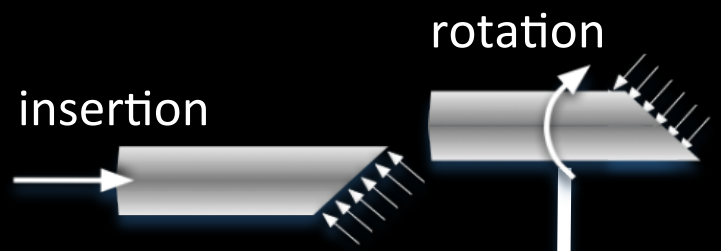
- **Motivation:** Steer needles around obstacles



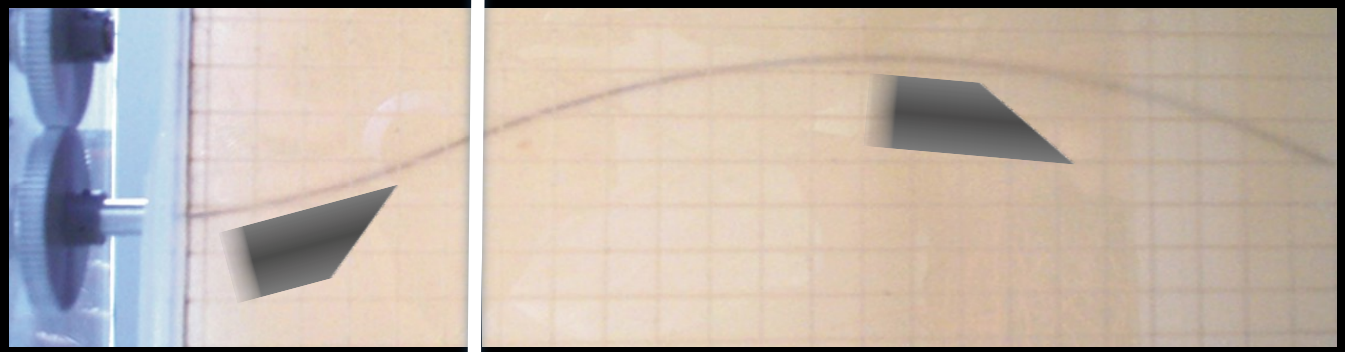
*Adapted from M. Choti – Surgical Congress '11

Robotic Needle Steering: A Case Study

- **Motivation:** Steer needles around obstacles
- **Mechanism:** insertion and rotation of flexible asymmetric-tip needles

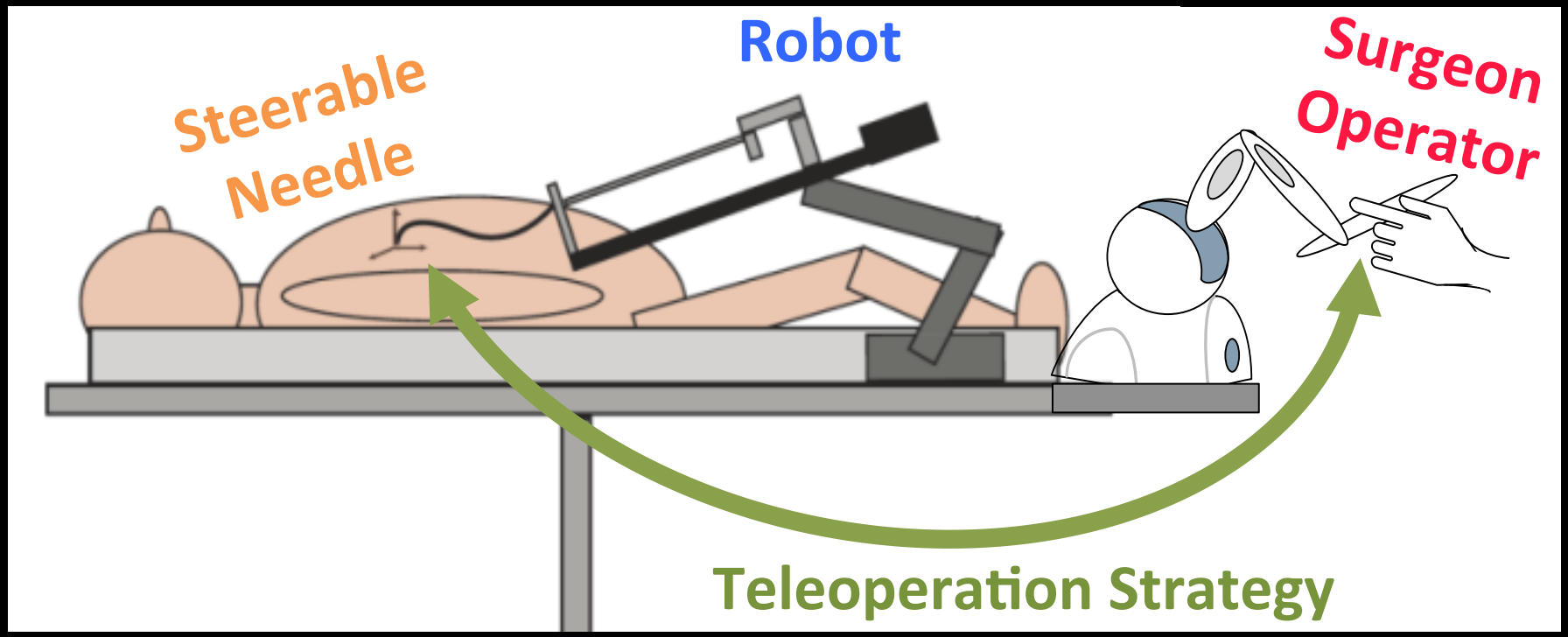


Nonholonomic kinematic model



Webster et al. IJRR 2006

Surgeon-in-the-Loop Control



Joint Control: user controls insertion and rotation

Cartesian Control: user controls needle tip position

Joint Space Teleoperation

User controls insertion and rotation

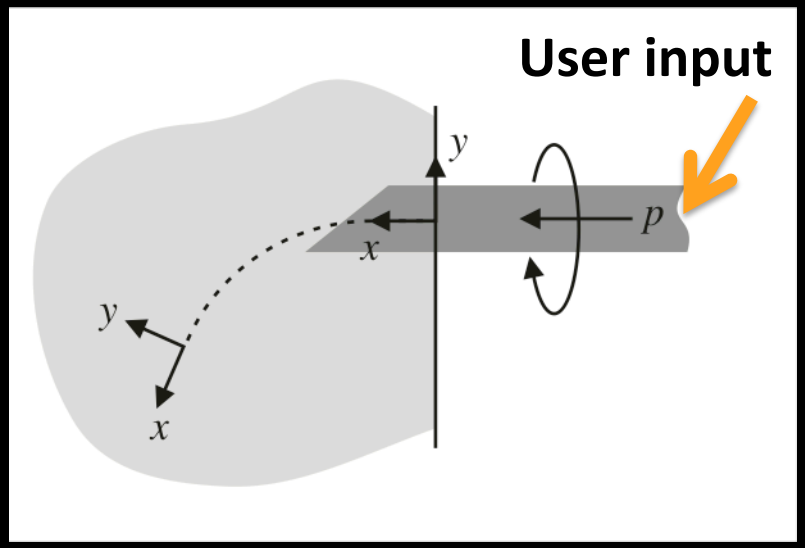


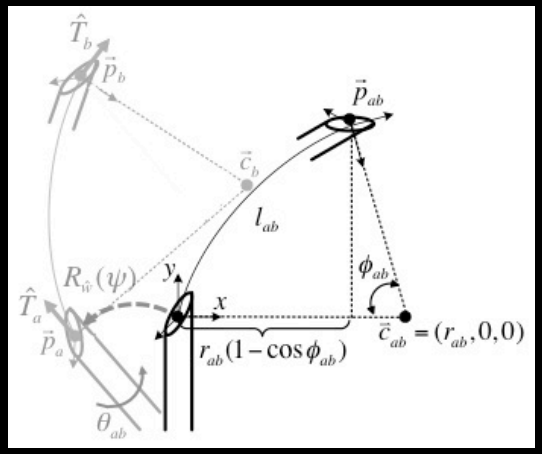
Image: Romano 2007

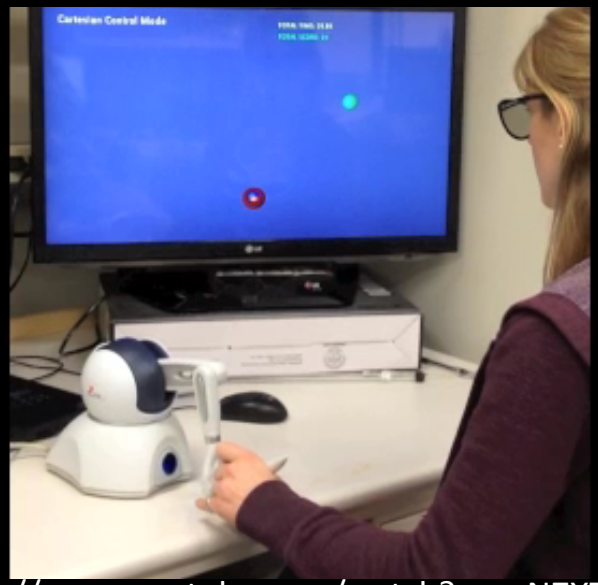
Mental model of nonholonomic kinematics

J. Romano, R. Webster, and A. Okamura, "Teleoperation of steerable needles," in Robotics and Automation, 2007 IEEE International Conference on. IEEE, 2007, pp. 934–939.

Cartesian Space Teleoperation

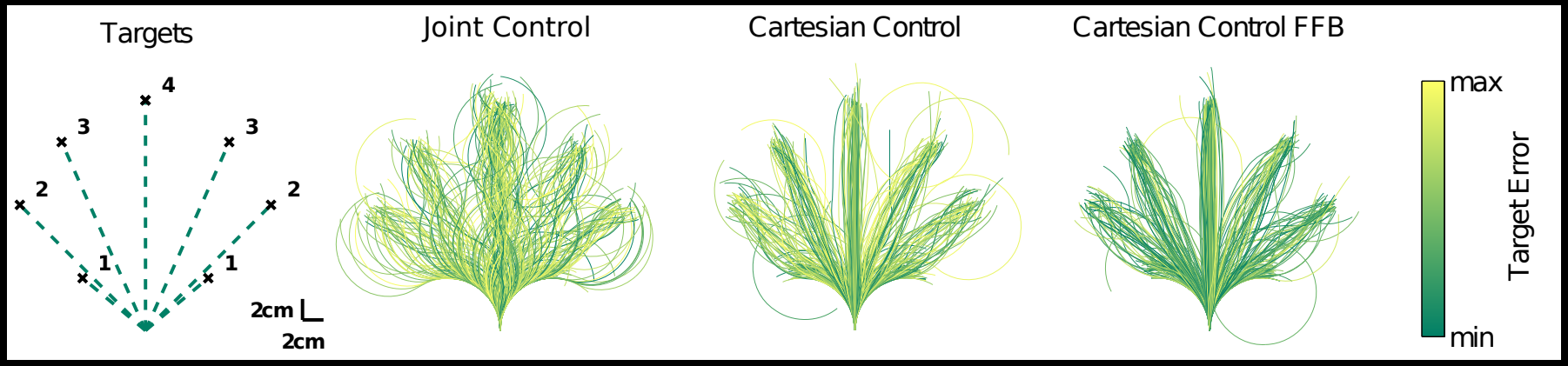
User controls needle tip directly.





https://www.youtube.com/watch?v=nxN7XT9j5mI

Reach targets faster … **.. with straighter paths.** **Force feedback helps too.**



Majewicz and Okamura, WHC 2013

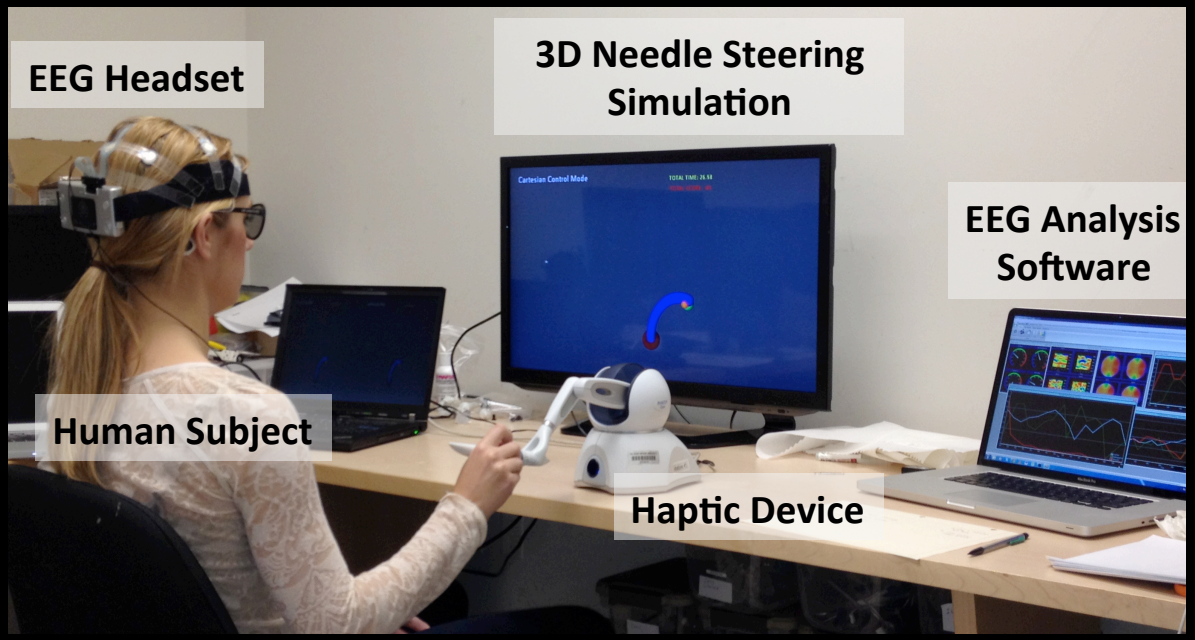
Future Research Direction

For an ***arbitrary*** dynamic system, can we identify the ***most intuitive*** way to control it?

Leading to improved user ***performance*** and ***confidence***

Intuitive Control of Arbitrary Systems

- **AIM 1: What is 'intuitive?'**
  - Quantitative performance metrics
    - Targeting error, time-to-target etc.
  - EEG, heart rate, skin galvanic response.



Preliminary EEG experiments with 3D Needle Steering and the B-Alert Wireless EEG from Advanced Monitoring, Inc.

Intuitive Control of Arbitrary Systems

- **AIM 1: What is 'intuitive?'**
  - Quantitative performance metrics
    - Targeting error, time-to-target etc.
  - EEG, heart rate, skin galvanic response
- **AIM 2: Modeling Man and Machine**
  - Develop models of 'intuitiveness' taking into account robot kinematic and dynamic properties, location and type of user input, user kinematics and dynamics, etc.
- **AIM 3: Optimal Control**
  - Identify optimal control policies for arbitrary systems and validate with intuitiveness measures.

Broader Impacts:

How could quantitative knowledge of intuitive control change how we design these systems?

http://www.uww.edu/news/photos/essay-mens-wheelchair-basketball-2012

Barrx Ablation Systems - Covidian

ATLS Surgical Training Simulator