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

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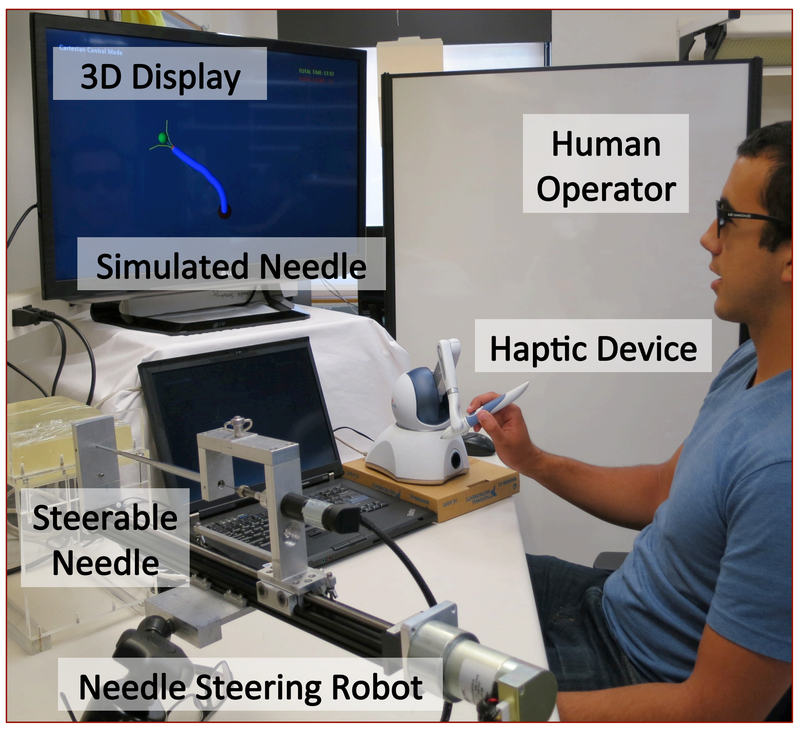
Intuitive Human-in-the-Loop Control

Effective and intuitive control interfaces are important for clinical adoption of medical CPS.

Improved performance and user confidence should be considered.



Medical CPS for Steerable Needle Insertion

Robotic Needle Steering: A Case Study

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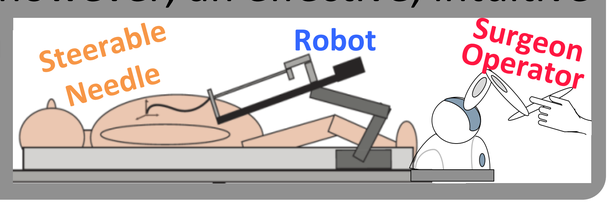
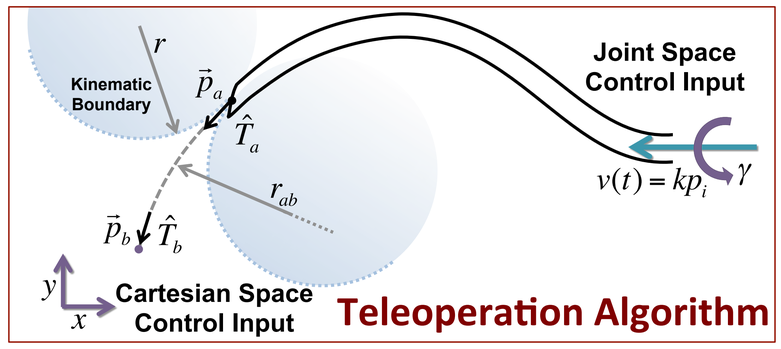
Steerable needles are able to reach targets while avoiding obstacles in tissue via curved paths. Needles steer due asymmetric tip forces during insertion and rotation.


Webster et al. IJRR 2006

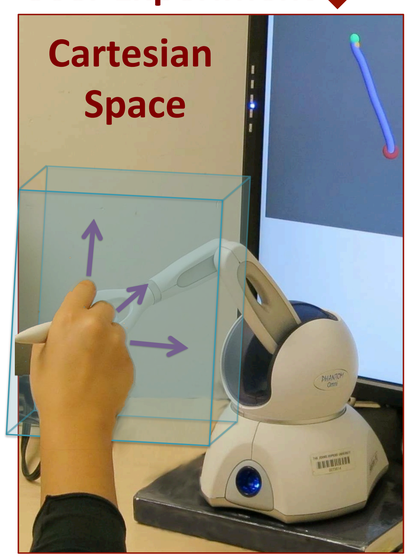
Teleoperation of steerable needles allows the surgeon to stay in the needle control loop; however, an effective, intuitive teleoperation algorithm is important.

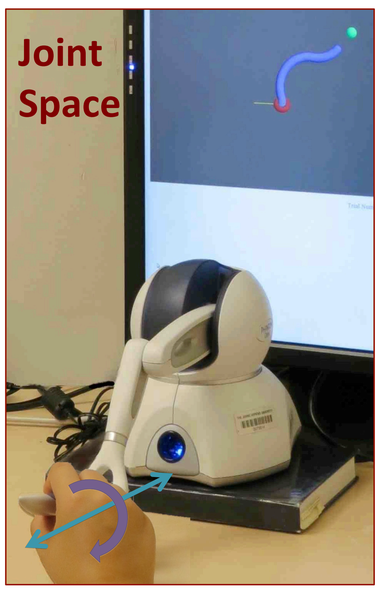




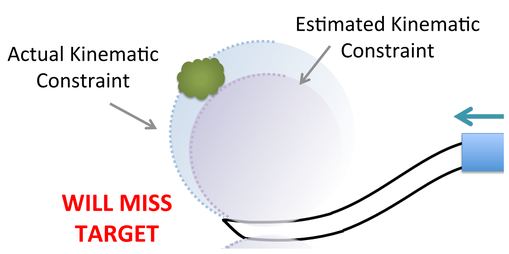
Teleoperation Algorithm

User Experiment

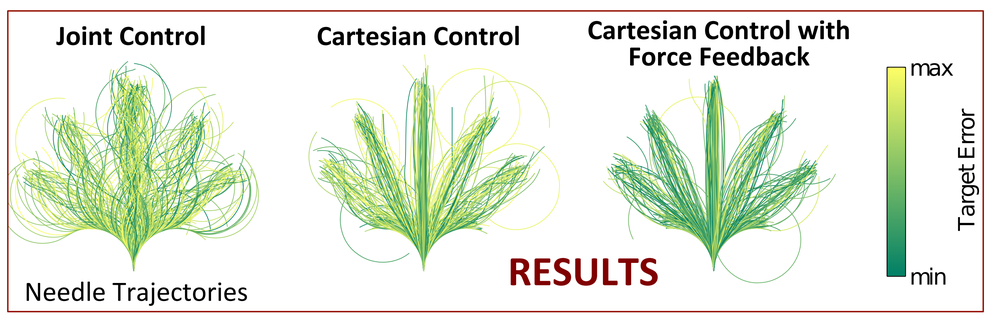




Objective: Evaluate user performance for steering needles in joint space (e.g. insertion and spin inputs) **and Cartesian space** (e.g. desired needle tip position input**).**

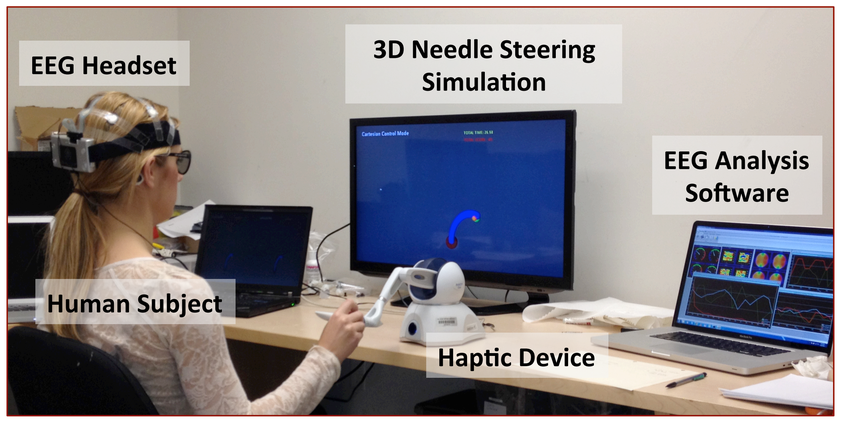


Joint space control can be difficult due to errors in estimating needle kinematics.

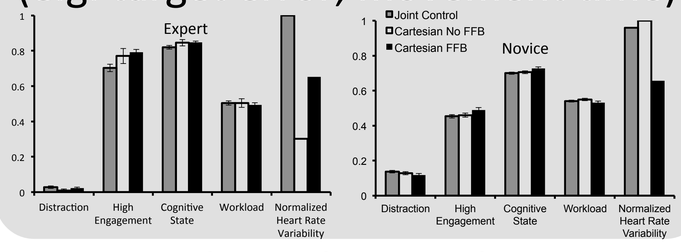


Future Research Direction: Intuitive Control of Arbitrary Dynamic Systems

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



Aim 1: What is 'intuitive?'
Benchmark EEG, heart rate, and skin galvanic response to measure 'intuitiveness' in comparison with quantitative performance metrics (e.g. target error, movement time).



Aim 2: Modeling Man and Machine
Develop models relating robot kinematics and dynamics, user inputs, and haptic feedback through extensive human subject experiments.

Aim 3: Optimal Control Using the models developed, formulate an optimization problem to solve for optimal human control policies for arbitrary dynamic systems. Validate results with 'intuitiveness' measures.

Preliminary EEG experiments with 3D Needle Steering using the B-Alert Wireless EEG System (Advanced Brain Monitoring, Inc.)

Can this lead to better design of human-in-the-loop CPS for surgery, rehabilitation, or transportation?

RELEVANT WORKS
[1] **A. Majewicz** and A. M. Okamura, "Cartesian and joint space teleoperation for nonholonomic steerable needles," in IEEE World Haptics Conf, Apr. 2013, pp. 395–400.
[2] V. Poorten, et al. "Powered wheelchair navigation assistance through kinematically correct environmental haptic feedback." in IEEE ICRA, 2012, pp. 3706-3712
[3] R. J. Webster, *et al.*, "Nonholonomic Modeling of Needle Steering," *The International Journal of Robotics Research*, vol. 25, no. 5-6, pp. 509–525, 2006.
[4] J. Romano, *et al.*,"Teleoperation of steerable needles," in *IEEE International Conference on Robotics and Automation*. IEEE, 2007, pp. 934–939.
[5] **A. Majewicz** and A.M. Okamrua, "Teleoperation of Robotically-Steered Needles". In prep.
[6] Gevins, et al. "Effects of prolonged mental work on functional brain topography." Clin EEG Neurosci, 76.4 (1990): 339-350.