Robot-assisted
Rehabilitation, Surgery and Therapy

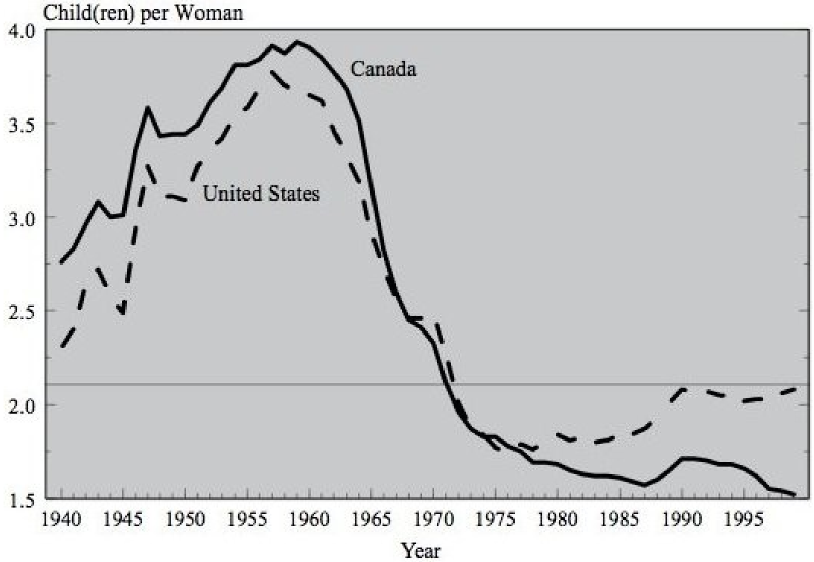
Mahdi Tavakoli, PhD, PEng
Associate Professor, University of Alberta
Edmonton, Alberta, Canada

UNIVERSITY OF ALBERTA

ELECTRICAL AND COMPUTER ENGINEERING

Canada’s changing demographics

- Fertility rose sharply in both Canada and the US in the immediate post-war period.
- Currently, seniors make up about 12% of Canada’s population.
- In 2036, 25% of the Canadian population will be 65 or over.



Source: Statistics Canada

Total Fertility Rate

Result: Increased load on the healthcare system

Enabling technologies

Objective:

- Develop new technologies that *reduce the burden on the healthcare system* by making interventions
  - **available to remote areas**
  - more efficient (i.e., better accuracy and reliability)
  - less traumatic (i.e., faster recovery and shorter hospital stay)

Case studies:

- **Post-stroke rehabilitation**
- Beating-heart surgery
- Prostate brachytherapy

Rehabilitation therapy paradigms

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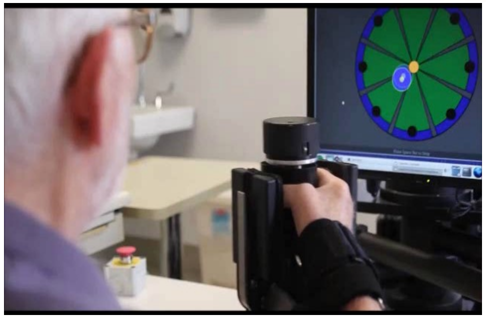

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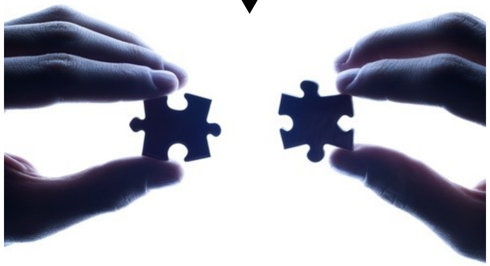
Therapist's Skills

Capabilities of Haptic Systems

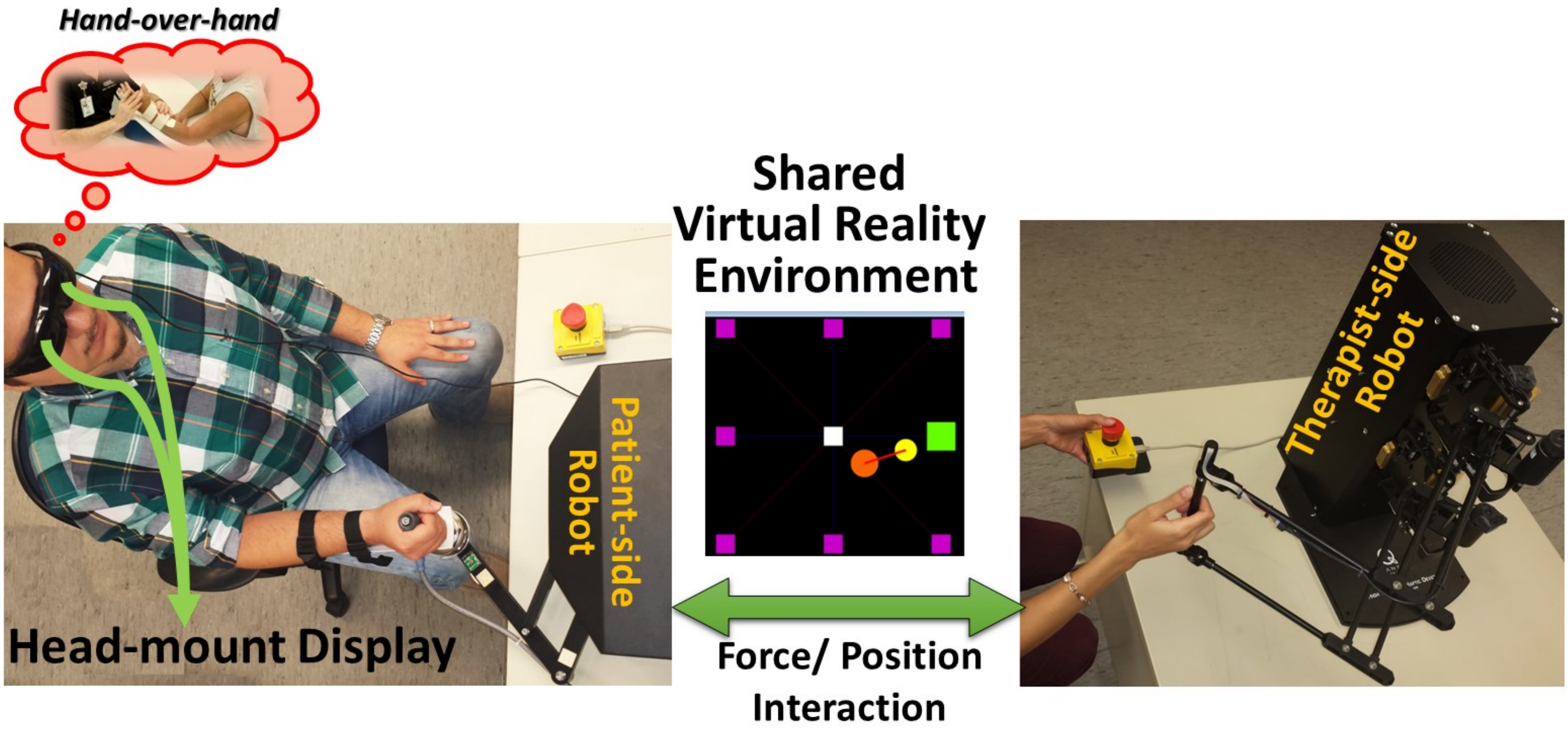
Fuse



Therapist-in-the-loop Telerobotic Rehabilitation

Assistive/resistive tele-rehabilitation

The feeling of *hand-over-hand therapy* is created if the patient and the therapist are at the two ends of a haptic teleoperation system.

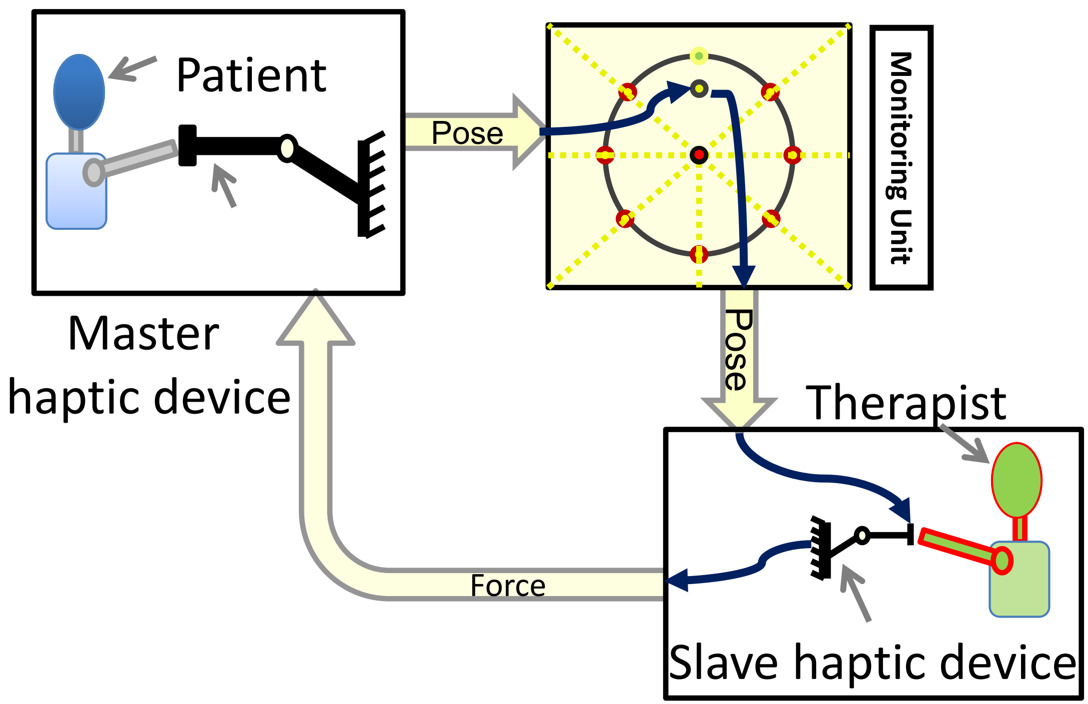


Assistive/resistive tele-rehabilitation

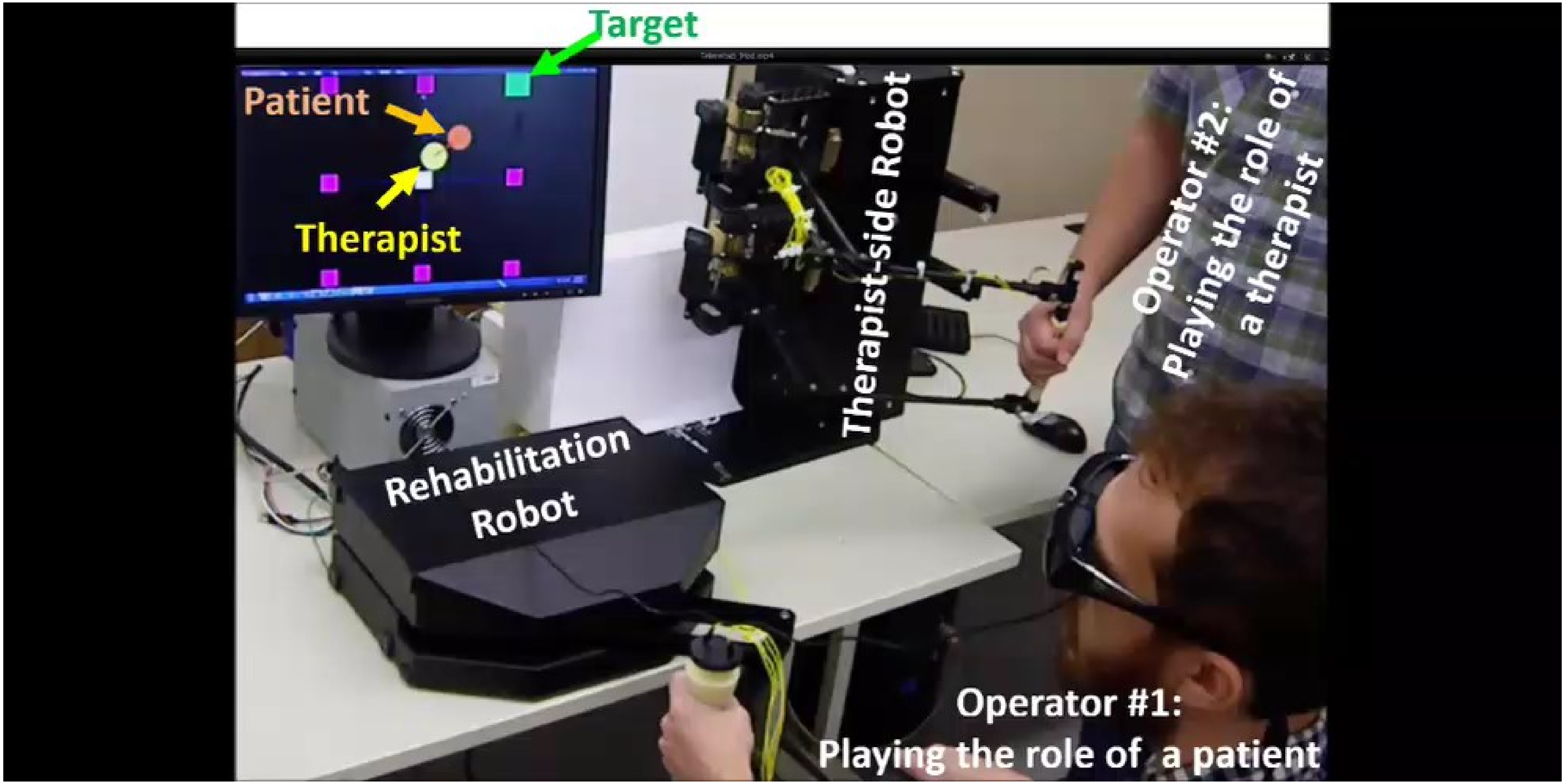
Advantages:

- Remote therapy services enabled
- Therapist-in-the-loop architecture
- Possible amplification of the therapist's efforts

Control architecture:

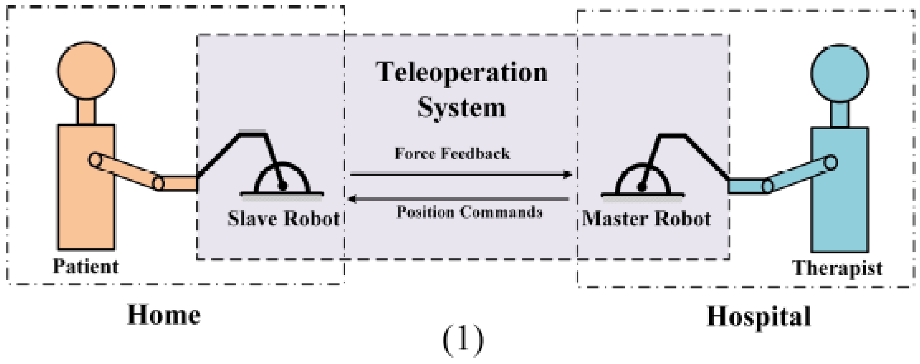


Assistive/resistive tele-rehabilitation

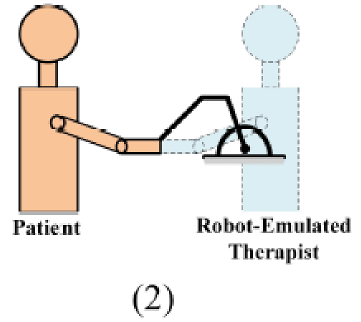


Functional task based tele-rehabilitation

Learn phase: Therapist-in-loop (TIL)



Replay phase: Therapist-out-of-loop (TOOL)



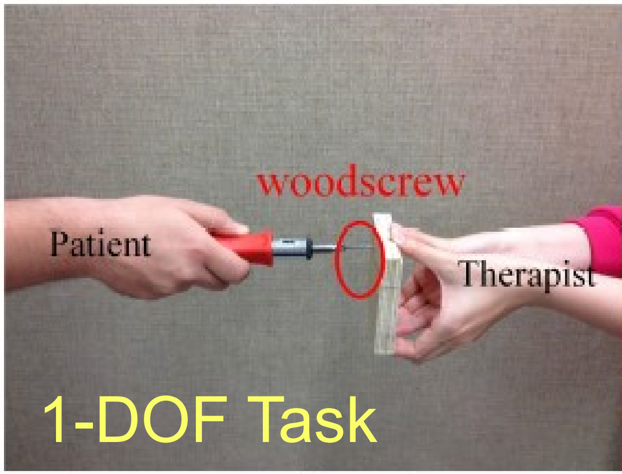
Two phases:

1. Therapist-in-loop (TIL) phase: The therapist interacts via the haptic teleoperation loop with the patient to perform one or more repetitions of the cooperative therapy task.
2. Therapist-out-of-loop (TOOL) phase: The therapist's cooperative role in completing the task is played out by the patient-side robot in future repetitions.

- Therapist's arm impedance measurement; learning and imitating therapist's behavior
- Completion of many collaborative therapy tasks; no need for robot re-programming
- Therapist's time sharing among several patients

Learn-and-replay tele-rehabilitation

Direct interaction | Patient-side robot | Therapist-side robot



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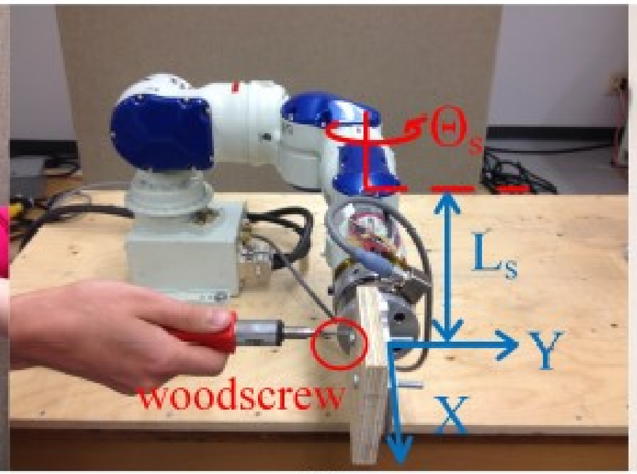

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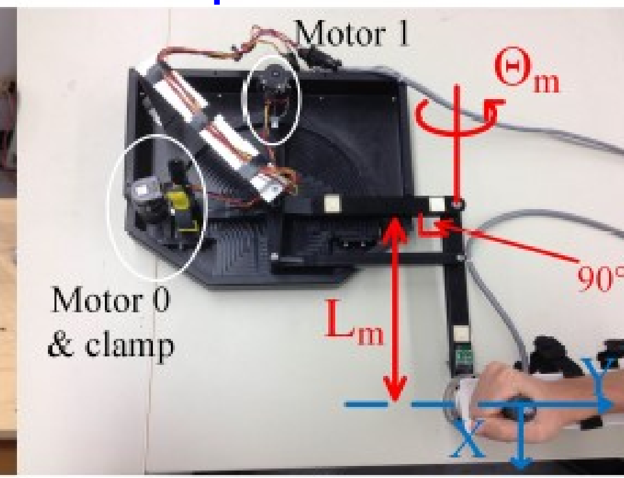

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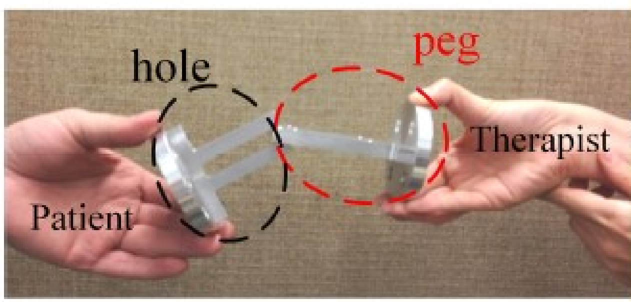
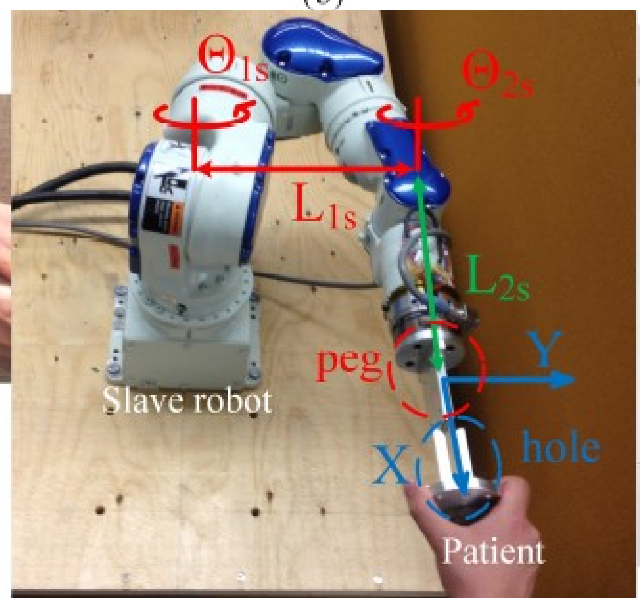


(a)

2-DOF Task



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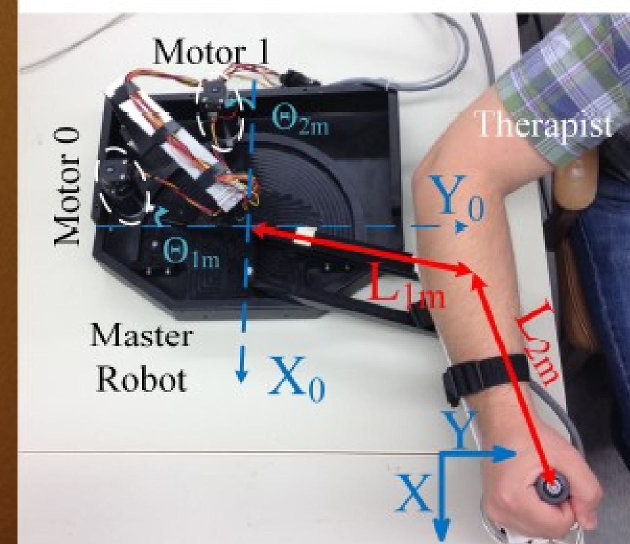

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Learn-and-replay tele-rehabilitation

Enabling technologies

Objective:

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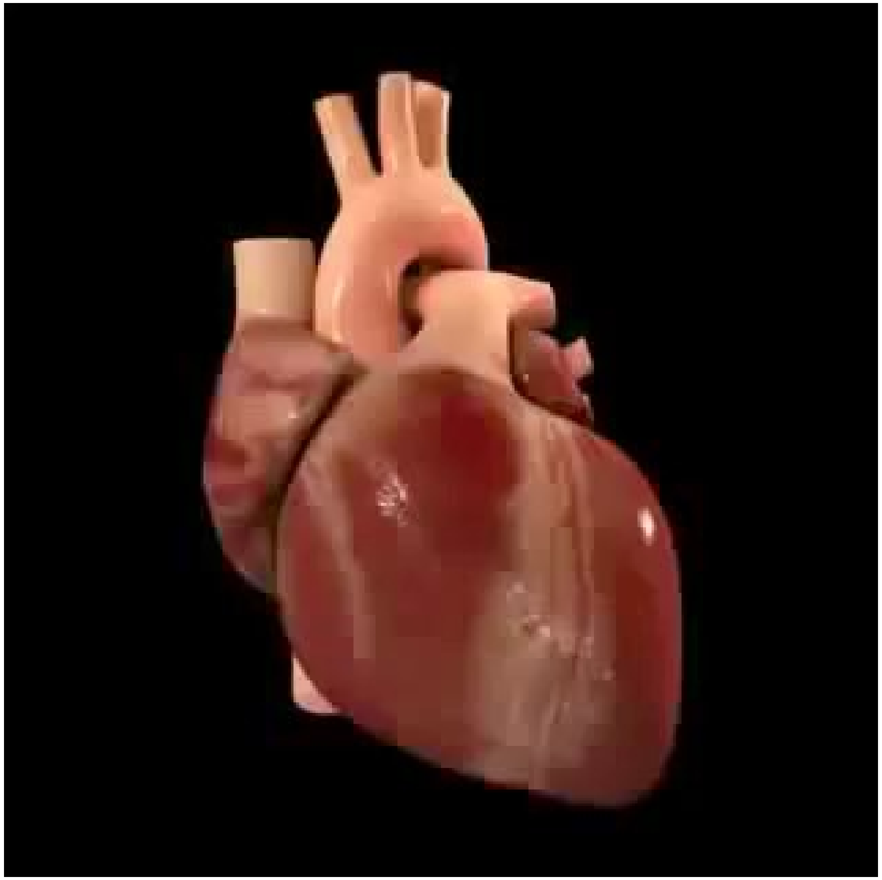
Case studies:

- Post-stroke rehabilitation
- **Beating-heart surgery**
- Prostate brachytherapy

Beating-heart surgery

http://www.youtube.com/watch?v=0NmWOHuy-o8



Is it possible to operate on the heart without stopping it?

- Extracardiac procedures
  - Pericardiocentesis
- Intracardiac procedures
  - Mitral valve repair

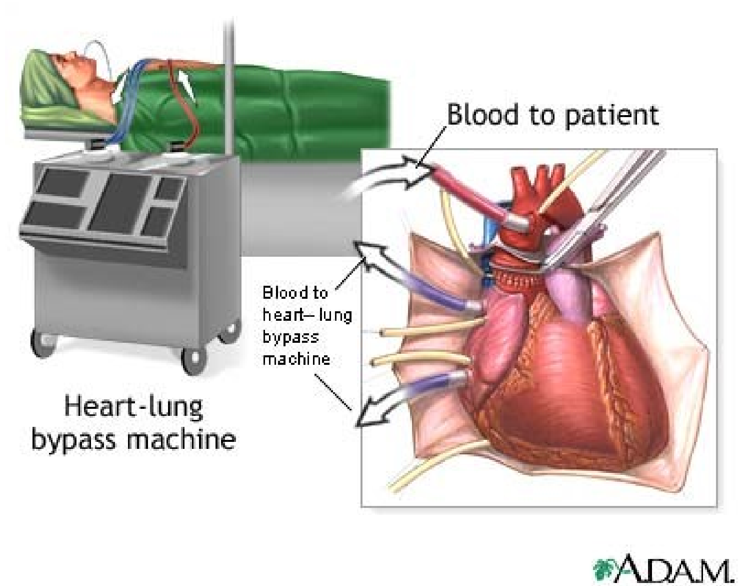
Heart motions are very hard to follow:

- Max velocity 210 mm/s, acceleration 3800 mm/s^2
- Quickly recoils 10-15 mm after contraction

Current surgical practice

Heart-lung Machine

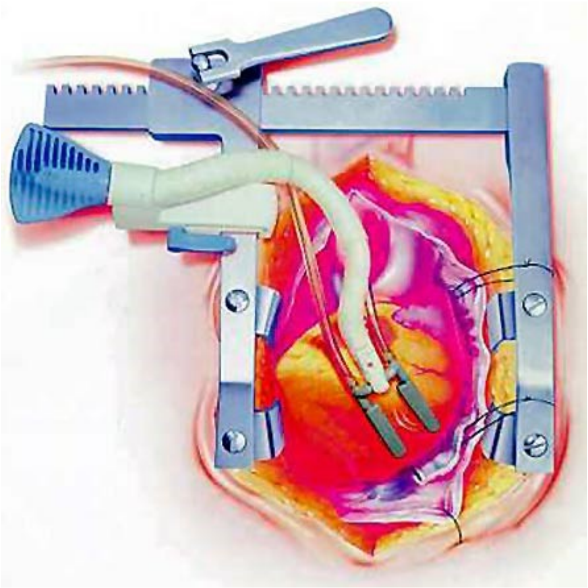
- Increased risk of stroke
- Possible long-term cognitive loss



From health.allrefer.com

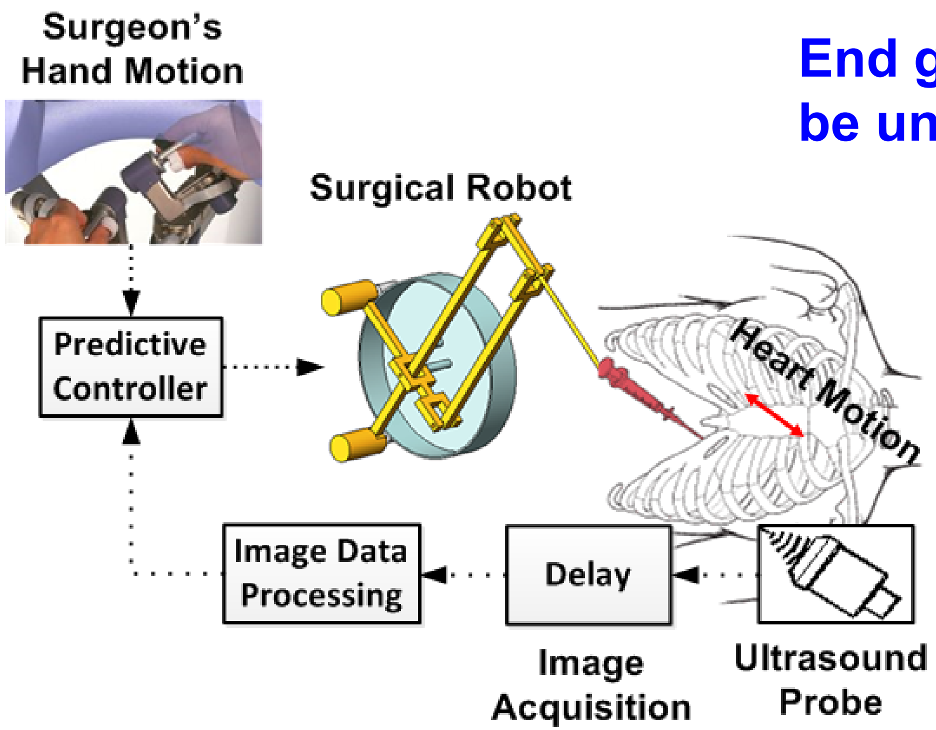
Heart Stabilizer

- Cannot completely cancel heart motion

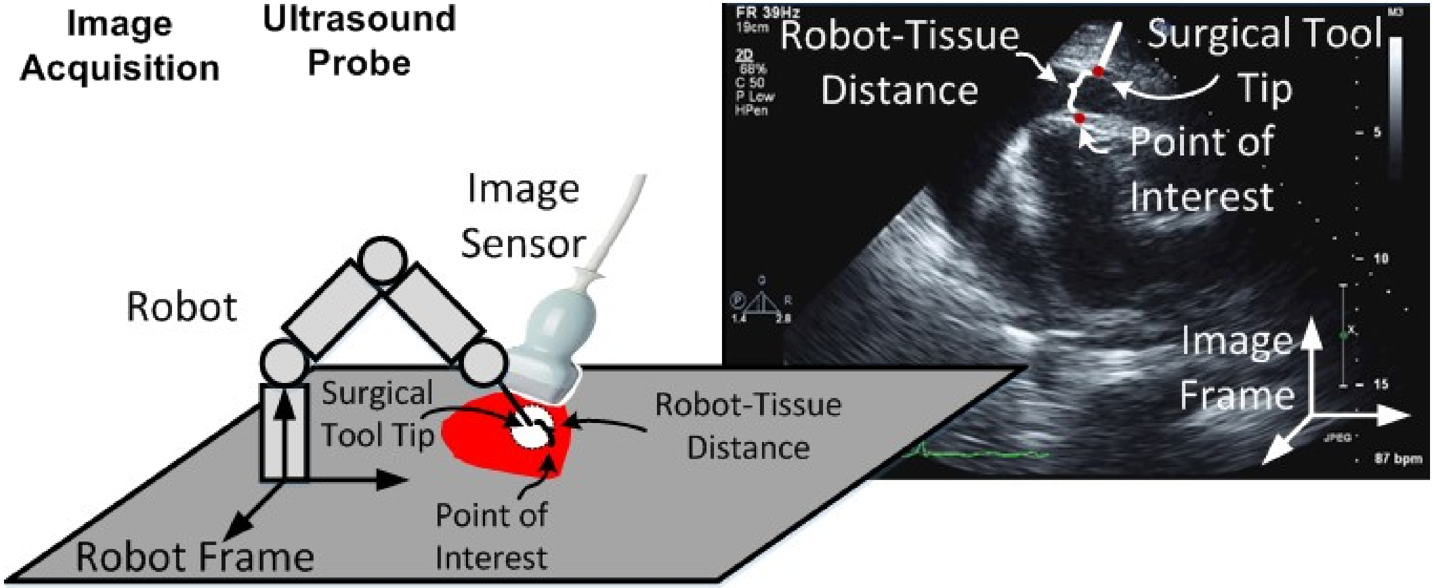


From www.ctsnet.org

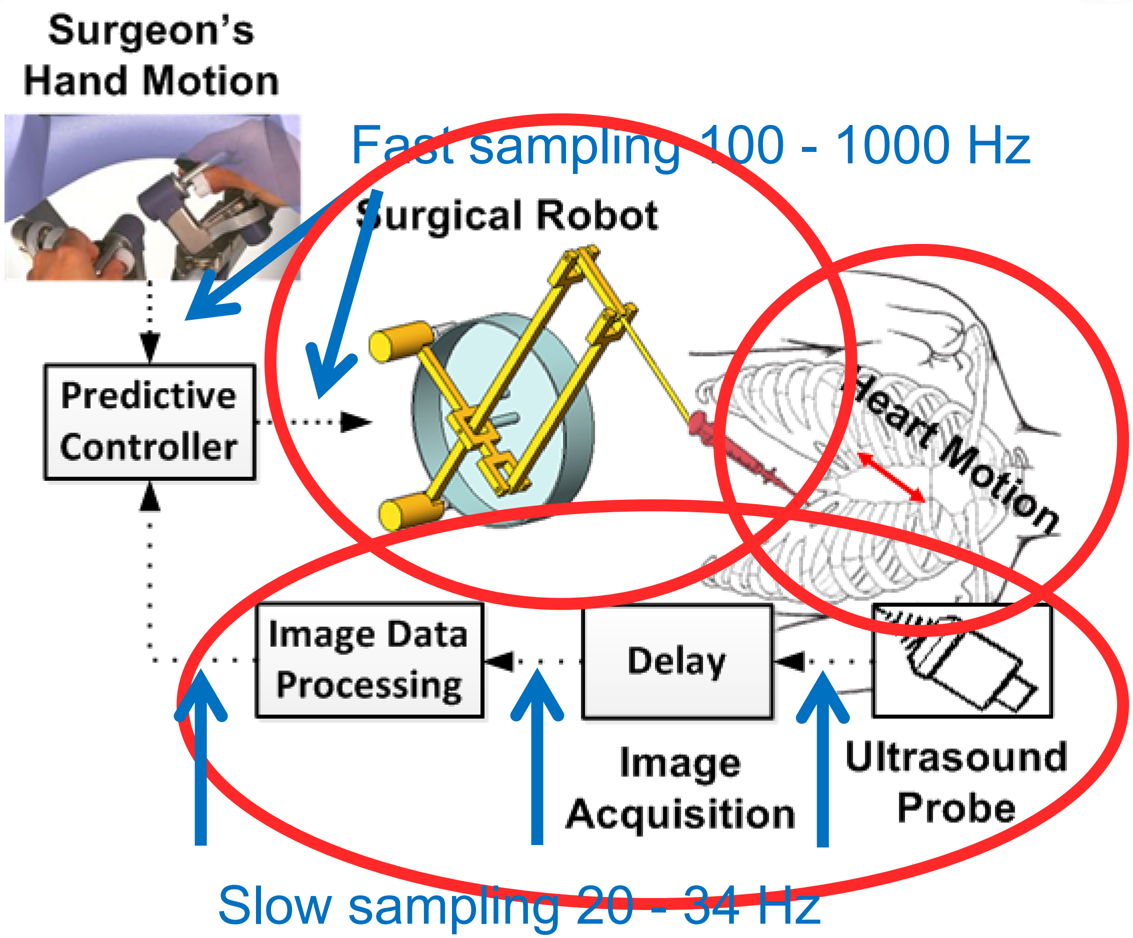
Robotic beating-heart surgery system



End goal: Robot-heart *distance* should be under the Surgeon's command

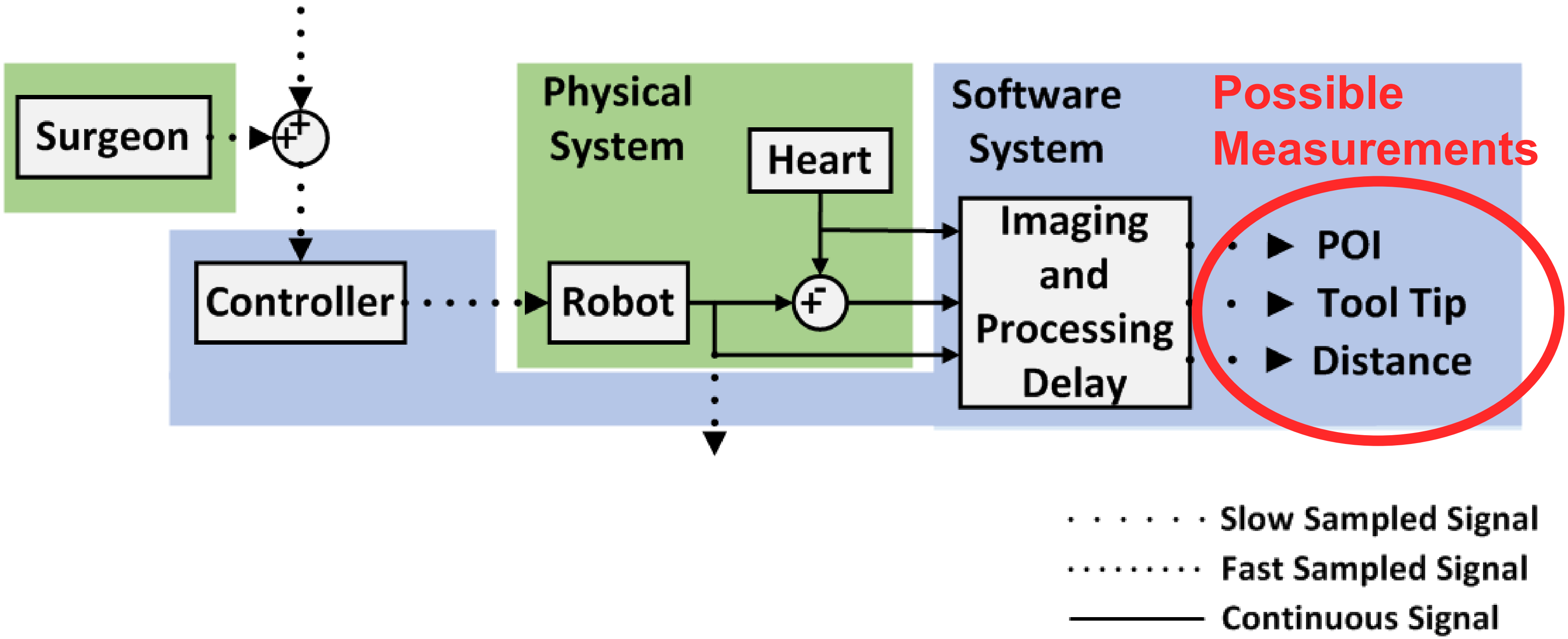


Challenges



- Delayed measurements
- Multi-rate system
- Unknown heart motion
- Precise tracking (< 2 mm error) required

Block diagram of the system

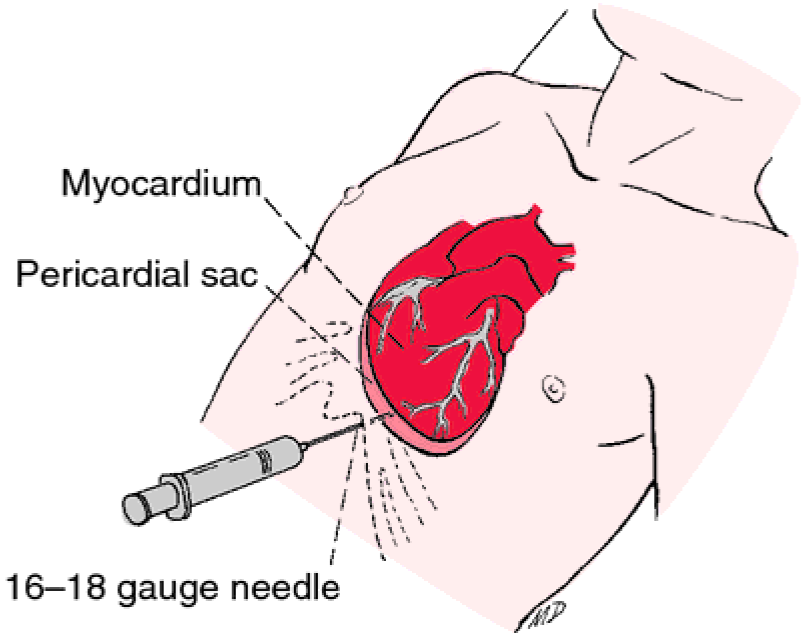


- Physical System cannot change
  - Same configuration regardless of the controller
- Software System changes depending on the controller

End goal: Robot-heart distance to follow Surgeon's motion

Pericardiocentesis

- Build up of fluid in the pericardial sac surrounding the heart
- Needle is inserted under ultrasound guidance or blind
- Guide wire is inserted through needle
- Drainage tube inserted around guide wire
- Coronary vessels cannot be punctured



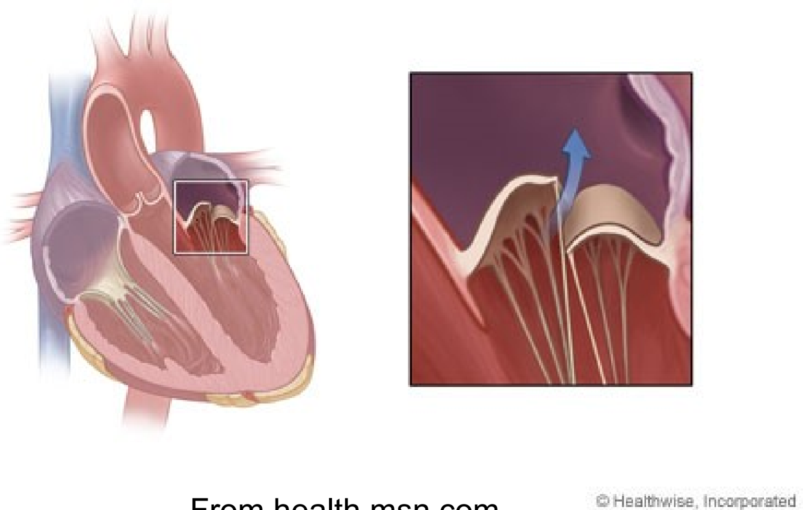
Predictive control of robot for pericardiocentesis

Robot Control in Beating Heart Surgery: Compensation for Physiological Motion and Delayed, Slowly Sampled Sensor Data

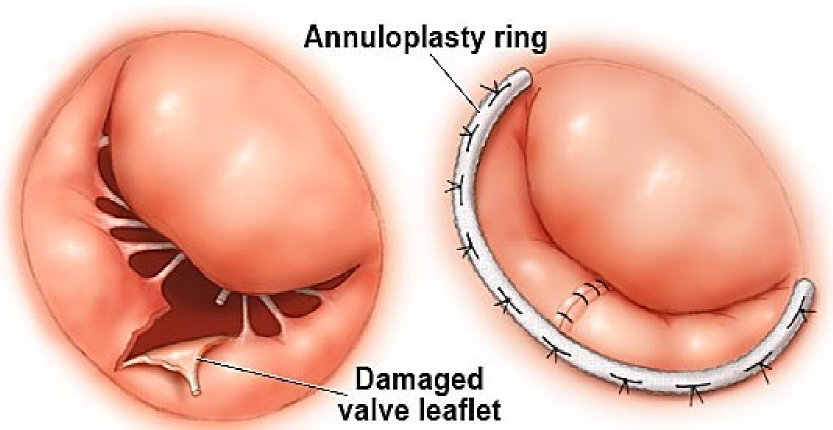
Meaghan Bowthorpe and Mahdi Tavakoli
University of Alberta, Edmonton, Canada

Annuloplasty for mitral valve repair

- Mitral valve does not close
- Regurgitation
- Reshape mitral valve with annuloplasty ring



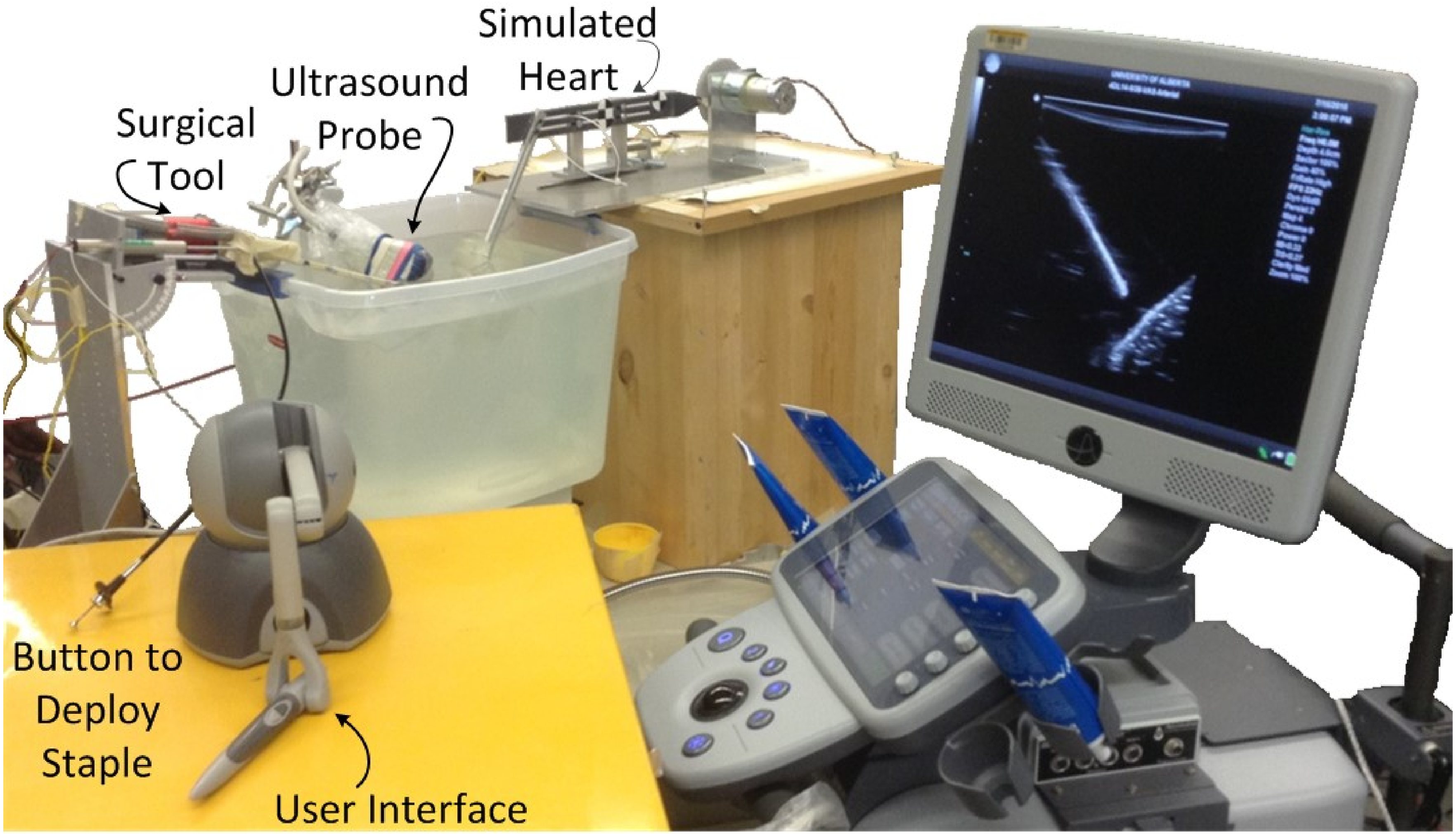
From health.msn.com



From www.heartl-valve-surgery.com

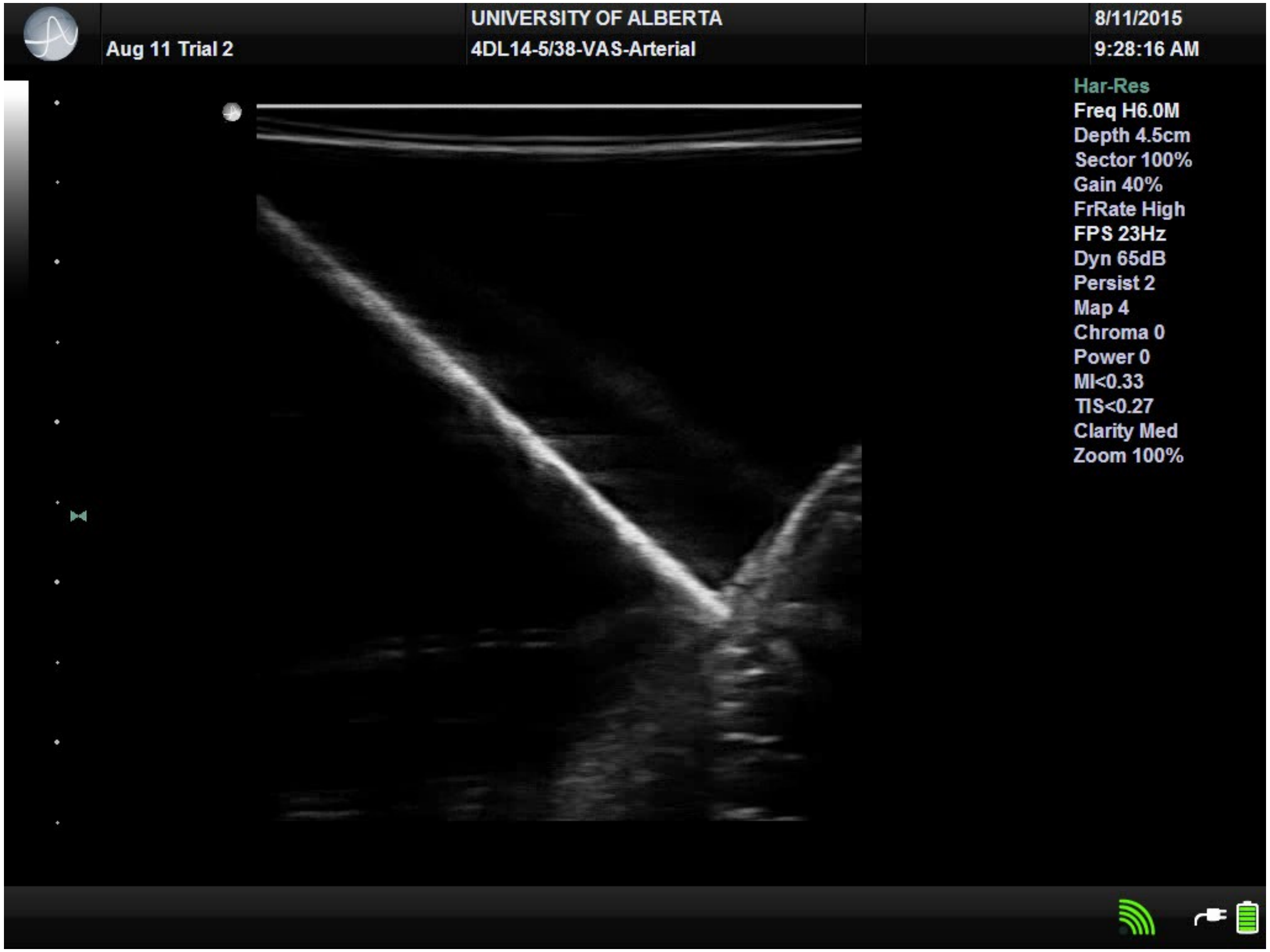
Thus, let us consider a stapling task.

Ultrasound-guided staple-insertion task

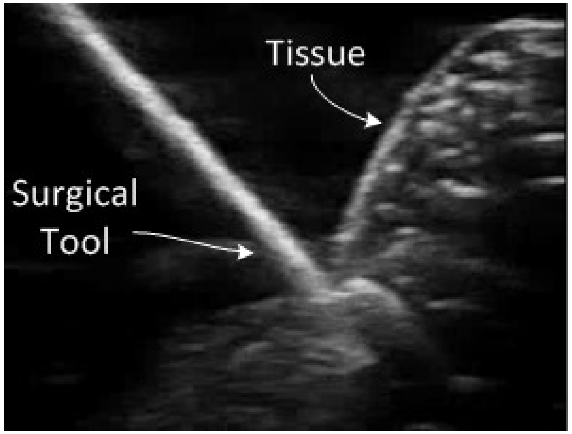


- 10 participants tried the task with and without motion compensation.

Results: No motion compensation

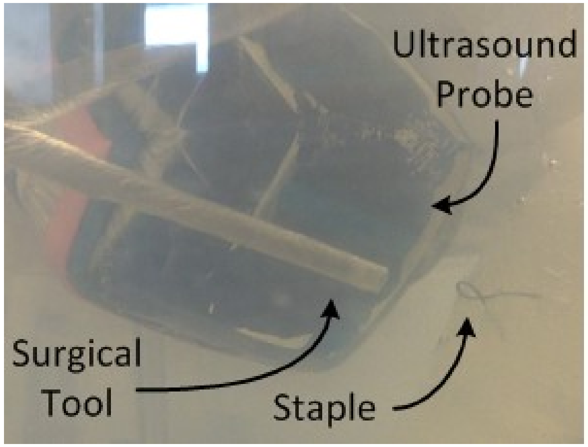


Use of excessive force

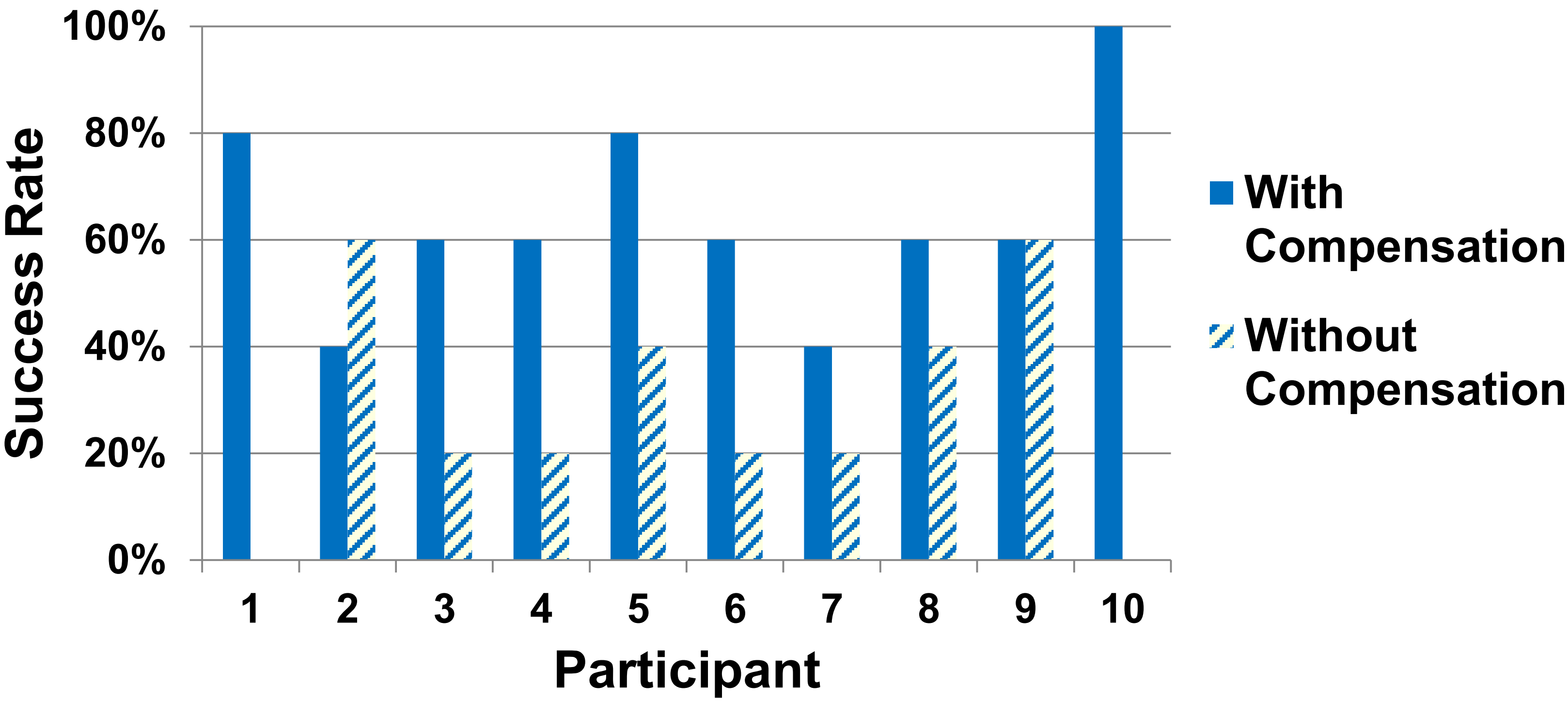


Results: Motion compensation

A correctly deployed staple



Results: Staple Insertion Task



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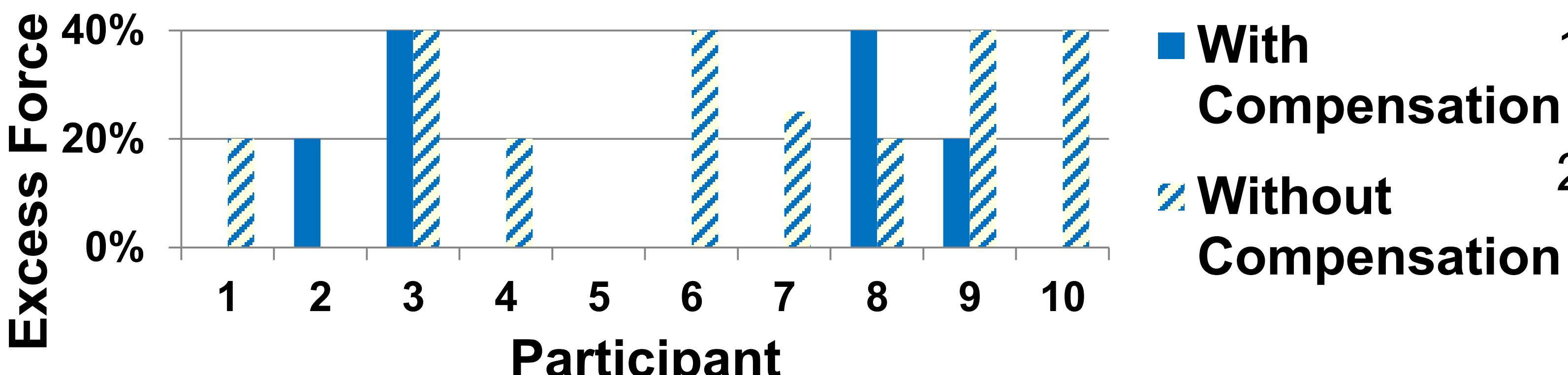

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Enabling technologies

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Case studies:

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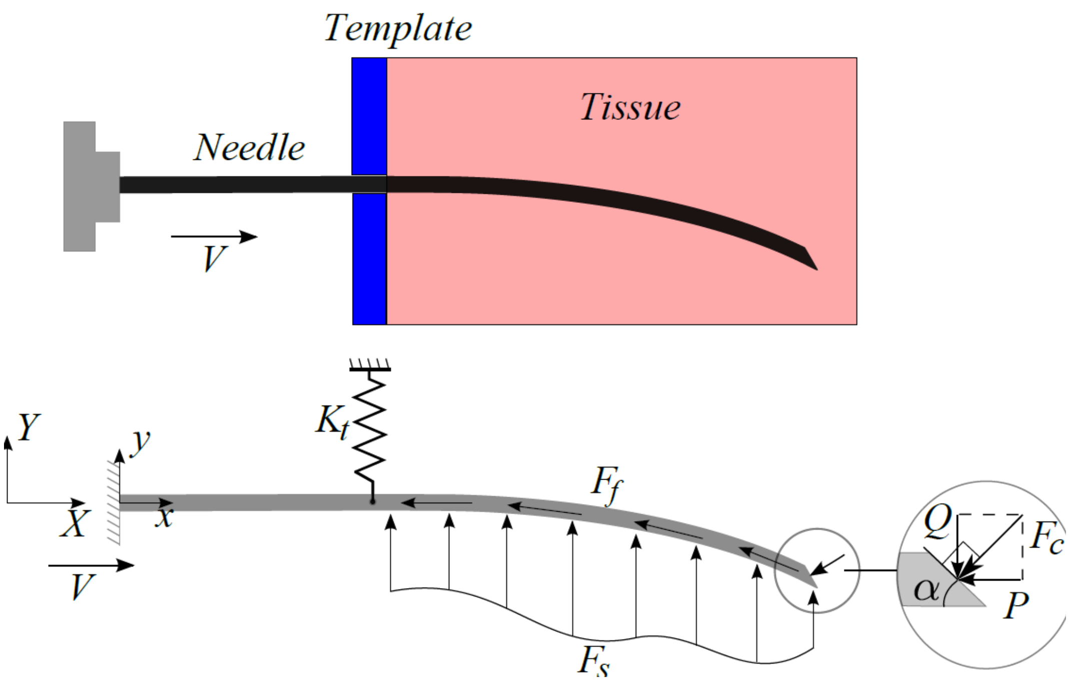
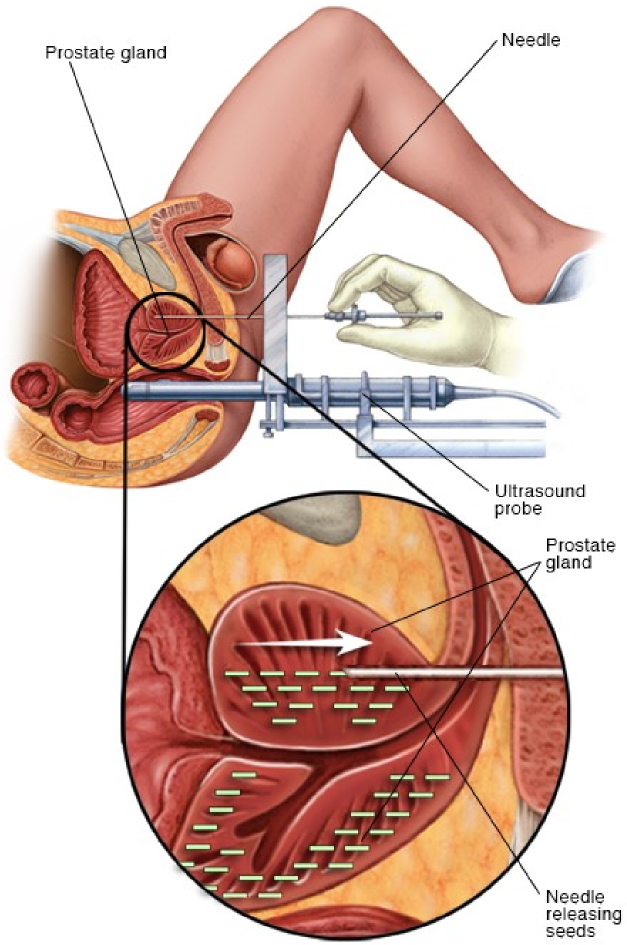
- **Prostate brachytherapy**

Prostate brachytherapy

- **Long, hollow needles** carrying **radioactive seeds** are inserted into the perineum.
- Seeds are deposited within the prostate to destroy cancerous tissue, *assuming* no needle bending and no tissue movement.
- Challenge: Needle deflection and tissue deformation during needle insertion.





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Manual prostate brachytherapy

Challenges:

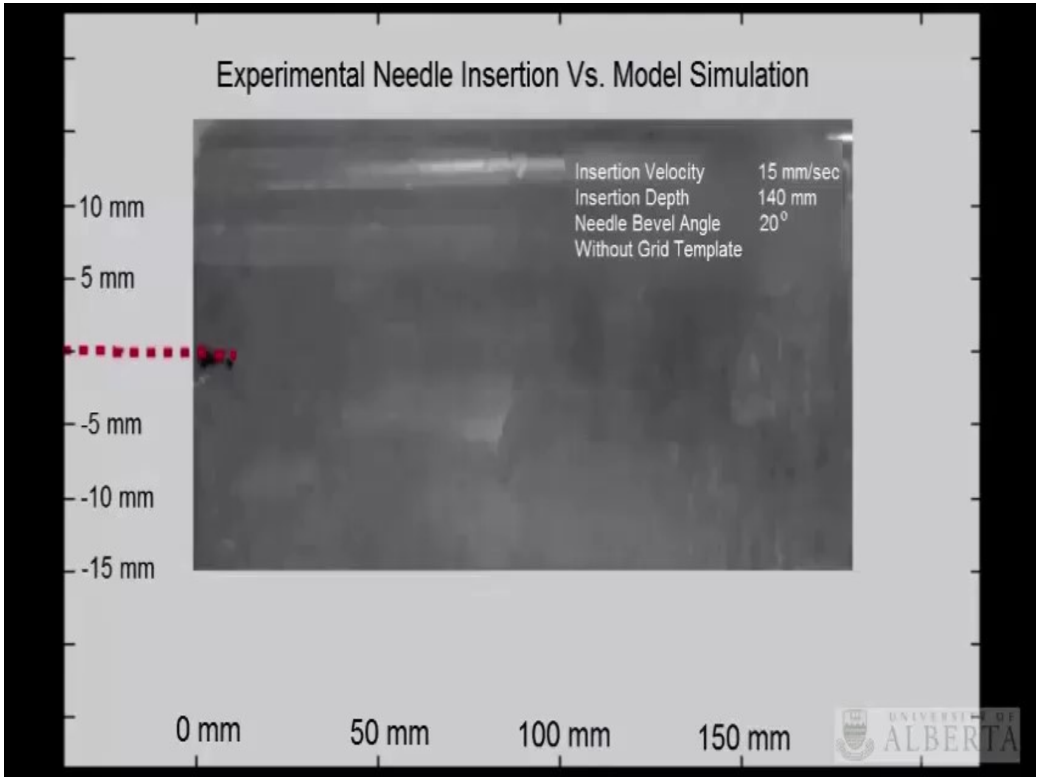
- Poor needle visibility in US images.
- Inadequate control over the needle.

Solutions:

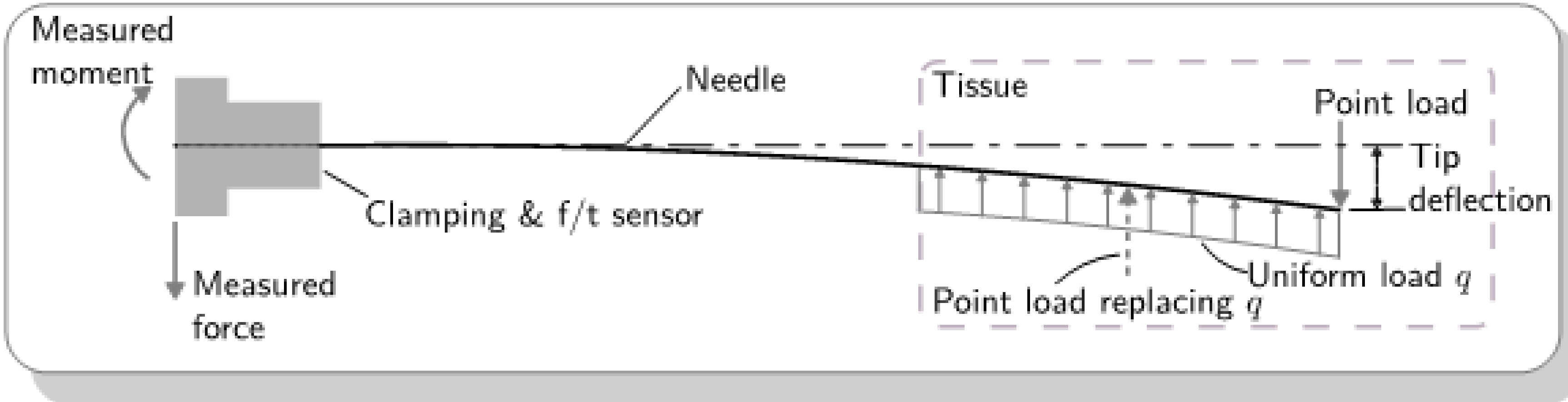
- Estimation, prediction and feedback control.

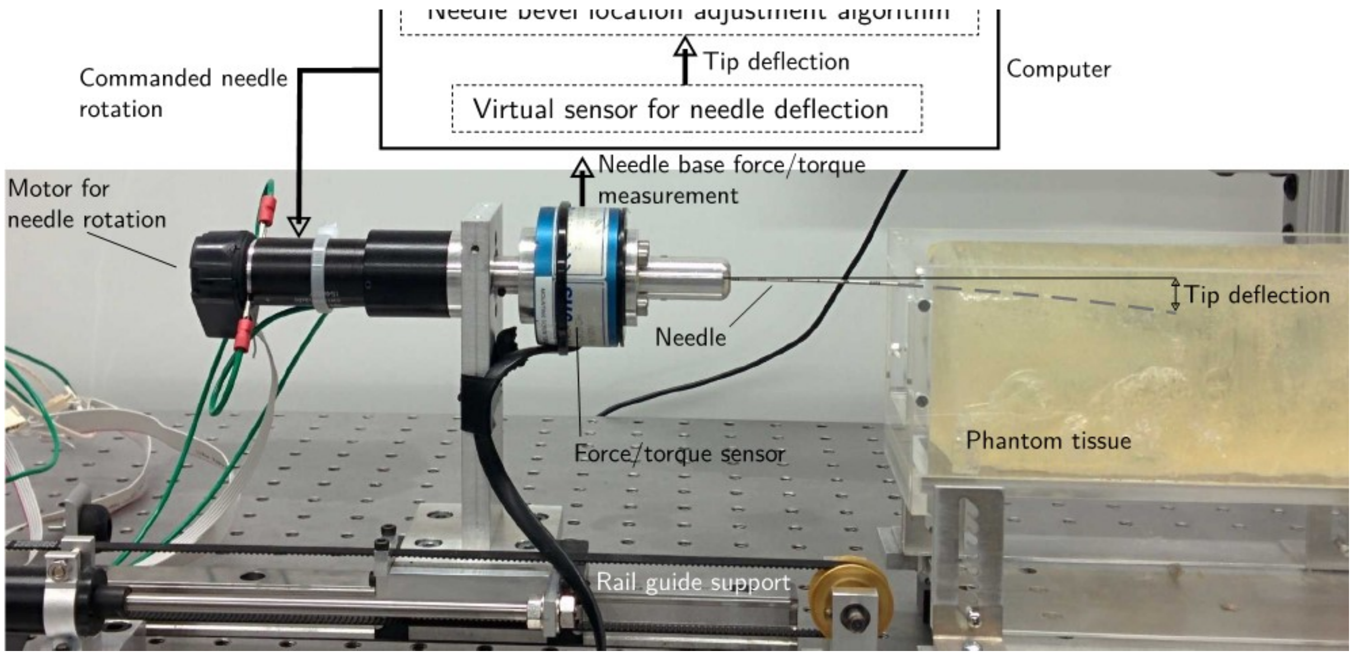
Model-based needle deflection estimation

- Accounts for bevel angle, grid template, tissue deformation, friction, and cutting force.
- Computationally efficient and appropriate for real-time control of needle tip position.
- The model uses both insertion velocity and bevel rotation as control commands for needle steering.



A virtual sensor for needle deflection estimation





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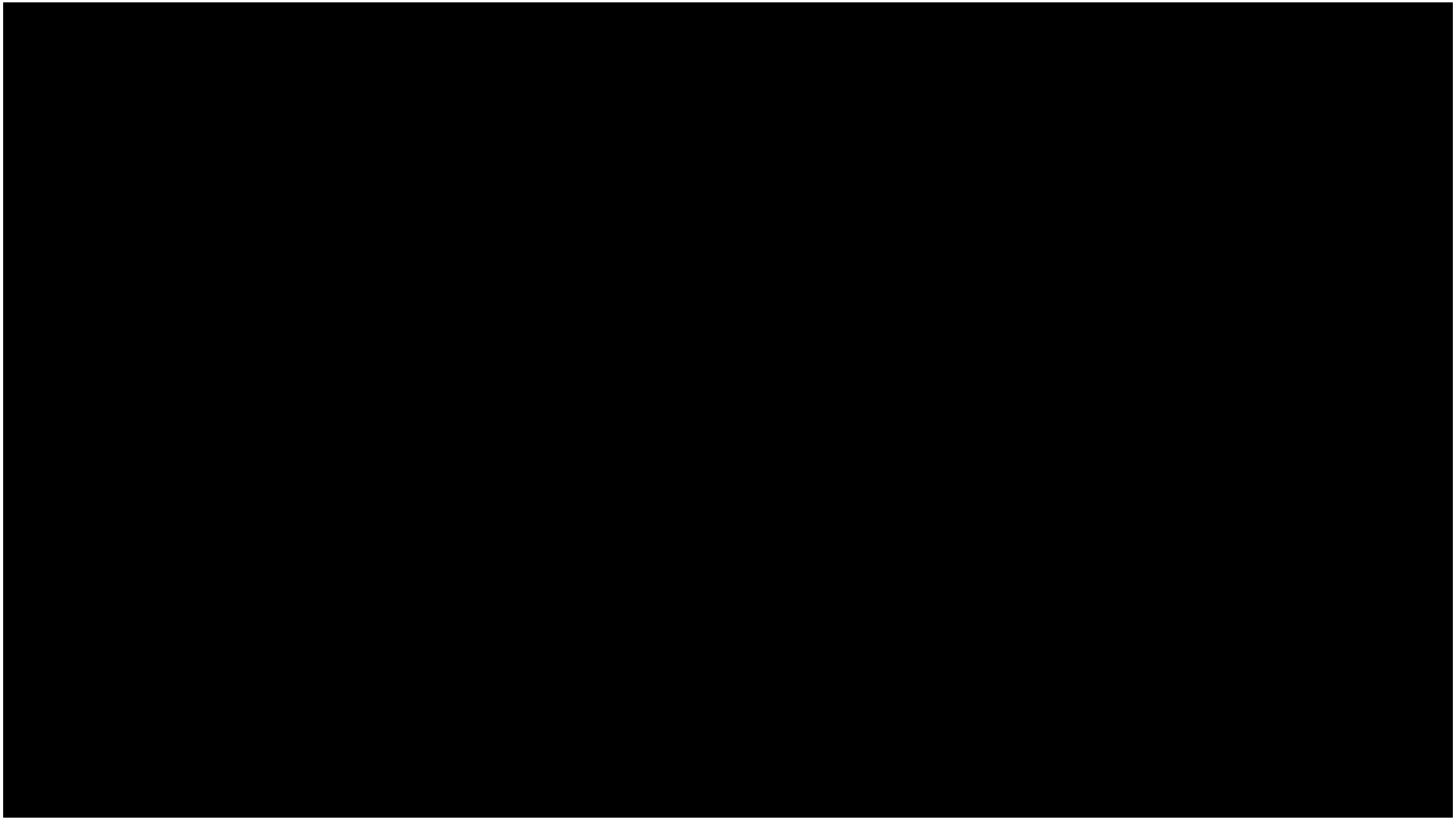
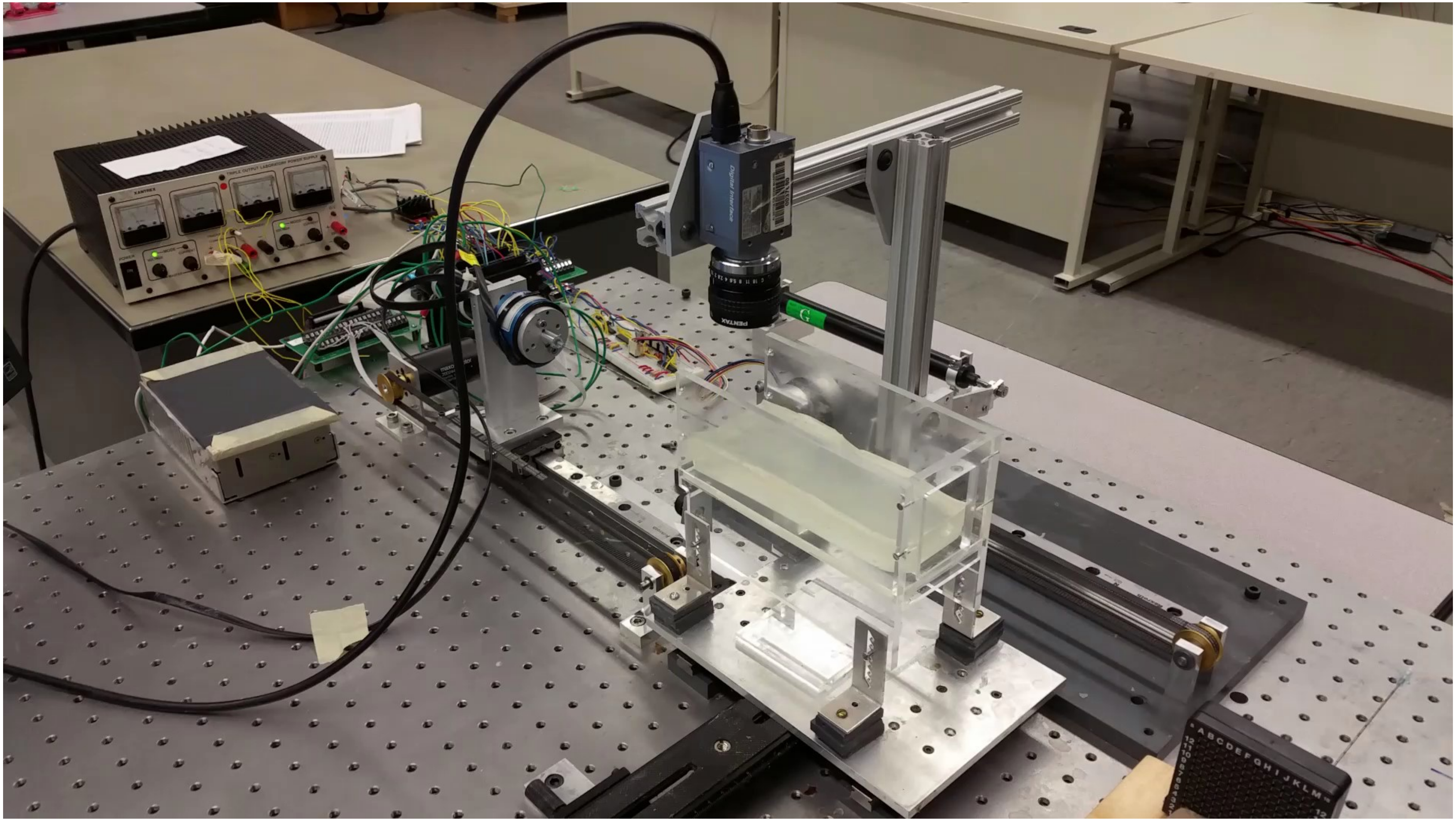
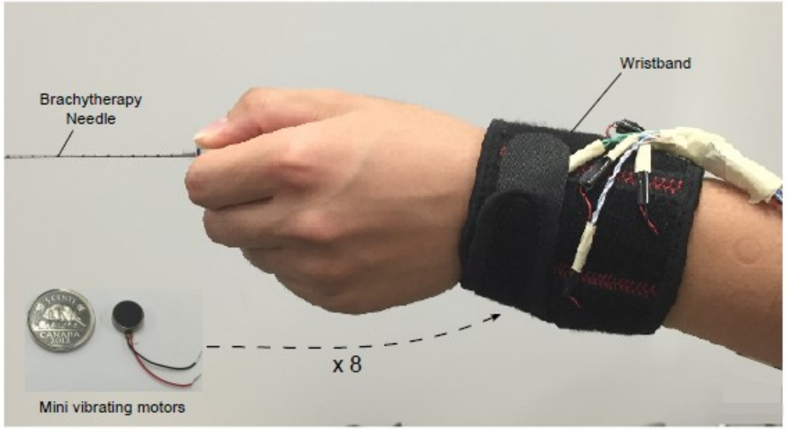


Needle steering through 180° needle rotations

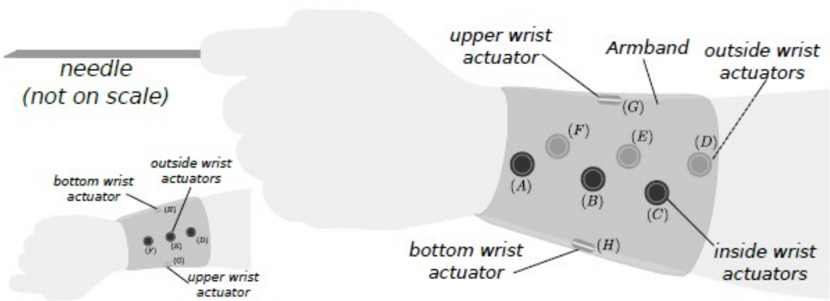


Haptic feedback on the wrist for manual needle steering

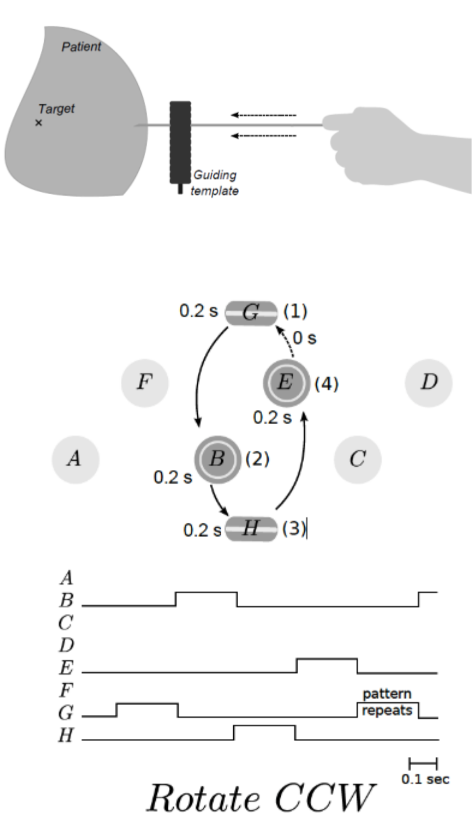
- Using haptic stimuli to inform the surgeon about a necessary needle steering maneuver.
- Eight mini vibrating motors are placed around the wrist.

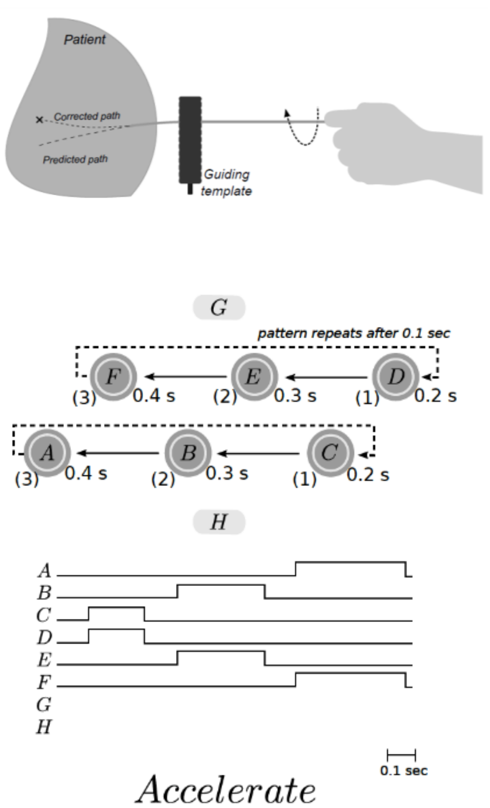


(a) Prototype of the haptic wristband



(b) Arrangement of the eight actuators

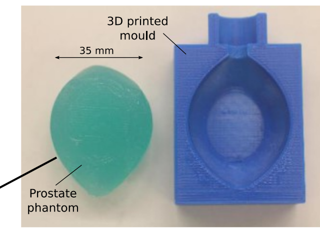


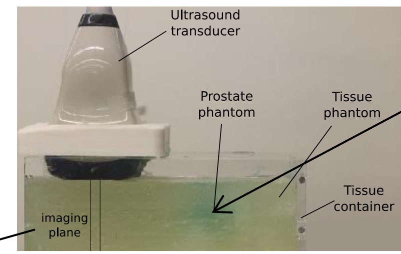


Haptic feedback on the wrist for manual needle steering

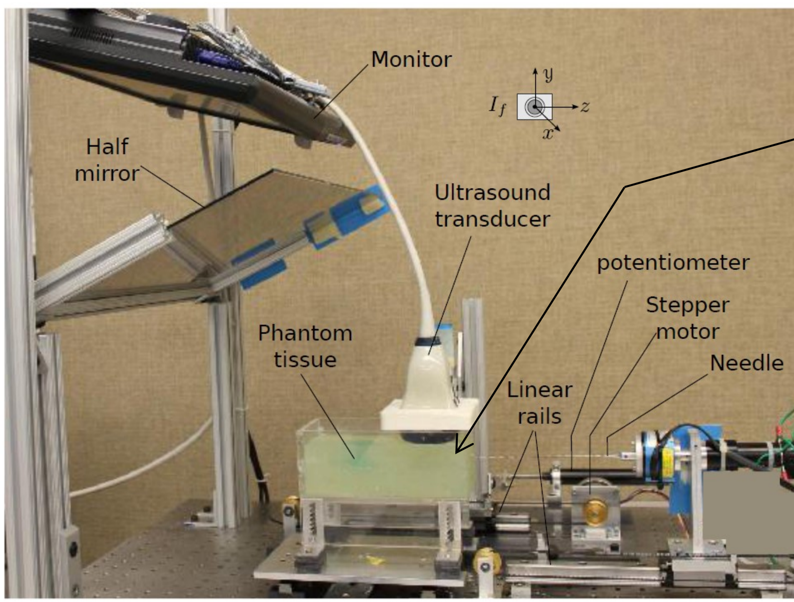
Augmented reality for manual needle steering

- Reconstructed images of the prostate are displayed in real time using a semi-transparent mirror.
- Predicted future needle deflection informs the user about required steering actions.

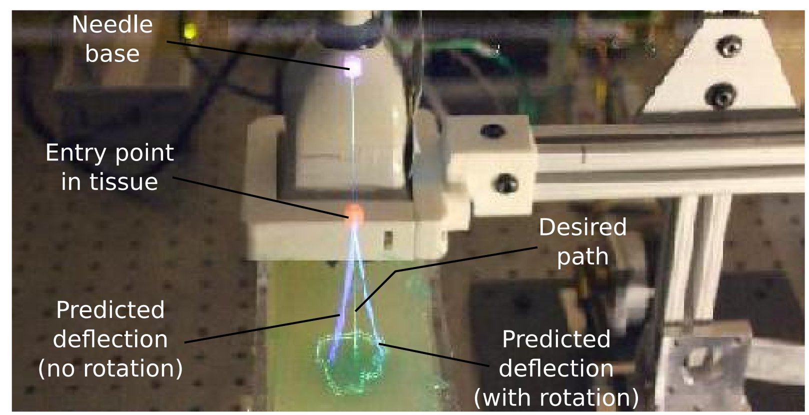




Phantom tissue



The augmented reality system



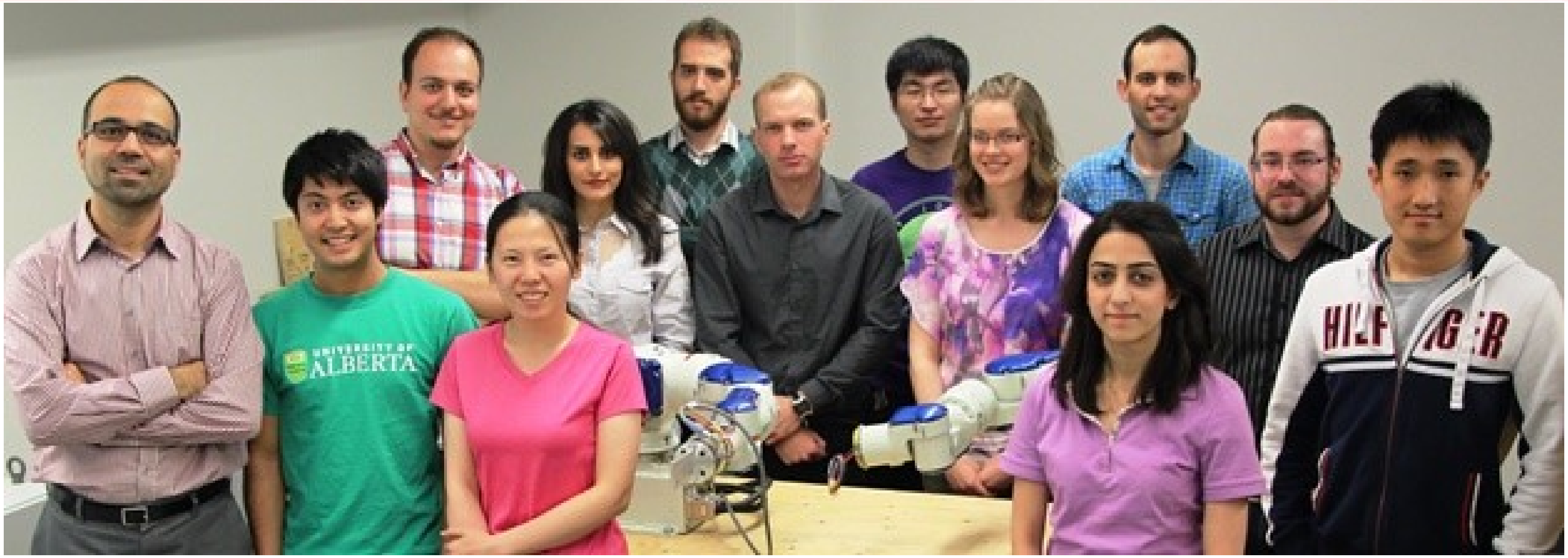
User's perspective

Augmented reality for manual needle steering

Conclusions

- Robots can make surgeries and therapies available to remote areas, more accurate and less traumatic.
  - Tele-rehabilitation
  - Beating-heart surgery
  - Brachytherapy
- The goal is not to replace the surgeon/therapist, but to extend his/her capabilities.
- Other possible advantages include creating new treatment options, increasing safety, enhancing documentation and follow-up, and saving on operating room times and costs.

Special thanks to



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