Robot-assisted Rehabilitation, Surgery and Therapy

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Currently, seniors make up about 12% of Canada’s population. In 2036, 25% of the Canadian population will be 65 or over.

Fertility rose sharply in both Canada and the US in the immediate post-war period.

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
Therapist’s Skills

Capabilities of Haptic Systems

Therapist-in-the-loop Telerobotic Rehabilitation

Fuse

Rehabilitation therapy paradigms
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)

- 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

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

1-DOF Task

(a) Patient-side robot

(b) Therapist-side robot

(c) Patient-side robot

2-DOF Task

(a) Patient-side robot

(b) Therapist-side robot

(c) Patient-side robot
Learn-and-replay tele-rehabilitation

Learn-and-replay Telerehabilitation Paradigm
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Beating-heart surgery

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/s²
- Quickly recoils 10-15 mm after contraction
Current surgical practice

Heart-lung Machine
- Increased risk of stroke
- Possible long-term cognitive loss

Heart Stabilizer
- Cannot completely cancel heart motion

From health.allrefer.com
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
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

Thus, let us consider a stapling 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

Success Rate

Participant

Excess Force

Participant

With Compensation

Without Compensation

With Compensation

Without Compensation

0%

20%

40%

60%

80%

100%

1

2

3

4

5

6

7

8

9

10

64%

28%

12%

24.5%
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.
**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
A virtual sensor for needle deflection estimation
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.
Conveying Needle Steering Manoeuvres via Tactile Stimuli
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.
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

http://www.ece.ualberta.ca/~tbs