Challenges in Adding Haptic Feedback to Surgical Robotics

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The da Vinci Xi Surgical System
Evolution of MIS Technology

1999
- da Vinci®
  - Eliminates lap compromises
  - Simple instruments

2006
- da Vinci® S™
  - 3D HD Vision (720p)
  - Cross-quadrant access
  - Streamlined set-up

2009
- da Vinci® Si™
  - Dual Console option
  - Enhanced HD Vision (1080i)
  - Upgradable architecture

2014
- da Vinci® Xi™
  - Multi-quadrant access
  - Crystal clear 3D HD vision
  - Platform for future technologies

- FIREFLY™
- XI SKILLS SIMULATOR™
- INTEGRATED ENERGY
- VESSEL SEALER
- STAPLER
- FUTURE INNOVATION SINGLE PORT SURGERY

2015 IEEE World Haptics Conference: Workshop on “Cutaneous Feedback for Teleoperation in Medical Robotics”
Haptic feedback on the da Vinci system

• Through the masters
  • Mostly kinesthetic
  • Motor effort based – limited sensitivity
  • Workspace limit
  • Haptic UI features

• Through vision
  • Fantastic 3D stereoscopic magnified wide FOV image
  • Surgeons use visual cues to understand forces applied to tissues

• Sensitive haptic feedback (both kinesthetic and cutaneous) remains of interest to the company
First Surgical Console and Patient-side Manipulators (1996)

- Haptic feedback has always been of interest
Sensitive haptic feedback requires a sensor

- Accurate force estimation is extremely difficult in practice
  - Requires good model of manipulator dynamics

- Dynamic parameters of the manipulators and instruments will change over their product life
  - Friction, compliance, tension
  - Adaptive models must be proven to be robust!

- 2014 da Vinci instrument numbers:
  - >550,000 procedures
  - >100,000 instruments produced
Sensitive haptic feedback requires a sensor

- Measuring the signal directly is a must
Design constraints for medical sensor

- Regulatory
- Cleaning
- Reliability
- Usability
- Sterilization
- Reimbursement
- Size
- Servicing
- Patient value
- Design verification
- Cost
- Manufacturability
- Safety
- Biocompatibility
- Cautery
- Robustness
- Packaging
- Servicing
Force sensor requirements

• Placement
  • Nearer to the instrument tip the better

• Size
  • 8mm (or smaller) instrument shaft

• Cleanability
  • Hermetically sealed and/or “flushable”
  • Steam autoclaved (2 ATM, 134-138°C)

• Biocompatibility
  • Limited material options
  • Material re-testing can be required depending on material treatment
Safety is critical

- Failure mode analysis
  - What are the likely points of failure
  - What is the severity of those failures

- Fault detection
  - Sensor redundancy
  - System models
  - There are >2 million lines of embedded run-time code. Almost half of this code is related to safety and redundancy.
Testing is endless

- Software verification testing
  - A typical software verification will consist of ~40,000 test cases

- Load tests of most mechanical components
System robustness
Instrument robustness

Instrument abuse/misuse can occur at any stage…not just in the OR!
Design constraints for medical devices

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Understanding patient value

\[ \text{Patient Value} = \frac{\text{Efficacy}}{\text{Invasiveness}^2} \]
Finding the patient value for cutaneous feedback

- Find good clinical partners
  - Honest feedback on the clinical impact
  - Vision to look outside the box
  - Ability to overlook limitation of prototypes

- Clinical feedback
  - Evaluation with clinical partners early and often

- Keep an eye on the other design constraints
  - Don’t design yourself in a corner
Closing thoughts on cutaneous feedback for surgical telemanipulators

- Display devices
  - Same design constraints

- Cutaneous + kinesthetic devices

- Focus on the patient value

- Additional opportunities in improved training