Medical Robotics
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da Vinci® surgical system

sources for this lecture
› http://www.intuitivesurgical.com/products/
› http://www.iwmr.polimi.it (presentation by Mike Yramategui)
difficulties of “manual” MIS

- Widely used in abdominal surgery

- Some difficulties:
  - 3 hands are mandatory
  - monocular vision (usually)
  - comfort of the surgeon
  - eye-hand coordination (fulcrum effect)
  - loss of internal mobility due to kinematics constraints induced by the trocar
  - restricted workspace
  - no force feedback (friction in the trocar)
  - ...

- Advantages of robots: may solve (more or less) most of these difficulties

(Source: US Surgical Corporation)
system overview

https://www.youtube.com/watch?v=Vj_3GJNz4fg
standard da Vinci® surgical system (introduced in 1999)
**Goal** preserve the benefits to the patient of endoscopic surgery skills while giving back to the surgeon the dexterity of open surgery

- eye-hand coordination, stereoscopic vision (→ depth)

- intuitive motion

- 7 dof at the tool tip
produced by INTUITIVE SURGICAL
http://www.intuitivesurgical.com/

• founded in 1995, public company in 2000
• headquarters in Sunnyvale, CA
• 2500+ da Vinci systems worldwide
• 2000+ employees
• ~450,000 da Vinci procedures performed in 2012
• 1,300,000+ in 1999-2011
• average cost ($ 1,0M - 2,3M) varies with instruments and accessories and service agreements
system installation through 2012
annual worldwide procedures

>500,000 in 2013
U.S. MALIGNANT HYSTERECTOMY MARKET BY MODALITY
Estimated Adoption of Minimally Invasive Surgery (MIS)
Percentage of all procedures

- da Vinci primarily displaces open surgery
- Prevalence of lap hysterectomy for cancer less than 15% at its peak
- Open surgery is now used in only about 20% of surgeries for cancer

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• *da Vinci* primarily displaces open surgery

• After the introduction of *da Vinci*, the prevalence of MIS (lap, vaginal and *da Vinci*) grew.

• Open surgery is now used in only about 20% of benign hysterectomies
system overview
OR layout

Vendittelli: Medical Robotics - *da Vinci® surgical system*
master console

• the serial manipulators operated by the surgeon act as a high-resolution input device
• the images of the surgical site are sent to the surgeon through two independent vision channels
• the virtual image plane is positioned right above the hands
• switches and foot-actioned buttons allow the surgeon to control the position of the endoscope, to reposition the master and to adjust the camera focus
3D vision system

- two optical channels with two independent 3-chip CCD
- two independent vision channels connected to two high-definition monitors with a frame rate of thousands of frames per second
- temperature at the endoscope extremity is automatically regulated
- image zooming, contrast improvement, noise reduction
- repositioning possible

Vendittelli: Medical Robotics - *da Vinci® surgical system*
• three/four articulated arms mounted on a base
• some joints are manually regulated at the beginning of the surgery and remain fixed during the surgery
• the remaining joints are actuated and remotely controlled by the surgeon (plus filtering and motion scaling)
• two/three arms hold the surgical tools while the third/fourth holds the endoscope
• standard sterilization procedures of the surgical tools are allowed
Endo Wrist® tools

- about 40 different types of forceps, needle drivers, scalpel, scissors, cautery instruments, . . . (5 mm, 8 mm)
- enhanced dexterity, precision and control
- 7 degrees of freedom, 90° degrees of articulation
- intuitive motion and finger-tip control
- ease of use: after an instrument is mounted to the da Vinci System, the interface recognizes the type and function of the instrument, and displays the number of uses
safety

- redundant sensors, hardware watchdogs, real-time fault detection
- transition to “safe state” before hazardous motion
- system can be easily removed from patient in fault condition

- no autonomous motion of instruments

- instrument motion is under surgeon view and control
• slow motion outside the body ⇒ assistant can anticipate and avoid contact
da Vinci single-site

Robotic Surgery through a single umbilical port
- US FDA Cholecystectomy Clearance Dec 2011
- benign hysterectomy / Salpingo Oophorectomy 510K filed Q3 12
- 450+ US hospitals have purchased Single-Site products through Q4 12
Product Development Cost and Complexity

- It took ~9 years and >$250M for Intuitive to reach profitability.
- 2013 R&D investment totaled $167 million, or ~$320 per patient.
- A *da Vinci* system is composed of >35,000 individual components (counting down to resistors) from >300 suppliers (direct).
- There are >2 million lines of embedded run-time code. Almost half of this code is related to safety and redundancy.
- A typical software verification will consist of ~40,000 test cases.
- The formally-maintained design history file is >10,000 pages of documentation.
Outcomes and Cost Comparisons After Introducing a Robotics Program for Endometrial Cancer Surgery

- Minimally invasive procedures increased from 17% to 98% in 2 years
- Historic cohort n=160; Robotic cohort n=143
- Robotic cohort:
  - Longer OR time (233 vs 206 minutes)
  - Fewer adverse events (13% vs 42%)
  - Less blood loss (50 ml vs 200 ml)
  - Reduced median hospital stay (1 vs 5 days)
  - Lower overall hospital costs ($7644 vs $10,368)
    - with amortization/maintenance, ($8,370 vs $10,368)
  - Reduced recurrence rates (11 cases vs 19)

still, costs are such that
manual laparoscopy < robotic < open surgery

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