Lecture 7: Medical imaging and image-guided interventions

Allison Okamura
Stanford University
Updates

Assignment 3

Deadline extended until next Monday!

Note that this assignment is purposely somewhat open-ended. This and the remaining assignments will continue be like “mini projects”.

Intuitive Surgical Tour: Friday, Nov. 11

We will leave campus at 2 pm (later than originally proposed). Manufacturing tour starts at 2:45 pm and ends at 3:45 pm. Hands-on demonstrations start at 3:45 and end when the drivers need to leave. I will send a poll for attendance and drivers. 40 people max.
first, a brief (re-)introduction to image-guided procedures

reference: Image-Guided Interventions, edited by Terry Peters and Kevin Cleary (link provided on course website)
idealized time-line description
of image-guided procedures

Phase I: Pre-operative planning

Phase II: Intraoperative plan execution

Phase III: Postoperative assessment
Intraoperative update model
update plan
real-time computer assistance

Preoperative computer-assisted planning
patient-specific modeling

Postoperative computer-assisted assessment
database

atlas
patient
Image guidance enables minimally invasive procedures

Previously:
surgery

Now:
A wide variety of specialties exist for medical interventions, and they are not all considered “surgery” (consider cardiology, radiology)
key technologies associated with image-guided procedures

- medical imaging and image processing
- data visualization and image segmentation
- registration, tracking systems, and human-computer interaction

replaces vision
replaces visual reasoning
replaces hand-eye coordination
Physicians mentally integrate their knowledge of anatomical structures with patient-specific medical images to produce a plan and execute it.

Image-guided systems use a similar approach, where all information sources are integrated and used to provide guidance to the physician.
medical imaging
why use medical images?

intensity values are related to physical tissue characteristics which in turn relate to
(1) anatomical information and/or
(2) a physiological phenomenon
what should you consider when selecting an imaging modality?

technical specifications:

• spatial resolution
• temporal resolution
• field of view
• types of biological and physiologic information

possible interaction between the imaging modality and intervention (e.g., does a metal robot cause image artifacts? does the magnet of the MRI machine cause the robot to malfunction?)
traditional imaging  vs.  functional imaging

physiologic information is interpreted  

physiologic information is computed
projection imaging:
• 2D cross images are generated by capturing a “view” from a single direction

vs.

tomographic images:
• 3D images are generated by stacking a set of 2D cross sectional image slices
• derived from the Greek tomos (slice) and graphein (to write)
most common types of imaging modalities

• **X-rays**: film, digital, fluoroscopy, Digital Subtraction Angiography (DSA)
• **CT**: Computed Tomography
• **Ultrasound**: 2D and 2.5D (stack of slices)
• **MRI**: Magnetic Resonance Imaging (discussed later)
• **Video**: laparoscopes and endoscopes (discussed later)
• **NM**: Nuclear Medicine (not covered)
  • PET -- Positron Emission Tomography
  • SPECT -- Single Photon Emission Tomography
in the beginning, there was x-ray physics: density of x-ray absorption (x-rays are a form of ionizing radiation)

first “medical” x-ray, 1895

http://www.britannica.com/
from film to digital

traditional X-ray film is replaced by solid-state detectors that convert X-rays into electrical signals (CCD camera)

Advantages:
1. there is no film to process, so the images are available immediately
2. digital images can be shared or enhanced electronically
3. digital images can be used for computer-assisted detection (helps doctors confirm or draw more attention to suspicious areas on a digital image)
4. essential for real-time decision making in robot-assisted interventions
mammogram machine

uses low-energy X-rays for detection of early cancer (microcalcifications)

common screening method, lately somewhat controversial
traditional configurations of x-ray and fluoroscopy machines

early fluoroscope (Britannica Film)

Philips digital multi-functional X-ray system
c-arm fluoroscopy

Philips XperCT (CT-like imaging, more on CT later)
digital subtraction angiography (DSA)

create a pre-contrast image, then subtract it from later images after a contrast medium has been introduced

iodine and barium are common types of contrast mediums for x-ray, since they attenuate x-rays (vessels become dark)
discussion

how can robots improve x-ray/fluoroscopy procedures?

how can x-ray/fluoroscopy be used in robotic interventions?
computed tomography (CT scan)

3D images are generated from a large series of 2D X-ray images taken around a single axis of rotation (produces a volume of data for analysis)

physics: same as x-ray

single slice

series of parallel slices 2mm apart

L. Joskowicz  © 2011
computed tomography (CT scan)

3D images are generated from a large series of 2D X-ray images taken around a single axis of rotation (produces a volume of data for analysis) physics: same as x-ray
emitter/receiver configuration

http://www.youtube.com/watch?v=M-4o0DxBgZk
CT machines

two examples from Philips (Brilliance 6 and 40) differ in number of images per second, number of detectors, etc.
discussion

what challenges might exist in performing CT-guided robotic interventions?
ultrasound imaging (diagnostic)

physics: variations of acoustic impedance

1. probe sends high-frequency sound waves (1-5 MHz) into the body
2. sound waves travel into tissue and get reflected by boundaries
3. reflected waves are recorded by the probe
4. time of flight gives spatial information about the boundaries

the desired frequency of signal is chosen based on a trade-off of resolution and attenuation
ultrasound

**A-mode (amplitude mode):** A single transducer scans a line through the body with the echoes plotted on screen as a function of depth.

**Therapeutic ultrasound** aimed at a specific tumor or calculus is also A-mode, to allow for accurate focus of the destructive wave energy.

**B-mode (brightness mode) or 2D mode:** A linear array of transducers simultaneously scans a plane through the body that can be viewed as a two-dimensional image on screen.
common application: fetal ultrasound

images courtesy Nora M. Su
ultrasound characteristics

- No radiation
- Poor resolution (~1 mm), non-uniform, distortion, noisy
- Low penetration properties
- One 2D slice or several slices (2.5D)
- Relatively cheap and easy to use
- Preoperative and intraoperative use
ultrasound machine

Ultrasonix

ultrasound transducers/probes

http://used-medical-equipment-blog.blogspot.com/
3D ultrasound

reconstruct 3D data from 2D slices

acquisition methods: linear, rotation, fan-like, hand
transrectal ultrasound

http://www2.cfpc.ca
https://myhealth.alberta.ca/

prostate brachytherapy
Doppler ultrasound employs the Doppler effect to determine whether structures (typically blood) are moving towards or away from the probe, and their relative velocity.

Color and pulsed Doppler of blood shunting across a muscular ventricular septal defect (in the heart).

http://www.glowm.com/
ultrasound elastography

Freehand palpation elastograms

Boctor, Rivaz, Fleming, Foroughi, Fichtinger, Hager (2008)
discussion

what challenges might exist in performing ultrasound-guided robotic interventions?
caution!

when introducing robotic (or any) technology into the interventional suite, you should consider what imaging modalities are already used and available.

there is a conflict between the potential for improving a procedure and the practical limitations in changing the workflow and resources required to perform the procedure.
<table>
<thead>
<tr>
<th>Modality</th>
<th>Intra-operative Availability</th>
<th>Accessability</th>
<th>Data Dimensionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computed Tomography (CT)</td>
<td>available (not widespread)</td>
<td>high</td>
<td>3D</td>
</tr>
<tr>
<td>Magnetic Resonance Imaging (MRI)</td>
<td>available (not widespread)</td>
<td>high</td>
<td>3D</td>
</tr>
<tr>
<td>X-ray</td>
<td>available</td>
<td>high</td>
<td>2D projection</td>
</tr>
<tr>
<td>functional Magnetic Resonance Imaging (fMRI)</td>
<td>not available</td>
<td>moderate</td>
<td>3D</td>
</tr>
<tr>
<td>Positron Emission Tomography (PET)</td>
<td>not available</td>
<td>moderate</td>
<td>3D</td>
</tr>
<tr>
<td>Single Photon Emission Computed Tomography (SPECT)</td>
<td>not available</td>
<td>moderate</td>
<td>3D</td>
</tr>
<tr>
<td>X-ray Fluoroscopy</td>
<td>available</td>
<td>high</td>
<td>2D projection</td>
</tr>
<tr>
<td>C-arm CT</td>
<td>available</td>
<td>low</td>
<td>3D</td>
</tr>
<tr>
<td>Ultrasound (US)</td>
<td>available</td>
<td>high</td>
<td>2D</td>
</tr>
<tr>
<td>optical imaging</td>
<td>available</td>
<td>high</td>
<td>2D projection</td>
</tr>
</tbody>
</table>

Table 1: Classification of imaging devices according to their availability for intra-operative use, their accessibility to physicians around the world, the dimensionality of the data they acquire and the type of information conveyed by the images.