Toward to Real-Time Optical IGRT

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Disclosure
• No founding from any vendor
• Co-developed a 3D Optical Surface-guided RT System with NIH SBIR Phase I Grants
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List of Topics
1. History of OG in Radiotherapy
2. Principles of 3D Optical Imaging
4. Initial Experiences of Surface-guided Radiotherapy

1. History of OG in RT
• In early 1990s, U. of Florida (led by Bova FJ) had introduced infrared marker-based stereotactic radiotherapy (Bova, et al, IJROBP. 1997, 38:875-82)
• Q1: Is it the time for real-time OG RT?
2. Optical 3D/4D Imaging Principles

A. Marker-based 3D optical system
   a). Passive Marker Tracking System
   b). Active Marker Tracking System
B. Time-of-Flight (TOF) Method
C. Laser Scanner
D. Triangulation-based 3D camera
   a). Passive stereovision
   b). Structured light 3D camera

A. Infrared 3D Marker Tracking Systems

Polaris Spectra has bump detection and laser positioning used by Elekta iGUIDE and Resonant US Image system

Tracking rate 60 fps

Active (left) and passive (right) markers
Courtesy to NDI company’s permission

An optic-guided SRT system established at Iowa University
Initiated at Florida U.
B. Time-of-Flight (TOF) Method

- 2D image data are provided by 2D camera
- The third dimension and time can be given by using TOF

\[
R(t_i) = \frac{\tau_i \cdot c_{\text{air}}}{2}t_i
\]

\(\tau_i\) is the time of flight of the light pulse, and \(c_{\text{air}}\) is the speed of light in air.

- Presently, TOF has difficulty in achieving the sub-millimeter accuracy.
C. 3D Laser scanners

- Swapping laser line and using triangulation

D. Triangulation-based 3D camera

- Passive stereovision (2 cameras)
- Structured light (projector + camera)

Any surface point \((X,Y,Z)\)

\[
R = \sin(\alpha) \frac{\text{Baseline}}{\sin(\alpha + \beta)}
\]

Q2: How to identify the corresponding point?
The 1st optical-surface-guided SRT system by Li et al., Med. Phys. 27:1433, 2000

- Pixel-based 3D surface: resolution 0.5 – 1-mm at 2-m focus distance
- Less room light & skin tone effects
- Adjustable power of projector

The Laplacian of Gaussian

- An projection image $I(x,y)$, is convolved by a Gaussian kernel
  $$ g(x, y, \tau) = \frac{1}{2\pi\tau} \exp\{ -\frac{1}{2} \left( x^2 + y^2 \right) / \tau \} $$
- Apply Laplace operator onto the function
  $$ \nabla^2 L = \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right) L = \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right) (I \otimes g) $$
  → large positive values for dark blobs
  → large negative values for bright blobs
- Accuracy and resolution depend on the blob size and the scale parameter $\tau$

Target refixation for none-coplanar beams/arcs
Two cameras increase the view of patient's body
Rapid imaging up to 7 fps
Resolution and accuracy depend on speckle size

Microsoft KINECT gets official on 11/4/2010

- Although the 30 fps imaging speed allows us to track body movements, 3D surface accuracy is not quite enough for optical-guided RT.

We now need an in-depth review of structured light imaging techniques by Dr. J. Geng, an expert in optical imaging