Electromagnetic Tracking for Real-Time Guidance and Fast Channel Reconstruction in HDR Brachytherapy

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Learning Objectives

• Provide an overview of EM tracking technologies
• Understand the expected accuracy and precision of EM tracking
• Illustrate possible usage scenarios

Definition - Tracking

Noun

1. the act or process of following something or someone

Collins English Dictionary. Copyright © HarperCollins Publishers

Tracking and beyond

Tracking = Real-time guidance
Augmented Reality

Google image search – PCMag.com

Google image search – Daniel Burrus, LinkedIn
2018-07-26

Tracking in RT

Interventional Procedures / Optical Tracking
Limited to line of sight
- Same for white light camera

Tracking in Brachytherapy?
- Position of needle, catheter or applicator in real-time
  - Angulation/rotation
- Automated, fast and accurate channel reconstruction
  - Tip localization
  - Detection of catheter motions
- Potentially tracking in real-time the source position
  - Detection of wrong connection between transfer tube and afterloader
- Enabler for new brachytherapy and interventional procedures
  - True on the fly decision -> dynamical replanning
Technologies

- Image-based tracking: CT, MR or US
  - Organ(s) and device(s) tracking

Accuracy of Catheter Reconstruction?

See e.g. F. - A. Selent et al., Med Phys 36 (2009) 3406-3412

Technologies

- Applicator-, catheter- and source-based tracking
  - Optical IR tracking
  - EM with passive sensors
  - EM with active MR coils
  - Optical Fiber Shape Sensing
    \(\{\text{Need direct line of sight}\}\)
    \(\{\text{MR compatible}\}\)
Electromagnetic tracking system (EMTS)

- Performance and suitability assessment of a real-time 3D electromagnetic needle tracking system for interstitial brachytherapy. Shafir A, Binnekamp D, Binnekamp D and Bonillas A. J Contemp Brachytherapy 7 (2015) [on page]
- And many more since 2016...

Example: Aurora® from Northern Digital Inc. (Ontario, Canada)


Planar field generator - AC

- NDI Aurora system (Principal: Seiler et al. PMB 2000)

Planar field generator - AC

- Sensor = induction coil
- Alternating current of ± 2 A at 12 kHz for 3.3 ms each differential coil will create 6 different voltages at the sensor
- If 5DOF needle: 6 measurements and 5 unknowns
- If 6DOF: 2 sensor coils

From Franz et al, 2014

Active MR micro-coils

- Use the MR as an intrinsic field generator.
- Sensors are active micro-coils
- Sensors positions are de facto in the imager reference frame!
ACTIVE MR TRACKING

Needle Guided MR Resampling of Initial Scan

EMT in the Clinical Environment

Electromagnetic tracking for catheter reconstruction in ultrasound-guided high-dose-rate brachytherapy of the prostate

Shyam Bhara1, Cynthia Kang1, Ehsan Dehghani1, Ananth Rav1, Niranjan Venugopal1, Antonio Botiller1, Doug Stanford1, Jochen Knuecher1

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Brachytherapy 13 640–50
EMT in the Clinical Environment

- Sub-mm and 1° accuracy/precision
- Insensitive to US probe and needles/catheters
- Metal close to (but not in) the field OK as long as the configuration does not move/change during the procedure (e.g. stir-up)

HDR Brachytherapy Applications
Error Simulations – 15 catheters

105 possible swap errors
105 possible mix errors
from 0 to 3 mm shifts (in 0.1 mm increments)
465 possible shift errors

100% Sensitivity and Specificity

Shift Error

1.8 mm mean detected shift
1.9 mm mean identified shift
100% Specificity (shifts ≥ 2.7mm)

Auto. Catheter/Applicator Channel Reconstruction

- EM reconstructions at 40 Hz
- μCT reconstruction (GE) at 89 μm (reference)
- CT reconstructions (Philips BigBore) at 2 mm
- Reconstructions using the EM stylet were compared to μCT and CT (3D distances used; tips as reference)
Auto. Channel reconstruction

Unpaired Student’s t-test show statistically significant difference.
Poulin et al., Medical Physics 2015;42(3):1227–32.


Tracking the Source Position: Afterloading Brachytherapy

- Automated applicator/catheter reconstruction
- Online channel set-up QA

Vision 2020 BrachyNext meeting, Miami, 2014

Next slides will present Research/Investigational Devices

- Not clinically available yet
  – Only to provide a sense of what such systems could look like

- One is waiting for Health Canada approval as investigational device for first-in men study
  – Extension of the UroNav™ EM tracked Biopsy System
    - New real-time TPS for brachytherapy

- Another is taking data under institutional ERB approval.
  – EMT system integrated in the afterloader.
Example: Flexitron with integrated EMT

- EMT data of ~50 patients collected since 2015
- 07/2016: Flexitron with EMT sensor on additional drive
- New acquisition workflow and algorithms
- Integration of sensor position data from afterloader feasible

Breast Data Collection

- Treatment: microSelectron
- EMT measurements: Flexitron prototype
- Improved sensor placement on skin
  - Compensation for breathing motion by three 8 def sensors on breast

Example data

Figure: Showing comparison of EMT to CT for patient 10. Figure (a) shows the EMT measurement after the third fraction of radiation. The registration is spread out evenly for this linear regression of Figure (b) versus the EMT catheter points with color maps indicating the black cross, defined in the planning CT image, which serves as reference. Figure (c) shows the deviation of the 2D plane to the reference. Figure (d) presents the course of the DTP in red along the curve of reference in the blue plane on one projection. Differences are indicated as points 1.3, which are superimposed on maps above the upper (75th) and 10th percentile for both catheters and below the lower (25th), and 10th percentile for the catheters. (b) shows the mean Euclidean distance z-direction [mm].

Example: Flexitron with integrated EMT

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Real-time EMT System: Lab Prototype

Workflow

Workflow Efficiency

- Image acquisition: 1 sec
- Contouring: 3-15 min
- Planning: 7.6±2.5 sec ➔ more time reviewing/rerun!
- Insertion:
  - 27.6±6.7 sec/catheter or needle on phantom
  - ≈ 60 sec/catheter or needle expected for actual patient
- Catheter/Tip Reconstruction:
  - First one included with insertion time (free!)
  - Additional: 10.5±3.1 sec/catheter or needle

Complete procedure under 1 hour potentially feasible
Real-time EMT Prostate HDR System: First-in-Men

Key Issue: Calibration to a Relevant Reference Frame

- Sensor to needle/stylet tip or relevant applicator position
- Template (if used) to EM coordinate system
- Image to EM coordinate system
  - i.e. US to EM in the example shown previously

Each of the above will have an impact on the overall accuracy of the clinical system

Possibilities / Limitations

<table>
<thead>
<tr>
<th>Quality Item</th>
<th>Selectability</th>
<th>EM coordinate system</th>
<th>Error probability and effect (2D)</th>
<th>Error probability and effect (3D)</th>
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Bert et al. JCM 2016

Courtesy: C. Bert
EM Tracking Technologies

They are coming
• Real-time position/angulation information
• Can be used in or couple to needle, catheter or applicator (iCatheter and iApplicator)
• Fast and accurate HDR channel and tips reconstr.

Could be incorporated in specific workflows
• Automated imaging plane display
• Real-time continuous dosimetry and replanning (Seed, HDR, Focal, …)
• QA of channels (reconstr., swapped, …)

Joint AAPM-ESTRO TG

In memory of Jean Pouliot

Early EMT Concepts and Ideas - Philips Laboratory, USA 2011