Seminar Presentation

Automatic image-to-world registration based on x-ray projections in cone-beam CT-guided interventions

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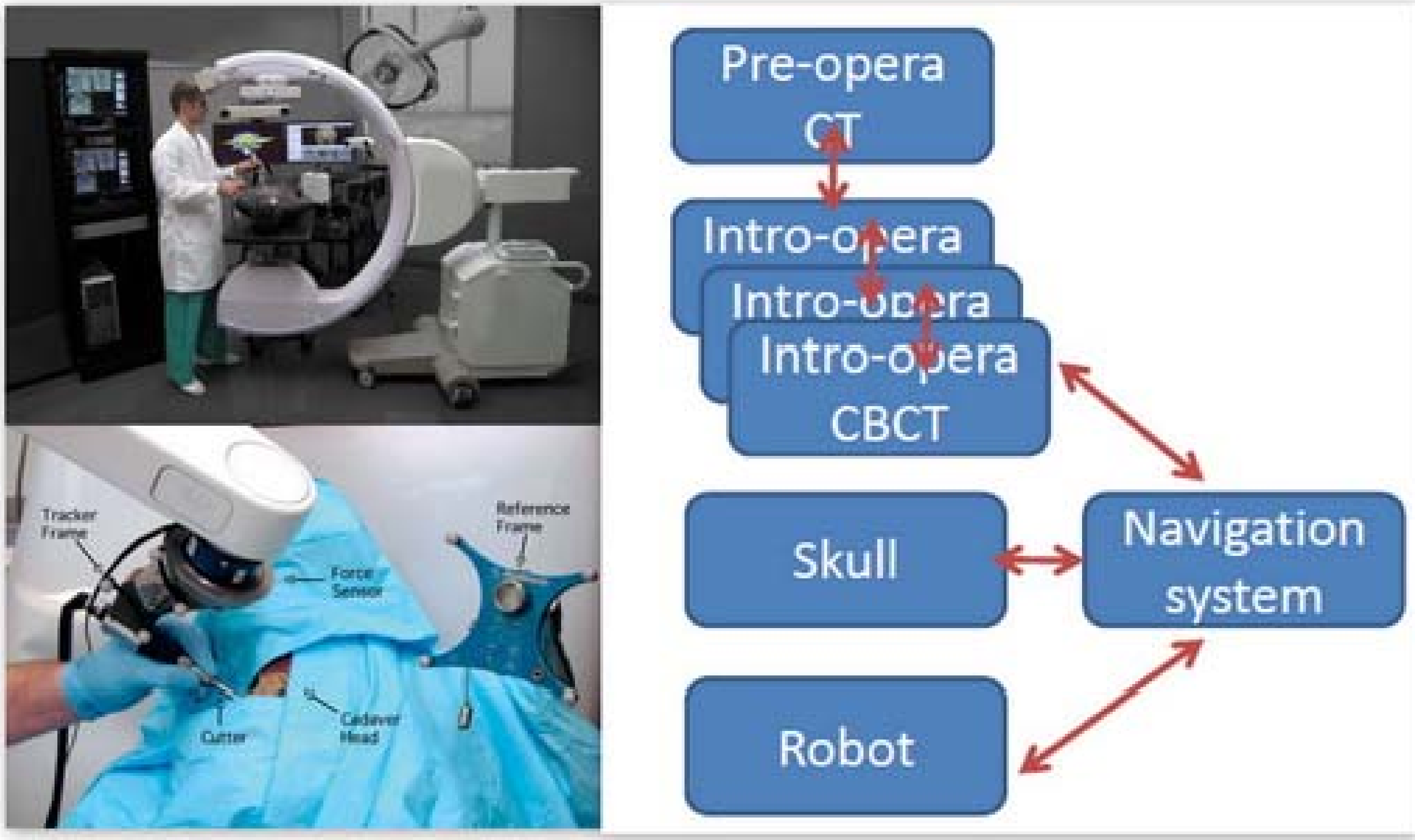
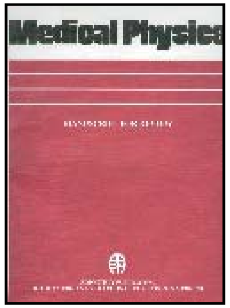
Project: Integration of CBCT and a skull base drilling robot



Paper selection and reason

- Name: **Automatic image-to-world registration based on x-ray projections in cone-beam CT-guided interventions**
- Authors: Hamming NM, Daly MJ, Irish JC, and Siewerdsen JH
- Journal: Medical Physics
- Publish time: April 2009

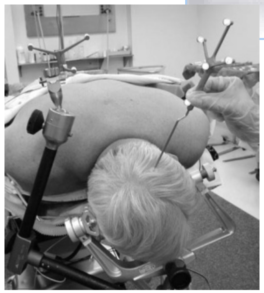


- Reason:
  - Illustrate important background on CBCT
  - <u>Bring innovation on a typical registration problem discussed in CIS1</u>
  - Have potential to be used in my project

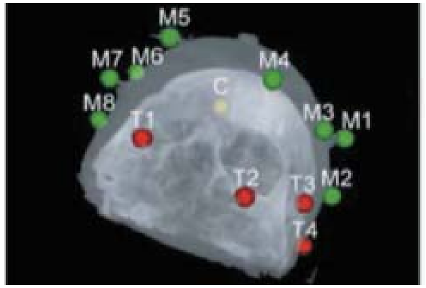
Problem, key result, significance

Requires

Real-time surgical navigation



Registration

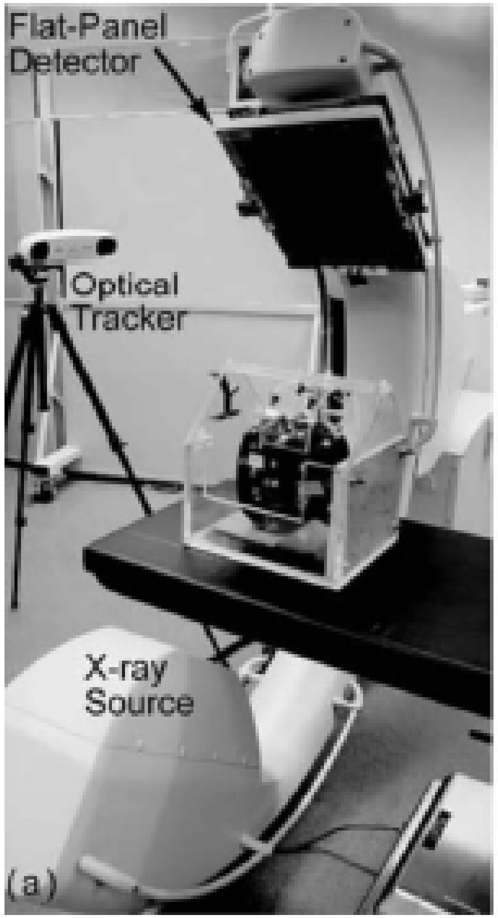


Manual registration: Bottleneck, fail

- Solution: automatic registration
  - New marker design: visible to both tracker and X-ray
  - Automatic marker-segmenting algorithm
  - Automatic paired-point registration
  - Key result: Equivalent or superior accuracy and reproducibility
- Significance: eliminate burden of manual registration on surgical workflow !

Fig1: Images are from An integrated system for planning, navigation and robotic assistance for skull base surgery.Tian Xia, Peter Kazanzides, etc*. The International Journal of Medical Robotics and Computer Assisted Surgery, Volume 4, Issue 4, pages 321–330, December 2008. Fig2: http://www.thebarrow.org/Education_And_Resources/Barrow_Quarterly/205222. Fig3: http://www.tech-ex.com/jsp/equipment/products/premium/ndi.jsp Fig4: Automatic image-to-world registration based on x-ray projections in cone-beam CT-guided interventions. Hamming NM, Daly MJ, Irish JC, Siewerdsen JH. Med Phys. 2009 May;36(5):1800-12. (From left to right)

Background/Material: CBCT

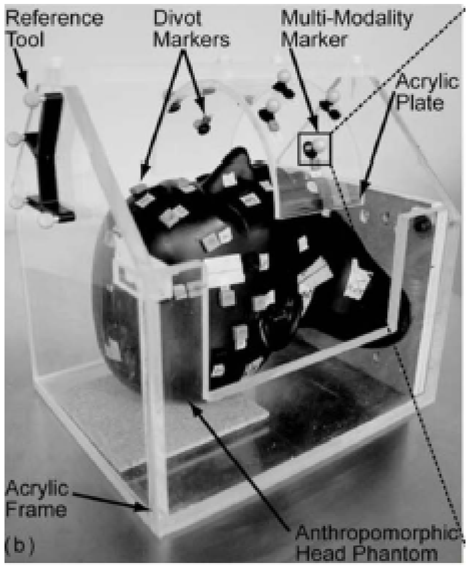


- Two modifications to common C-Arm:
  - Motorization of C-Arm orbit: ~200 projections
  - Large area Flat Panel Detector(FPD)
    - 20*20*15 cm
    - Soft tissue visibility
- Imaging capability
  - Acquisition: ~60 sec. 0.194mm-><u>0.388mm</u>
  - Reconstruction: ~20 sec. 256*256*192 voxel
- Geometric calibration

Voxel coordinate in 3D image ⟺ Pixel position in 2D projection domain

- <u>Multi-Modality marker</u>
  - 5.8mm radius reflective marker—Tracker
  - 1.0mm radius tungsten BB marker—CT

  Two centers are coincident within 0.15-0.04mm



- Marker placement

(1) MM markers (automatic)

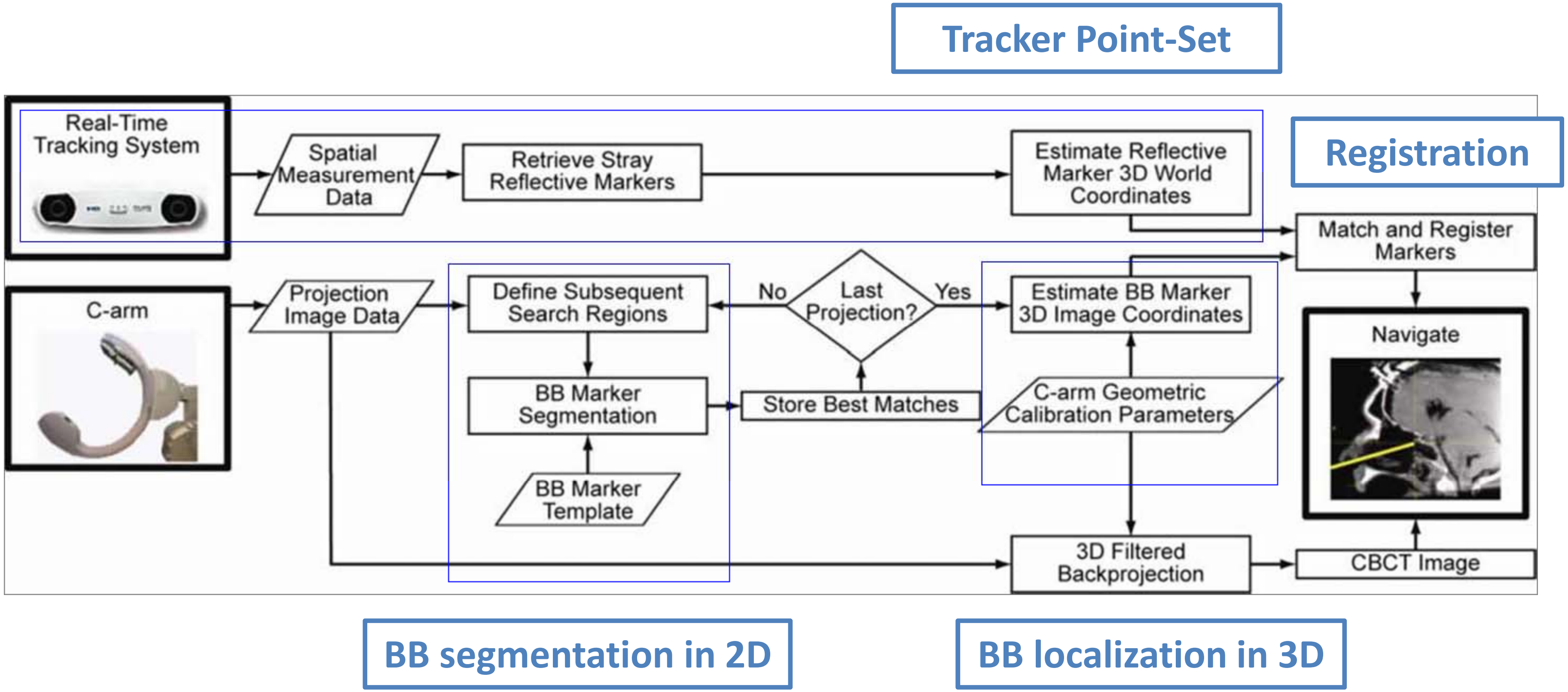
  - 8 on skin surface (traditional)
  - <u>8 on a curved plate </u>(novel, no need of fixing markers to skin surface)

(2) Divot markers (manual)

  - 8 as fiducials (adjacent MM, skin/plate)
  - 4 as targets (skin)

Theory

Automatic registration algorithm



Registration: Rigid point-based method involving unit quaternions, by Horn, CIS1

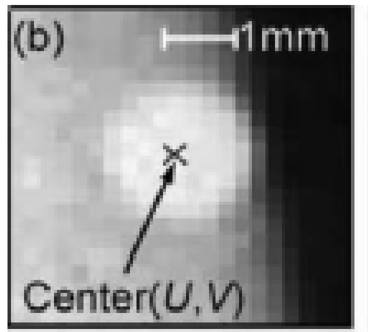
Segmentation of BB markers in 2D projections

Intensity threshold -> detect regions of high attenuation

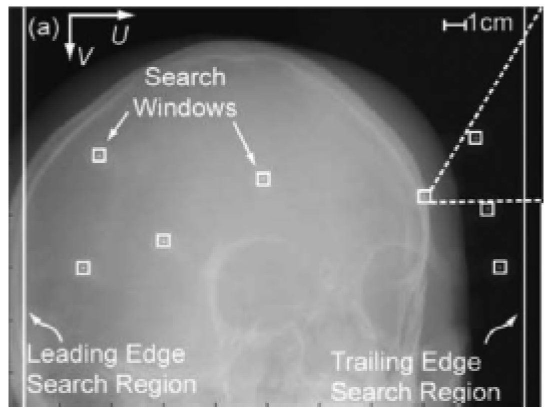
Pattern matching (2-5 pixels radius circle)

Calculate centroids of all candidates

Exclude false positive by consistency of presence



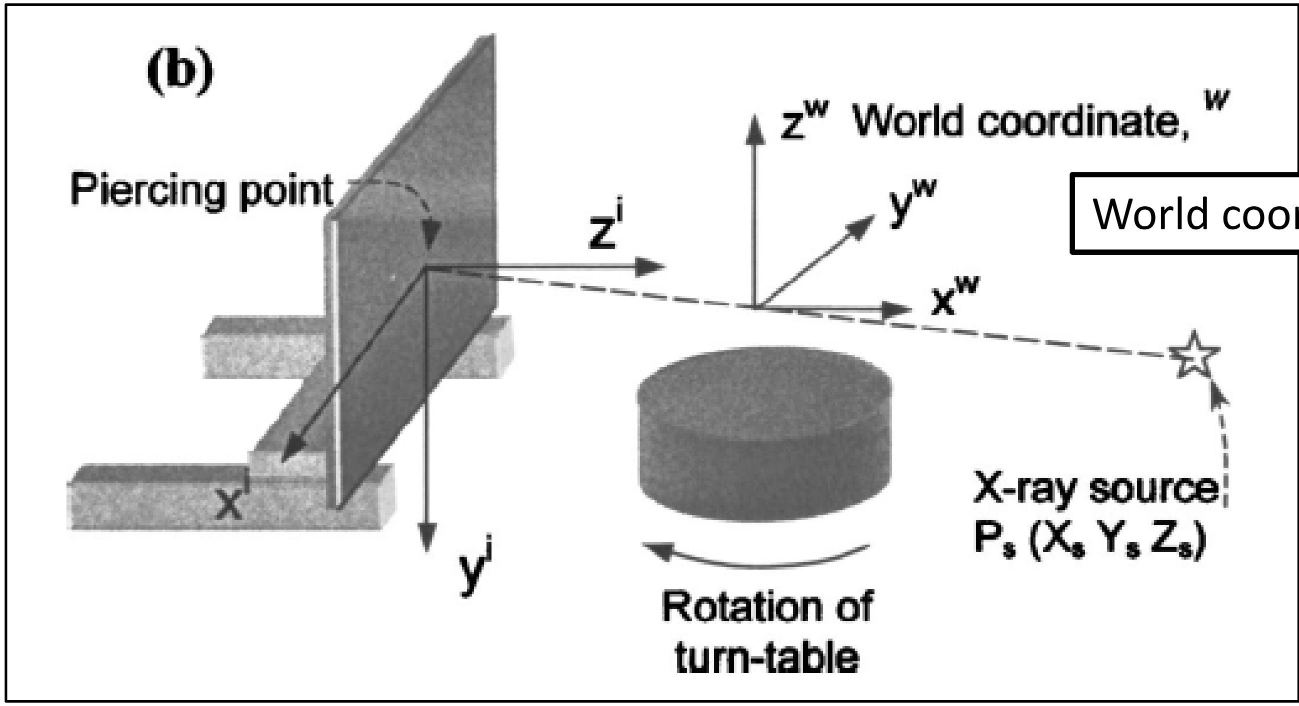
- Search windows: 20*20 pixels
- Edge search windows: 30 pixels width



Localization of BB markers in 3D image coordinates

Real detector coordinate

Virtual detector coordinate

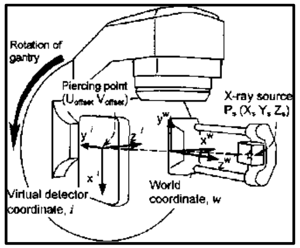


World coordinate

Detector pixel coordinate

laboratory bench

Gantry



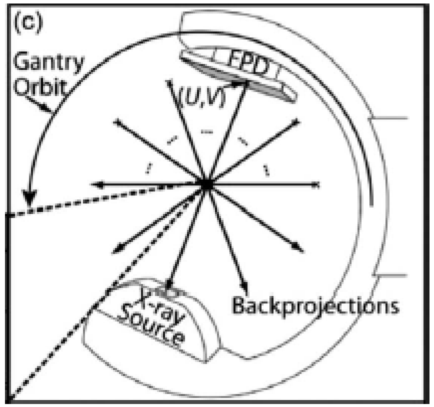
From detector pixel coordinate system to image coordinate system

- Pixel to Real
  (U,V) -> P

$$\begin{cases} P^r(x) = -a_u(U^p - U_o^p), \\ P^r(y) = -a_v(V^p - V_o^p), \\ P^r(z) = 0, \end{cases}$$

- Real to Image

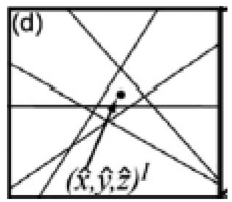
$$P^I = R_i^I R_r^i P^r + T_i^I,$$



- Back projection
  – Lines between 3D position on the surface of detector and 3D source
- Linear least square

$$\sum_{j=m}^{n} d_j^2 = \sum_{j=m}^{n} a_j x^{I^2} + b_j y^{I^2} + c_j z^{I^2} + e_j x^I y^I + f_j x^I z^I + g_j y^I z^I + h_j x^I + k_j y^I + l_j z^I + q_j,$$

$$X\beta = y \ni X = \begin{bmatrix} \sum_j 2a_j & \sum_j e_j & \sum_j f_j \\ \sum_j e_j & \sum_j 2b_j & \sum_j g_j \\ \sum_j f_j & \sum_j g_j & \sum_j 2c_j \end{bmatrix} \quad \beta = \begin{bmatrix} x^I \\ y^I \\ z^I \end{bmatrix}, \quad y = \begin{bmatrix} \sum_j h_j \\ \sum_j k_j \\ \sum_j l_j \end{bmatrix}, \quad \hat{\beta} = (X^t X)^{-1} X^t y,$$



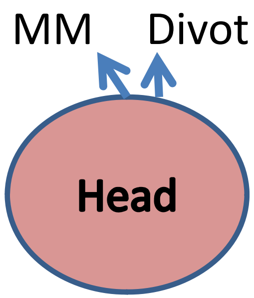
Experiment method

- Manual registration

  (divot) { image point-set: manually segment (<u>true location</u>)
  tracker point-set

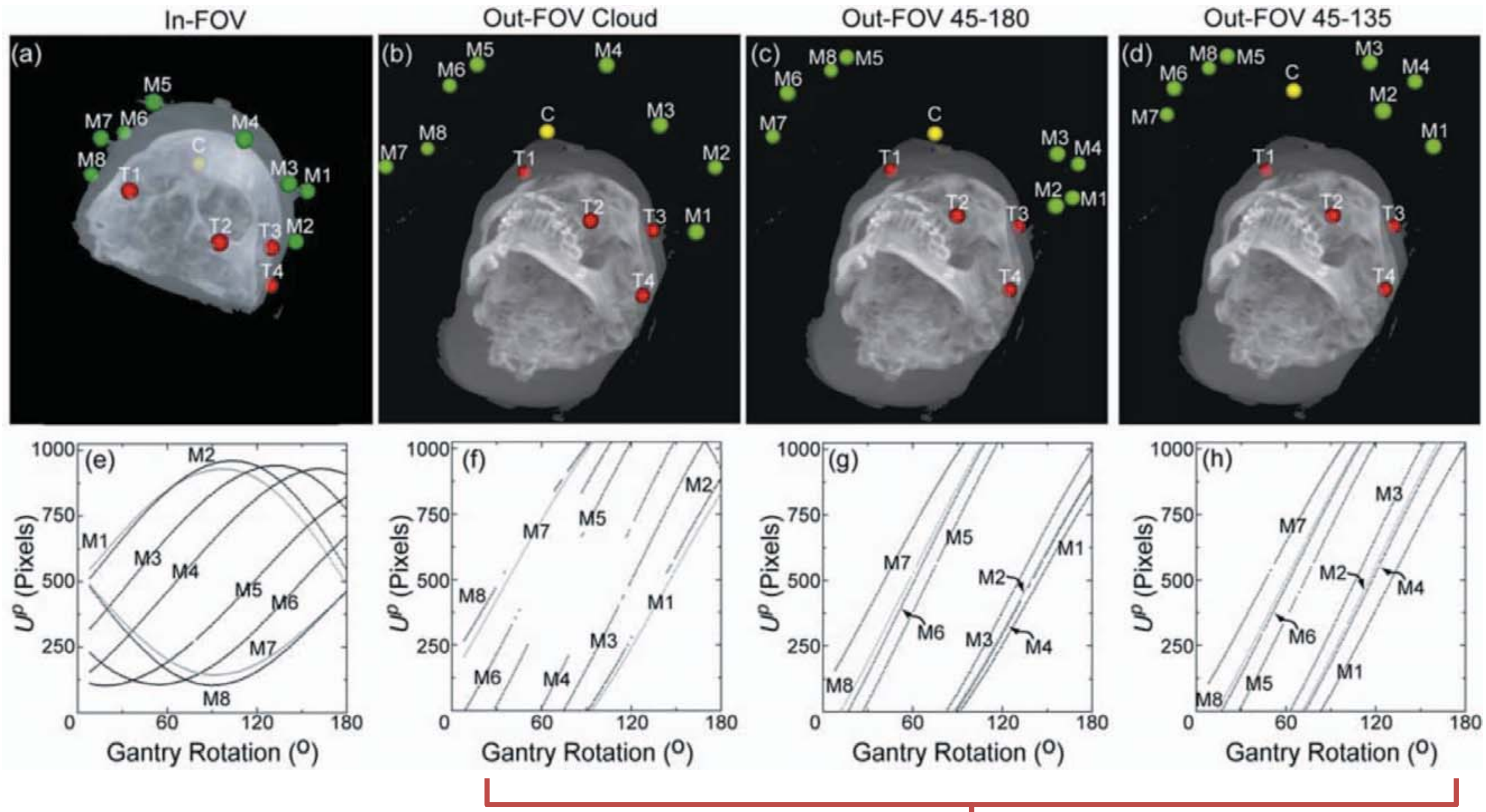
- Automatic registration

  (MM) { image point-set
  tracker point-set



- Ten times for each registration -> mean and standard deviation

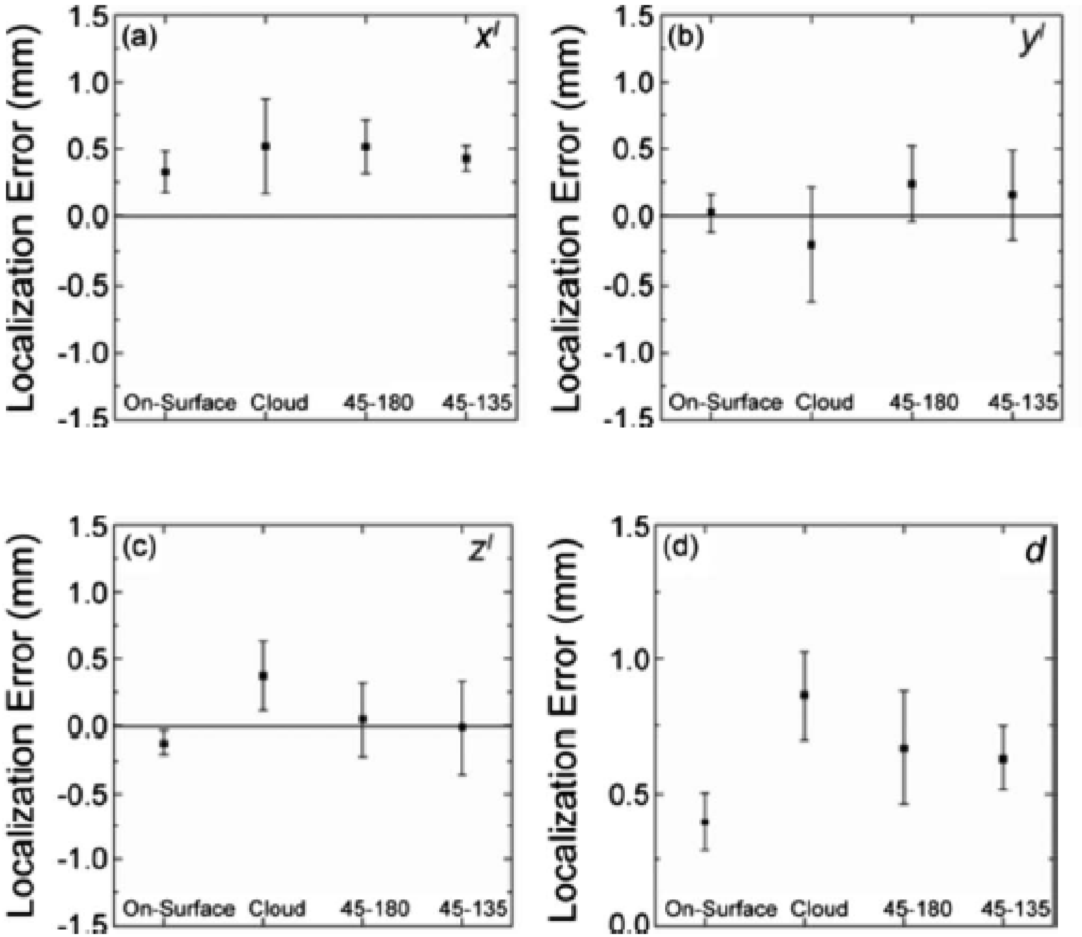
Marker configuration



Novel configuration on curved plate:

(1) Overcome the lack of rigid anatomy
(2) Centroid nearer to subcranium target
(3) Surgically unobtrusive

Image point-set localization accuracy



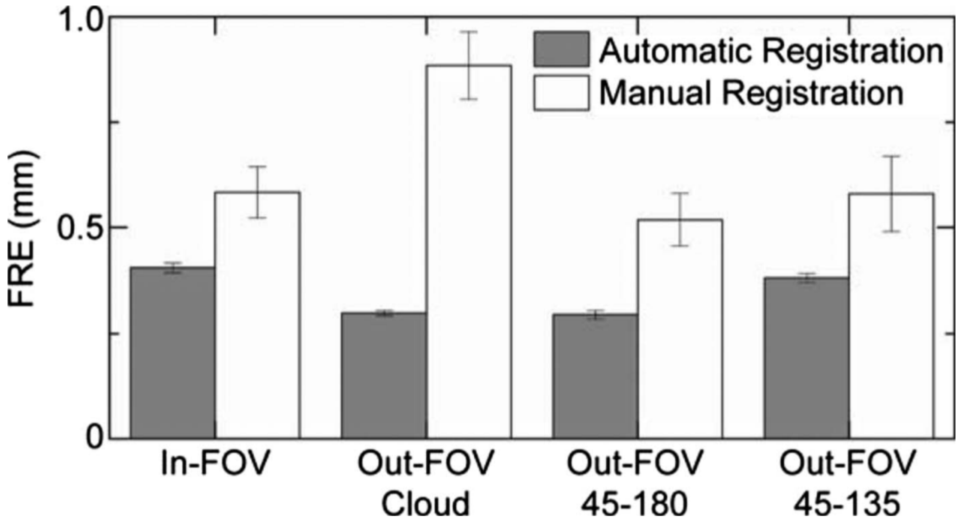
- Localization error

difference { True location / Location by auto-segment

- In-FOV: 0.39 ±0.11mm
- Out-FOV:
  - Cloud: 0.86 ±0.16mm
  - 45-180: 0.67 ±0.21mm
  - 45-135: 0.63 ±0.11mm

Time:
In-FOV: 30s
Out-FOV: 20s

Automatic vs. manual registration(1)



- FRE: fiducial registration error

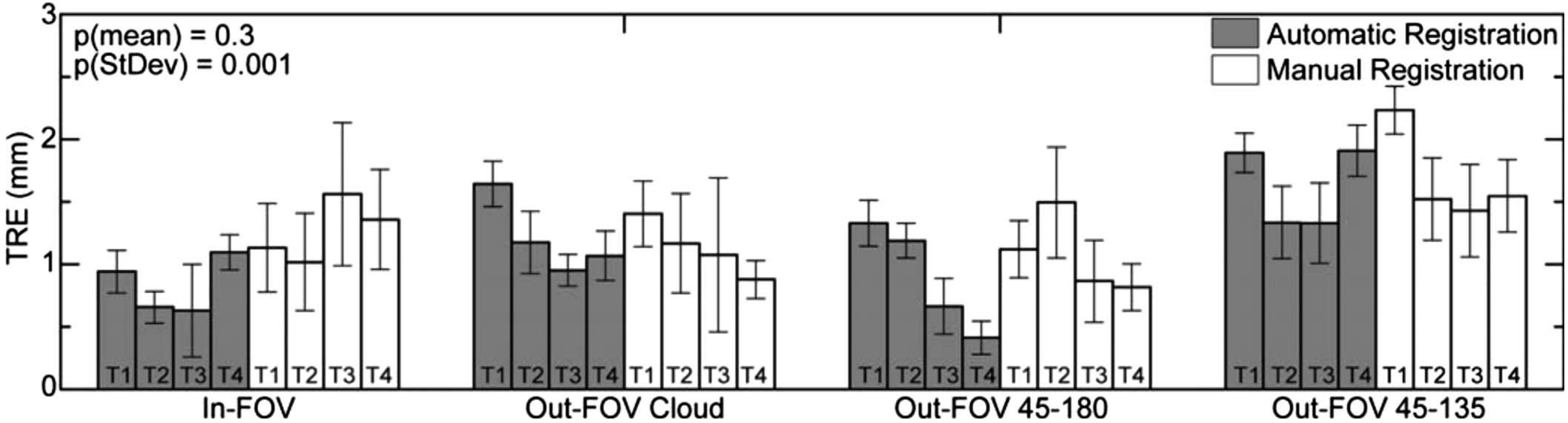
difference { true point sets / registered point sets (transformed from tracker point sets)

- Result

Lower FRE { automatic: 0.3-0.4mm / manual: 0.5-0.8mm (agree with previous studies)

Greater reproducibility

Automatic vs. manual registration(2)



- TRE: target registration error

difference { true point sets / registered point sets (transformed from tracker point sets)

- Result

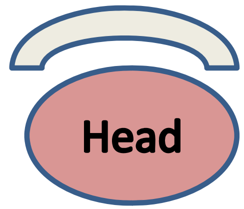
Not statistically significant { automatic: 1.14 $\pm$ 0.20mm / manual: 1.29 $\pm$ 0.34mm

Greater reproducibility

The TRE here is experiment-based, not theoretical.

- Conclusion
  - The automatic technique demonstrates equivalent or superior performance to manual one → replace manual
  - Various out-FOV configurations exhibits similar TRE to in-FOV ones → design novel marker plate
- Assessment
  - <u>Importance</u>: bring innovation to typical image-to-world registration in computer integrated surgery field
  - <u>Relevance to me</u>: Integrate into our CBCT-Robot system, may put it in parallel with CBCT reconstruction
  - <u>Challenges to this paper</u>:
    - Can update registration only after a CBCT imaging
    - Based on Matlab, low software portability
    - Segmentation parameters requires pre-knowledge.
      - In some cases, markers are not segmented due to interference from overlying bony anatomy.

Curved plate



Thank you!

Q &A