3D-2D registration for surgical guidance: effect of projection view angles on registration accuracy.

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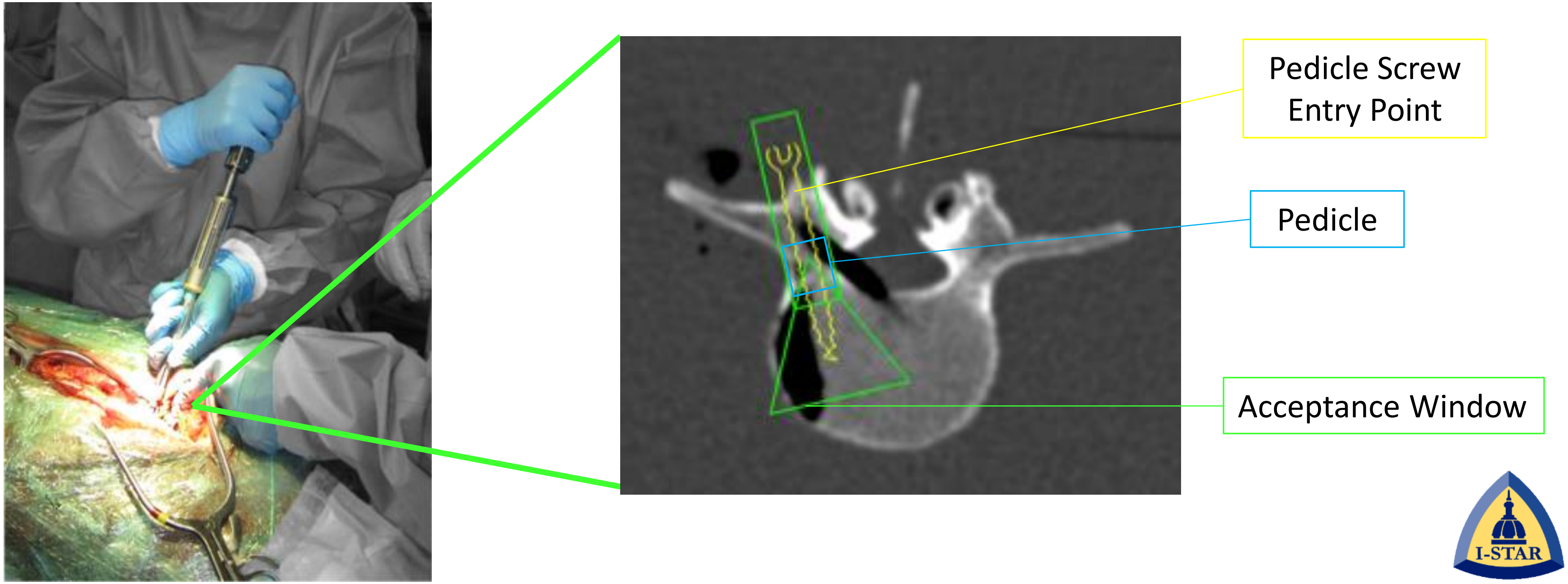
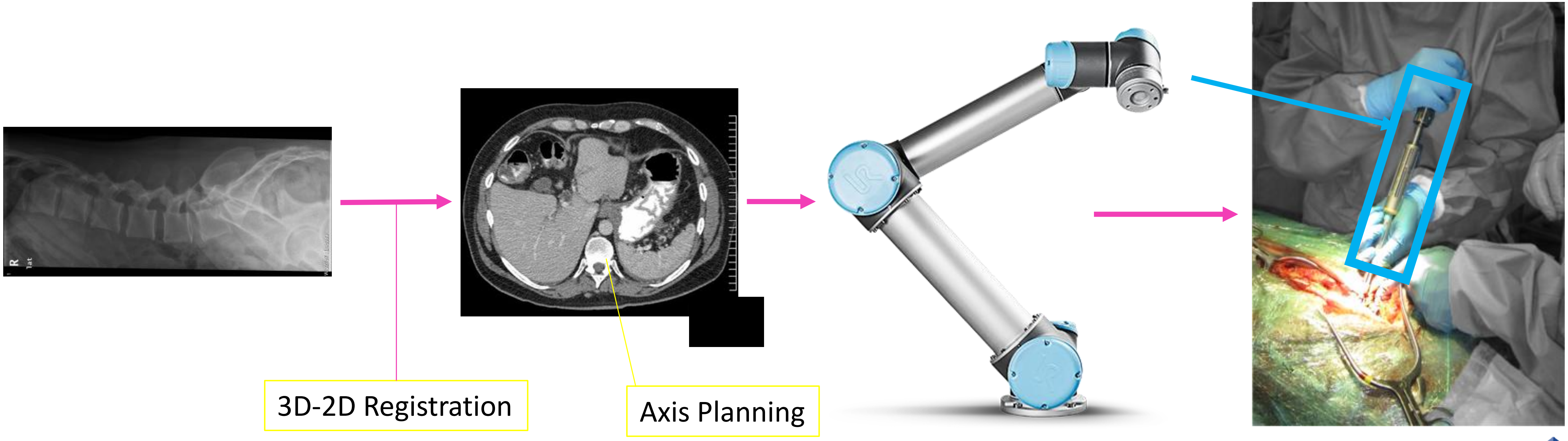
Project Summary

- Procedure is generally performed manually
- Precision could be increased with some assistance



Project Summary

- Noninvasive integration of the UR5 robotic arm into the pedicle screw placement procedure



3D-2D Registration

Axis Planning

Background 3D-2D Registration

- Used to maximize similarity between 2D image (radiograph or fluoro) and a DRR
- This paper uses the gradient information metric (GI) to define the similarity between fixed image and moving image.

Background 3D-2D registration (cont.)

- $GI(p_F, p_M) = \sum_{(i,j)\epsilon\Omega} w_{i,j} \min\left(\left|g_{F,i,j}\right|, \left|g_{M,i,j}\right|\right)$
- $g_{i,j} = \nabla p(i,j) := \left(\frac{d}{d_i} p(i,j), \frac{d}{d_j} p(i,j)\right)$
- $w_{i,j} = \frac{1}{2}\left(\frac{g_{F,i,j} g_{M,i,j}}{\left|g_{F,i,j}\right|, \left|g_{M,i,j}\right|} + 1\right)$
- $GI = \sum_{n=1}^{N} GI(p_{F,n}, p_{M,n})$
- $T_{Fluoro}^{CT} = argmax\ GI\left(p_F, p_M\left(T\left(t_x, t_y, t_z, r_x, r_y, r_z\right)\right)\right)$

Setup

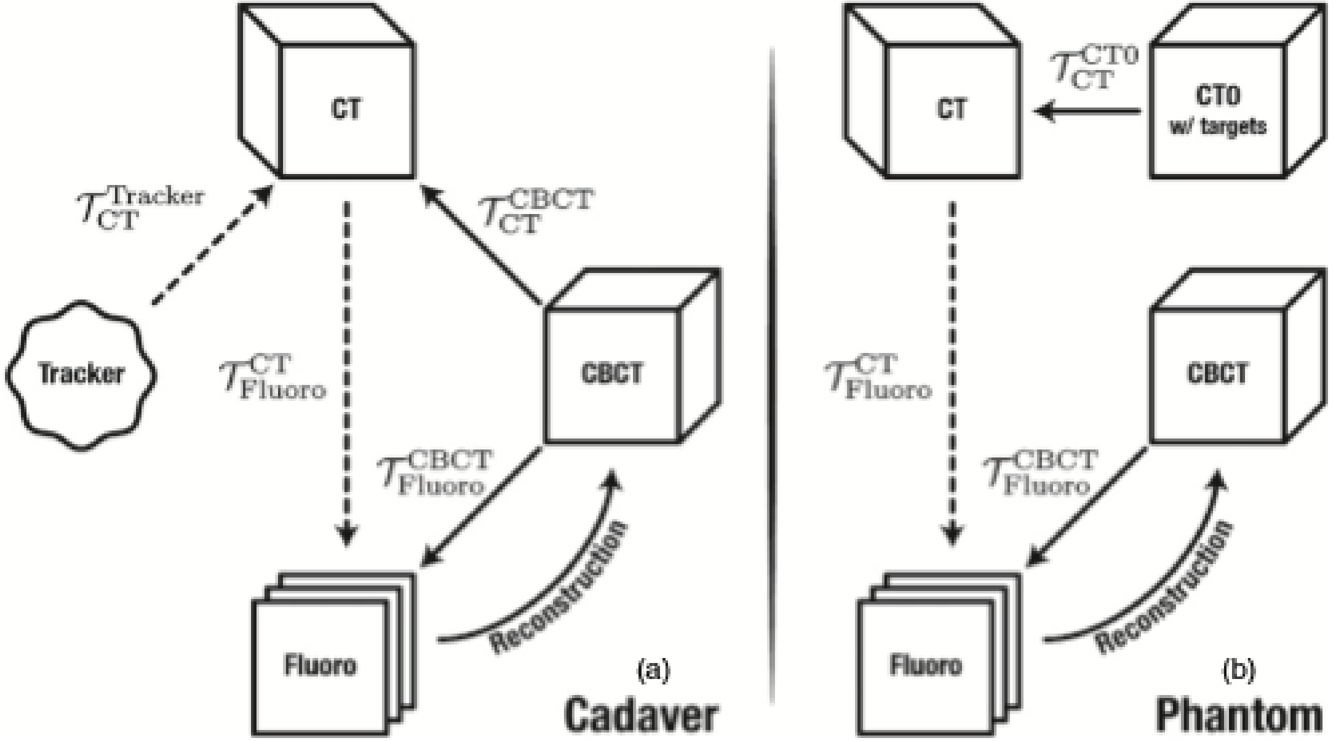


Figure 3. Flowcharts depicting the coordinate transforms for (a) cadaver and (b) phantom studies. Dotted lines signify the final registrations used for both fluoroscopy and tracker guidance.

Experiment – Angular Separation

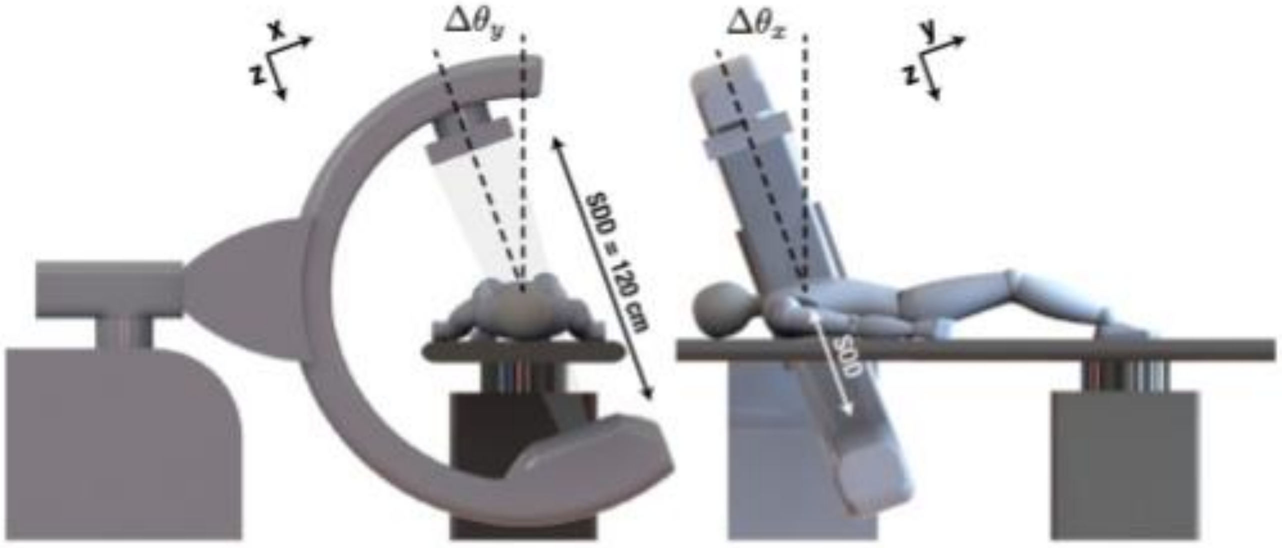


Figure 1. Illustration of mobile C-arm geometry, coordinate frames and angulations ($\Delta\theta$ about the longitudinal or lateral axis) to achieve projection image pairs.

Experiment – Registration Accuracy

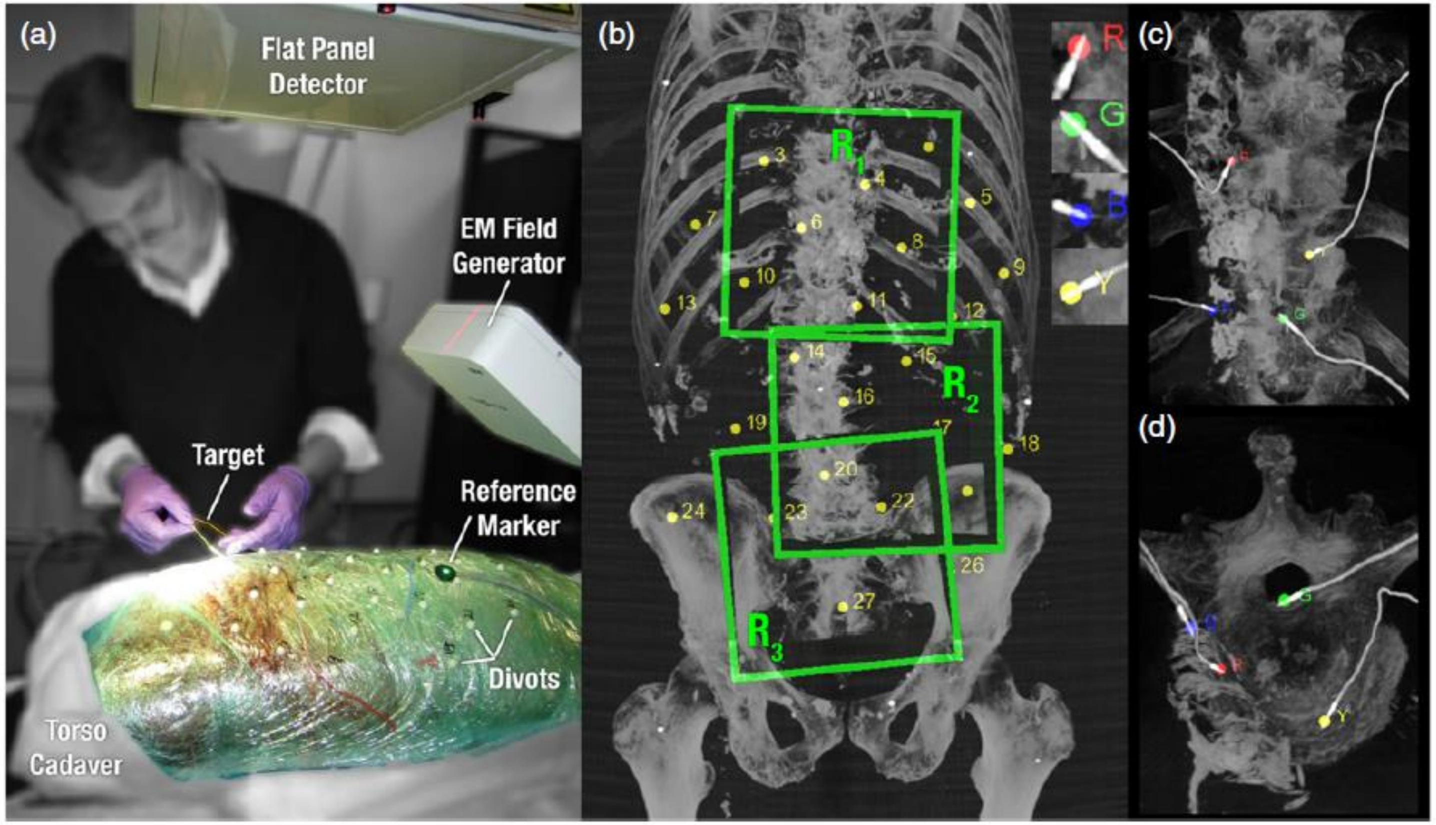


Figure 2. Illustration of: (a) experimental setup and materials in the cadaver study; (b) three anatomical regions spanning the thorax, abdomen and pelvis, along with surface fiducials used for tracker registration; and (c) MIP renderings (in the R_1 thoracic region about the spine) showing the four implanted EM coils (labeled R, G, B, Y) used as targets.

Experiment – Magnification

$$m := \frac{SDD}{SOD}$$

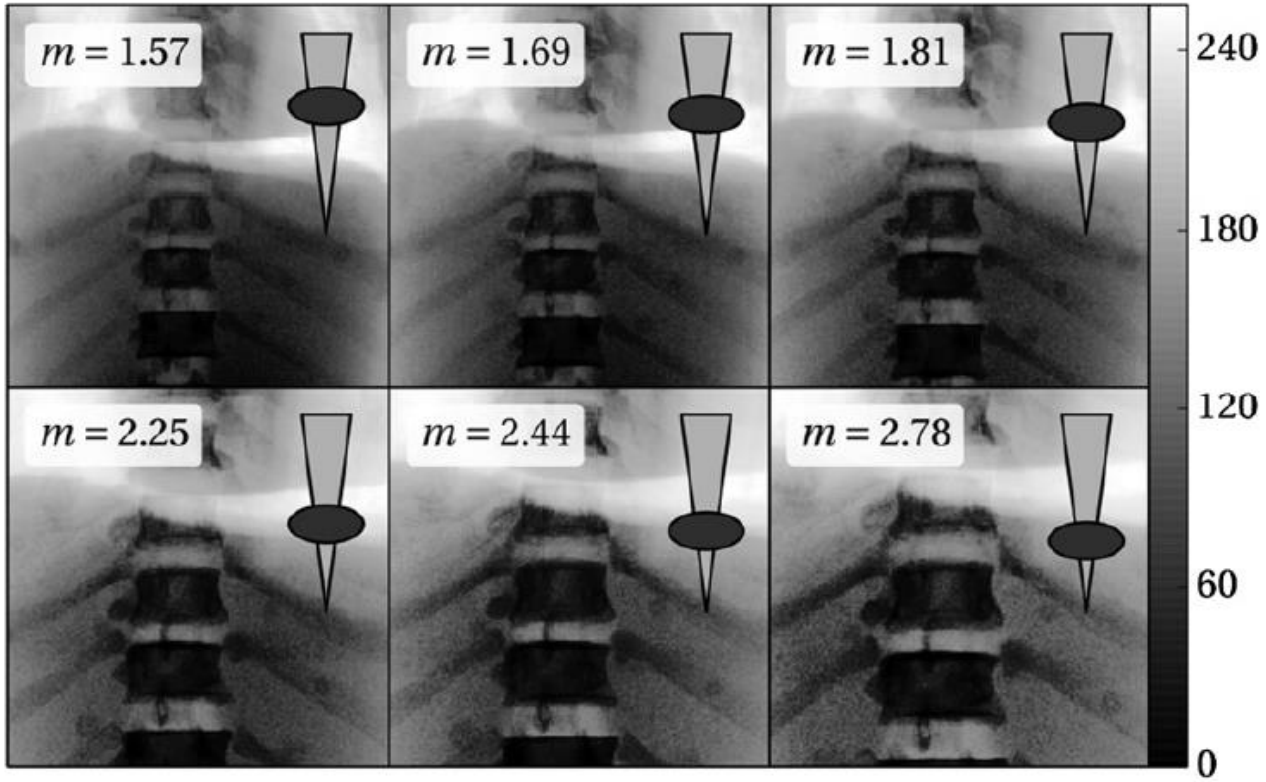


Figure 4. PA radiographs of the chest phantom (histogram-equalized for purpose of display) at varying C-arm magnification. Note the reduction in FoV as the magnification is varied from $m = 1.6$ to 2.8. The superimposed ellipse (body) and triangle (x-ray beam) illustrate the change in table height giving the corresponding magnification.

Experiment – Pixel and Voxel Binning

- Pixel Binned: 0.3 – 2.4 mm
- Voxel Binned (along z): 0.6-4.8 mm

- Siddon projection used to avoid bias

PDE and TRE

- $PDE_{3D2D} = L2_{norm}\Big(\big(P_{Fluoro}T_{Fluoro}^{CT}T_{CT}^{CBCT}x_{CBCT}\big) - \big(P_{Fluoro}T_{Fluoro}^{CBCT}x_{CBCT}\big)\Big)$

- $PDE_{Tracker} = L2_{norm}\Big(\Big(P_{Fluoro}T_{Fluoro}^{CBCT}\big(T_{CT}^{CBCT}\big)^{-1}T_{CT}^{Tracker}x_{Tracker}\Big) -$

Results

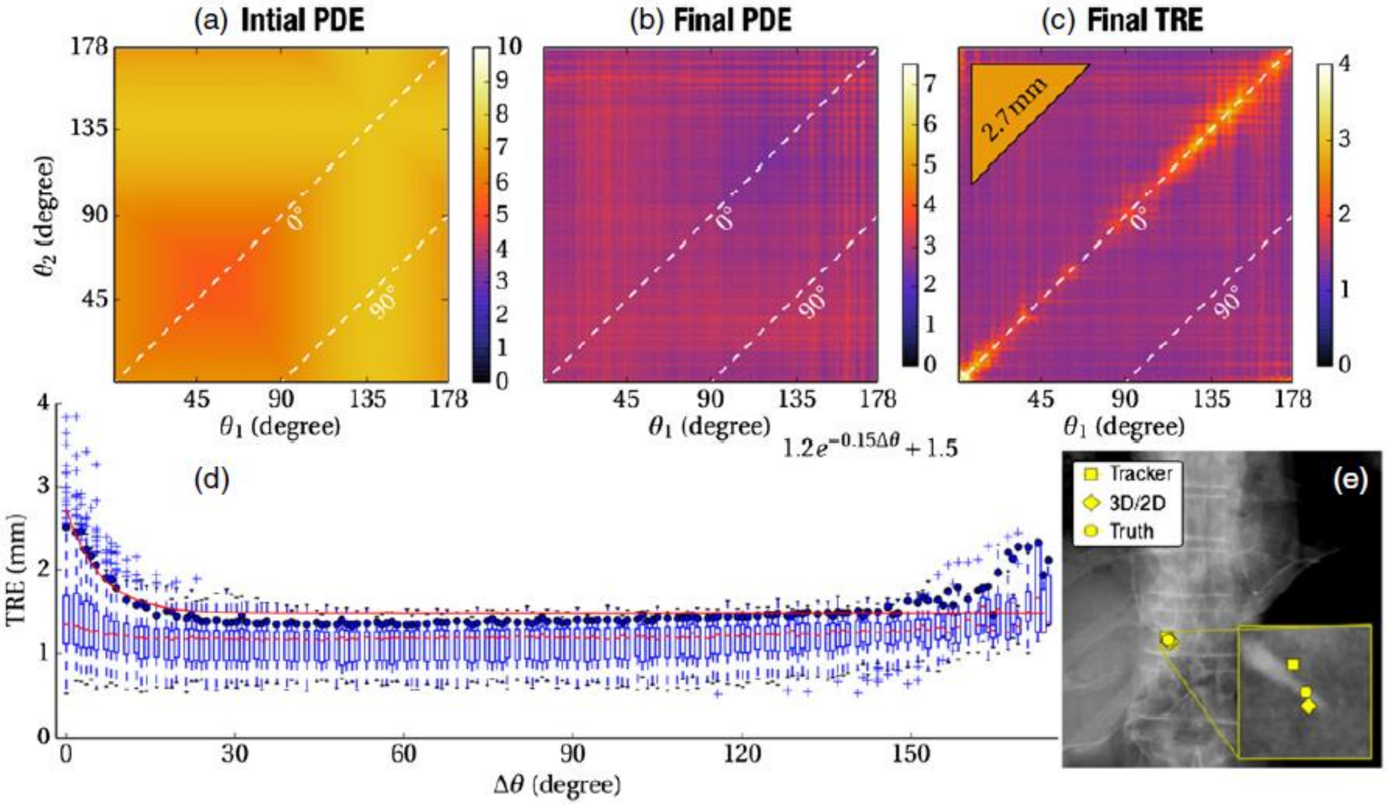
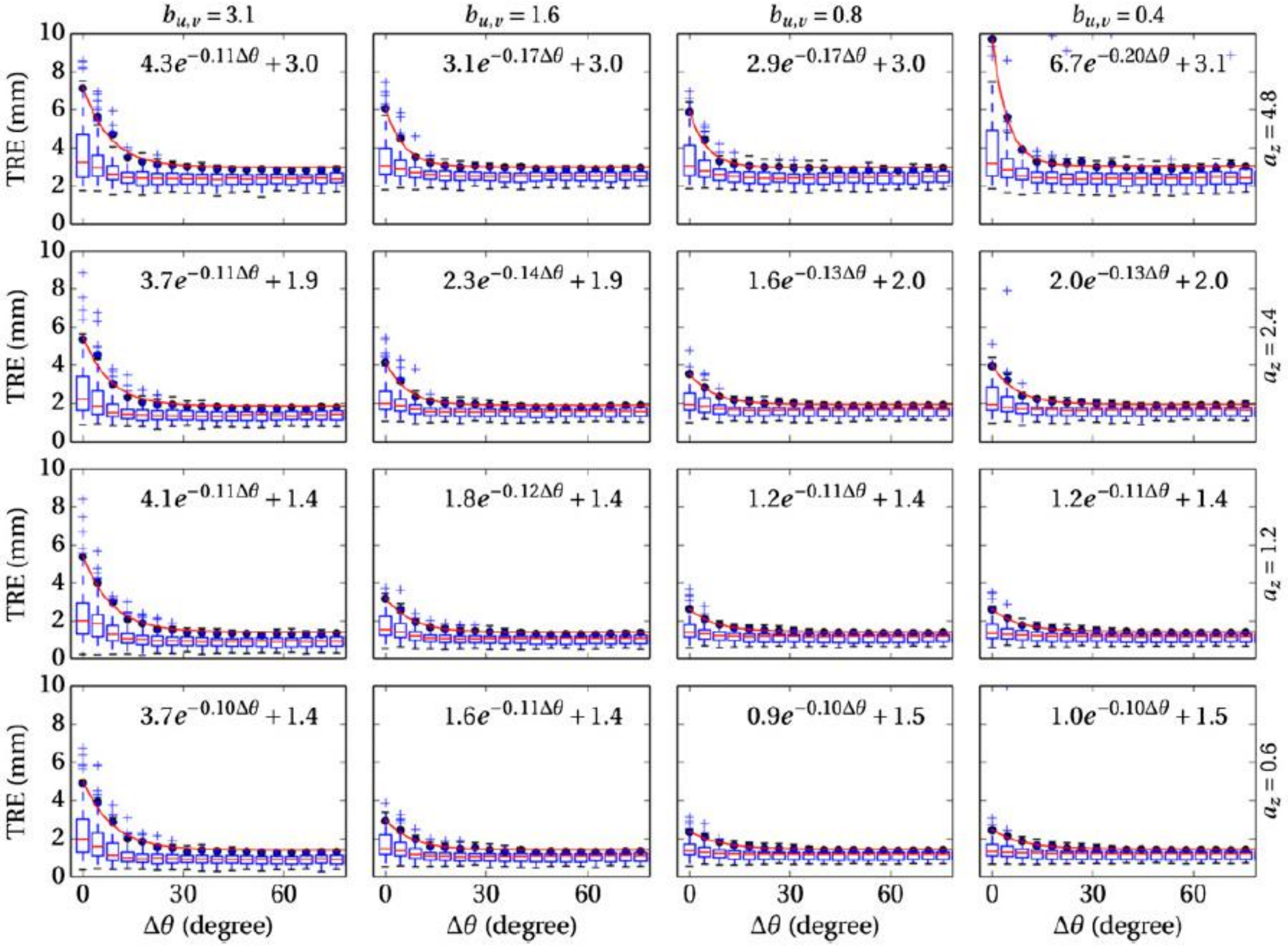


Figure 5. Effect of angular separation on 3D–2D registration accuracy. (a) The initial PDE prior to registration. (b) The PDE following 3D–2D registration. (c) The TRE following 3D–2D registration, (d) TRE plotted versus the angular separation ($\Delta\theta$) between projection views. (e) Example PA fluoroscopy image of the cadaver overlaid by the target position as assessed by (circle) truth, (diamond) 3D–2D registration and (square) the EM tracker.

Results (cont.)



Results (cont.)

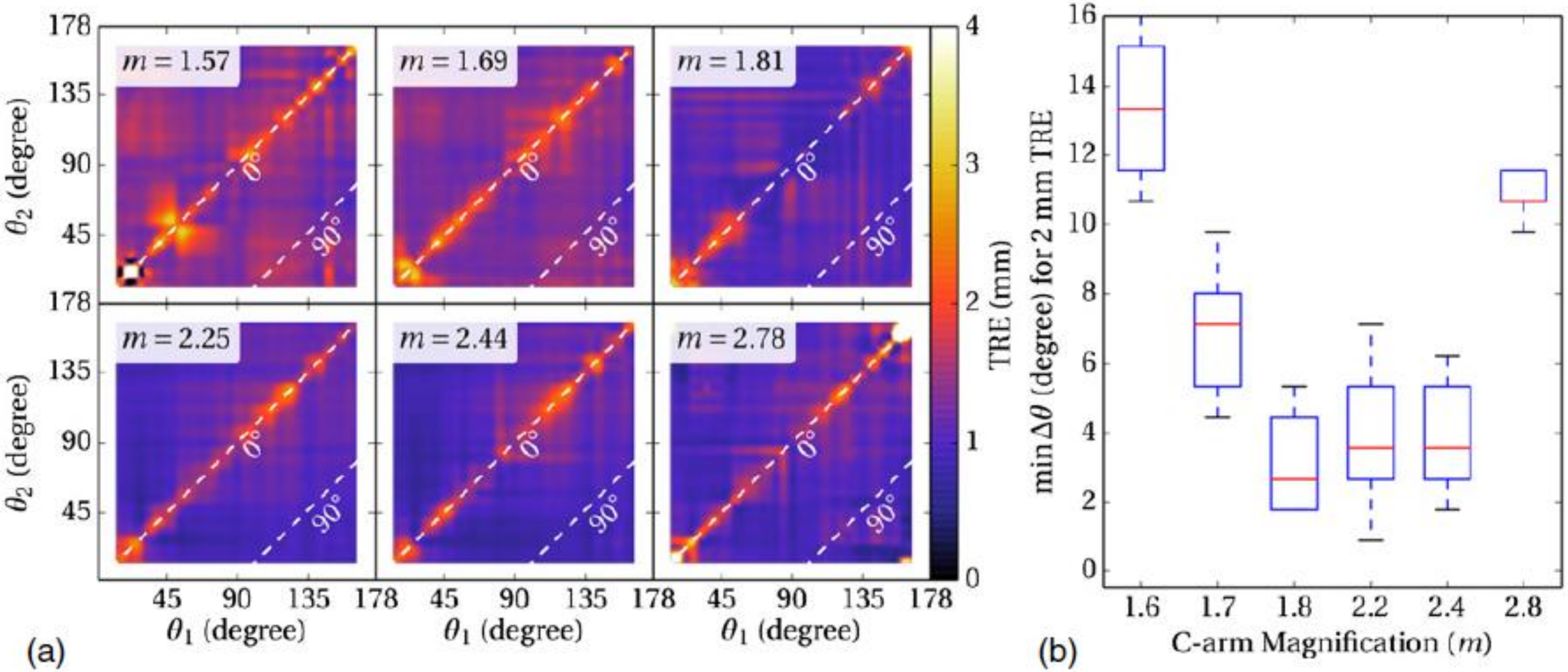


Figure 7. Effects of C-arm magnification on 3D–2D registration accuracy. (a) TRE as a function of projection view angles. (b) Minimum angular separation required to achieve TRE better than 2 mm measured as a function of C-arm magnification.

Discussion

- The primary result of the paper is to demonstrate that even a small angular separation $(\Delta\theta \sim 10\ degrees)$ is sufficient to get a TRE < 2mm.
- The paper demonstrates (both using PDE and TRE) that 3D-2D registration is more accurate than the EM tracker (which is the conventional method in use).
- TRE was shown to be a more robust metric for characterizing 3D localization especially in the case where there is low depth resolution.

Pros/Cons

- Pros
  - Easy to read/concepts well explained
  - Relevance to topic
  - Characterization of error metrics
- Cons
  - Detail for experimental setup were not well drawn out
  - Could have used more figures

Questions?