Estimation of Guidewire Inclination Angle for 3D Reconstruction

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Contents

This presentation has 20 slides.

This research has been supported by the European Community's Seventh Framework Programme under grant No. 285939 (ACROSS).

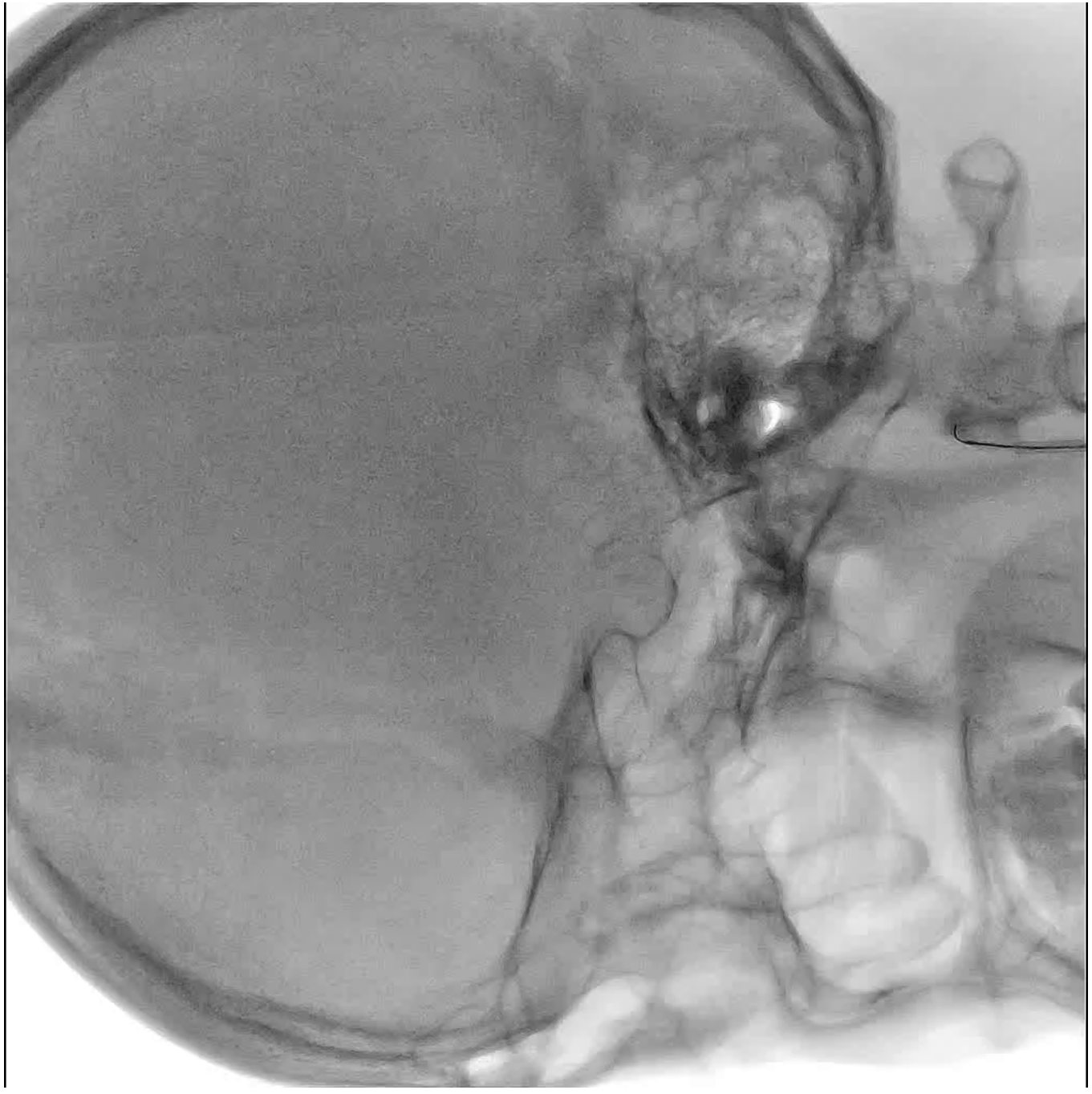
The authors would like to sincerely thank Robert Homan of Philips Healthcare for provided X-ray images.

Minimally invasive endovascular interventions

- Enable access to many regions via blood vessels.
- Minimize risk to the patient and improve health outcomes
- A guidewire is used to navigate to a point of interest.
- Fluoroscopic X-ray imaging is used as an navigational aid, however:
  - Soft tissue differentiation is difficult or impossible.
  - Fluoroscopy is inherently 2D (no 3D position).

Motivation

We want to extract as much information from the X-ray image to make the 3D position reconstruction possible and to further improve upon existing 3D reconstruction techniques proposed in the literature.



Multiplicative imaging model

Observed X-ray intensity may be approximated as:

$$I = I_0 \exp\left(-\sum_i \mu_i d_i\right) = I_0 \prod_i \gamma_i \tag{1}$$

where

- μ_i [cm^{-1}] is the linear attenuation coefficient
- $\gamma_i = e^{\mu_i d_i}$ is the multiplicative attenuation factor

Model of Eq. (1):

- is valid for a narrow energy band
- disregards the beam diffusion

Imaging model and the guidewire

- Let γ_{gw} denote the multiplicative term of the guidewire.
- Intensity where the guidewire is ABSENT:

$$I_1 = I_0 \prod_i \gamma_i \tag{2}$$

- Intensity where the guidewire is PRESENT:

$$I_2 = \exp(-\mu_{\text{gw}} d_{\text{gw}})\, I_0 \prod_i \gamma_i = \gamma_{\text{gw}} I_1 \tag{3}$$

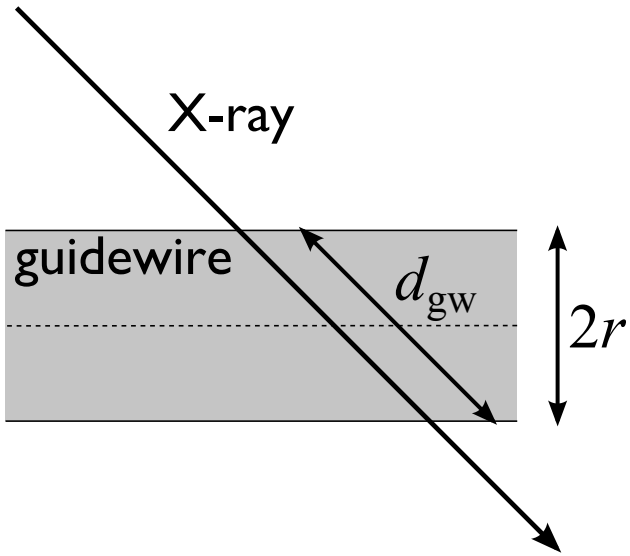
- We assume a thin guidewire.

Projected thickness

Assume we know the intensities of a pixel with and without the guidewire.

- Guidewire attenuation factor is recoverable by division:

$$\frac{I_2}{I_1} = \frac{I_1 \gamma_{\text{gw}}}{I_1} = \gamma_{\text{gw}}$$



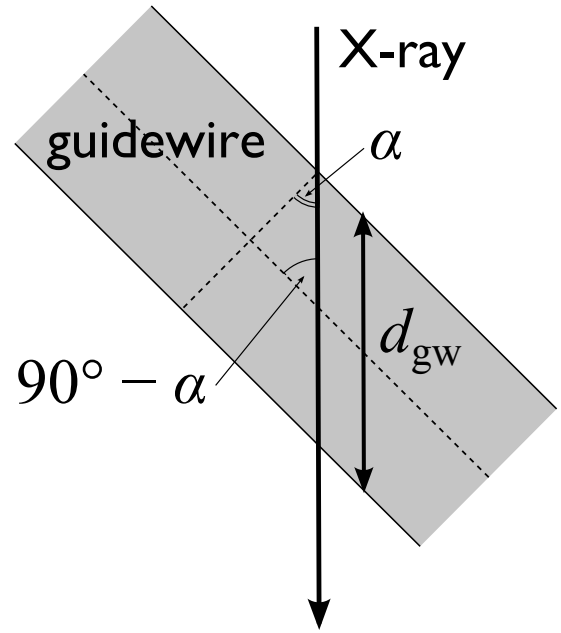
- Given μ_{gw} projected thickness is

$$d_{\text{gw}} = -\frac{1}{\mu_{\text{gw}}} \log \gamma_{\text{gw}} = -\frac{1}{\mu_{\text{gw}}} \log \frac{I_2}{I_1}$$

Projected thickness

Limitations:

- d_{gw} is the length of the X-ray path through the guidewire
- to recover d_{gw} the value of $\mu_i\,[\text{cm}^{-1}]$ must be known
- X-ray imaging system must be calibrated

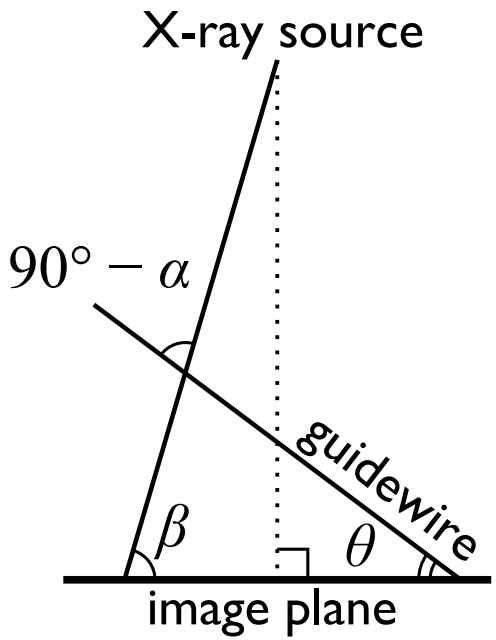


However:

- angle α may be recovered without calibration

$$2r = d_{\text{gw}} \cos(\alpha)$$

Inclination angle



- Inclination angle θ is the angle between the image plane and the guidewire center-line.
- Given known imaging geometry the inclination angle is:

$$\theta = 90° + \alpha - \beta$$

- Angle α is:

$$\cos(\alpha) = \frac{2r}{d_{\text{gw}}} = \frac{\log \gamma_{\text{gw,min}}}{\log \gamma_{\text{gw}}}$$

- Angle β is given by C-arm imaging geometry.

Steps to estimate the inclination angle

1. Segment the guidewire in the X-ray image and measure intensity values I_2.
2. Estimate the background values I_1 using intensity values adjacent to pixels identified in step 1.
3. Compute the ratio

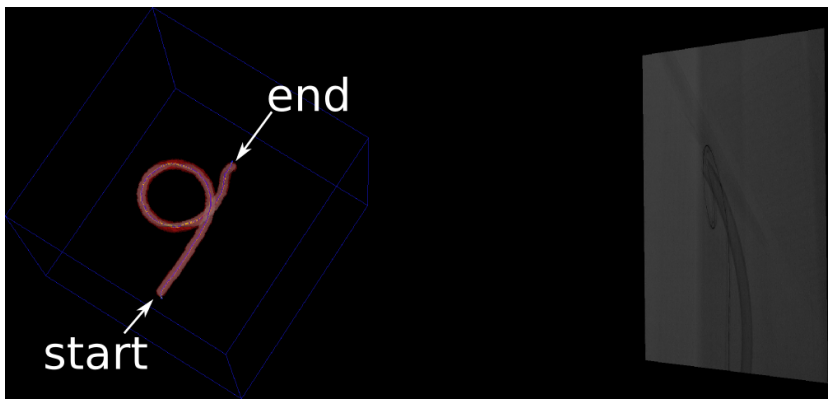
$$\frac{I_2}{I_1} = \frac{I_1 \gamma_{\text{gw}}}{I_1} = \gamma_{\text{gw}}$$

   and estimate the value $\gamma_{\text{gw,min}}$.
4. Estimate angles α and θ using equations

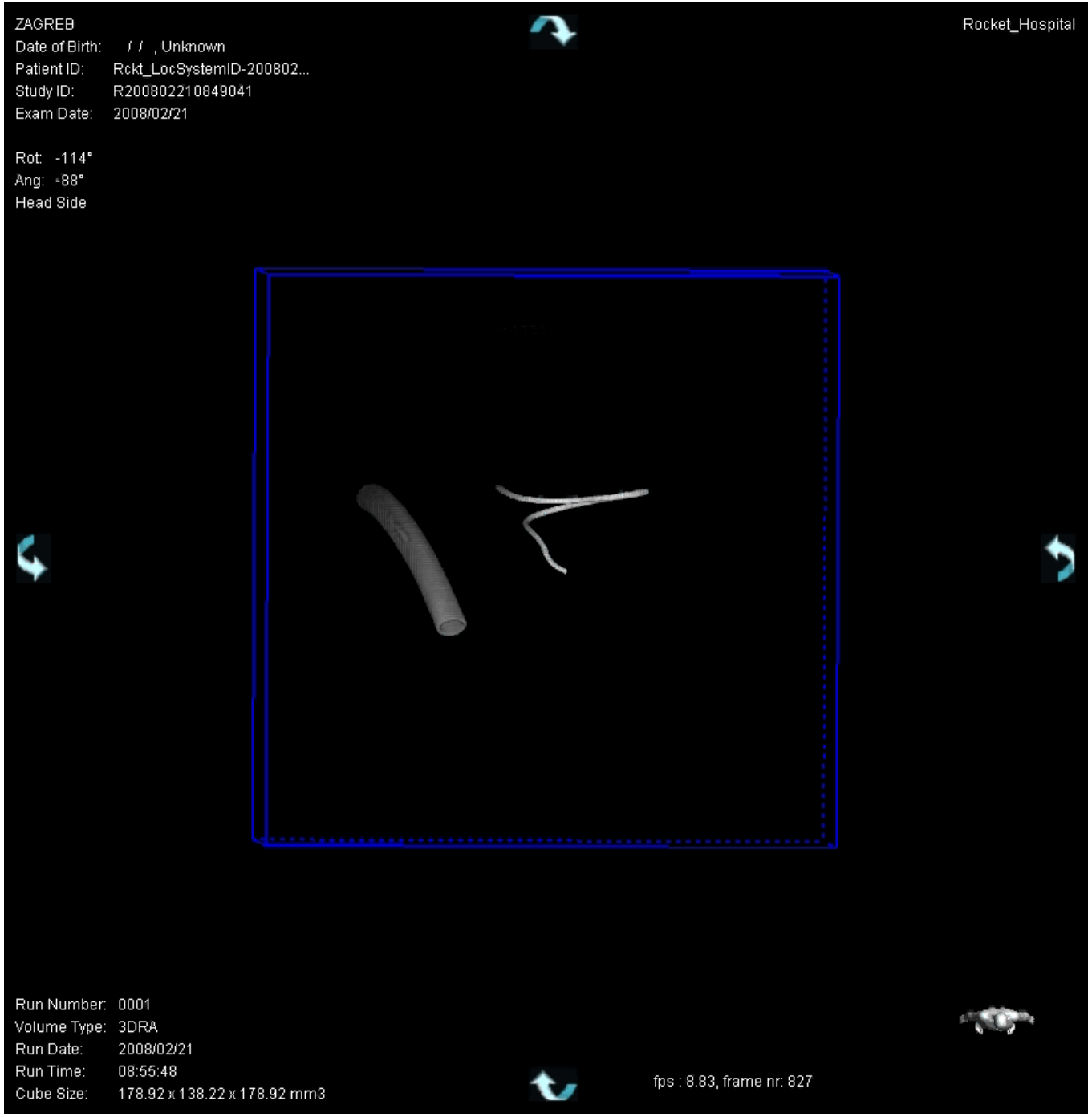
$$\cos(\alpha) = \frac{2r}{d_{\text{gw}}} = \frac{\log \gamma_{\text{gw,min}}}{\log \gamma_{\text{gw}}} \quad \text{and} \quad \theta = 90^\circ + \alpha - \beta.$$

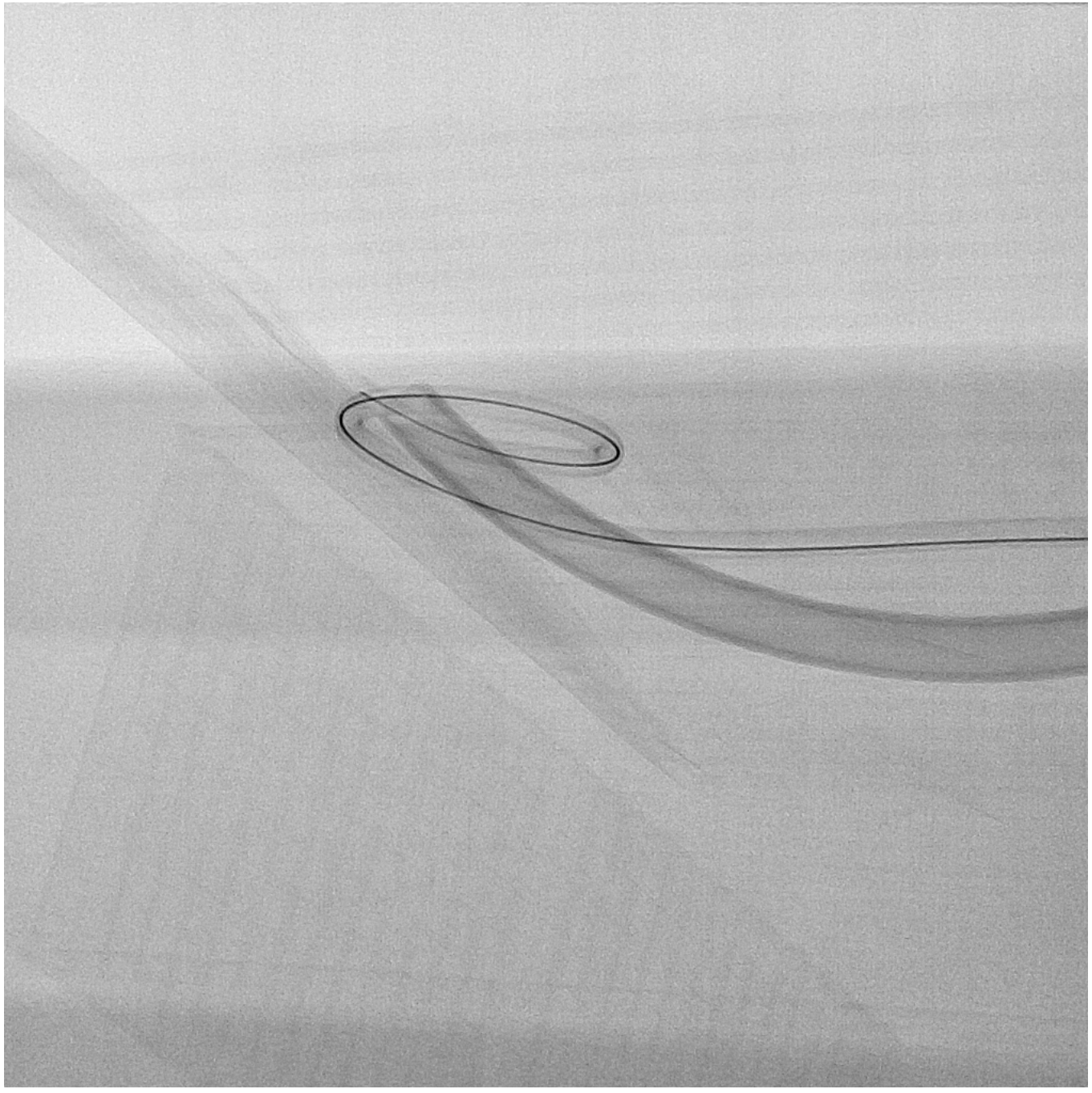
Experimental setup

- A trial image was acquired:
  - The guidewire forms a large circle located mostly in a plane orthogonal to the image plane.
  - Starting inclination angle is about 40°
  - This placement covers whole range of inclination angles of interest.

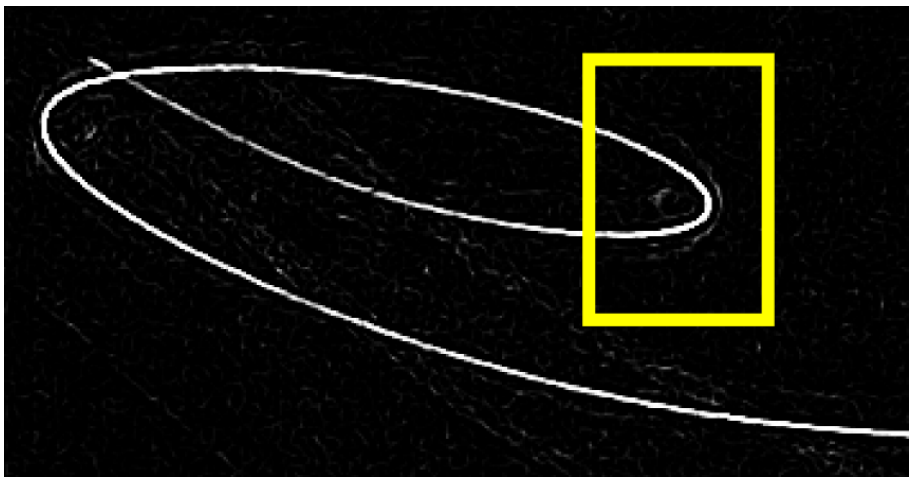


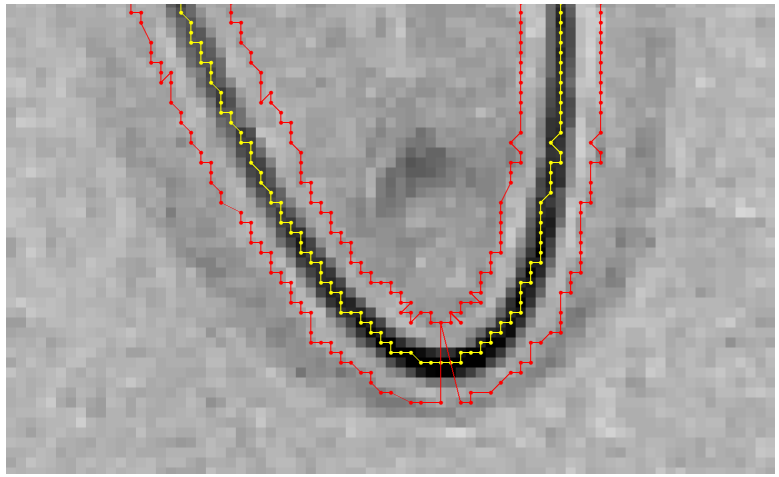
- Philips Allura X-ray imaging system:
  - 14 bits per pixel, pixel size 0.217 mm, image size 1016×1016


ZAGREB
Date of Birth: / / , Unknown
Patient ID: Rckt_LocSystemID-200802...
Study ID: R200802210849041
Exam Date: 2008/02/21
Rot: -114°
Ang: -88°
Head Side
Rocket_Hospital
Run Number: 0001
Volume Type: 3DRA
Run Date: 2008/02/21
Run Time: 08:55:48
Cube Size: 178.92 x 138.22 x 178.92 mm3
fps : 8.83, frame nr: 827



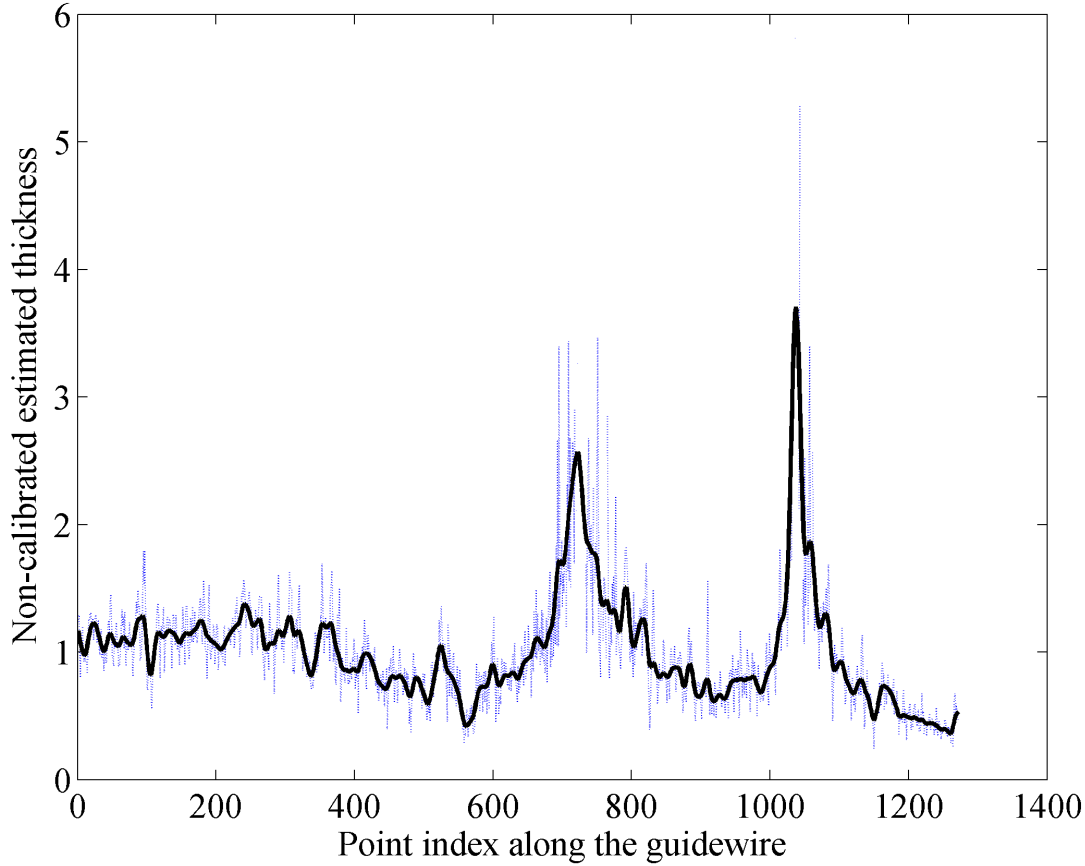
Segmentation and background estimation





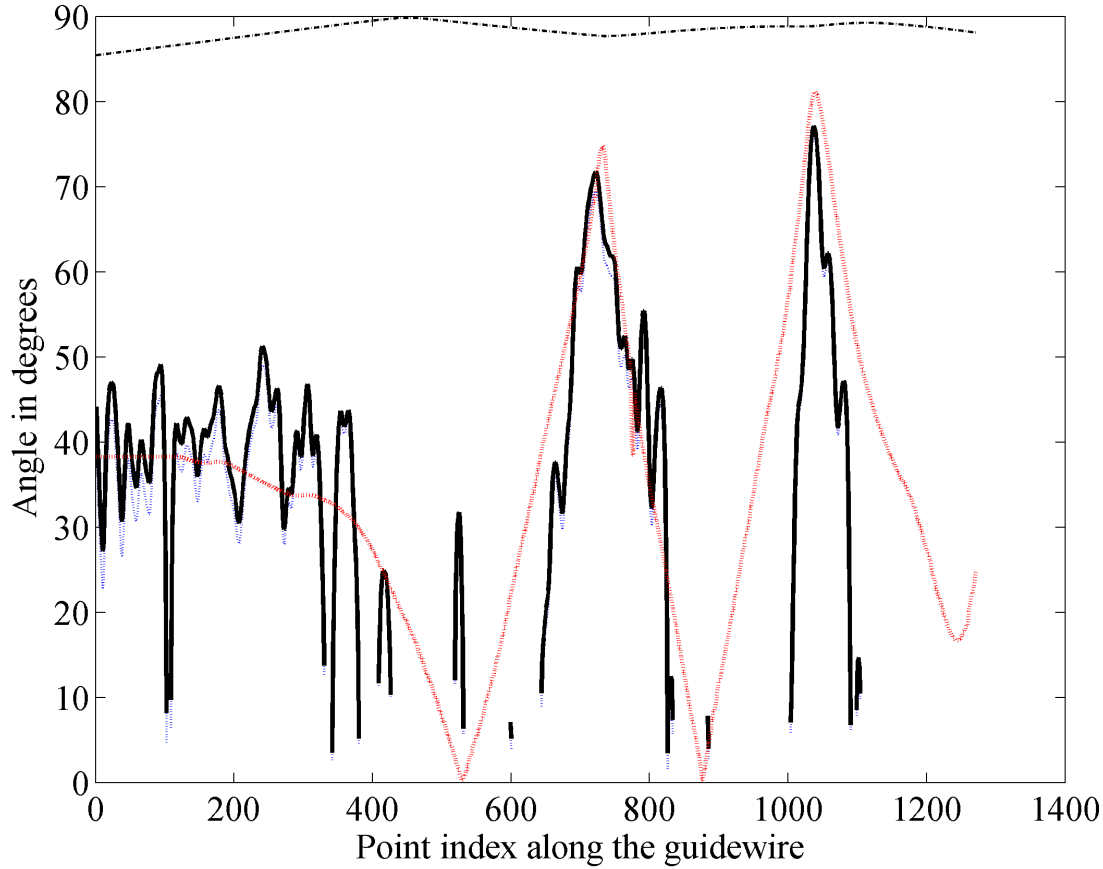
- Intensity I_2 is measured directly:
  - read intensity at guidewire pixels
  - adaptive vesselness (above) gives both guidewire position and its orientation
- Background I_1 is estimated (above):
  - guidewire pixels (yellow) are shifted $\sim 3\,\text{px}$ outside (marked red)
  - estimate is an artihmetic mean of adjacent pixels

Non-calibrated thickness d_{gw}



For this experiment we have manually estimated $\gamma_{gw,min} \approx 0.9$ using the value at the central position between the two peaks (position corresponds to the segment parallel to the imaging plane).

Estimated inclination angle θ



α is represented by a thin blue line; β is represented by a dotted black line; estimated θ is represented by a thick black line; and true θ is represneted by a thin red line.

Some statistics

- A total of 1272 pixels is segmented as the guidewire:
  - estimation succeeded for 678 pixels
  - estimation failed [1] for 594 pixels
- The average inclination angle error is $8.6 \pm 8.2^\circ$ (good first result).
- The maximum error is 52.5° (further work is needed).

The average error is a promising first result for application in 3D reconstruction, especially as further improvements are expected.

[1] Due to ratio $\log \gamma_{\text{gw,min}} / \log \gamma_{\text{gw}}$ being larger than one so a direct inverse cosine is undefined.

Conclusion

We have presented a novel estimation technique:

1. to recover the local angle between the guidewire and the X-ray path, up to an orientation, and
2. to recover the guidewire inclination angle toward the image plane, up to an orientation,

using a single fluoroscopic image.

Future work should focus on improving the estimation, including using sub-pixel precision and the Poisson noise formalism.

Furthermore, partial volume effects and beam diffusion must be included in the imaging model.

Questions?