Seminar Presentation:
Self-calibration of cone-beam CT geometry using 3D-2D image registration

04/28/16

Group 5 : Ju Young Ahn
Mentor: Dr. Jeff Siewerdsen
Dr. Matthew Jacobson, Dr. Tharindu da Silva, Dr. Joseph Goerres

Project Overview

Goal: Develop user-friendly interfaces to simulate fluoroscopic views of mobile C-arm

Challenge: “Fluoro-hunting”

- Multiple fluoroscopic shots taken for an optimal view
- Time consuming, radiation exposure, physically cumbersome, safety issue

Solution: Digitally Reconstructed Radiograph (DRR) generated from preoperative 3D CT data.

- Less time consuming
- Less radiation exposure for both physicians and patients
- Less user variability, more consistency

http://www.simeks.com.tr/en/portfolio-item/siemens-cios-alpha/

Paper Selection

Ouadah, S., J. W. Stayman, G. J. Gang, T. Ehtiati, and J. H. Siewerdsen. "Self-calibration of Cone-beam CT Geometry Using 3D–2D Image Registration."Physics in Medicine and Biology Phys. Med. Biol. 61.7 (2016): 2613-632. Web.

Goal: Geometric calibration method that registers the 2D projection data to a previously acquired 3D image of the subject, providing a ‘self calibration’ of the system

Challenges: 1) Out-of-date calibration (over-time, irreproducibility in the orbit)
2) Complicated non-circular orbits, inability to anticipate all possible trajectories

Relevance: One of our maximum deliverables is 3D-2D patient-CT image registration to get rid of optical tracking system

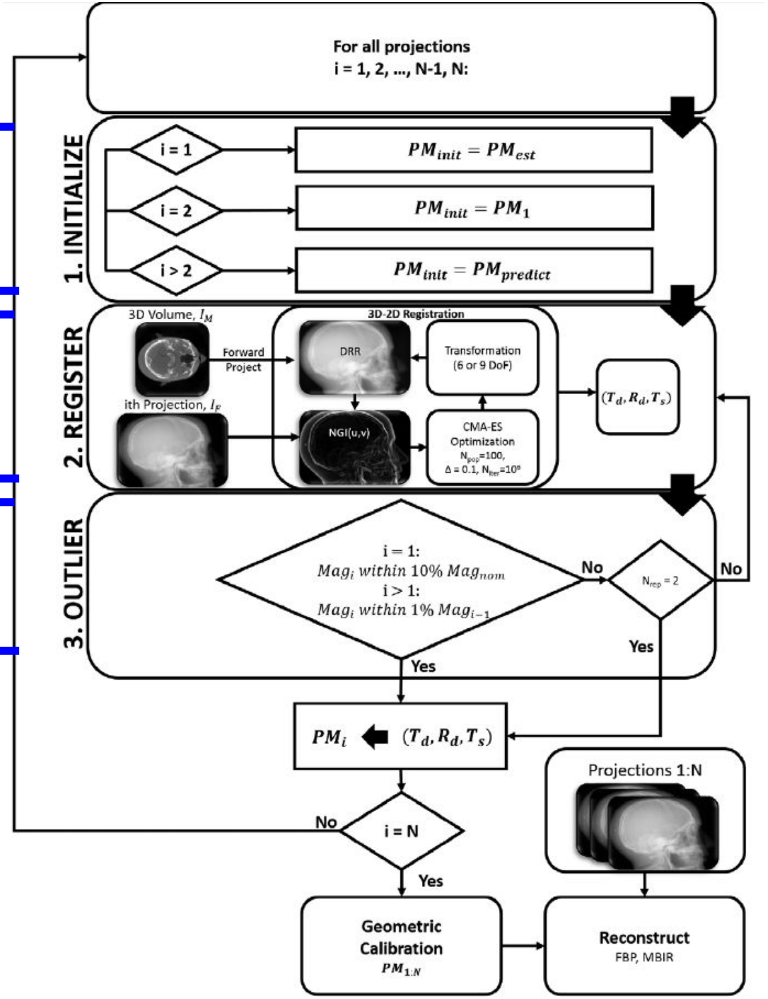
Technical Approach - Overview

Step 1. Registration is initialized

Step 2. 3D-2D Registration

: Solving for 6 or 9 DoF using **normalized gradient information (NGI)** as similarity metric and **covariance matrix adaptation-evolution strategy (CMA-ES) optimizer**

Step 3. Check for outliers



Technical Approach - 1. Initialization

i = 1 (first projection)

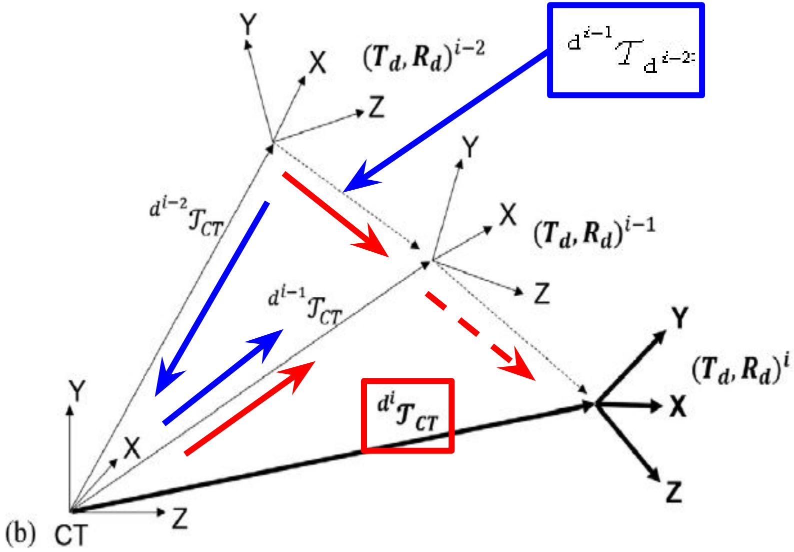
- Coarse estimation based on geometry: $T_{d,z}$ and $T_{s,z}$ are initialized as object-detector distance and detector-source distance
- For orientation, use brute force (rotate 90° about the 3 cardinal axes) to check for all possible 24 orientations and select whichever yielded maximum similarity as PM_1.

i = 2 (second projection)

- Initialized using PM_1

i > 2

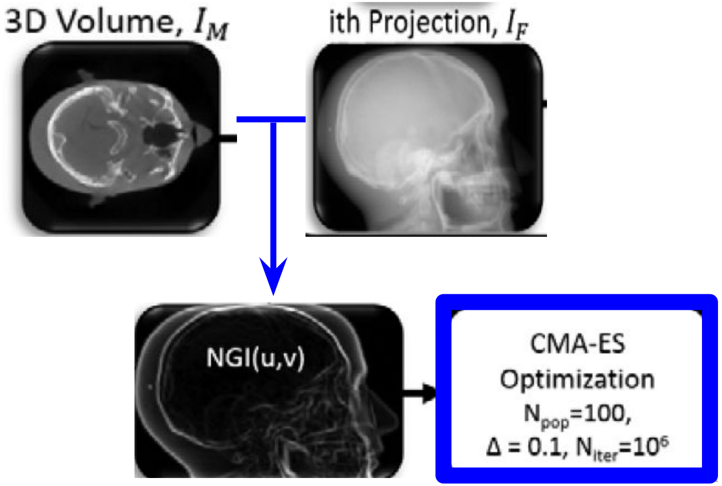
- $PM_{predict}$ is based on the geometries of the previous two views
- $${}^{d^{i-1}}\mathcal{T}_{d^{i-2}} = {}^{d^{i-1}}\mathcal{T}_{CT}\left({}^{d^{i-2}}\mathcal{T}_{CT}\right)^{-1}.$$
- $${}^{d^{i}}\mathcal{T}_{CT} = {}^{d^{i-1}}\mathcal{T}_{d^{i-2}}\left({}^{d^{i-1}}\mathcal{T}_{CT}\right),$$: Taken as initialization for *i*th view



Technical Approach - 2. 3D-2D Image Registration

- Based on work of Otake *et al* (2012, 2013)
- Incorporates **normalized gradient information (NGI)** as a robust similarity metric within the covariance matrix adaptation-evolution strategy (**CMA-ES**) optimizer
- **Similarity(NGI)** between CT (I_M) and 2D projection (I_F)
- $$\widehat{\boldsymbol{T}_s}, \widehat{\boldsymbol{T}_\mathbf{d}}, \widehat{\boldsymbol{R}_\mathbf{d}} = \underset{\boldsymbol{T}_s, \boldsymbol{T}_\mathrm{d}, \boldsymbol{R}_\mathrm{d} \in S}{\arg\max} \mathrm{NGI}(I_\mathrm{F}, I_\mathrm{M}(\boldsymbol{T}_s, \boldsymbol{T}_\mathbf{d}, \boldsymbol{R}_\mathbf{d})).$$
- PM is composed in this way:

$$\boldsymbol{PM} := \begin{pmatrix} T_{s,z} & 0 & T_{s,x} & 0 \\ 0 & T_{s,z} & T_{s,y} & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} \boldsymbol{R}_{3\times3}(R_{\mathrm{d},x}, R_{\mathrm{d},y}, R_{\mathrm{d},z}) & \begin{matrix} T_{\mathrm{d},x} \\ T_{\mathrm{d},y} \\ T_{\mathrm{d},z} \end{matrix} \\ 0 \quad 0 \quad 0 & 1 \end{pmatrix},$$



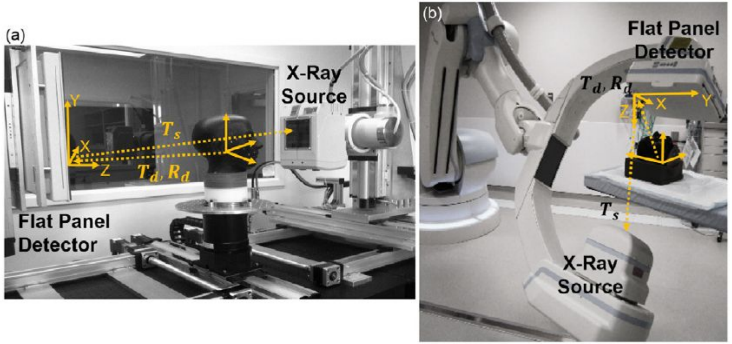
$$\mathrm{NGI}(I_\mathrm{F}, I_\mathrm{M}) = \frac{\mathrm{GI}(I_\mathrm{M}, I_\mathrm{F})}{\mathrm{GI}(I_\mathrm{F}, I_\mathrm{F})}$$

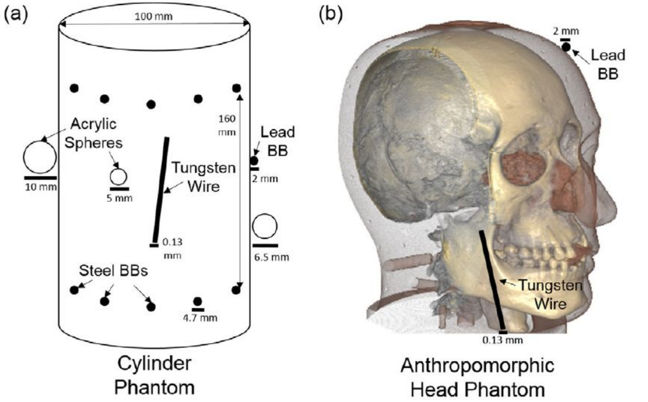
*3D-2D registration is performed for either 6 or 9 DoF.
An assumption that the source position (Ts) is fixed with respect to the detector reduces the system geometry from 9 DoF to 6 DoF.

Experimental Method - Overview

- **Experiment 1**: Cylinder phantom on imaging bench
- **Experiment 2**: Anthropomorphic head phantom on imaging bench
- **Experiment 3**: Anthropomorphic head phantom on robotic C-arm
- **Experiment 4**: non-circular orbit

- **Performance Evaluation Criterions**
  - Full-width at half maximum **(FWHM)** of a point spread function (PSF) (measured from the tungsten wire in each phantom) for spatial resolution evaluation
  - Reprojection error **(RPE)** associated with the position of the lead BB on the surface of both phantoms
  - Quality of 3D image reconstructions in terms of blur, noise, and artifacts (e.g. streak artifacts and distortion of high contrast details)

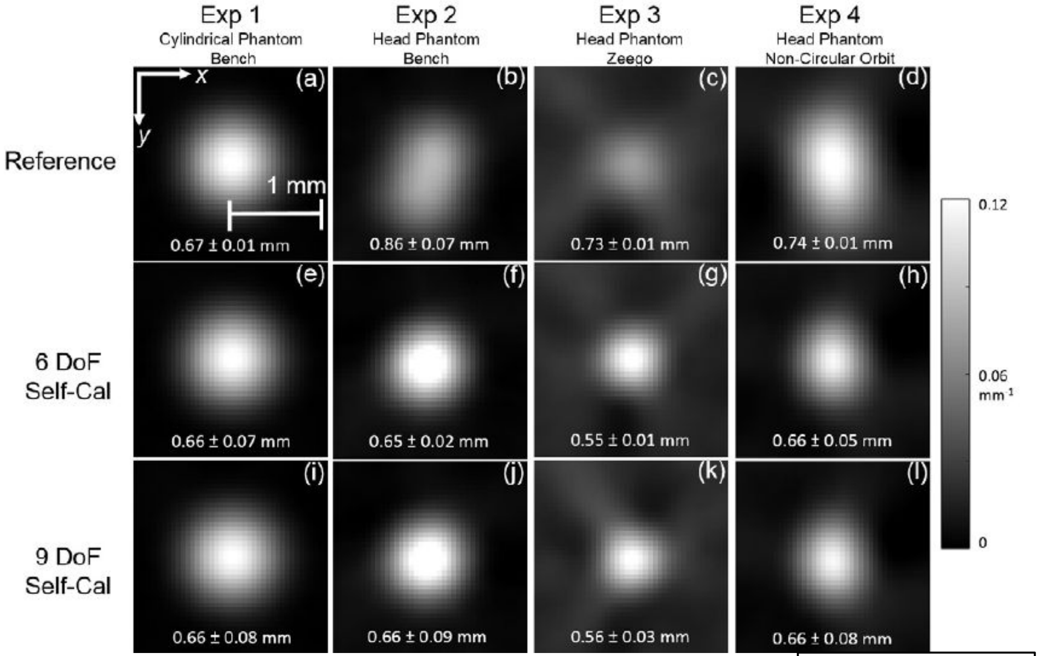




Results - 1. Spatial Resolution (FWHM of the PSF)

	EXP 1 (mm)	EXP 2 (mm)	EXP 3 (mm)	EXP 4 (mm)
Ref	0.67	0.86	0.73	0.74
6 DoF	0.66	**0.65**	**0.55**	**0.66**
9 DoF	0.66	**0.66**	**0.56**	**0.66**

- Exp 1 has similar results.
- Exp 2 and 3 shows improvement in FWHM. General shape and intensity of PSF is improved.
- Exp 4 shows feasibility of self-calibration method for non-circular orbits.



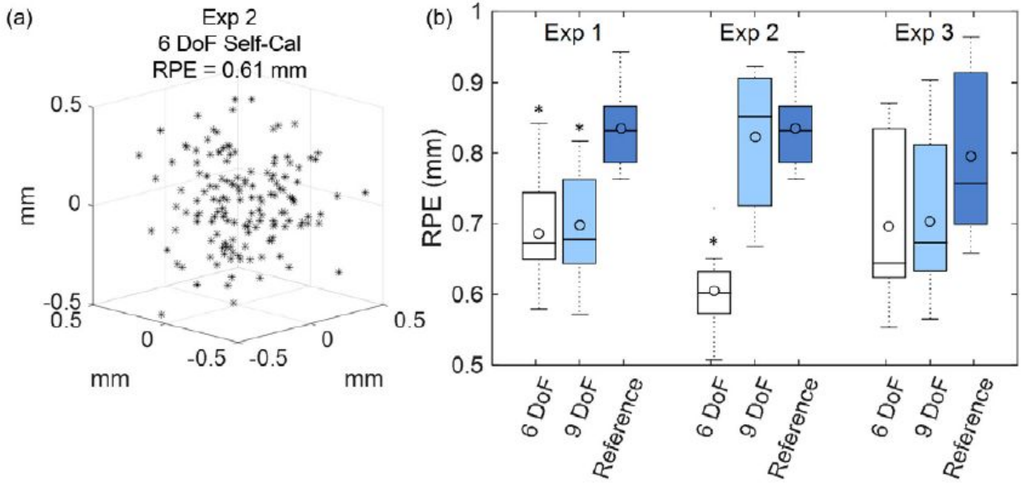
Exp1: Cylindrical phantom + bench
Exp2: Head phantom + bench
Exp3: Head phantom + C-arm
Exp4: non-circular orbit, head phantom + bench

Note: Reference calibration for exp 4 is for circular orbit

Results - 2. RPE

	EXP 1 (mm)	EXP 2 (mm)
Ref	0.83	0.84
6 DoF	**~0.69**	**0.61**
9 DoF		**0.82**

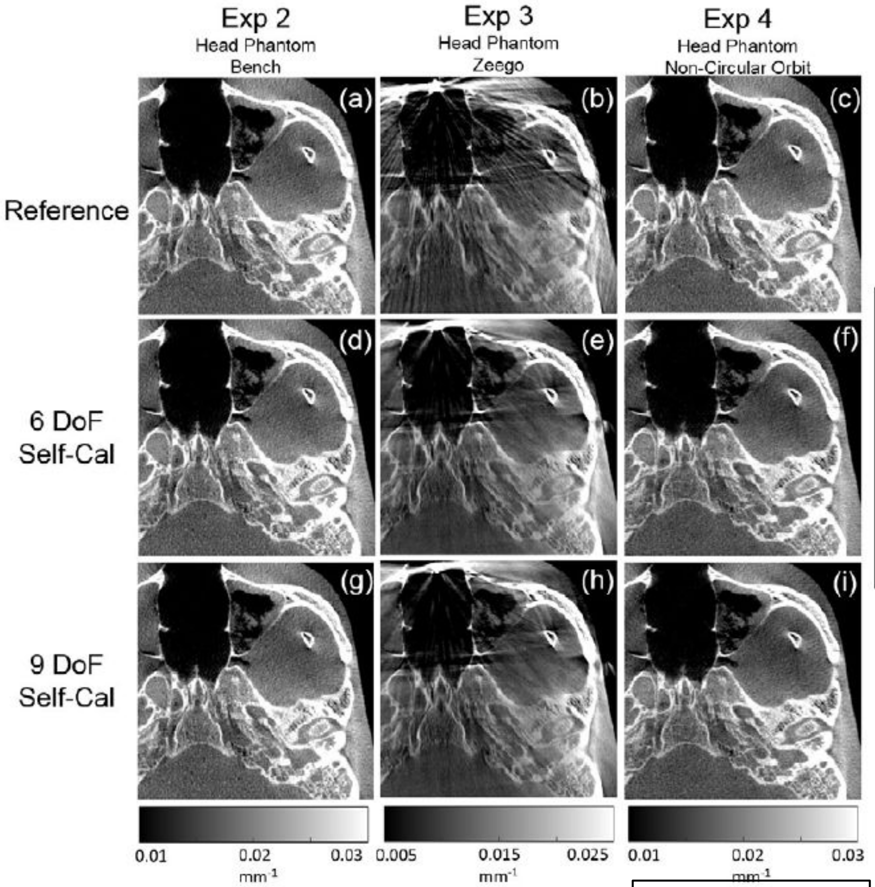
- In exp 1, statistically significant improvement in RPE for self-calibration
- In exp 2, 6 DoF self-calibration method shows significant improvement in RPE
- In exp 3, mean and median of RPE values are improved for self-calibration but the difference is not statistically significant.



Exp1: Cylindrical phantom + bench
Exp2: Head phantom + bench
Exp3: Head phantom + C-arm

Results - 3. Image Quality

- Exp 2 shows qualitatively accurate reconstruction of the skull image for both reference and self-calibration methods.
- Exp 3 shows noticeable improvement using self-calibration as streak artifact is reduced.
- Exp 4 shows that self-calibration using a saddle orbit (non-circular orbit) has qualitatively identical image reconstruction



Exp2: Head phantom + bench
Exp3: Head phantom + C-arm
Exp4: non-circular orbit, head phantom + bench

Note: Reference calibration for exp 4 is for circular orbit

Assessment

Pros:

- Experiments on multiple set-ups using simple object (cylindrical phantom) and complex object (head phantom) on imaging bench and robotic C-arm
- Tested multiple criterions (FWhM, RPE, image quality)
- Shows feasibility of geometric calibration on non-circular orbits

Cons:

- Image quality does not include quantitative supports.
- No mention of run-time for a complete scan.
- Refer to other paper for explanation (e.g. 3D-2D image registration), only listing of equations.

Conclusion

- Good possible method for 3D-2D image registration for one of our maximum deliverable in our project

- Applicable to our project since our C-arm can make oblique movements with non-circular trajectories.

Questions?