Checkpoint Presentation: Computer-Guided X-Ray C-arm Positioning

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Project Background: Motivation

C-arm: An X-ray imaging device with flexible positioning of X-ray source.

- Widely used for diagnostic imaging or surgical procedures in many areas including orthopedic surgeries.
- Multiple degrees of freedom (DOF) of the arm with angular and orbital movements allow guidance and localization for surgeons to set an optimal viewpoint

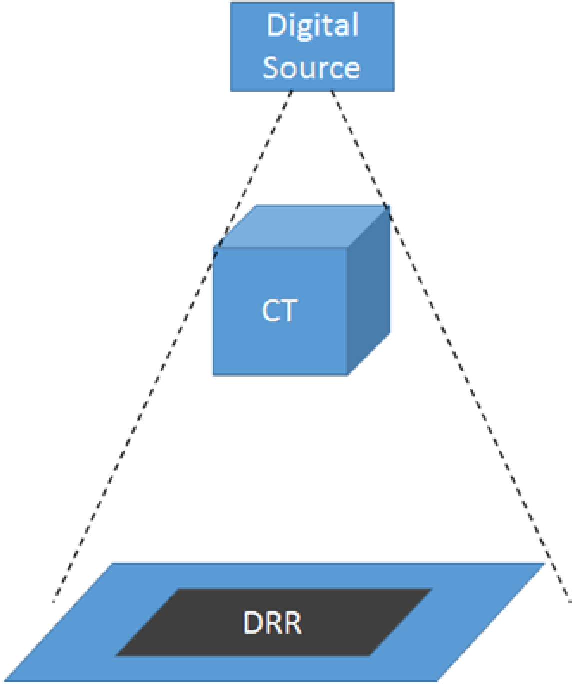
http://www.simeks.com.tr/en/portfolio-item/siemens-cios-alpha/

Challenge: "Fluoro-hunting"

- Surgeons should take multiple to set an optimal fluoroscopic view.
- Time-consuming, more radiation exposure to both patients and physicians, physically cumbersome, safety issues.

Project Background: Solution

Goals: Develop user-friendly interfaces to find an optimal C-arm position with a digitally reconstructed radiograph (DRR) generated from preoperative 3D CT data.



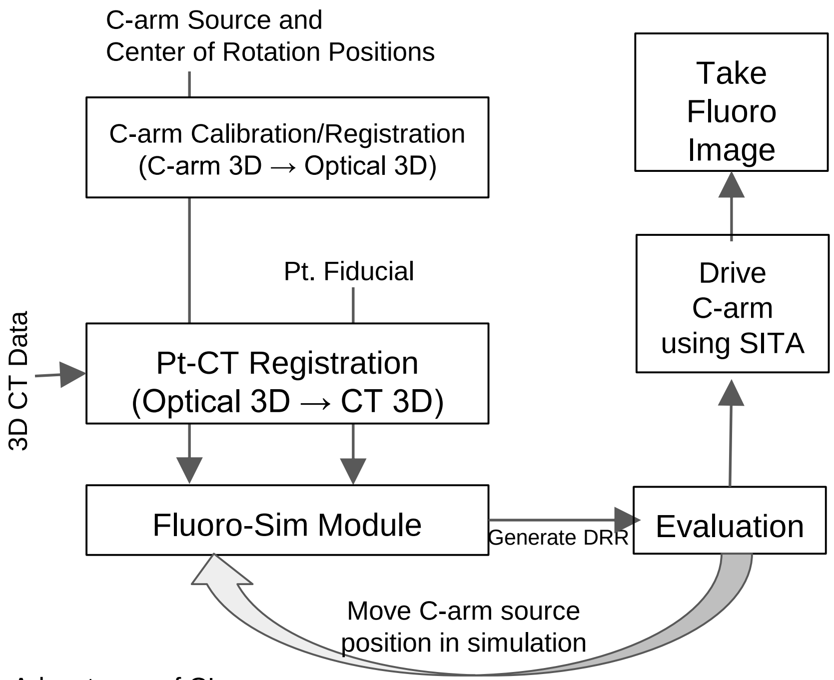
Advantages:

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

2 Approaches: Computer interface / Physical interface

Project Background: 2 Approaches (CI/PI)

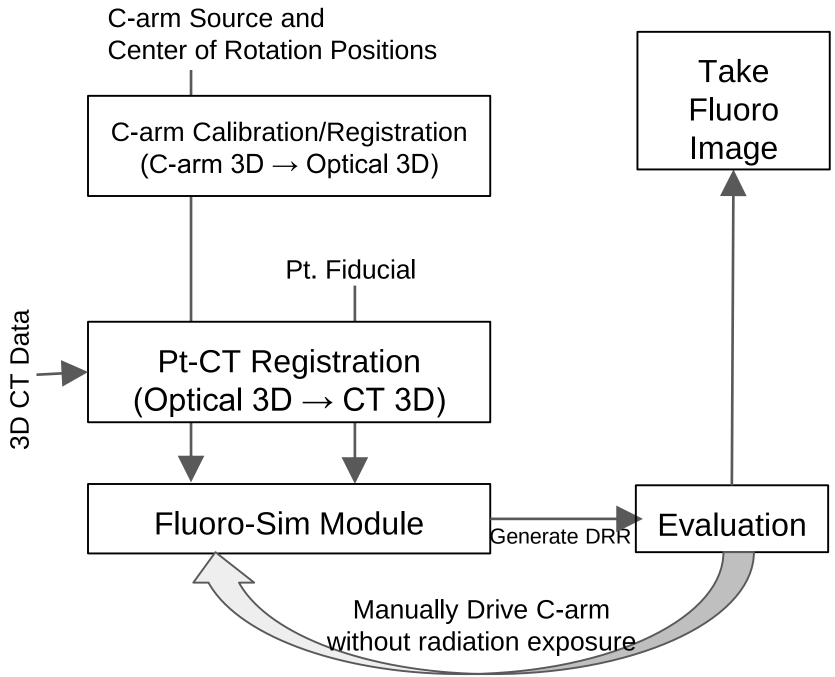
1. Computer Interface (CI)



Advantages of CI

- Less physically cumbersome
- Motorized movement of C-Arm to the desired position

2. Physical Interface (PI)



Advantages of PI

- Seamless integration to surgury workflow

Original Deliverables

MIN

- Registration of C-arm, patient, and patient CT data with an optical tracker/markers
  - Verification: measure Target Registration Error (TRE)
- Modify existing DRR generation module to define source position i/t/o orbital/angular position

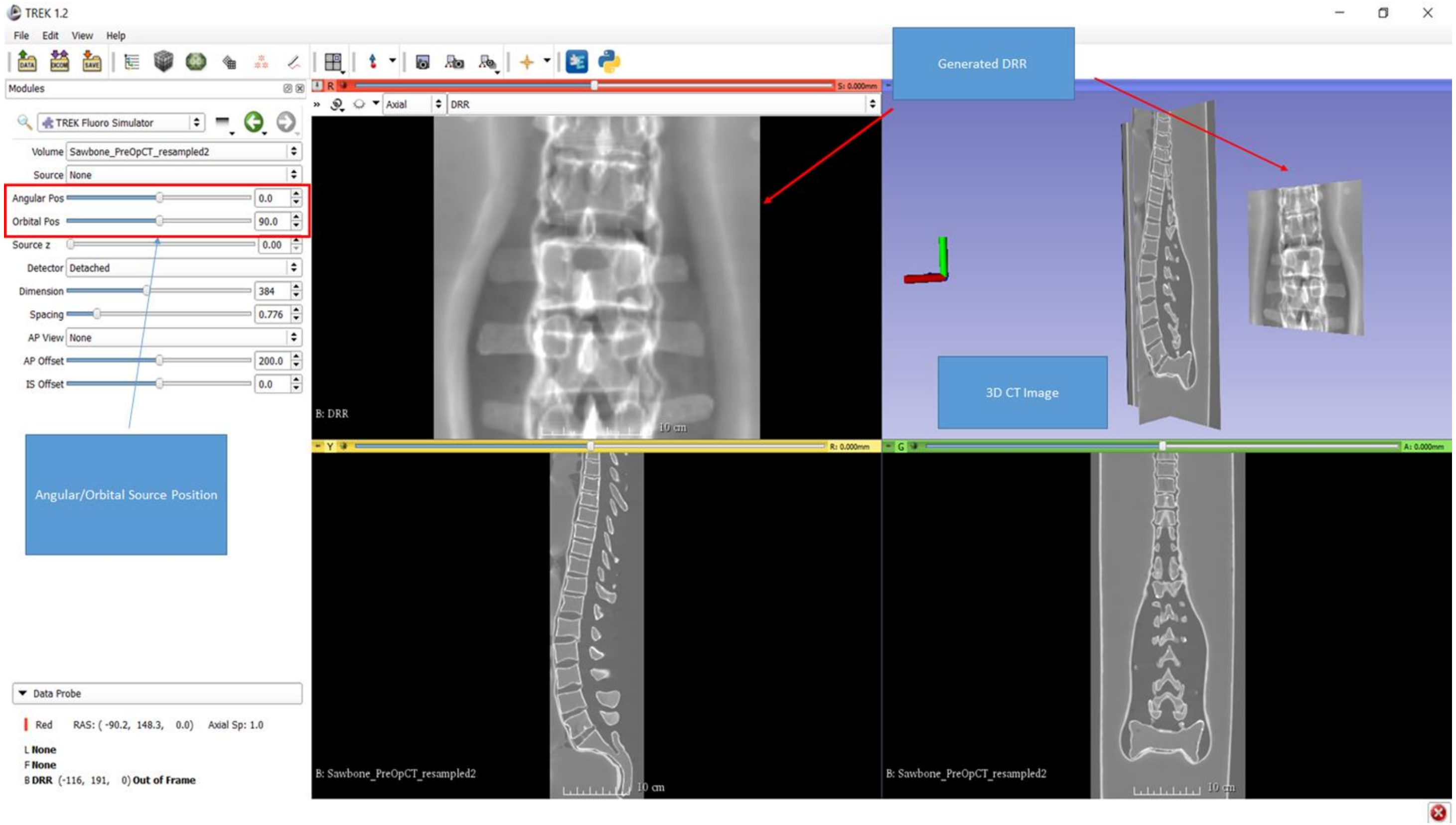
EXP

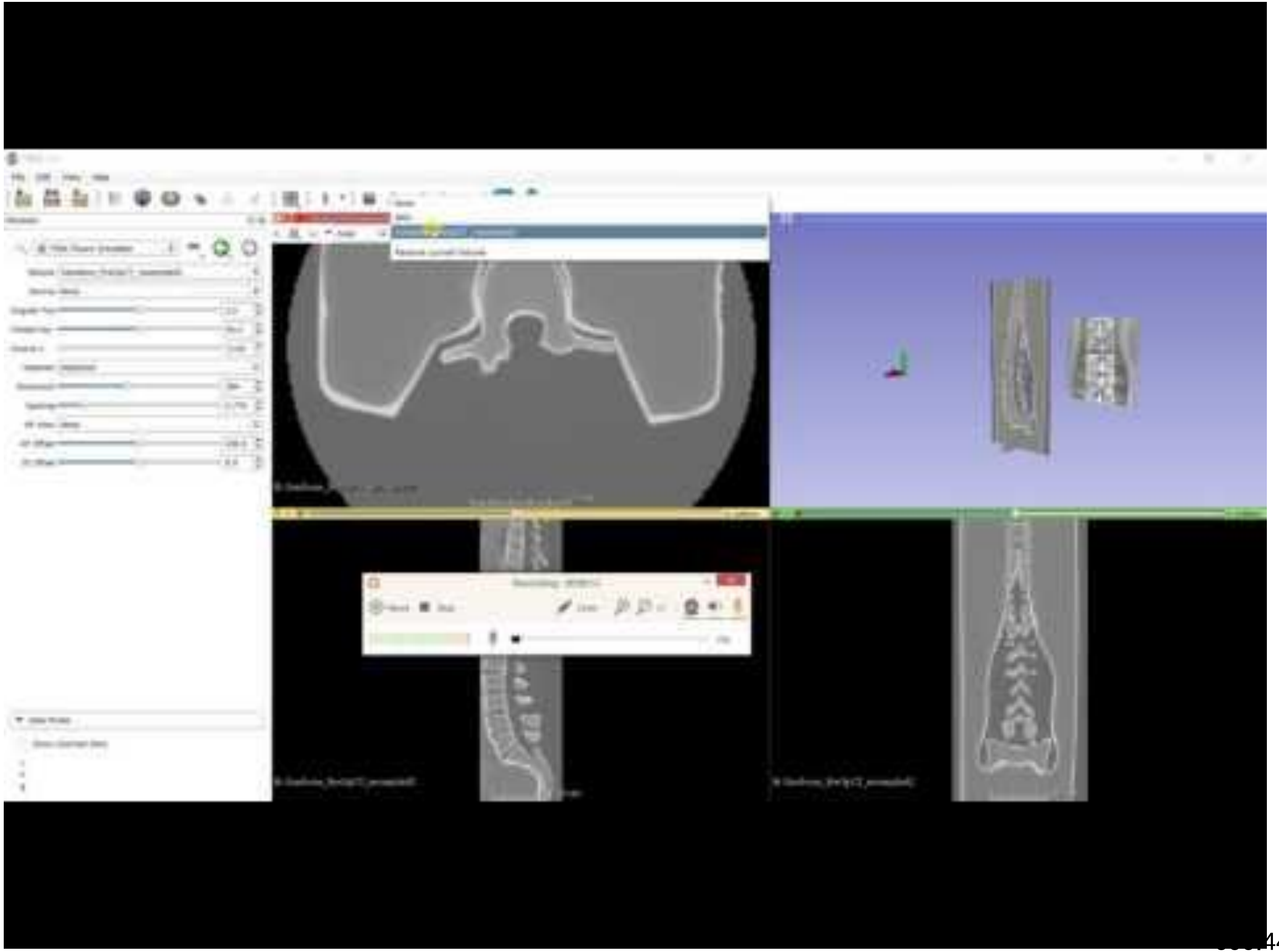
- Physical Interface: acquire pyhsical C-arm position and display DRR
- Computer Interface: define virtual C-arm position and display DRR
  - Validation measure Projection Distance Error (PDE) between generated DRR and actual fluoroscopic image

MAX

- Physical/Computer Interfaces:
  Encoder-based C-arm positioning, Pt-CT reg. w/ 3D-2D image registration
- Computer Interface: Drive the C-arm to preferred position with SITA interface
  - Verification: Measure accuracy of C-Arm positioning, TRE.

DRR genereration based on C-arm source position





istar.jhu.edu

DRR genereration based on C-arm source position

Where

$$T_w^d = \begin{bmatrix} R_d & p_d \\ 0 & 1 \end{bmatrix}$$

Source is defined in detector coordinate as

$$T_d^s = {T_w^d}^{-1} T_w^s = \begin{bmatrix} I & p_s \\ 0 & 1 \end{bmatrix}$$

Where $p_s = [u_0 \; v_0 \; SDD]$

Then projection matrix P_i defined as:

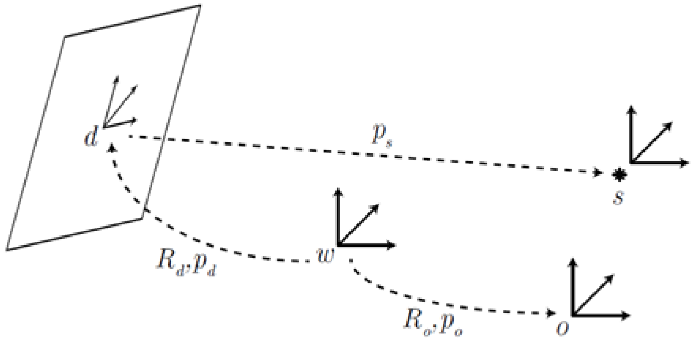
$$P_i = I_i \cdot T_s^w$$

Where intrinsic/extrinsic matrices I_i and T_s^w are:

$$I_i = \left[\begin{array}{ccc|c} -SDD & 0 & u_0 & 0 \\ 0 & -SDD & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{array}\right]$$

$$T_s^w = \left(T_w^d T_d^s\right)^{-1} = \begin{bmatrix} R_d & R_d \cdot p_s + p_d \\ 0 & 1 \end{bmatrix}^{-1}$$

$$x_A = T_A^B x_B$$



A. Uneri, Y. Otake, A. Wang, J. Siewerdsen. “Projection Geometry.” The I-STAR Lab. Johns Hopkins University. April 2014

Registration

Geometric Calibration (C-arm) Coordinates	Optical Coordinate	CT Coordinate
· C-arm center of rotation · Source Position	· Patient fiducials	· Preoperative 3D CT data

C-arm Registration

$$F_{Carm}^{Optical} : C\ arm\ 3D \rightarrow Optical\ 3D$$

Pt.-CT Registration

$$F_{Optical}^{CT} : Optical\ 3D \rightarrow CT\ 3D$$

Registration

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C-arm Registration

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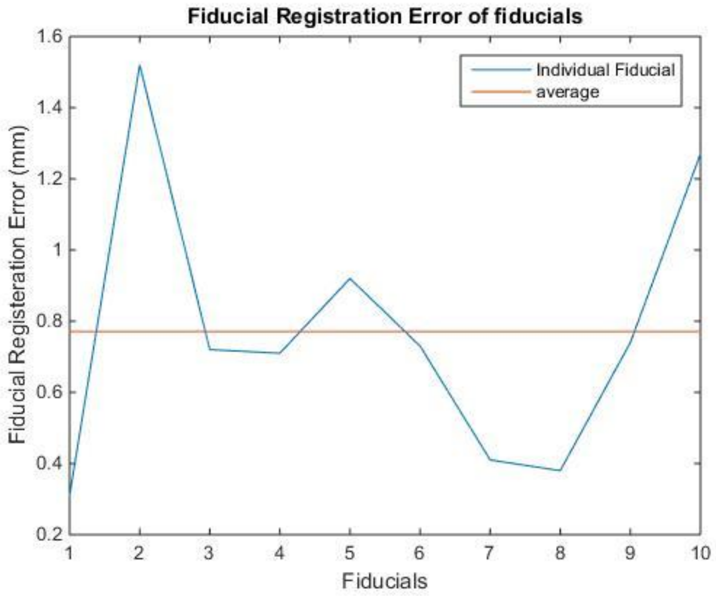
Pt.-CT Registration

$$F_{Optical}^{CT} : Optical\ 3D \rightarrow CT\ 3D$$

Patient-CT Registration

- Tracked phantom's 10 fiducial points, already known in 3D CT data, using an optical tracker.
- Utilized TREK's built-in fiducial registration, existing software from Dr. Siewerdsen's Lab
- Horn's method with Quarternion Technique to peform fiducial registration
- Obtained Phantom to CT transformation matrix defined by fiducial registration using an optical tracker.

Patient-CT Registration: Verification



The registration process validated using Fiducal Registration Error (FRE)

Transformation obated from fiducial registration process registers CT and Phantom fiducials with mean FRE = 0.77 mm.

Other validation methods such as Target Registration Error (TRE) should also be explored

Registration

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C-arm Registration

$$F_{Carm}^{Optical} : C\ arm\ 3D \rightarrow Optical\ 3D$$

Pt.-CT Registration

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C-arm Registration

Original Plan: use optical marker attached on the C-arm

Issues:
- Limited field of view of optical tracker
- Accurate location of X-ray source

Encoder: provides orbital/angular position, no FOV issues. Could locate sources by calibration

Change of plan:
- Use encoder-based approach (originally a maximum deliverable)
- Take multiple shots of multi-modal markers in different angles, acquire 3D position of the markers in optical/C-arm coordinate

- Calibration step required in prior to registration

C-arm Registration: Calibration

9 DoF 3D-2D registration used to solve for projection matrix.

Images of calibration object taken from angles *i*. Then projection matrix P_i in the given angle *i* satisfies

$$X_{2d}^{i} = P_i \cdot X_{3d}$$

To solve for P_i, we set

$$z_i = P_i \cdot X_{3d}$$

Where z_i is a 1x3 matrix defined as $X_{2d}^{i} = \begin{bmatrix} z_1/z_3 \\ z_2/z_3 \end{bmatrix}$

Then, we solve for $P_i = \begin{bmatrix} -p_{s,z} & 0 & p_{s,x} \\ 0 & -p_{s,z} & p_{s,y} \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} R_d & R_d p_s + p_d \\ 0 & 1 \end{bmatrix}^{-1}$ which has nine parameters:

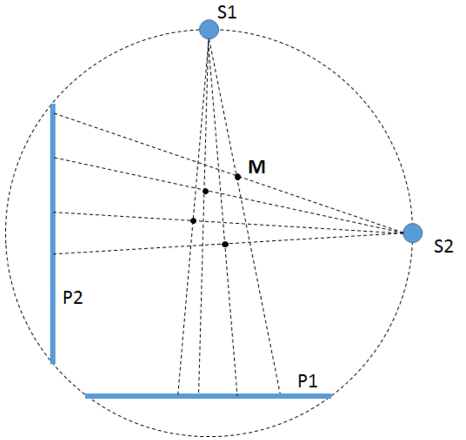
$$\Big[\underbrace{p_{d,x} \quad p_{d,y} \quad p_{d,z}}_{\substack{\text{detector}\\\text{position}}} \quad \underbrace{\theta_{d,x} \quad \theta_{d,y} \quad \theta_{d,z}}_{\substack{\text{detector}\\\text{rotation}}} \quad \underbrace{p_{s,x} \quad p_{s,y} \quad p_{s,z}}_{\substack{\text{source}\\\text{position}}}\Big]$$

Source position p_s^i for angles *i* could be computed from the projection matrix.

Center of rotation acquired by fitting a circle on acquired source positions.

A. Uneri, Y. Otake, A. Wang, J. Siewerdsen. “Projection Geometry.” The I-STAR Lab. Johns Hopkins University. April 2014

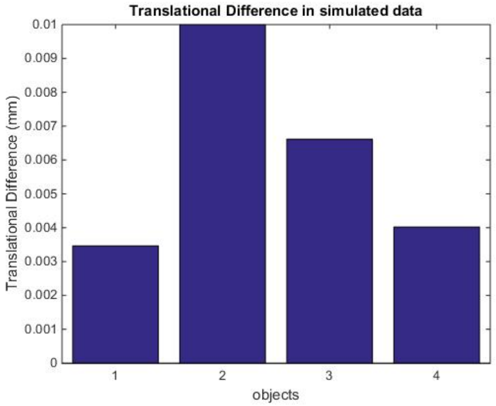
C-arm Registration



COR/projection matrices in multiple angles known from calibration

1. Acquire 2D projections of optical markers from varying angles
2. Compute marker position (centroid) in each projection
3. Triangulate 3D position of the markers in C-arm coordinate
4. Obtain optical positions of the markers
5. Define $T_{Carm}^{optical}$: 3D C arm → 3D optical using marker based on 3, 4
6. Where X_{Carm} is source position in C-arm coordinate

$$X_{optical} = T_{Carm}^{optical} \cdot X_{Carm}$$
$$X_{CT} = T_{optical}^{CT} \cdot X_{optical}$$



Accurate registration in simulation
Next: work with actual data.

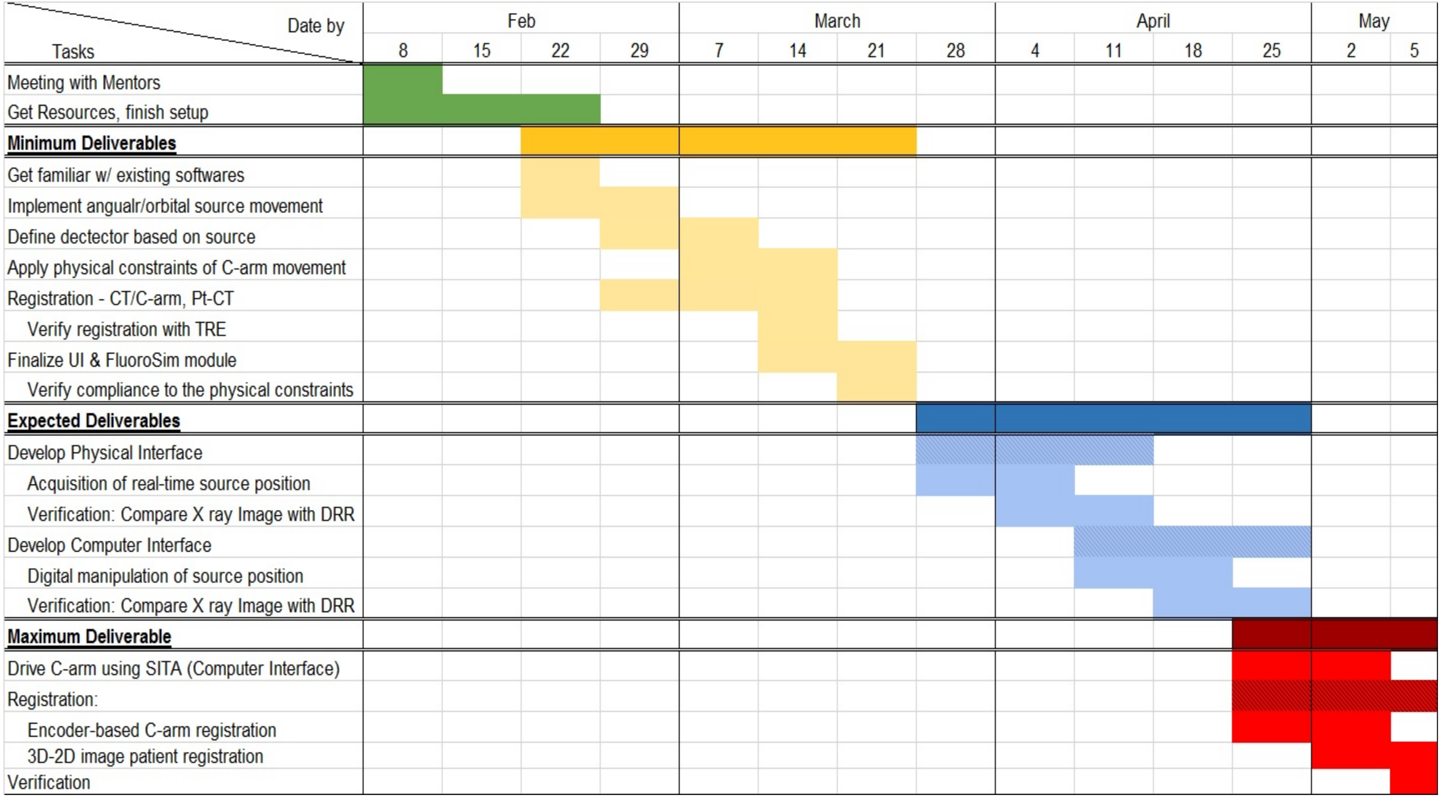
Updated Delilverables

Deliverables	Status	Verification
Minimum deliverable		
Registration: CT-Phantom	Completed	In progress
Registration: C-arm (Encoder-based)	Completed	In progress
Modify existing DRR generation to describe source position in orbital/angular position	Completed	~
Expected deliverable (expected starting date: 03/28/16)		
Physical Interface, capable of acquisition of pyhsical C-arm position and display of DRR	Not yet started	Not yet started
Computer Interface, capable of specifying virtual C-arm position and displaying DRR	Not yet started	Not yet started
Maximum deliverable		
Pt-CT reg. w/ 3D-2D image registration	Not yet started	Not yet started
Computer Interface: Drive the C-arm to preferred position with SITA interface	Not yet started	Not yet started

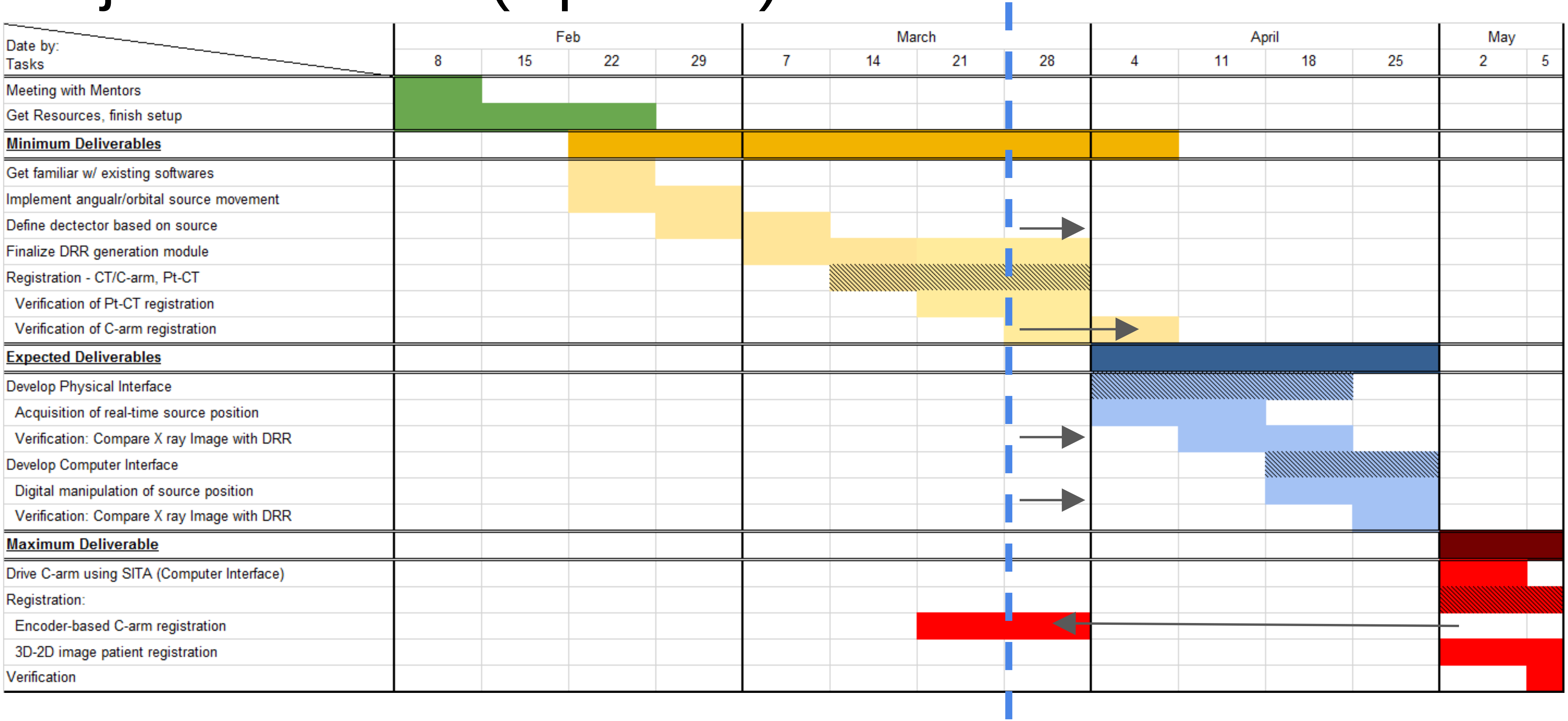
Dependencies

A. Equipment Accessibility - resolved
   a. Access to C-arm, optical tracker, optical markers, and 3D phantoms
B. Software/Existing tools - resolved
   a. Necessary softwares for modules, 3D CT data of phantoms.
C. Version Control/Documentation - resolved
D. Safety Training - In progress (Completed by end of this week)
E. Schedule with mentors - resolved
F. Access to the lab - resolved

Project Timeline (before)



Project Timeline (Updated)



Upcoming Milestones

- Physical Interface
  - Build a bridge so physical movement of C-arm/Source can be tracked and inputted to the module in real-time (by ~~04/04/16~~ → 04/11/16)
  - Acquire X-ray image of preferred view, error check with generated DRR (Validation) (by ~~04/11/16~~ → 04/18/16)
- Computer Interface
  - Read C-arm/Source position with an optimal fluoroscopic preview (by ~~04/18/16~~ → 04/25/16)
  - Verification process by comparing a DRR preview to an acquired X-ray image (by 04/25/16)
- Advanced Features (MAX)
  - Using SITA interface, allow computer interface to drive C-arm to a desired position. (by 05/02/16)
  - Encoder-based C-arm position measurement (by ~~05/02/16~~ → 03/28/16)
  - Pt.-CT registration via 3D-2D registration with 2 X-ray shots (by 05/05/16)
  - Verification process by comparing a DRR preview to an acquired X-ray image (by 05/05/16)

Questions?