

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.



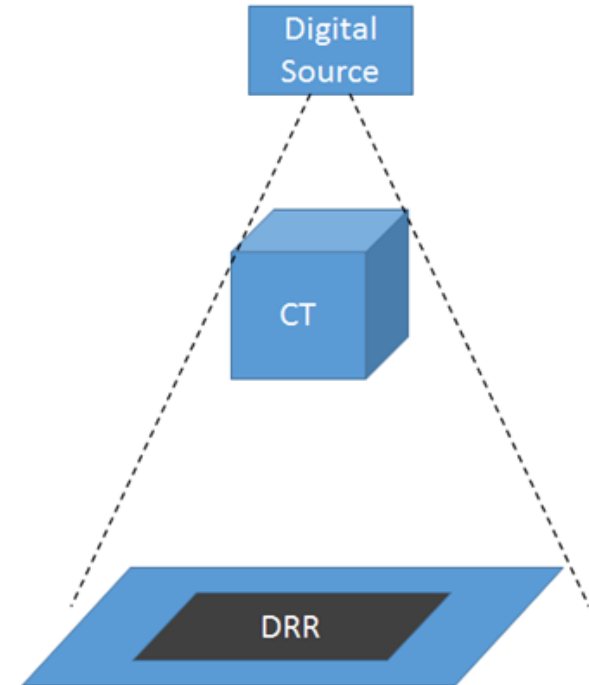
Project Background: Solution

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:

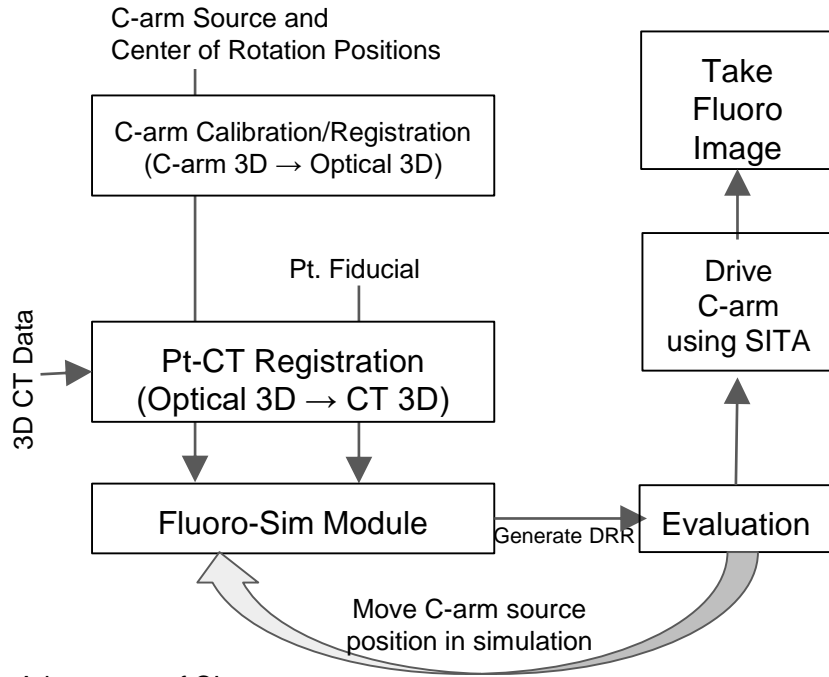
- Less time consuming
- Less radiation exposure for both physicians and patients
- Less user variability, more consistency

2 Approaches: Computer interface / Physical interface



Project Background: 2 Approaches (CI/PI)

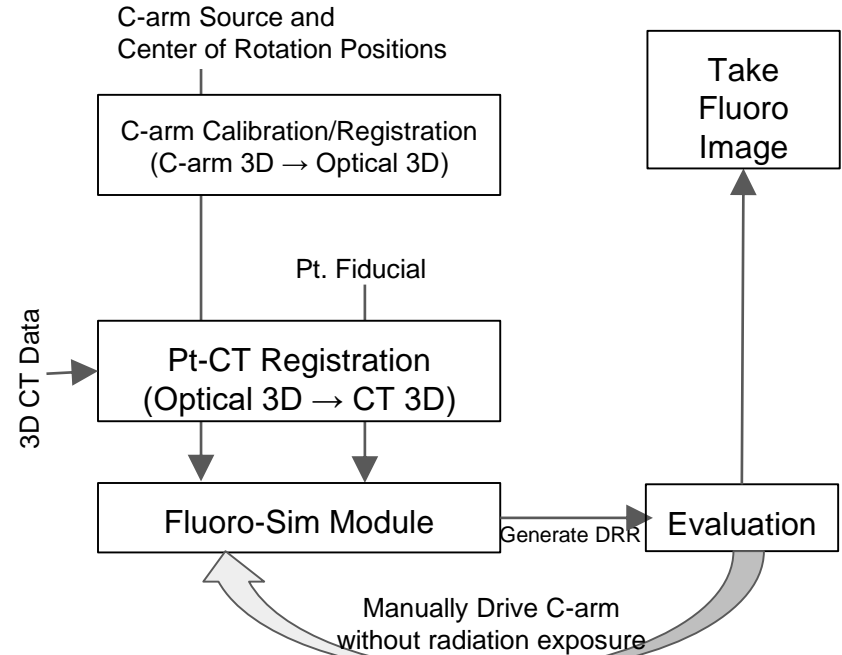
1. Computer Interface (CI)



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 surgery 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 physical 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 generation based on C-arm source position

TREK 1.2

File Edit View Help

Modules

TREK Fluoro Simulator

Volume Sawbone_PreOpCT_resampled2

Source None

Angular Pos 0.0

Orbital Pos 90.0

Source z 0.00

Detector Detached

Dimension 384

Spacing 0.776

AP View None

AP Offset 200.0

IS Offset 0.0

Angular/Orbital Source Position

Data Probe

Red RAS: (-90.2, 148.3, 0.0) Axial Sp: 1.0

L None

F None

B DRR (-116, 191, 0) Out of frame

Generated DRR

3D CT Image

B: DRR

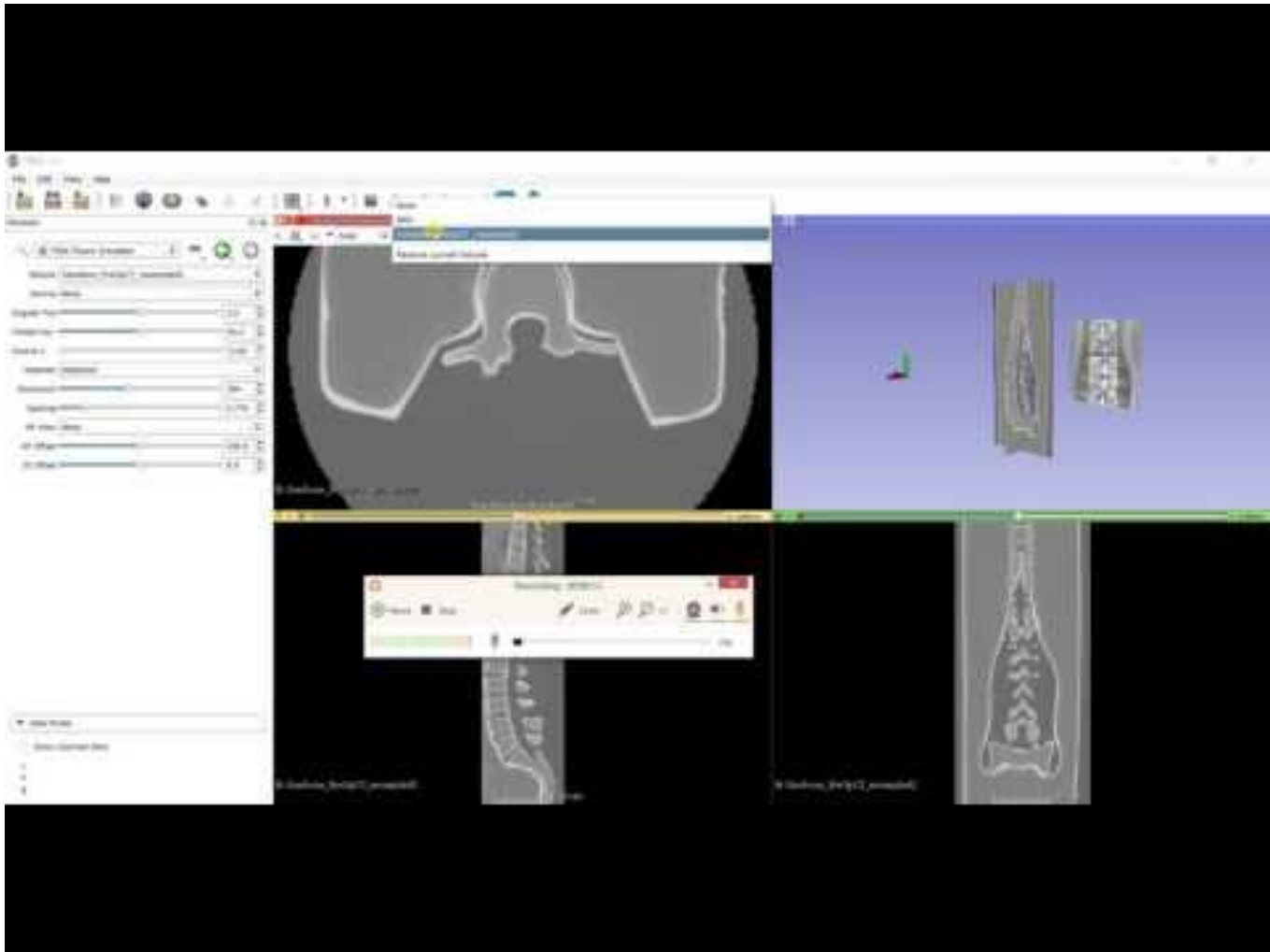
R: 0.000mm

G

A: 0.000mm

B: Sawbone_PreOpCT_resampled2

B: Sawbone_PreOpCT_resampled2



DRR generation 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:

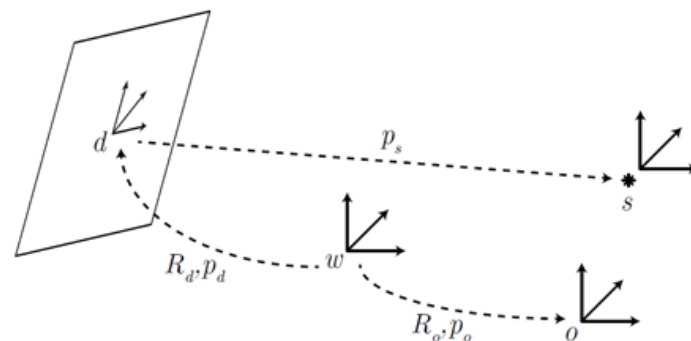
$$P_i = I_i \cdot T_s^w$$

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

$$I_i = \begin{bmatrix} -SDD & 0 & u_0 & 0 \\ 0 & -SDD & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

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

$$x_A = T_A^B x_B$$



Registration

Geometric Calibration (C-arm) Coordinates	Optical Coordinate	CT Coordinate
<ul style="list-style-type: none"> · C-arm center of rotation · Source Position 	<ul style="list-style-type: none"> · Patient fiducials 	<ul style="list-style-type: none"> · Preoperative 3D CT data



C-arm Registration

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



Pt.-CT Registration

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

Registration

Geometric Calibration (C-arm) Coordinates	Optical Coordinate	CT Coordinate
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C-arm Registration

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



Pt.-CT Registration

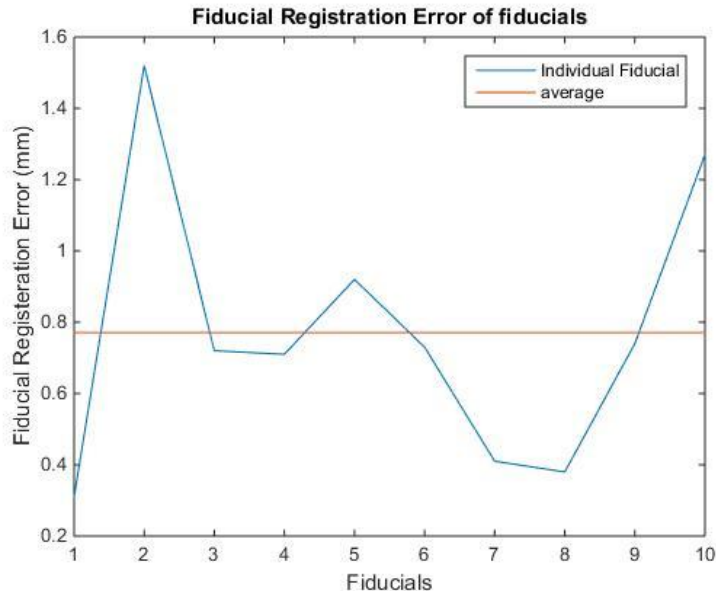
$$F_{Optical}^{CT} : Optical \ 3D \rightarrow CT \ 3D$$

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 perform fiducial registration
- Obtained Phantom to CT transformation matrix defined by fiducial registration using an optical tracker.



Patient-CT Registration: Verification



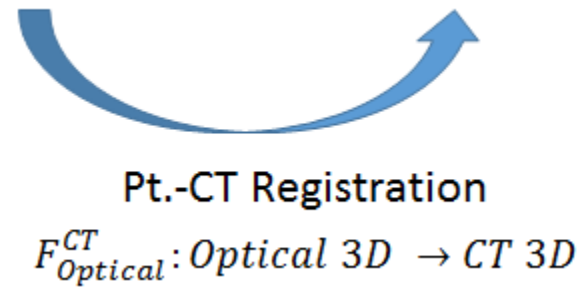
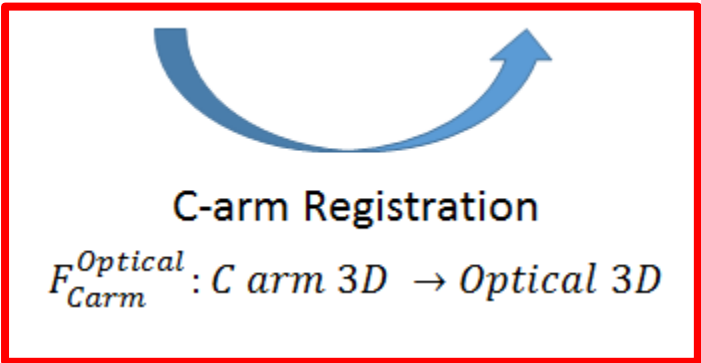
The registration process validated using Fiducial Registration Error (FRE)

Transformation obtained 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

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

Background	Original Deliverable	Current Status	Updated Deliverable	Dependencies	Project Timeline
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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:

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

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.



C-arm Registration

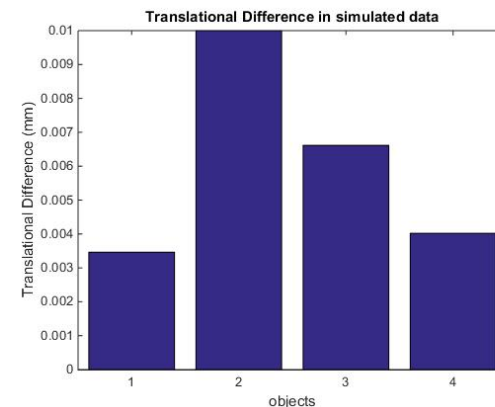
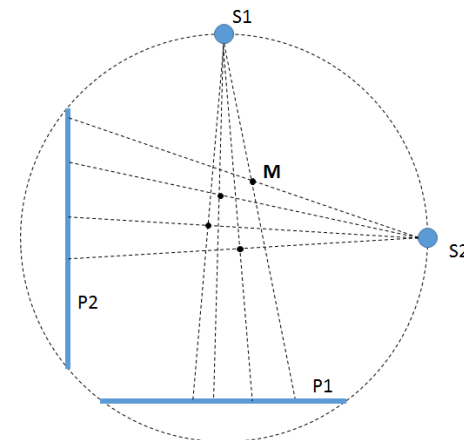
COR/projection matrices in multiple angles known from calibration

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 \rightarrow 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 Deliverables

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 physical 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



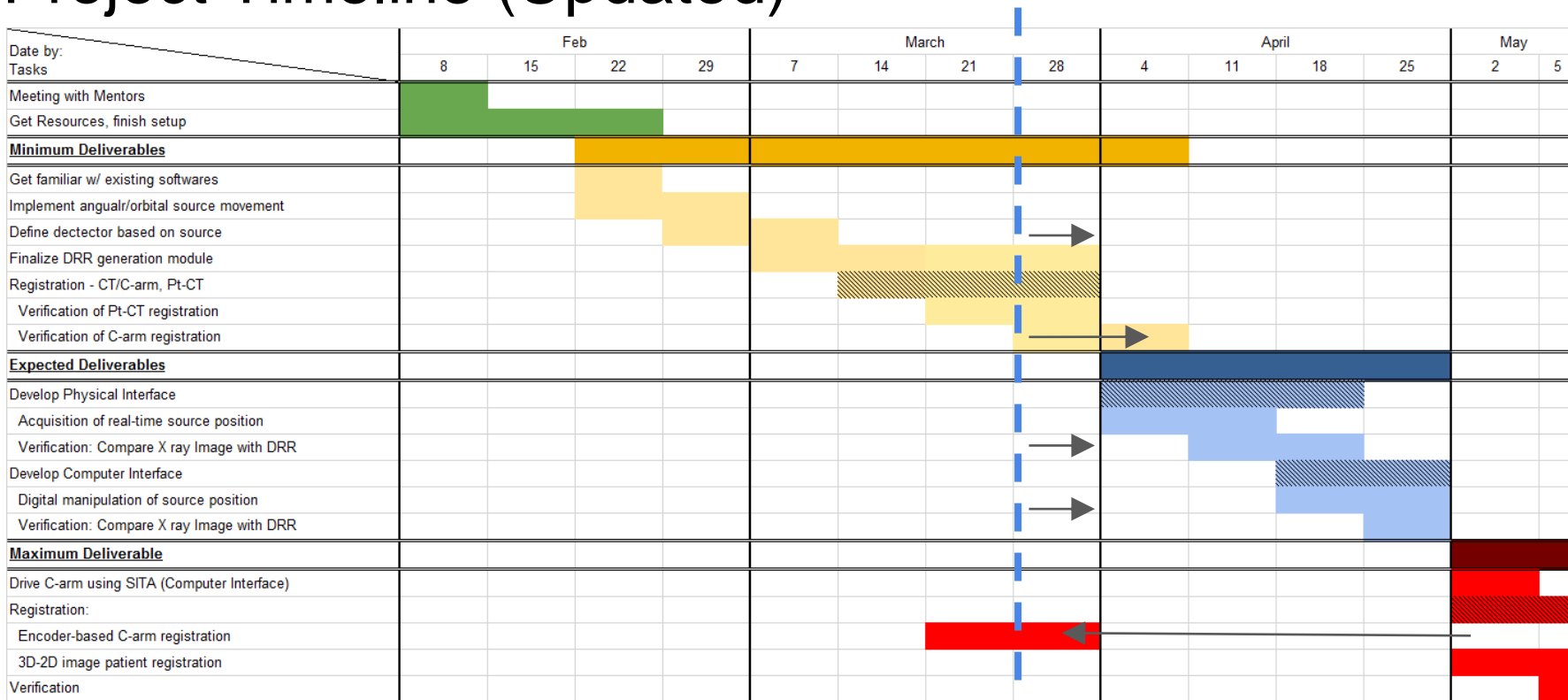
Dependencies

- 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)

Tasks	Date by	Feb				March				April				May	
		8	15	22	29	7	14	21	28	4	11	18	25	2	5
Meeting with Mentors		█													
Get Resources, finish setup		█	█	█											
Minimum Deliverables															
Get familiar w/ existing softwares			█	█											
Implement angular/orbital source movement			█	█	█										
Define detector based on source				█	█	█									
Apply physical constraints of C-arm movement				█	█	█	█								
Registration - CT/C-arm, Pt-CT				█	█	█	█	█							
Verify registration with TRE					█	█	█	█							
Finalize UI & FluoroSim module						█	█	█							
Verify compliance to the physical constraints							█	█							
Expected Deliverables															
Develop Physical Interface															
Acquisition of real-time source position															
Verification: Compare X ray Image with DRR															
Develop Computer Interface															
Digital manipulation of source position															
Verification: Compare X ray Image with DRR															
Maximum Deliverable															
Drive C-arm using SITA (Computer Interface)															
Registration:															
Encoder-based C-arm registration															
3D-2D image patient registration															
Verification															

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?