Computer Guided X-ray C-arm Positioning

600.446. Computer Integrated Surgery II

Group 5: Seung Wook Lee, Ju Young Ahn

Mentors: Dr. Jeff Siewerdsen, Dr. Matthew Jacobson, Dr. Tharindu da Silva, Dr. Joseph Goerres

Contents

1. Stated topic and goal

Mobile C-arm is an X-ray imaging device with motors, which allows flexible positioning of its X-ray source. This device is widely used for diagnostic imaging or surgical procedures in many areas including orthopedic surgeries. Its usage in surgical procedures requires “fluoro-hunting,” a process to achieve a fine placement of the C-arm in order to display a preferred fluoroscopic view. Here, we propose a user interface (UI) that allows a simulation of fluoroscopic previews of the C-arm. The UI generates a digitally-reconstructed radiograph (DRR) of a pre-acquired patient CT data based on an X-ray source position, which is defined either virtually or physically, and provides a preview of the fluoroscopic view corresponding to the source position.

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

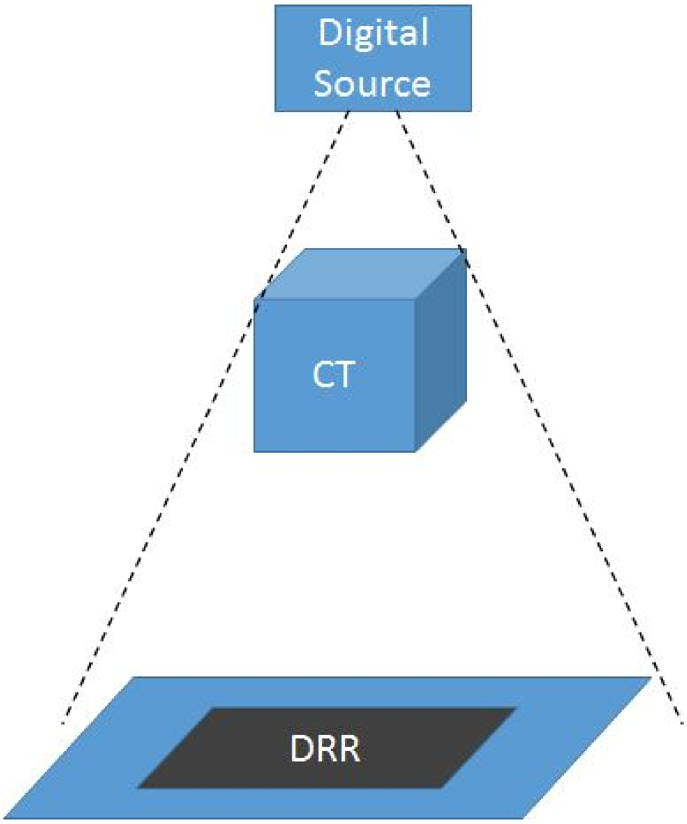
<Fig. 1.1 Cios-alpha C-arm>

<Fig. 1.2 Example Fluoro images>

2. Short statement of relevance/importance

Mobile C-arm is widely used by surgeons as a means of providing fluoroscopy-based surgical guidance. Multiple degrees of freedom (DOF) of the arm with angular and orbital movement allows surgeons to set an optimal viewpoint for surgeries. However, placing the C-arm to the preferred position, a process called “fluoro-hunting”, often requires surgeons to manually drive the C-arm to various positions to take 5 to 10 X-ray shots. This process is time consuming, and may expose both patients and surgeon to more radiation. Also, it is physically cumbersome and requires skills for surgeons to manually maneuver the C-arm during the fluoro-hunting.

Our solution, a user interface capable of the optimal positioning of the C-arm based on digitally reconstructed radiograph (DRR) can resolve the problems followed by the fluoro-hunting; guidance of the C-arm based on radiation-free fluoroscopic preview is less time consuming and reduces the risk of radiation exposure of both surgeons and patients.



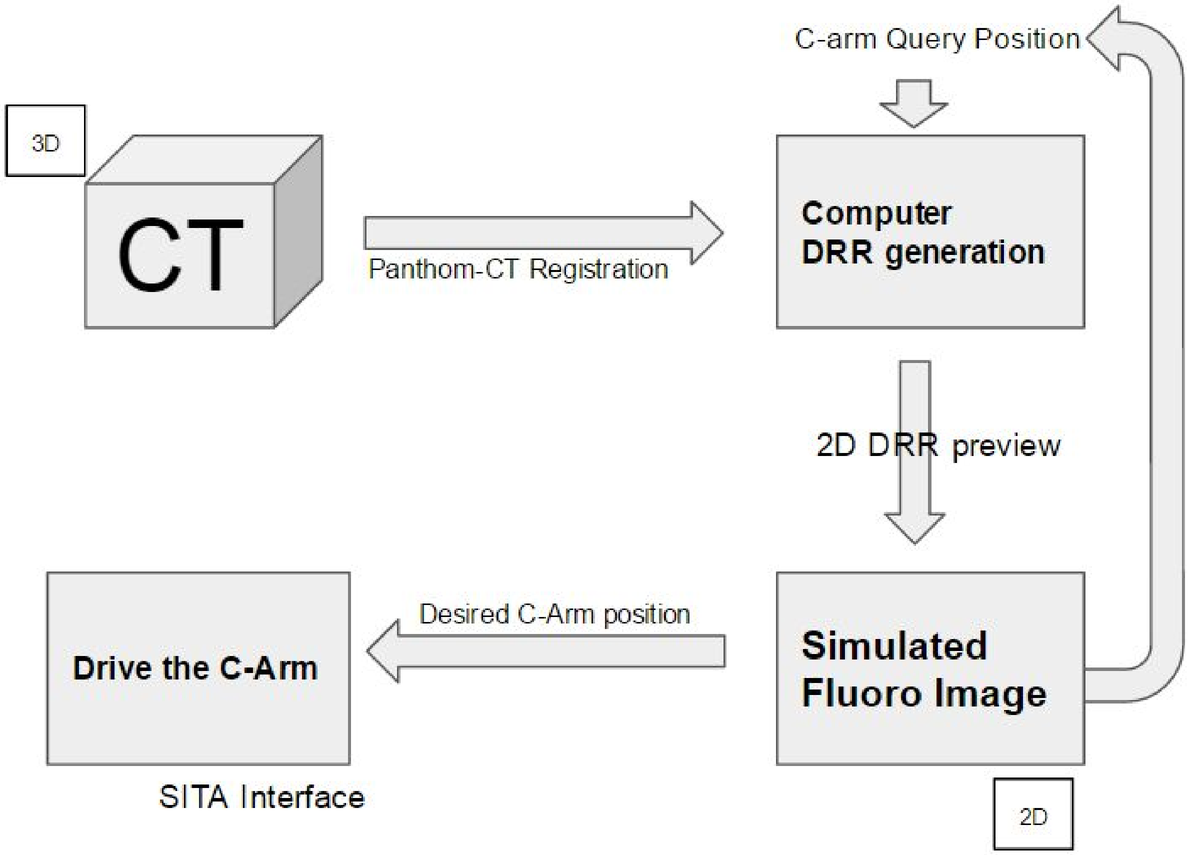
<Fig. 2 Diagram of DRR generation. Digital source projects 2D DRR on a specified detector plane>

3. Short technical summary of approach

3.1 Computer Interface

Computer Interface allows users to find their preferred view by driving a virtually defined C-arm source position. DRR corresponding to the virtual source position is generated and displayed on screen.

In order to implement the computer interface, 3D CT data of a patient is acquired first. Then, CT-patient-registration will be performed to align the patient position to the CT data. Also, C-arm position will be measured by optical trackers or an encoder embedded inside the C-arm. Using the registered CT data and C-arm position, the computer DRR generation module will produce a 2D DRR preview, a simulated fluoro image. Then, as the C-arm query position is manipulated, the DRR generation module will produce a 2D DRR preview in real-time. Once the operator is satisfied with the preview, the computer will drive the C-arm to the desired position using the SITA interface and will acquire an X-ray image. SITA is a built-in interface of the C-arm which allows motorized movement of the C-arm. Advantage of this method is that it is not physically cumbersome, as C-arm is driven and controlled solely based on the computer interface.

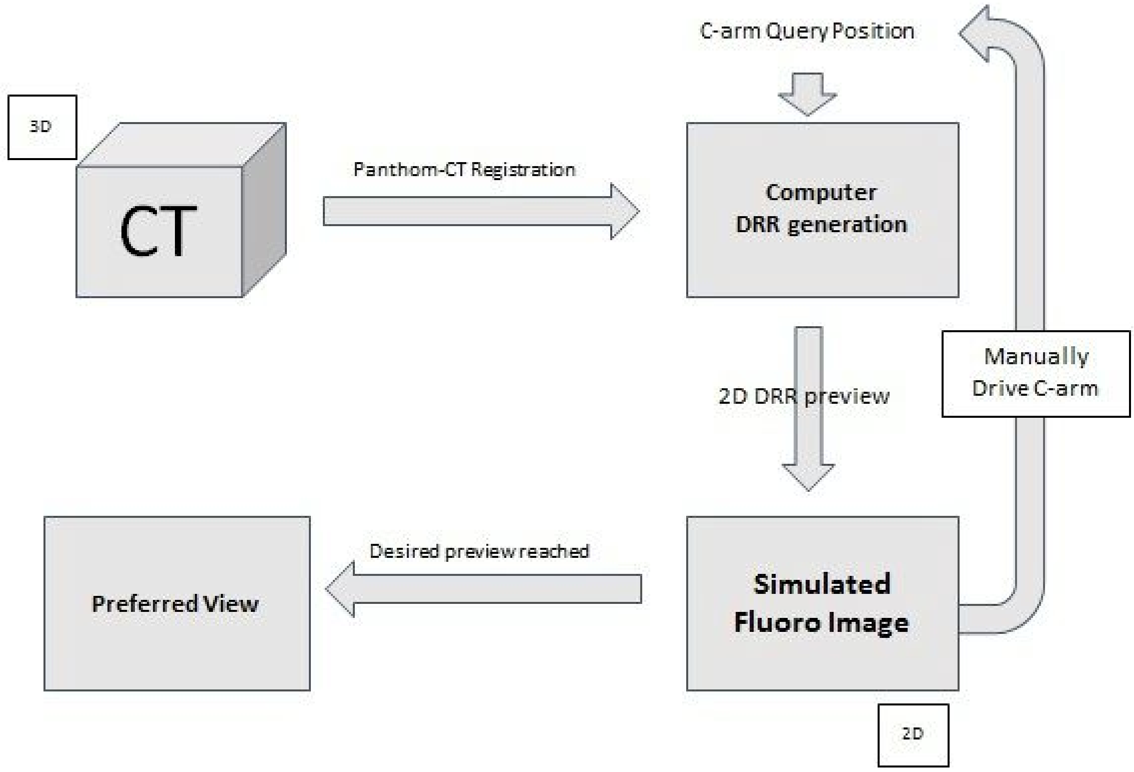


<Fig. 3.1 Computer Interface Flow Diagram>

3.2 Physical Interface

Physical Interface allows users to find their preferred view by manually driving actual C-arm and checking corresponding DRR. DRR corresponding to the physical source position is generated and displayed on screen.

Physical interfaces shares many features with the computer interfaces. 3D CT data of a patient is acquired, and the CT data is registered to the patient using an optical tracker. One key difference is the method to acquire C-arm position. In the physical interface, C-arm query position is directly acquired from the C-arm as physicians move the C-arm to various test positions. Then, based on the registered CT data and C-arm query position, the DRR generation module will produce a 2D DRR preview. The preview is updated based on physical C-arm source position, and physicians can adjust position of the C-arm based on the DRR until they find the C-arm position for their preferred view. Once an operator locates the DRR, corresponding to the desired preferred view, surgeon can start their procedures right away as the C-arm is already located at the desired position. Advantage of this method is its smooth integration with surgical workflow; surgeons do not need to access computers during the procedure to change source positions.



<Figure 3.2 Physical Interface Flow Diagram>

3.3 C-arm Position Measurement

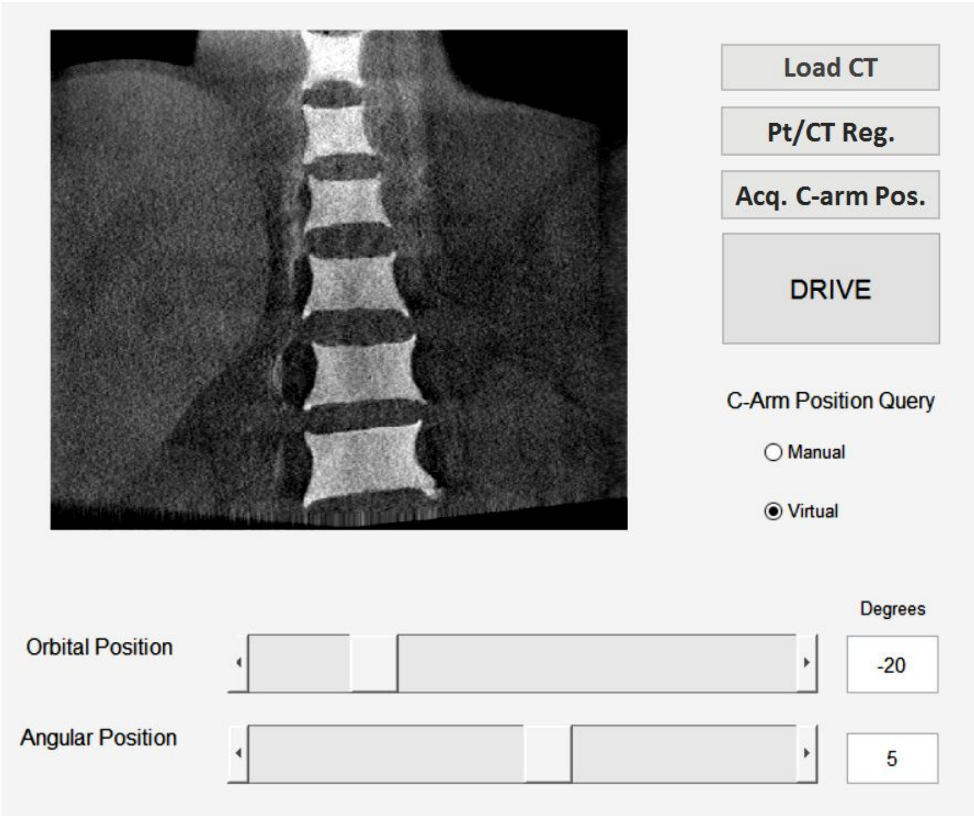
We propose two methods for C-arm position measurement. One is a tracker-based measurement and the other is an encoder-based measurement. For the tracker-based measurement, an optical marker will be attached to the C-arm and C-arm position will be tracked by an optical tracker with high precision. For the encoder-based measurement, the orbital and angular information about rotation of C-arm can be read from the encoder embedded inside the C-arm. Using this information, we can omit an on-going real time tracking of the source of the detector.

3.4 CT-patient Registration

We propose two methods for the CT to patient registration. One is a tracker-based registration and the other is a 3D-2D image registration. For the tracker-based registration, an optical marker will be attached to the patient and the CT data will be registered to the patient through an optical tracker. For the 3D-2D image registration, two X-ray scans will be taken. Then, using those two images, 3D CT data will be registered to the 2D images; thereby registering CT to a patient.

Ideally, by using encoder based C-arm position measurement and 3D-2D image registration for CT-Patient registration, we will not require tracking of the C-arm device anymore.

3.5 GUI



<Figure 3.3. Sample GUI for the computer-guided X-ray C-arm positioning>

GUI should be capable of the followings:

A. Loading CT data: Allow user to select/load patient CT data.
B. CT-Pt. registration: Register the patient CT data to patient, using optical trackers
C. Acquisition of C-arm position: Acquire C-arm query position in two different modes:
    a. Manual: Physically define C-arm position by driving C-arms to a various test positions. (For physical interface)
    b. Virtual: Virtually define C-arm query position by specifying virtual query positions in the GUI. (For computer interface)
D. Sliders representing source positions: Define source position with angular/orbital positions. For the computer interface, moving the sliders allows movement of a virtual source. For the physical interface, the sliders displays current physical source position in terms of angular/orbital positions.
E. Drive: In Computer Interfaces, allows users to drive the C-arm position to virtual source position defined by the slider.

4. List of "deliverables" (MIN, EXP, MAX)

4.1 Minimum deliverable

- Registration of C-arm, phantom, and phantom CT data with an optical trackers and markers
  (Note: For development purposes, we will work with 3D phantoms and phantom CT data instead of actual patients and patient CT data)
- Verification of registration processes through Target Registration Error (TRE).
- Modify existing DRR generation module to comply with physical constraints of the C-arm
- Verification of compliance of the module to physical constraint of C-arm

4.2 Expected deliverable

- Physical Interface, capable of acquisition of physical C-arm position and display of DRR
- Computer Interface, capable of specifying virtual C-arm position and displaying DRR
- Validation that generated DRR matches the actual X-Ray image through a test object with physiological landmarks and measure geometric error/ alignment

4.3 Maximum deliverable

- Physical/Computer Interface: 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.

5. List of dependencies & plan for resolving

A. Equipment Accessibility

Our project requires access to equipments like C-arm, optical tracker, optical markers, and 3D phantoms. The equipments are all available in Dr. Siewerden's lab.

B. Software/ Existing tools

Necessary softwares such as VTK, Visual Studio, TREK, Team Viewer, Smart Git, etc are downloaded. We have access to all of existing tools from Dr. Siewerdsen's lab through git repository. Also, we have a sample 3D CT data of a phantom that we can initially work with.

C. Version Control/Documentation

We downloaded Jupyter and smart git to deal with version control. We have our own separate branch where we can modify codes and then commit/push our changes.

D. Safety Training

Dr. Siewerdsen agreed to set up a safety training for us. Exact dates for the training not yet determined. Not imperative until we reach the validation of the expected deliverable.

E. Schedule with mentors

We have a weekly meeting with Dr. Siewerdsen. We will work at Dr. Siewerdsen's lab on Monday and Wednesday and we will be able to discuss any complications and problems to our mentors during that time. (Refer to 7.3 Weekly Schedule)

F. Access to the lab

We are given an access to Dr. Siewerdsen's lab.

6. Key dates & assigned responsibilities

6.1 Milestones (due dates)

- Common
  - Allow angular/orbital movement of the source position (by 02/29/16)
  - Define detector transformation in accordance with the source position (by 03/07/16)
  - Allow source position to mimic actual/physical C-arm movement (apply physical constraints, non-perfectly circular movement of C-arm) (by 03/14/16)
  - Register C-arm to CT data and phantom to CT data (possibly calibrate C-arm position) (by 03/14/16)
  - Verify registration process through TRE (by 03/14/16)
  - Finalize UI for the DRR generation module (by 03/21/16)
  - Verify compliance of the module to physical constraints of C-arm (by 03/21/16)
- 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)
  - Acquire X-ray image of preferred view, error check with generated DRR (Validation) (by 04/11/16)
- Computer Interface

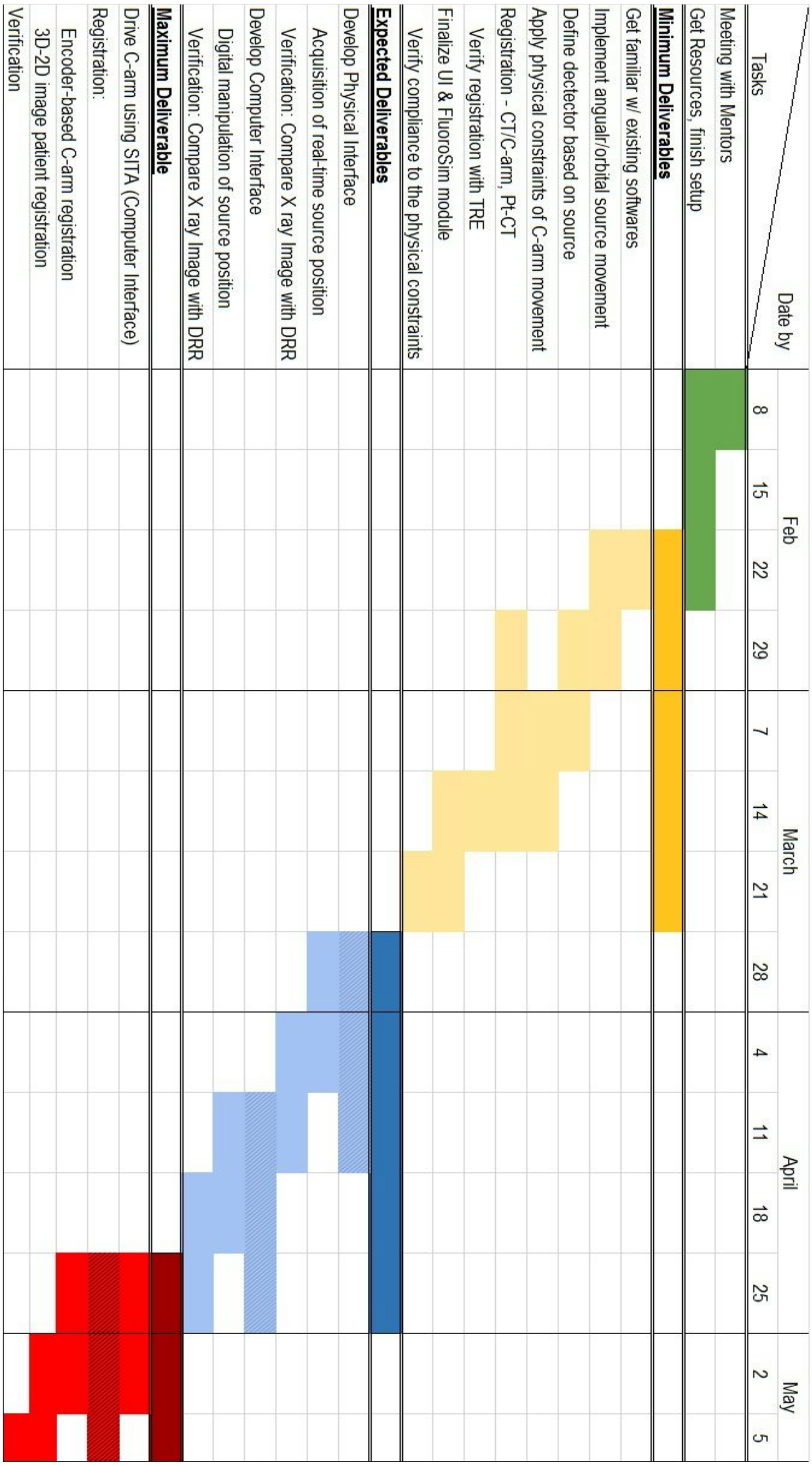
  - Read C-arm/Source position with an optimal fluoroscopic preview (by 04/18/16)
  - Manually move C-arm to a desired position and acquire an X-ray image, Verification process by comparing a DRR preview to an acquired X-ray image (by 04/25/16)
- Advanced Features (MAX)
  - Using SITA interface, allow computer interface to drive C-arm to a desired position. (by 05/02/16)
  - Encoder-based C-arm position measurement (by 05/02/16)
  - 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)

6.2 Responsibilities

- Seung Wook Lee
  - Background: Medical imaging, Instrumentation, Matlab, Python
  - Responsibility: C-arm based DRR module/UI Development
- Ju Young Ahn
  - Background: Matlab, C/C++, Java, Python
  - Responsibility: CT/Pt/C-Arm Registration, UI Development

7. Management Plan

7.1 Project Timeline



7.2 Documentation/Version Control

- We will utilize smart git for version control.
- All significant updates will be committed and pushed with detailed comments.
- Any additional features in codes will be explained as comments with details
- During bi-weekly meeting, we will discuss any ambiguity and plan ahead of time for any future code implementations so that there would be no conflicts.

7.3 Weekly schedule

- Monday/Wednesday from 3:00PM to 6:00PM at Dr. Siewerdsen's Lab
- Saturday from 2:00PM to 6:00PM at Homewood
- Meeting with Dr. Siewerdsen on Wednesday for progress check/guidance

8. Reading list

[1] Navab, Nassir, Stefan Wiesner, Selim Benhimane, Ekkehard Euler, and Sandro Michael Heining. "Visual Servoing for Intraoperative Positioning and Repositioning of Mobile C-arms." Medical Image Computing and Computer-Assisted Intervention – MICCAI 2006 Lecture Notes in Computer Science (2006): 551-60.

[2] Siddon, Robert L. "Fast Calculation of the Exact Radiological Path for a Three-dimensional CT Array." Med. Phys. Medical Physics 12.2 (1985): 252.

[3] Hartley, Richard, and Andrew Zisserman. "More Single View Geometry." Multiple View Geometry in Computer Vision: 153-163.

[4] Long, Yong, Jeffrey A. Fessler, and James M. Balter. "3D Forward and Back-Projection for X-Ray CT Using Separable Footprints." IEEE Transactions on Medical Imaging IEEE Trans. Med. Imaging 29.11 (2010): 1839-850.

[5] Otake, Y. et al. "Automatic Localization of Vertebral Levels in X-Ray Fluoroscopy Using 3D-2D Registration: A Tool to Reduce Wrong-Site Surgery."Physics in medicine and biology 57.17 (2012): 5485–5508.

[6] Uneri, A. et al. "Known-Component 3D-2D Registration for Image Guidance and Quality Assurance in Spine Surgery Pedicle Screw Placement."Proceedings of SPIE--the International Society for Optical Engineering 9415 (2015): 94151F.