LABORATORY FOR Computational Sensing + Robotics

JOHNS HOPKINS WHITING SCHOOL of ENGINEERING

Team 07: Real-time Integration of Fully Automatic 2D/3D Pelvic Registration with Robotic X-ray Acquisition

Students:

- Jiaming Zhang
- Zhangcong She

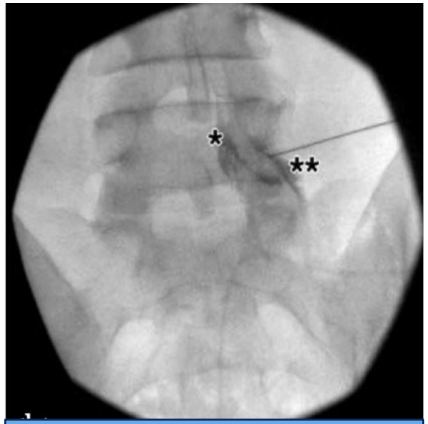
Mentors:

- Benjamin Killeen
- Prof. Mathias Unberath

Background - Intraoperative Fluoroscopy

- In minimally invasive surgery, clinicians use **intraoperative fluoroscopy** to overcome the occlusion and ascertain the poses of anatomy, surgical instruments or artificial implants[1,6].
- The registration between 2D X-ray (fluoroscopy) image and 3D CT/MR images are necessary for precisely localizing the target intraoperatively.

Illustration of spine injection

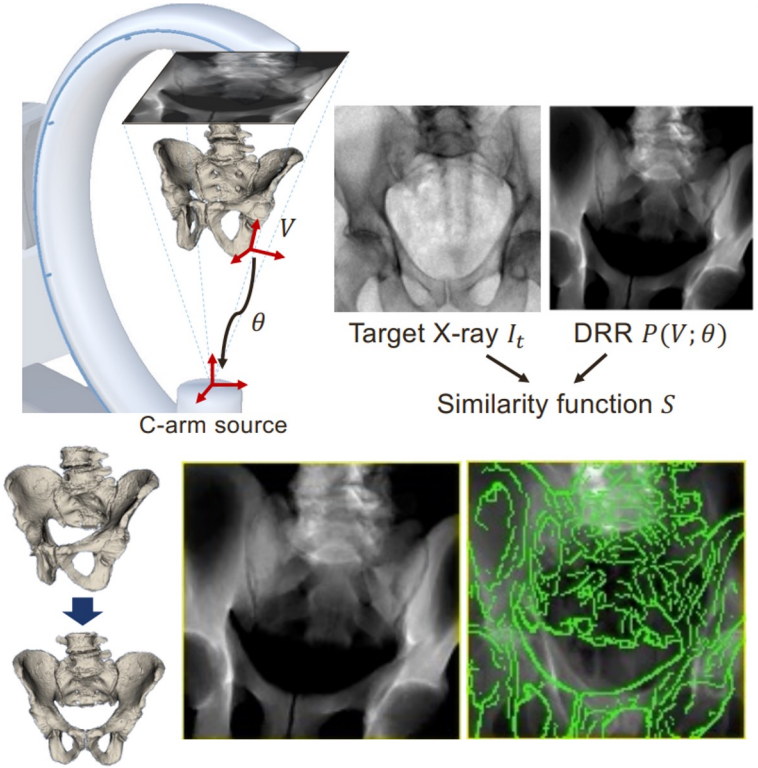


Intraoperative X-ray

Mandell, J. C., Czuczman, G. J., Gaviola, G. C., Ghazikhanian, V., & Cho, C. H. (2017). The Lumbar Neural Foramen and Transforaminal Epidural Steroid Injections: An Anatomic Review With Key Safety Considerations in Planning the Percutaneous Approach. *AJR. American journal of roentgenology*, *209*(1), W26–W35.

Background - 2D/3D Registration

- **2D/3D registration** is the process that estimates the pose of the 3D objects, such as the CT, based on 2D images, such as the X-ray[3].
- Image-based 2D/3D registration approach, where intraoperative X-ray images are used to solve the registration, does not require physical contact, like screws, with the anatomical ROI in the patient. In other words, it's a fiducial-less approach.
- Intensity-based registrations, which we are using in our project, rely solely on voxels and pixels of 3D and 2D images, respectively.



Clinical Motivation

- Performing registration tasks relies on multiple subroutines. Yet different subroutines, i.e., packages or softwares are **not well-cooperated** and therefore **not straightforward to use intraoperatively**.
- Different packages are developed under various environments and sometimes **not compatible with each other**[1]. Some packages are poorly documented and therefore **hard to maintain and difficult to employ**.
- Over-complicated procedure can prolong the learning curve for users and also increase the probability of misoperation.

https://www.philips.com/a-w/about/news/home

Project Goal

- Our project aims to develop a pipeline that **automatically perform the 2D/3D registration** process between X-ray images and CT Scan intra-operatively.
  - To be specific, we need to integrate the image acquisition process, data synthesizing process, landmark detection, and online registration into one sole software with a user-friendly GUI.
- We also seek to visualize the data with novel projective paradiams on HoloLens.

https://www.brainlab.com/surgery-products/overview-platform-products/robotic-intraoperative-mobile-cbct/

Previous Work

01 SyntheX [1]

- SyntheX is a novel neural network architecture developed by Dr. Cong Gao, to create realistic synthesis for X-ray image analysis. In this project, we mainly use it to generate synthetic X-ray image and to initialize automatic registration.

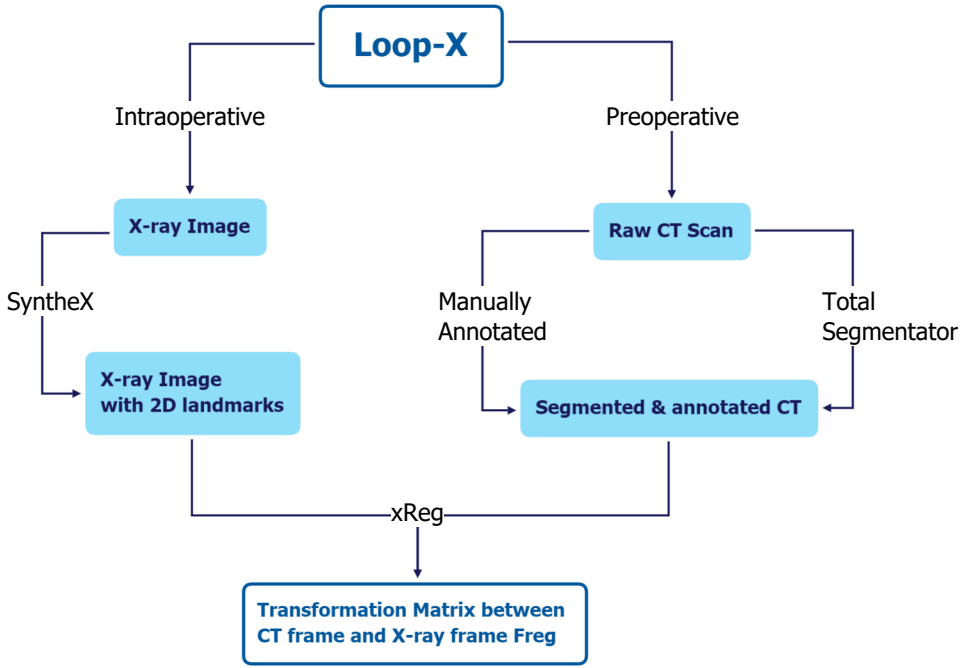
02 xReg[4]

- A library developed by Dr. Robert Grupp, with online and intraoperative registration strategy. It leverages image intensities and CNN features to compute registration matrix between CT frame and X-ray frame.

Technical Approach

- Initially, we would implement a script to retrieve the X-ray image from Loop-X to local device in the real-time.
- Then, the landmark detection of X-ray image would be done by applying SyntheX.
- While, in preoperative period, we would apply Total segmentator to perform segmentation and manually annotate the CT scan.
- Finally, processed X-ray image and CT scan would be used as input of xReg to get $F_{X\text{-}ray,CT}$

Pipeline Architecture



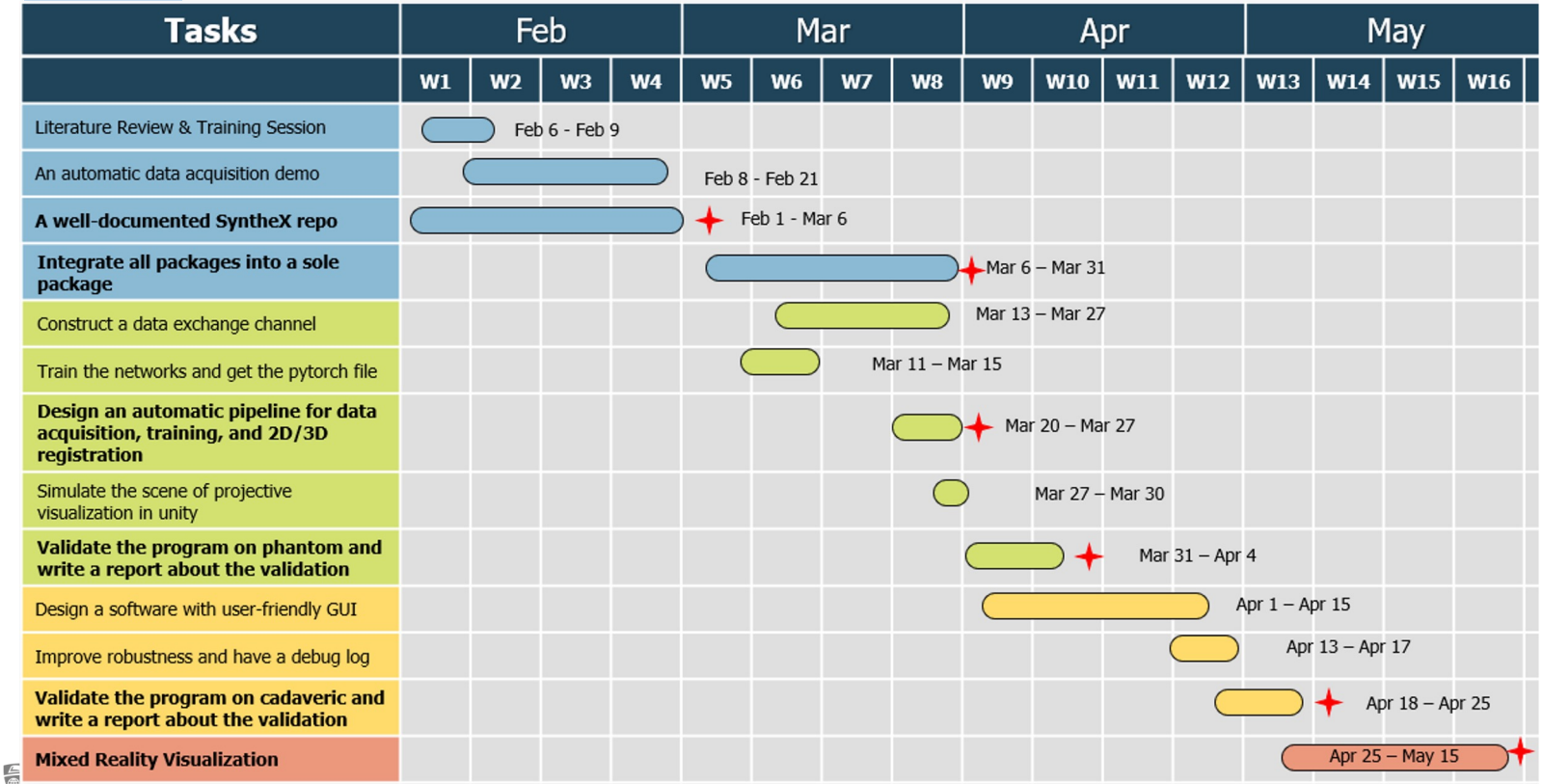
Deliverables

	Deliverable
Minimum	Documentation for SyntheX, provide applicable interfaces
	Automatic Data Acquisition script
	A well-documented program integrating previous works
Expected	A fully automatic pipeline
	A view-rendering application for projective visualization
	A report for Validating our software on cadaveric images
Maximum	Integration with mixed reality visualization of relevant anatomy

Key Milestones

	Planned - expected
Complete documenting and organizing the SyntheX repository	*Mar 6 - Mar 11*
→ Finish developing python scripts incorporates previous work	*Mar 23 - Mar 28*
→ Accomplish designing and documenting automatic pipeline	*Mar 27 - Apr 1*
→ Present a well-analyzed report about validating pipeline	*Apr 4 - Apr 10*
→ Complete developing visualization software on HMD	*May 15 - May 20*

Project Timeline



Dependency

	Need	Status	Followup	Contingency Plan	Planned	Hard DL
MOCK OR Lab Access	manipulate Loop-X	Get access	N/A	Ask Benjamin for access	Feb 06	Feb 10
Loop-X	Generate X-ray and CT Scan	Ready to use	N/A	Ask Benjamin for access	Feb 06	Feb 10
SyntheX	Generate Domain Generalized X-ray	Open source github repository	N/A	Request the source code from Dr. Cong Gao	Feb 01	Feb 06
Model Checkpoint	hyper parameters of SyntheX	On private onedrive folder	Keep secured		Feb 08	Feb 12
xReg	Compute registration parameter between CT scan and X-ray Image	Open source github repository	N/A	Request the source code from Dr. Grupp	Feb 08	Feb 12
CT DataSet	As a input used in Xreg	Ready to use	Keep secured	N/A	Feb 06	Feb 20
Total Segmentator	Do CT Scan segmentation	Open source software	Downloaded	N/A	Feb 18	Feb 20
Computers	Our own computer with an environment for software development	Install python, C++, Unity	Ready to use	"PACKMAN" ARCADE Server	Jan 23	N/A
HoloLens	Do mixed reality visualization	Plan to request at Mar 10 from mentor	N/A	N/A	Mar 15	Mar 20
Unity Code for visualization	Connecting our pipeline to HMD		N/A	N/A	Mar 15	Mar 20
Optional: Wifi Memory Stick	Synchronizing data	Plan to purchase	Send the request to the lab manager	Research agreement to get API of Loop-X	Mar 10	Mar 23

Responsibility Arrangement

- Jiaming Zhang :
  - Mainly responsible for managing SyntheX section, basically includes:
    - Implement interfaces for each package for future development.
    - Make a user-friendly documentation.
- Zhangcong she :
  - Mainly Responsible for managing Intensity-based registration section:
    - Configure a proper environment for Compiling the existing functionalities of xReg.
- Both of us are also responsible for pipeline design, mixed reality visualization part, including:
  - Design a pipeline to automatically swap data between Loop-X, SyntheX and 2D/3D Registration.
  - Implement a program to manage these packages and integrate them into a single executable application with a Graphics User Interface.
  - Develop an executable application on Hololens for projective visualization

Management

Meetings with Benjamin Killeen:

- 3:00 pm every Monday, in-person

ARCADE Lab meetings:

- 4:15 pm every Thursday, in-person

Discussions between group members:

- Twice a week, 9:30 am every Monday and Wednesday, in-person

Communication:

- Email/Discord

All files are uploaded to private repository in Github and the wiki page

Reference

[1]. Gao, C., "SyntheX: Scaling Up Learning-based X-ray Image Analysis Through In Silico Experiments", *arXiv e-prints*, 2022. doi:10.48550/arXiv.2206.06127.

[2]. Arcadelab, "Arcadelab/synthex," *GitHub*. [Online]. Available: https://github.com/arcadelab/SyntheX. [Accessed: 21-Feb-2023].

[3]. C. Gao, "Fluoroscopic navigation for robot-assisted orthopedic surgery," dissertation, 2022.

[4]. P. Markelj, D. Tomaževič, B. Likar, and F. Pernuš, "A review of 3D/2D registration methods for image-guided interventions," *Medical Image Analysis*, vol. 16, no. 3, pp. 642–661, 2012.

[5]. R. B. Grupp, M. Unberath, C. Gao, R. A. Hegeman, R. J. Murphy, C. P. Alexander, Y. Otake, B. A. McArthur, M. Armand, and R. H. Taylor, "Automatic annotation of hip anatomy in fluoroscopy for robust and efficient 2D/3D registration," *International Journal of Computer Assisted Radiology and Surgery*, vol. 15, no. 5, pp. 759–769, 2020.

[6]. Y. Otake, M. Armand, R. S. Armiger, M. D. Kutzer, E. Basafa, P. Kazanzides, and R. H. Taylor, "Intraoperative image-based multiview 2D/3D registration for image-guided orthopaedic surgery: Incorporation of fiducial-based C-arm tracking and GPU-acceleration," *IEEE Transactions on Medical Imaging*, vol. 31, no. 4, pp. 948–962, 2012.