The Johns Hopkins University
EN.601.656 Advanced Computer-Integrated Surgery Course Project
Instructor: Russell H. Taylor

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

Group 7 Project Proposal

Jiaming Zhang
jzhan282@jhu.edu

Zhangcong She
zshe1@jhu.edu

Mentors: Benjamin Killeen; Prof. Mathias Unberath

Contents

1 Background

In minimally invasive surgery, clinicians use intraoperative fluoroscopy to overcome the occlusion and ascertain the poses of anatomy, surgical instruments, or artificial implants[2]. Registration is used to align the pre- and intra-interventional data just before and also during an operation in such a way that corresponding anatomical structures in the two data sets are aligned [1]. Intraoperative 2D/3D registration is a commonly used technique for finding a rigid pose of a 3D image, for instance, CT Scan so that it aligns with the target 2D image. Further, the frame transformation between the preoperative image and the intraoperative patient's coordinate system can be solved accordingly [4].

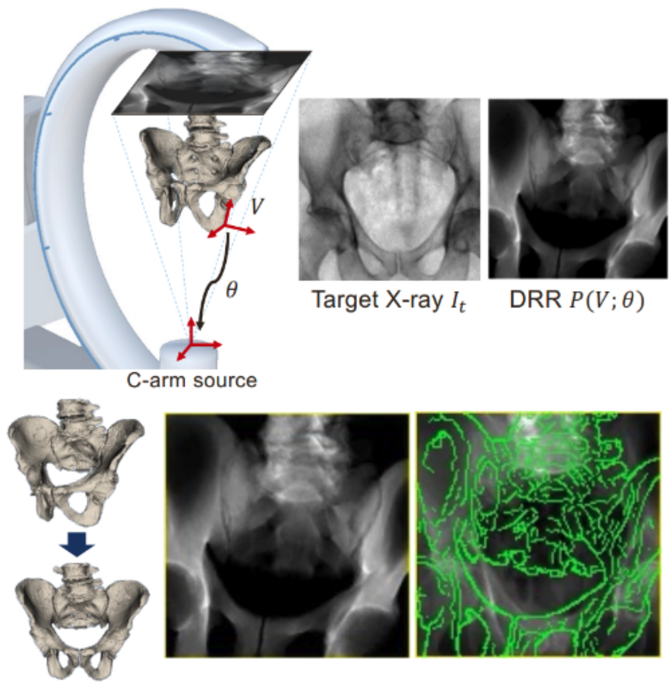

Figure 1: 2D/3D Registration

We could solve registration more efficiently with the help of Loop-X. Loop-X is a robotic platform used to produce 2D X-ray image and 3D CT scan on a high resolution with an extra-large field of view. Image-based 2D/3D registration is a fiducial-less approach [5]. Compared to the traditional 2D/3D registration method, image-based registration doesn't need physical contact, such as screws. During the operative process, it only needs real-time X-ray images, which would be used to solve the registration with the anatomical region of interest in the patient[3]. In conclusion, this method greatly reduces the additional damage to the patient's body and shortens the preparation time for the operations.

2 Clinical Motivation

Image-based 2D/3D registration mainly relies on the image of the anatomical structures. (Robert B. Grupp et al., 2020, p441) proposed a novel intensity-based 2D/3D registration pipeline that can successfully recover the fragment pose in Periacetabular Osteotomy. Unfortunately, the ineffectiveness of manual annotations has an impact on this strategy [3]. To overcome this deficiency, (Cong Gao, 2022) proposed SyntheX, which is a learning-based X-ray image transfer paradigm that can be used to generate synthesized fluoroscopic images with landmarks annotated synchronously. Combining SyntheX and the registration pipeline could potentially provide these methods with a more comprehensive outlook and eventually, these methods can be seamlessly utilized in the O.R. Fig. 2 demonstrates the basic idea of SyntheX [1].

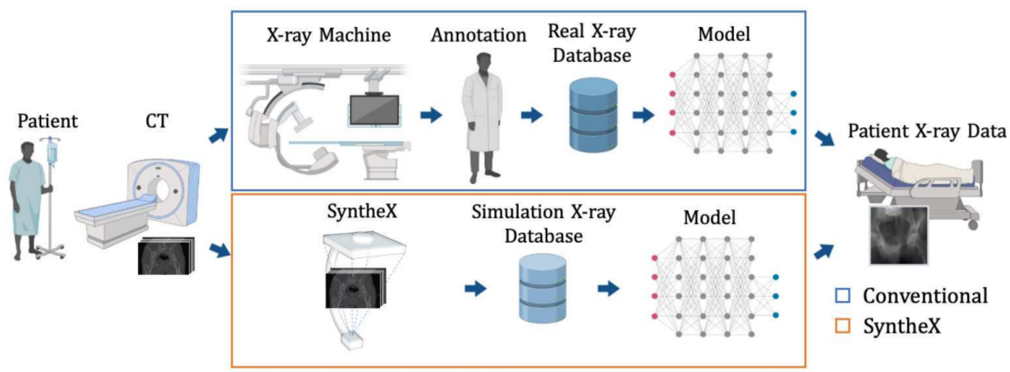

Figure 2: SyntheX Workflow [1]

Except for these two core steps, a complete registration task would rely on multiple other subroutines. These subroutines may come in the form of software or packages, which are not well coordinated. As a result, it is not straightforward for surgeons to use them during the intraoperative process. In addition, these packages are usually programmed in different developing environments and sometimes they are not compatible with each other. Besides, some of these packages are too poorly documented, making them hard to maintain and employ. These potential problems make the procedure over-complicated for intraoperative usage and it may lead to a higher probability of misoperation. Therefore, to reduce risks, a user-friendly, well-documented, and automatic pipeline that combines all subroutines needs to be introduced.

3 Project Goal

The primary goal of our project is to create a pipeline that automatically perform the 2D/3D registration process between X-ray images intraopeatively. This process involves integrating several procedures into a single software, the subroutines includes:

- Image Acquisition: Retrieve X-ray from Loop-X automatically.
- Data Synthesis: Apply SyntheX to generate annotated X-ray images.
- CT Annotation: Annotate pre-operative CT scan through TotalSegmentator.
- Online Registration: Use xReg to compute intensity-based registration.

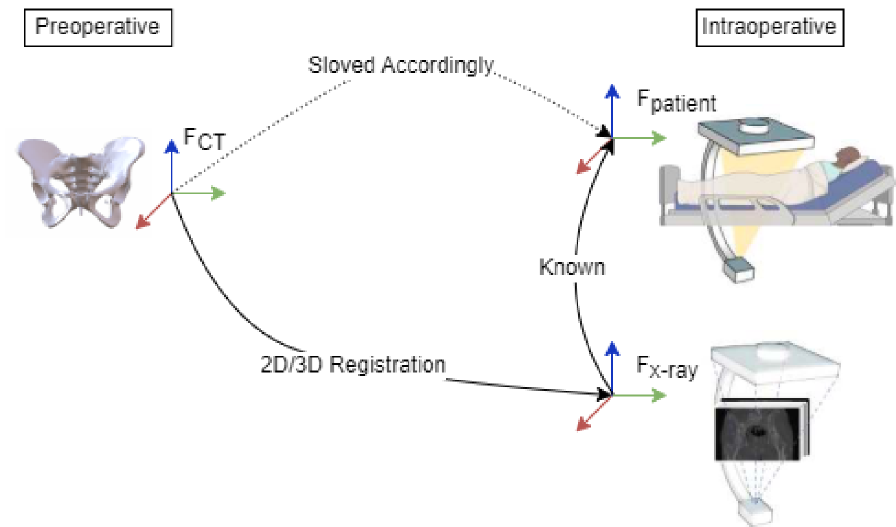

Figure 3: Frame Transformation

Fig. 3 demonstrates the basic goal of our project. To be specific, we aim to integrate the aforementioned process and provide a software with user-friendly graphical user interface(GUI) to simplify the overall online registration process. Our pipeline will mainly focus on the 2D/3D registration part, but it also includes preoperative annotation for the CT Scans. Ideally, we hope to make the software run in the real-time. Once the registration process is complete, we also look forward to use the registration result to visualize the data using novel projective paradigms on Hololens, which can be used to guide surgical procedures more accurately and efficiently.

4 Technical Approach

The overall architecture of our pipeline is shown in 4.

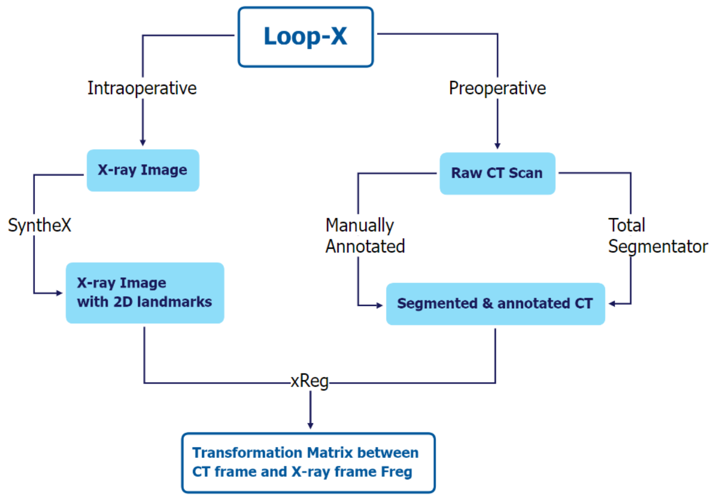

Figure 4: Pipeline Workflow

Our objective can be broken down into the following components.

Initially, we would implement a script to retrieve the X-ray image from Loop-X to the local device in the real-time. We seek to set up a communication channel between Loop-X and the local device either via TCP/IP or another data-switching protocol. The backup plan for this is to stick a wireless flash drive on the USB-C port of the teaching pendant of Loop-X.

Then, the landmark detection of the X-ray image would be done by applying SyntheX. SyntheX has several model checkpoints provided with little documentation. Our job is first to organize the repository and write proper documentation for it. That step would be followed by integrating the functionalities as interfaces for the convenience of the software development.

While, in the preoperative period, our pipeline requires the annotated CT scans of the patients. In our project, an open-source software named TotalSegmentator will be applied to perform segmentation of the CT image retrieved from Loop-X. The manual landmark annotation would be done by professionals. The landmarks will be used for obtaining the initial registration estimates of the pelvis.

Finally, the synthesized X-ray image and annotated CT scan would be used as input of xReg to get the frame transformation between the X-ray coordinate system and CT coordinate system, i.e., F^{CT}_{X-ray}.

5 Project Deliverables

- Minimum Deliverables (expected delivery by March 31)
  - Documentation for SyntheX and provide an application interface for users
  - Python script that retrieves image data from Loop-X automatically
  - A well-documented program that combines all subroutines
- Expected Deliverables (expected delivery by April 25)
  - Fully automatic pipeline
  - A view rendering application for projective visualization
  - Report for validating our programs on cadaveric images
- Maximum Deliverable s(expected delivery by May 15)
  - An application that integrates our program results with mixed reality visualization of relevant anatomy

6 Timeline

Our timeline is shown in the form of Gantt Chart as 5.

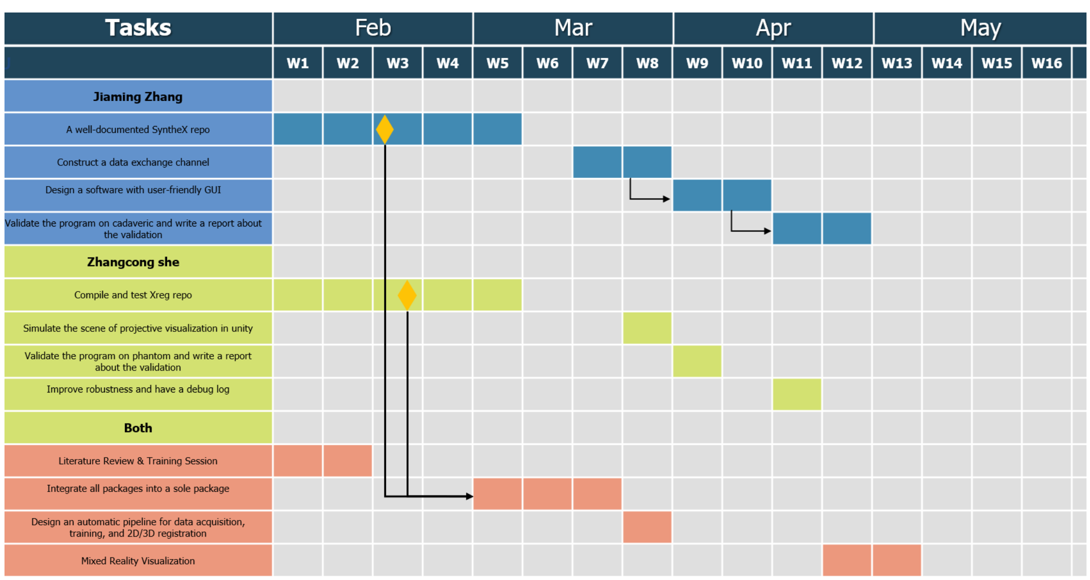

Figure 5: Gantt Chart

7 List of Dependencies and Plan for Resolving

Lists	Need	Status	Followup	Contingency plan	Planned	Hard DL
MOCK OR Lab Access	Operate Loop-X	Acquired 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	Acquired access	N/A	Request source code from Dr. Cong Gao	Feb 01	Feb 06
Model Checkpoint	Integrate SyntheX	Acquired access	Keep secured	Request the source code from Dr. Cong Gao	Feb 08	Feb 12
xReg	Compute registration parameter between CT scan and X-ray Image, open source github repository	Acquired access	N/A	Request the source code from Dr. Grupp	Feb 08	Feb 12
CT DataSet	Testset for the pipeline	Ready to use	Keep secured	N/A	Feb 06	Feb 20
Total Segmentator	Do CT Scan segmentation	Ready to use	Downloaded	N/A	Feb 18	Feb 20
Computers with Python, C++ and Unity	Our own computer with an environment for software development	Ready to use	N/A	"PACKMAN" ARCADE Server	Jan 23	N/A
HoloLens	Mixed reality visualization	Plan to request at Mar 10 from mentor	N/A	N/A	Mar 15	Mar 20

Lists	Need	status	Followup	Contingency plan	Planned	Hard DL
Unity Code for visualization	Connecting our pipeline to HMD	Plan to request at Mar 10 from mentor	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

By now, most of dependencies are ready to use except the last three parts. Hololens and Unity code for visuliaztion are planned to ask our mentor after we complete the prototype. The Wifi Memory stick is an optional dependency that makes our automatic image acquisition easier. We have sent the request to lab manager to purchase it.As a contingency plan, we would ask for research agreement to get API of Loop-X.

8 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
  - 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

9 Group 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:
  - Mainly use Email and Discord
  - All files are uploaded to private GitHub repository and OneDrive folders

10 Reading List

- Grupp, Robert & Hegeman, Rachel & Murphy, Ryan & Alexander, Clayton & Otake, Yoshito & McArthur, Benjamin & Taylor, Russell. (2019). Pose Estimation of Periacetabular Osteotomy Fragments with Intraoperative X-Ray Navigation.

- Arcadelab, “Synthex”, GitHub. Available: https://github.com/arcadelab/SyntheX.

- rg2,”xreg”,GitHub. Available: https://github.com/rg2/xreg

- Grupp, R.B., Unberath, M., Gao, C. et al. Automatic annotation of hip anatomy in fluoroscopy for robust and efficient 2D/3D registration. Int J CARS 15, 759–769 (2020). https://doi.org/10.1007/s11548-020-02162-7

- R. B. Grupp et al., ”Pose Estimation of Periacetabular Osteotomy Fragments With Intraoperative X-Ray Navigation,” in IEEE Transactions on Biomedical Engineering, vol. 67, no. 2, pp. 441-452, Feb. 2020, doi: 10.1109/TBME.2019.2915165.

- C. Gao et al., ”Fiducial-Free 2D/3D Registration for Robot-Assisted Femoroplasty,” in IEEE Transactions on Medical Robotics and Bionics, vol. 2, no. 3, pp. 437-446, Aug. 2020, doi: 10.1109/TMRB.2020.3012460.

- Gao C, Farvardin A, Grupp RB, Bakhtiarinejad M, Ma L, Thies M, Unberath M, Taylor RH, Armand M. Fiducial-Free 2D/3D Registration for Robot-Assisted Femoroplasty. IEEE Trans Med Robot Bionics. 2020 Aug;2(3):437-446. doi: 10.1109/tmrb.2020.3012460. Epub 2020 Jul 28. PMID: 33763632; PMCID: PMC7982989.

References

[1] Cong Gao. *Fluoroscopic navigation for robot-assisted orthopedic surgery.* PhD thesis, Johns Hopkins University, 2022.

[2] Cong Gao, Benjamin D. Killeen, Yicheng Hu, Robert B. Grupp, Russell H. Taylor, Mehran Armand, and Mathias Unberath. SyntheX: Scaling Up Learning-based X-ray Image Analysis Through In Silico Experiments. *arXiv e-prints*, page arXiv:2206.06127, June 2022.

[3] Robert B. Grupp, Mathias Unberath, Cong Gao, Rachel A. Hegeman, Ryan J. Murphy, Clayton P. Alexander, Yoshito Otake, Benjamin A. Mcarthur, Mehran Armand, and Russell H. Taylor. Automatic annotation of hip anatomy in fluoroscopy for robust and efficient 2d/3d registration. *International Journal of Computer Assisted Radiology and Surgery*, 15(5):759–769, 2020.

[4] P. Markelj, D. Tomaževič, B. Likar, and F. Pernuš. A review of 3d/2d registration methods for image-guided interventions. *Medical Image Analysis*, 16(3):642–661, 2012. Computer Assisted Interventions.

[5] 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*, 31(4):948–962, 2012.