JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Recreating Pelvic Trauma Surgery in Virtual Reality

Students:

- Han Zhang
- Zixuan Liu
- Liam Wang

Mentors:

- Benjamin Killeen
- Mathias Unberath

Project Proposal

ARCADE

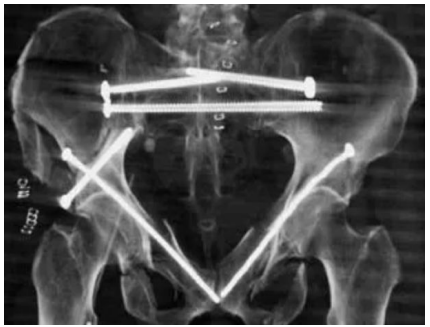
Background

Percutaneous pelvic fracture surgery is a **minimal invasive surgery**, providing better wound healing, less damage to major vessels and nerves and less possibility of infection. However:

- ➔ Inadequate visualization
- ➔ Require more training for surgeons
- ➔ More radiation exposure for surgeons when k-wire insertion.

Open Pelvic Fracture Surgery(a)

Percutaneous Pelvic Fracture Surgery with C-arm(b)



K-wires in Pelvis shown in Intraoperative Fluoroscopy(c)

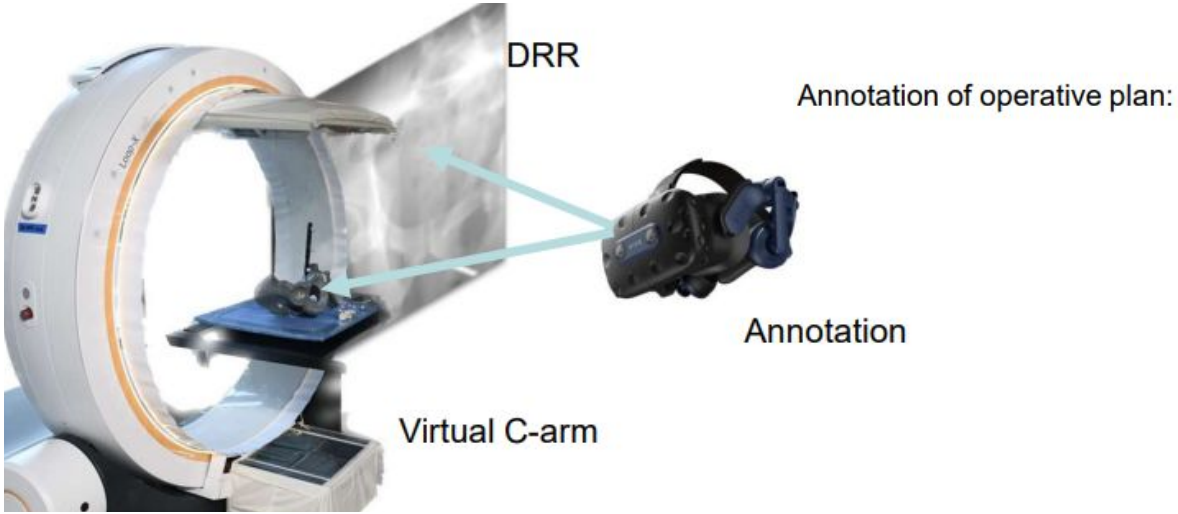
(a)Wang, Z.-h. and Li, K.-n. (2019), Regional Injury Classification and Treatment of Open Pelvic Fractures. Orthop Surg, 11: 1064-1071. https://doi.org/10.1111/os.12554
(b)Rami Mosheiff, Chip Routt.Percutaneous fixation of pelvic fractures. orthoinfo - aaos. OrthoInfo. (n.d.). Retrieved February 8, 2023, from https://orthoinfo.aaos.org/en/treatment/internal-fixation-for-fractures

Clinical Motivation

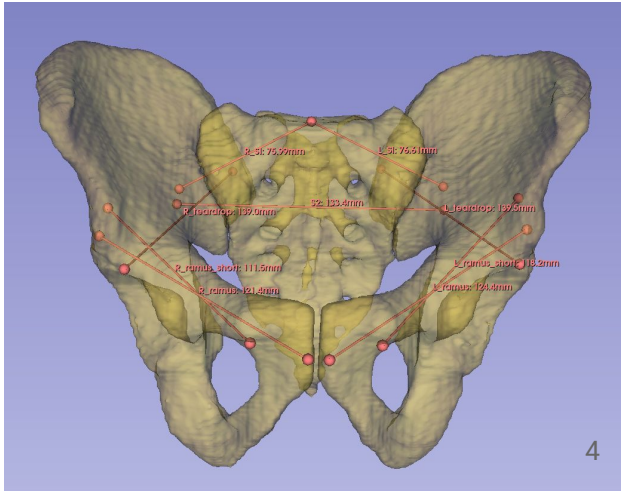
Clinicians need a training environment for **percutaneous pelvic fracture surgery under C-arm fluoroscopy,** enabling **practice** of the procedure without exposure to ionizing radiation and easy **collection** of **detailed operation data**.

Project

We are creating a **virtual reality environment** with patient models and an interactable C-arm for recreating internal fixation of pelvic fractures. To achieve this, **DeepDRR** is used to provide a fast and realistic simulation of digitally reconstructed radiographs (DRR) from CT scans to show in the **head-mounted display**.



Annotation of operative plan:



Clinical Motivation

Training - no ionising radiation exposure
- Orthopedic surgeons
- Surgical residents

Data collection - less pressure on clinicians, more ethical and easier to collect big data
- Statistical analysis can answer:
  - How many images were taken by experts and from what perspectives?
  - What radiation dose is expected for a certain procedure?
  - How accurate and consistent is k-wire placement?
- Used to train future algorithms to…
  - Determine the phase of real surgical procedures
  - Give advice on C-arm positioning
  - Give performance feedback to surgical residents learning the procedure

Testing experimental protocols or techniques
- AR in VR: Designing an AR HUD for orthopedic surgeons
- Techniques for positioning C-arm for better accuracy or fewer x-ray images

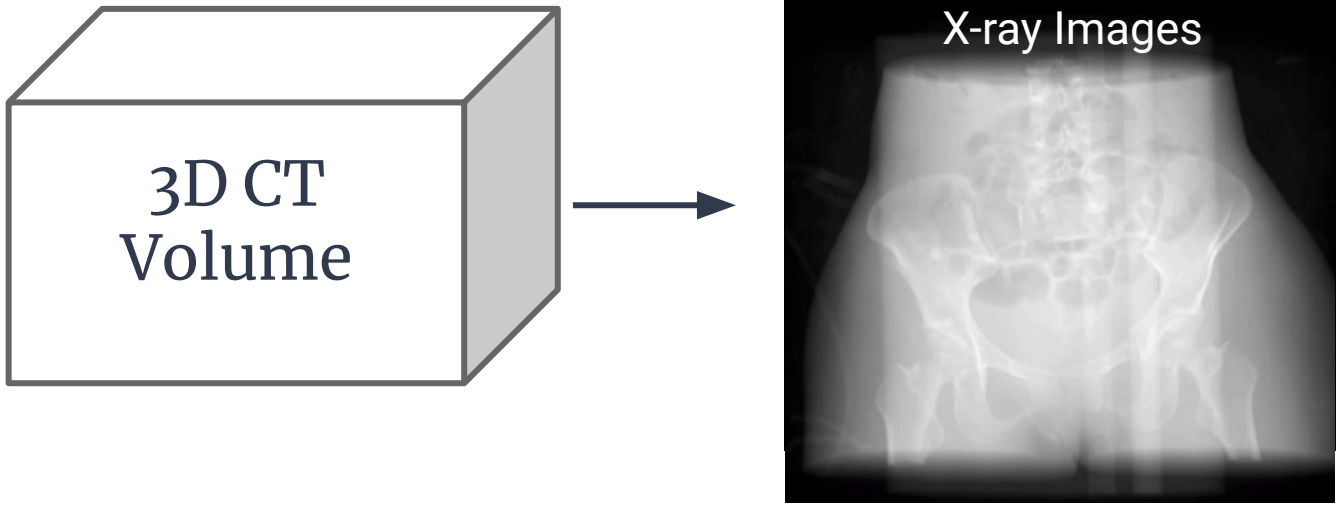
Clinical Motivation

Who will it benefit?

- **Residents and surgeons**
  - Using the VR headset - VR training without ionising radiation and low cost
  - Expert-generated 2D educational content
    - Can be used to create POV videos from experts
    - Save X-ray images/poses and generate procedure statistics from experts
  - Benefit from computer-integrated surgical support technologies developed as a result of simulation-collected data
- **Patients**
  - Indirectly, from better surgeons and computer support technologies which can do more accurate procedures with a smaller x-ray dose

Background

(Unberath at el. 2018) proposed a framework, DeepDRR, that can generate realistic DRRs from 3D CT with more accurate anatomical landmark detection and localization of robot end-effectors than conventional naive DRRs.

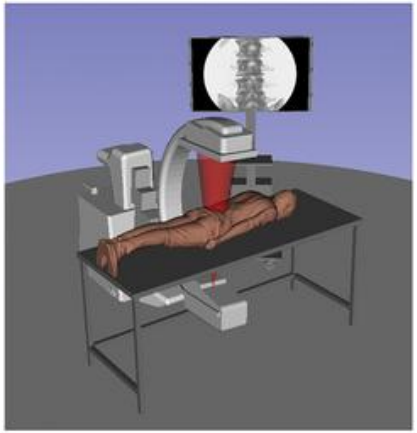


Unberath, M., Zaech, J.-N., Lee, S. C., Bier, B., Fotouhi, J., Armand, M., & Navab, N. (2018). DeepDRR – A Catalyst for Machine Learning in Fluoroscopy-guided Procedures. arXiv. https://doi.org/10.48550/ARXIV.1803.08606

Background

(Allen et al. 2022) used a virtual C-arm model in the VR environment to train residents who had few experience observing C-arm procedures, they showed an overall significant improvement in C-Arm placement with regards to angular accuracy (mean ~2 degree improvement), and total procedure time (mean 11 minutes less time) for interventional spine procedures.

(a)



(b)

We intend to improve upon the limitations of this work by adding:

- Interaction with surgical tools
- Simulation of needle-tissue interaction
- Use the more accurate DRRs generated by DeepDRR rather than the naive ray tracing method

Daniel R. Allen, Collin Clarke, Terry M. Peters & Elvis C.S Chen (2022) Development and evaluation of an open-source virtual reality C-Arm simulator, Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, DOI: 10.1080/21681163.2022.2152374

Goals

Minimal:

- A set of planned fixation procedures in an already obtained database of CT data.

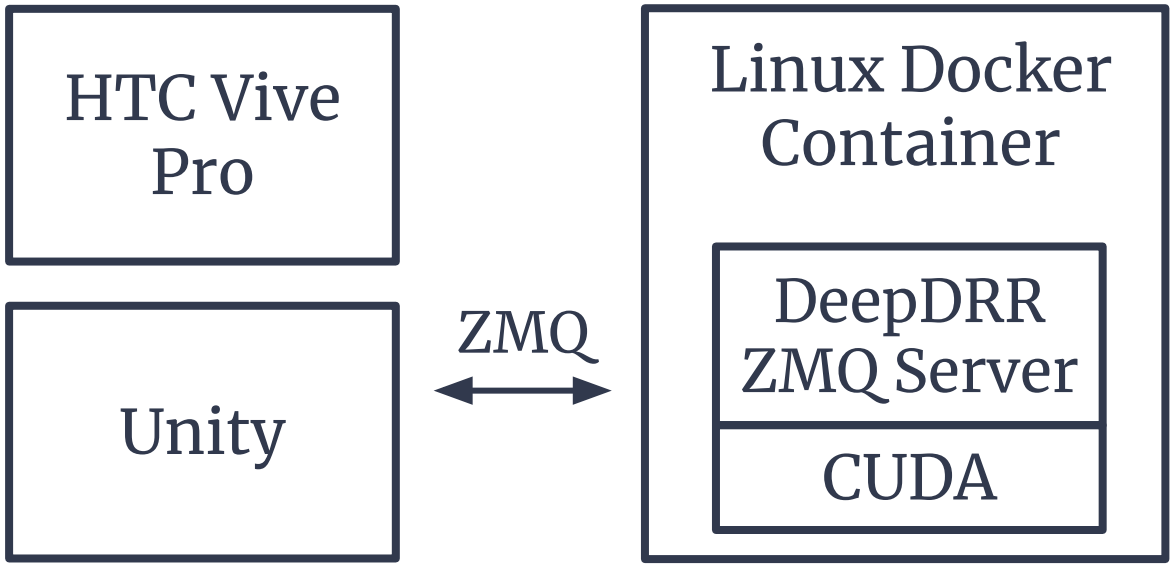
Expected:

- A interactable virtual reality environment visualizing the pelvic fixation procedure with simulated X-ray images.

Maximum:

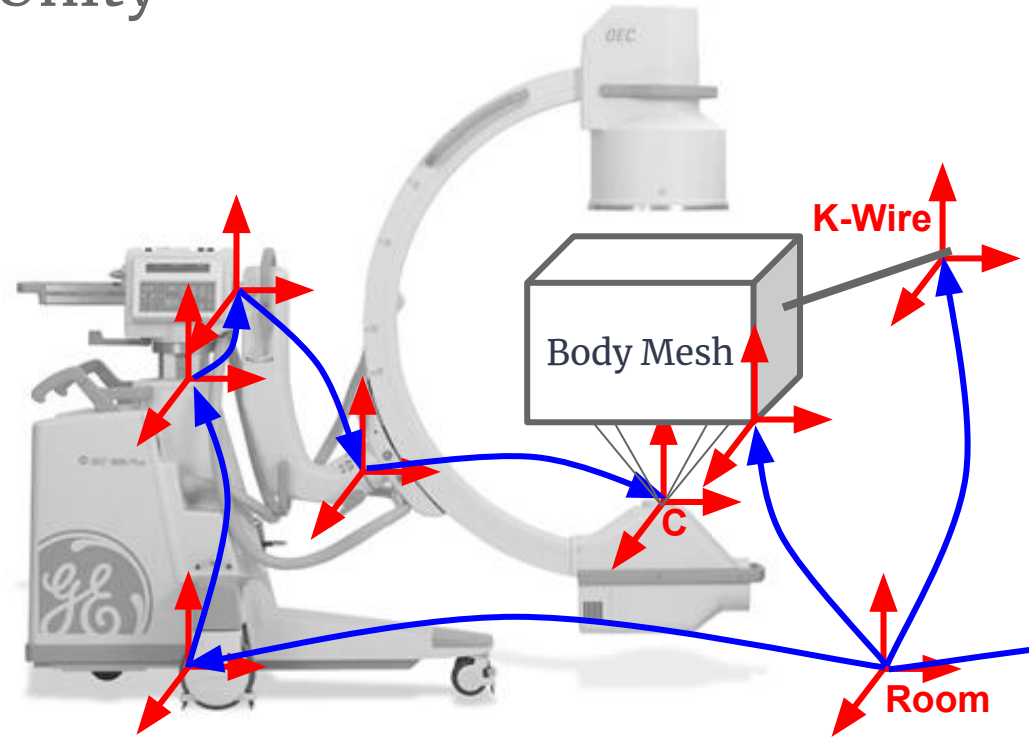
- An interactable tools and virtual C-arm for developing novel human machine interfaces.
- A K-wires insertion Interaction simulation

Technical Approach Overview

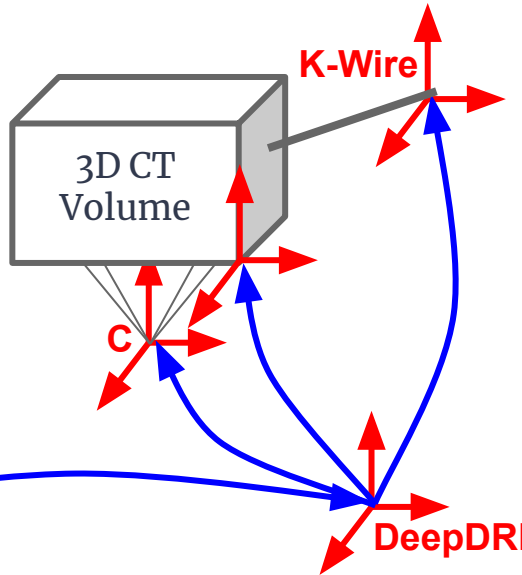


Transform Diagram

Unity



DeepDRR

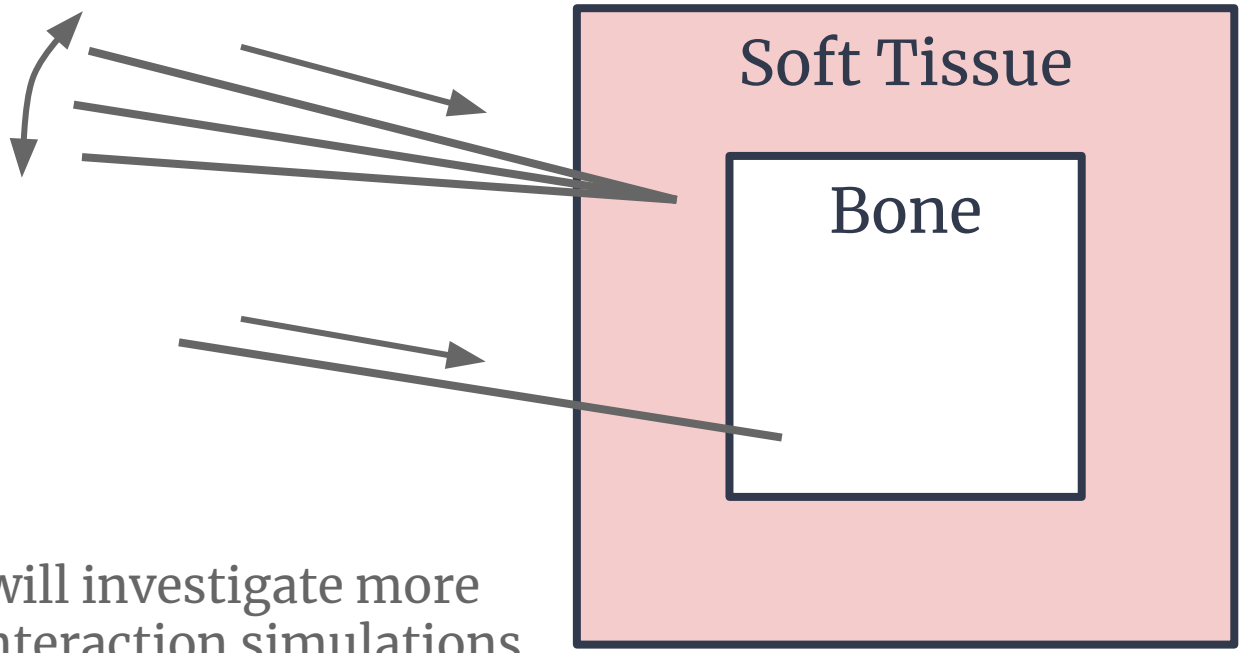


Simple K-Wire Tissue Interaction Simulation

K-wire can be tilted slightly in soft tissue

K-wire is not able to be tilted as far in the bone, only inserted/retracted

Time permitting, we will investigate more sophisticated tissue interaction simulations

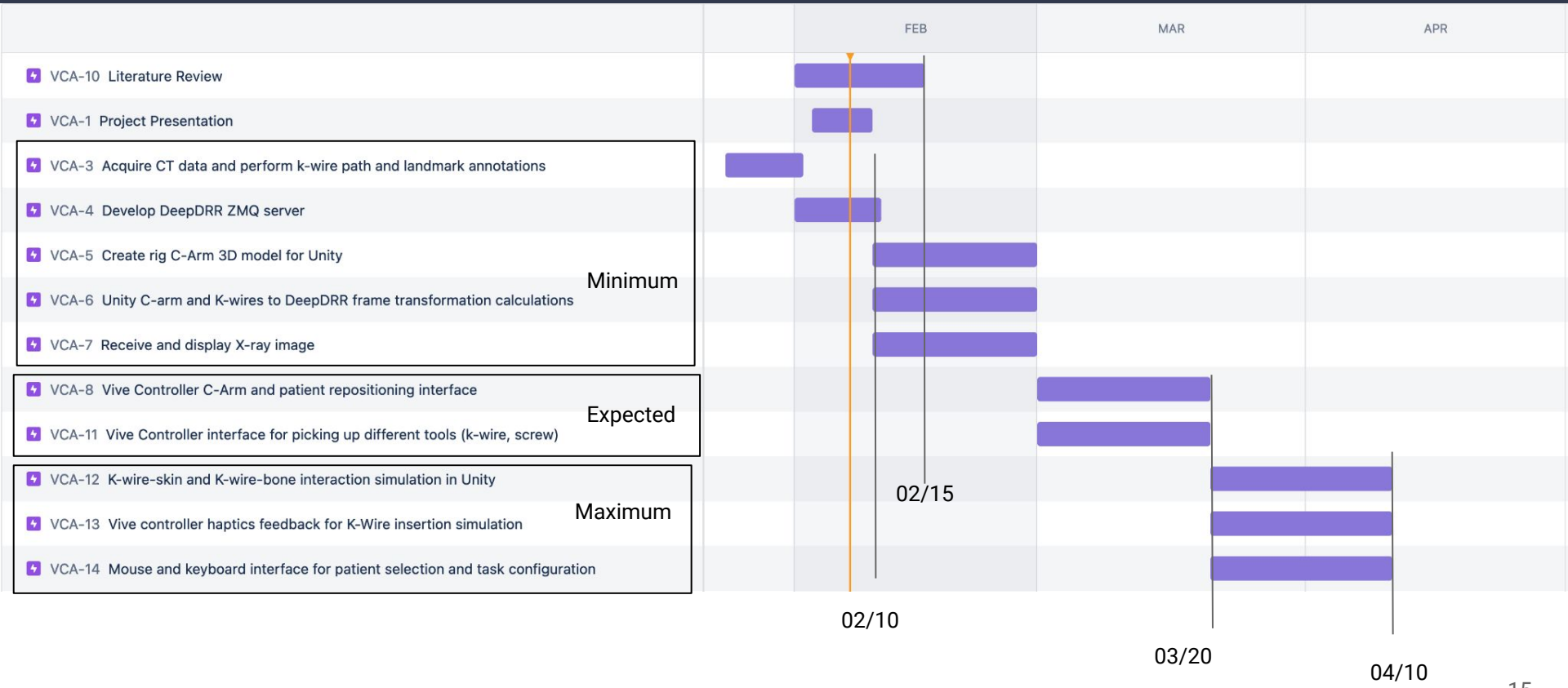


Dependencies

Dependency	Need	Status	Followup	Contingency Plan
Computing Power	Running DeepDRR and VR application	Ready to use	Install DeepDRR and Unity	`pong` workstation
DeepDRR	Generate realistic X-ray images	Done	Develop DeepDRR ZMQ server	Python Package
3D Slicer	Annotate landmarks	Done	Perform annotations	Python Package
HTC Vive Pro	Display VR simulation	Ready to use	Connect to PC	N/A
Unity	Develop VR environment	Installed	Create Scene and Asset	Use Slicer VR
C-Arm 3D Model	Simulate the C-arm in VR	Implementing	Rig with kinematics	Open-source Asset
Pelvis CT Dataset	Input to DeepDRR and segment for ground truth	Acquired	Perform annotations	N/A

	Key Milestones/Activities	Results/Deliverables
Minimum	Acquire CT data and perform k-wire path and landmark annotations	Annotated CT Data
	Develop DeepDRR ZMQ server	DeepDRR ZMQ server python package
	Create/rig C-Arm 3D model for Unity	Rigged C-Arm model
	Unity C-arm and K-wires to DeepDRR frame transformation calculations	Frame transformation calculation with unit tests
	Receive and display X-ray image	Image send unit tests
Expected	Vive Controller C-Arm and patient repositioning interface	Unity executable with user interface
	Vive Controller interface for picking up different surgical tools (k-wire, screw, drill)	Unity executable with user interface
Maximum	K-wire-skin and K-wire-bone interaction simulation in Unity	Unity executable with k-wire simulation
	Vive controller haptics feedback for K-Wire insertion simulation	Unity executable with k-wire haptics
	Mouse and keyboard interface for patient selection and task configuration	Python package which launches GUI interface

Timeline


FEB
MAR
APR
VCA-10 Literature Review
VCA-1 Project Presentation
VCA-3 Acquire CT data and perform k-wire path and landmark annotations
VCA-4 Develop DeepDRR ZMQ server
VCA-5 Create rig C-Arm 3D model for Unity
VCA-6 Unity C-arm and K-wires to DeepDRR frame transformation calculations
VCA-7 Receive and display X-ray image
Minimum
VCA-8 Vive Controller C-Arm and patient repositioning interface
VCA-11 Vive Controller interface for picking up different tools (k-wire, screw)
Expected
VCA-12 K-wire-skin and K-wire-bone interaction simulation in Unity
VCA-13 Vive controller haptics feedback for K-Wire insertion simulation
VCA-14 Mouse and keyboard interface for patient selection and task configuration
Maximum
02/10
02/15
03/20
04/10

Testing Plan

Code Validation: Is our code robust and stable?

Create unit tests to verify correctness of math functions. Create tests to ensure Unity-DeepDRR network communication can recover from unstable network conditions and invalid data. Create and perform manual test procedures to ensure the VR user interface works correctly.

Testing of C-Arm Model: Are our C-Arm kinematics correct?

Compare our Unity C-arm kinematics with DeepDRR C-arm kinematics. Evaluate the accuracy of the C-Arm 3D model by comparing its movements and positions actual C-Arm devices.

Simulation Verification: How accurately does our simulation mimic real pelvic trauma surgery?

Conduct a user study. Have experienced surgeons perform simulated procedures and provide qualitative feedback. Collect quantitative procedure metrics and compare to real pelvic fracture surgery outcomes. We will have succeeded if expert surgeons believe their use of the simulation is a fair enough representation of their skills. Additionally, statistics such as the approximate number of X-ray images taken should match analogous real procedures.

Roles

- Team members
  - Han Zhang
    - *Master's Student, BME Major, responsible for interactive C-arm model and Kinematics*
  - Zixuan Liu
    - *Master's Student, CS Major, responsible for VR tools interaction and k-wire simulation*
  - Liam Wang
    - *Undergraduate Junior, BME & CS Major, responsible for DeepDRR ZMQ Server and Unity Client*
- Team mentors
  - Benjamin Killeen
    Ph.D. Student
  - Mathias Unberath
    Assistant Professor in the Department of Computer Science at Johns Hopkins University with affiliations to the Laboratory for Computational Sensing and Robotics.

Management

- Weekly Meetings
  - **Student Team Meeting**: Brainstorming
  - **Mentor Meeting**: Progress Report
  - **Lab Meeting**: Progress Report
- Platforms
  - **Github**: Code
  - **Zoom Meeting**, **Discord Text, Email, Message**: Communications
  - **Google Drive**: Write-ups
  - **Jira**: Task Timeline, administrative Stuff

References

1. Unberath, M., Zaech, J.-N., Lee, S. C., Bier, B., Fotouhi, J., Armand, M., & Navab, N. (2018). DeepDRR – A Catalyst for Machine Learning in Fluoroscopy-guided Procedures. arXiv. https://doi.org/10.48550/ARXIV.1803.08606
2. Daniel R. Allen, Collin Clarke, Terry M. Peters & Elvis C.S Chen (2022) Development and evaluation of an open-source virtual reality C-Arm simulator, Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, DOI: 10.1080/21681163.2022.2152374
3. Rommens, P. M., Graafen, M., Arand, C., Mehling, I., Hofmann, A., & Wagner, D. (2020). Minimal-invasive stabilization of anterior pelvic ring fractures with retrograde transpubic screws. Injury, 51(2), 340-346.
4. Würfl, T., Hoffmann, M., Christlein, V., Breininger, K., Huang, Y., Unberath, M., & Maier, A. K. (2018). Deep learning computed tomography: Learning projection-domain weights from image domain in limited angle problems. IEEE transactions on medical imaging, 37(6), 1454-1463.
5. *Rami Mosheiff, Chip Routt.Percutaneous fixation of pelvic fractures. orthoinfo - aaos*. OrthoInfo. (n.d.). Retrieved February 8, 2023, from https://orthoinfo.aaos.org/en/treatment/internal-fixation-for-fractures
6. Wang, Z.-h. and Li, K.-n. (2019), Regional Injury Classification and Treatment of Open Pelvic Fractures. Orthop Surg, 11: 1064-1071. https://doi.org/10.1111/os.12554