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PelvisVR: Recreating Pelvic Trauma Surgery in Virtual Reality

Students:

- Han Zhang
- Zixuan Liu
- Liam Wang

Mentors:

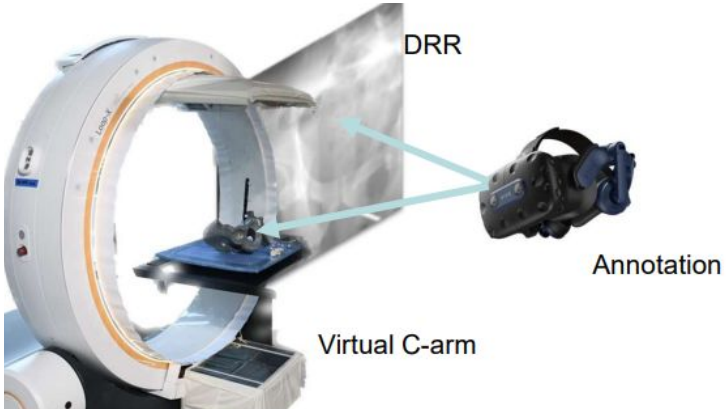
- Benjamin Killeen
- Mathias Unberath

Checkpoint Presentation

Project Summary

Due to the inadequate visualization and excessive radiation exposure for surgeons under intraoperative fluoroscopy, there is a need for clinicians to have a fluoroscopy-guided training environment without radiation exposure. This project aims to build a virtual reality environment with patient models and an interactable C-arm for recreating the internal fixation of pelvic fractures, using digital reconstructed radiographs(DRR) from CT scans.

Percutaneous Pelvic Fracture Surgery with C-arm(a)



Training Environment with DRRs

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(a)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

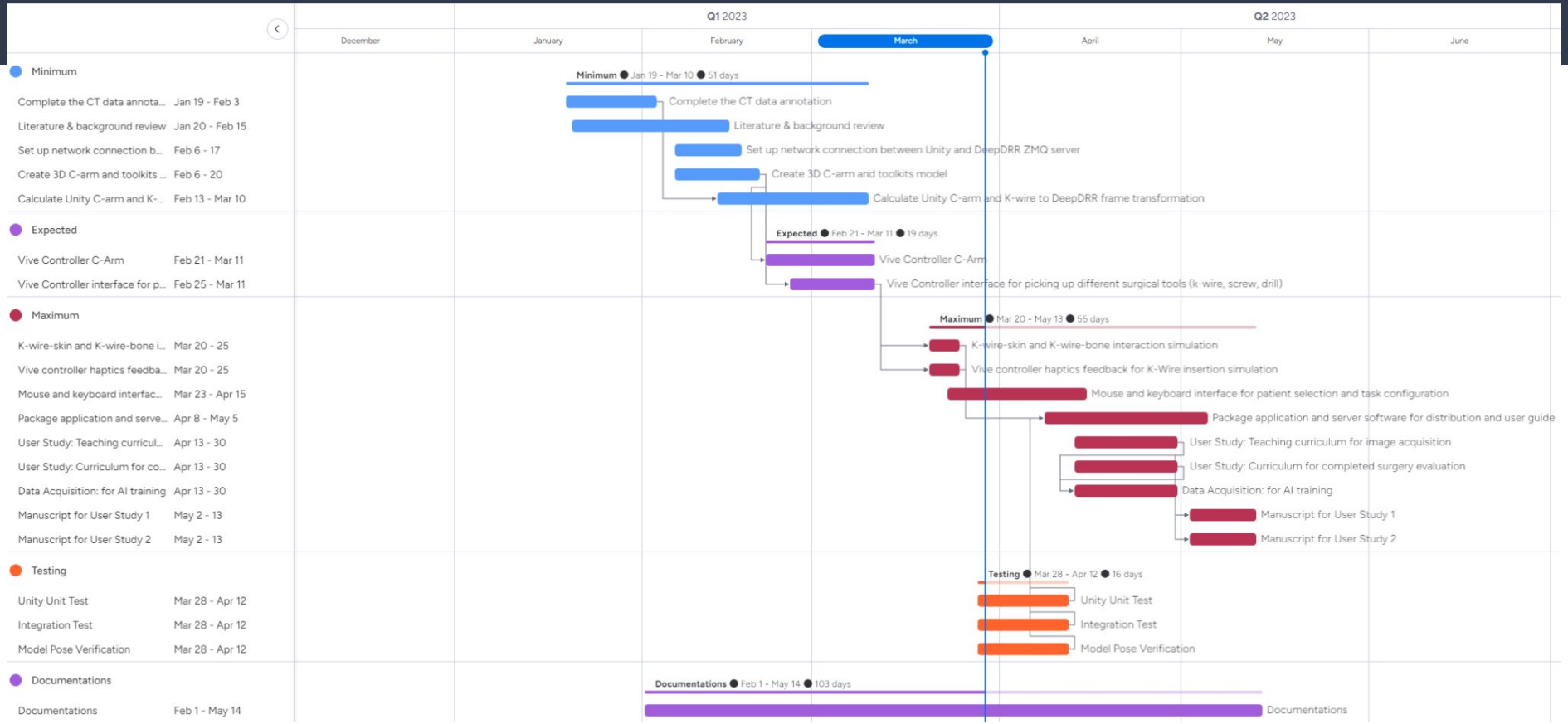
Project Status-Dependencies

Dependency	Need	Followup	Expected Date	Hard Deadline	Contingency Plan	Status
Pelvis CT Dataset	Input to DeepDRR	Perform annotations	02/03	02/23	N/A	
3D Slicer	Annotate landmarks	Perform annotations	02/03	02/23	Python Package	
Computing Power	Running DeepDRR and VR application	Install DeepDRR and Unity	02/13	02/23	`pong` workstation	
DeepDRR	Generate realistic X-ray images	Develop DeepDRR ZMQ server	02/15	03/03	Python Package	
HTC Vive Pro	Display VR simulation	Connect to PC	02/13	03/03	N/A	
Unity	Develop VR environment	Create Scene and Asset	02/13	03/03	Use Slicer VR	
C-Arm 3D Model	Simulate the C-arm in VR	Rig with kinematics	02/20	03/03	Open-source Asset	
IRB Approval	Approval to conduct the user study	Run the user study	04/15	04/30	N/A	

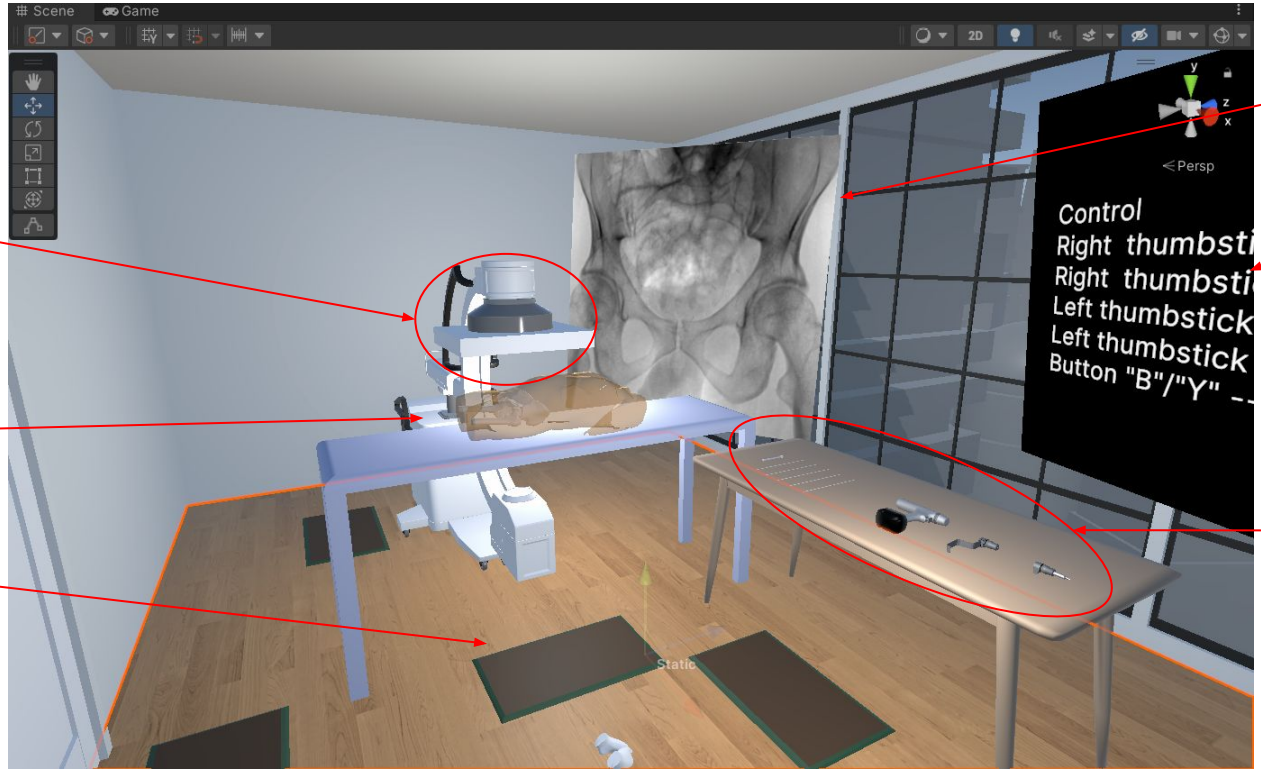
Project Status-Updated Milestones

	Key Milestones/Activities	Results/Deliverables	Deadline	Status
Minimum	Completion of the CT data annotation	Annotated CT data that includes landmarks and K-wire paths	Feb 3	Done
	Literature & background review	Project proposal document	Feb 15	Done
	Set up network connection between Unity and DeepDRR ZMQ server	A documented and unit-tested python DeepDRR server package and Unity project that can display live X-ray images from a CT model corresponding to different angles of the camera.	Feb 17	Done
	Model 3D C-arm and surgical tool models	Static Unity prefabs containing C-arm and tool models.	Feb 20	Done
	Rig C-arm kinematics and calculate C-arm and K-wire to DeepDRR frame transformations	A Unity prefab that can be imported and is capable of reporting the live K-wire position and orientation in the simulated X-ray images, along with corresponding documentation and unit tests.	Feb 28	Done
Expected	Vive Controller C-Arm movement controls	Documented MonoBehaviour script components that allow the user to adjust the C-Arm model in VR. A set of manual test procedures for ensuring working VR C-Arm movement interactions.	Mar 20	Done
	Vive Controller interface for picking up different surgical tools (k-wire, screw, drill)	Documented MonoBehaviour script components that allow the user to operate the tools smoothly and realistically. A set of manual test procedures for ensuring working VR interactions. Documentation for VR interaction interfaces.	Mar 20	Done
	Write a guide for extending our VR simulation for future enhancements	A documented guide to extending our simulation environment for future C-arm devices, use-cases, and techniques.	Mar 23	Done
Maximum	Implement a basic K-wire-skin and K-wire-bone interaction simulation	Documented MonoBehaviour script components in the project that can restrict the movement of the K-wire insertion in different stages. A series of test cases to verify the behavior functions as defined .	Apr 15	Done
	Implement Vive controller haptics feedback for K-Wire insertion simulation	Documented MonoBehaviour script components which provide VR controller vibration haptics to help the user recognize and adjust their movements during the K-wire insertion process.	Apr 15	Done
	Implement a mouse and keyboard interface for patient selection and task configuration	GUI for the user headset. Documentation and instructions for using the GUI.	Apr 15	Incomplete
	Conduct a User Study for image acquisition training to analyze the usability of our simulation	A paper analyzing the effectiveness of virtual C-arm training with DeepDRR	April 30	Incomplete
	Conduct a User Study for K-wire/Screw alignment training to analyze the usability of VR surger	A paper analyzing the effectiveness of virtual pelvic surgery training	April 30	Incomplete
	Annotate C-arm pose, multi camera view and X-ray data from user study	A dataset of surgical training procedures	April 30	Incomplete
	Package application and server software for distribution, user guide	A GitHub page with package download links and “Getting Started” instructions, user guide	May 5	Incomplete

Updated Timeline



Current Approach-Unity Scene



C-arm

Cadaver Model
(Bone and tissue)

Teleport Mat

DeepDRR

Canvas

Surgical Tools

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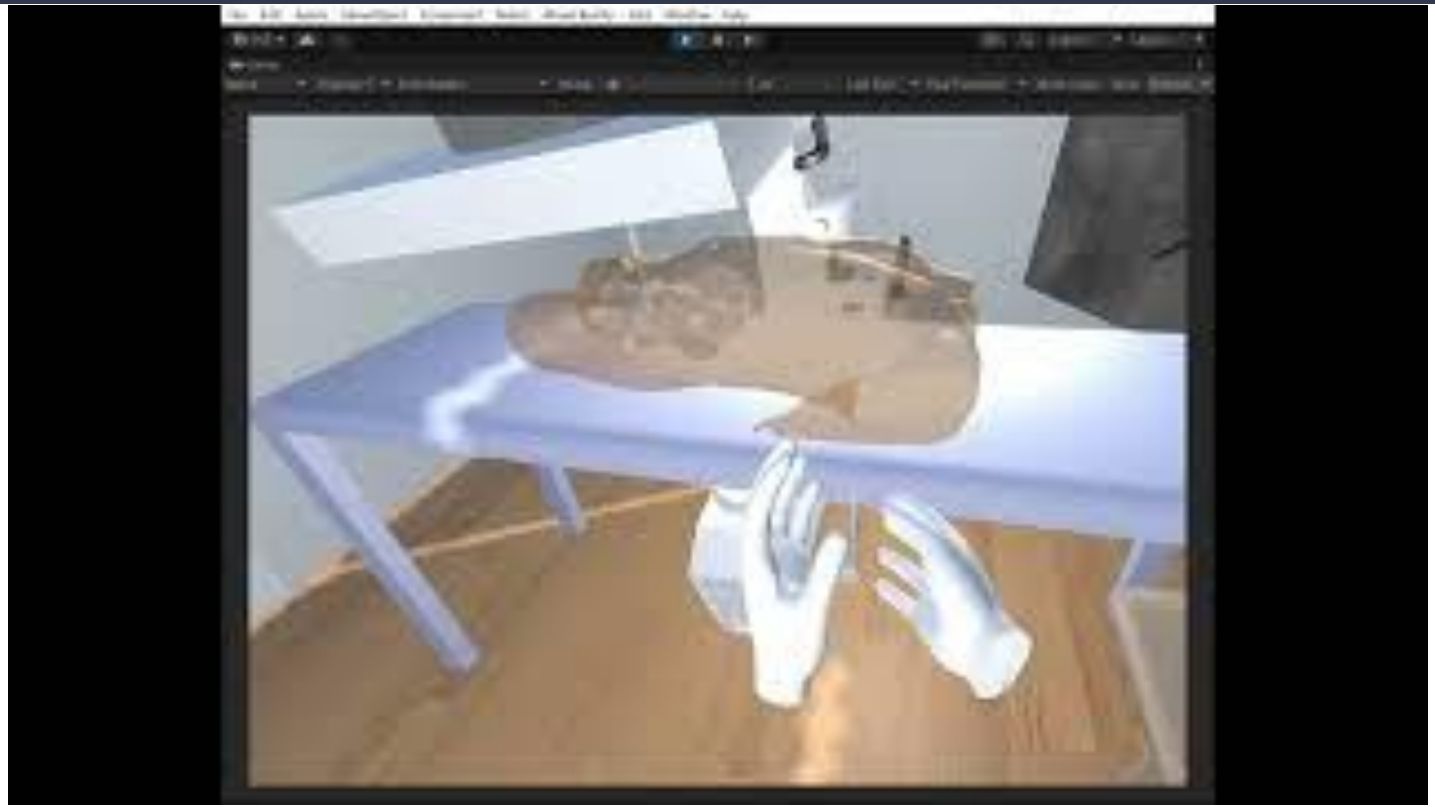
Unity

Current Approach-Demo Video



Current Approach–Model Design

- Fully interactable C-arm
  - Modified from GE Healthcare OEC One C-arm
- K-wire Sets
  - 300mm & 450mm length, 2.8 mm diameter
- 6.5mm Surgical Screw Sets
  - 6.5mm Diameter, 12 & 32 mm thread length, 30 - 130 mm length
- Surgical Drill Bit Kits
  - Drill body, kwire adaptor, screw adaptor
- Surgical driver Kits
- Surgical Table

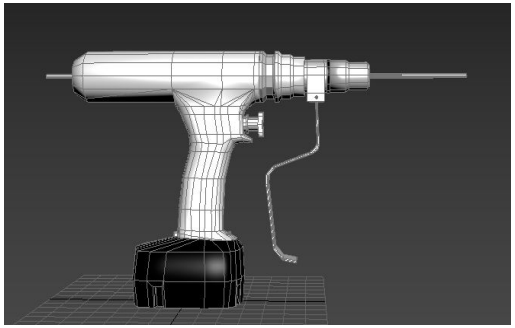
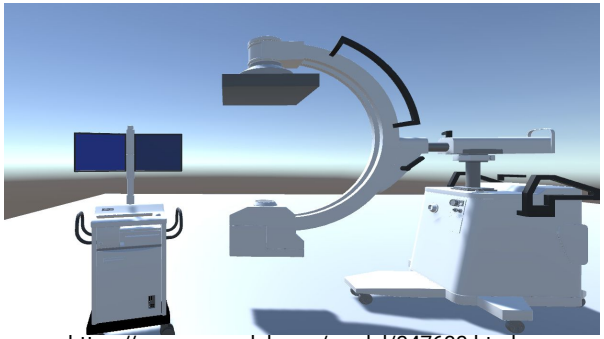


Figure: Drill with k-wire



https://www.cgmodel.com/model/347633.html

Figure: C-arm with Display Cart

Current Approach-Model Design

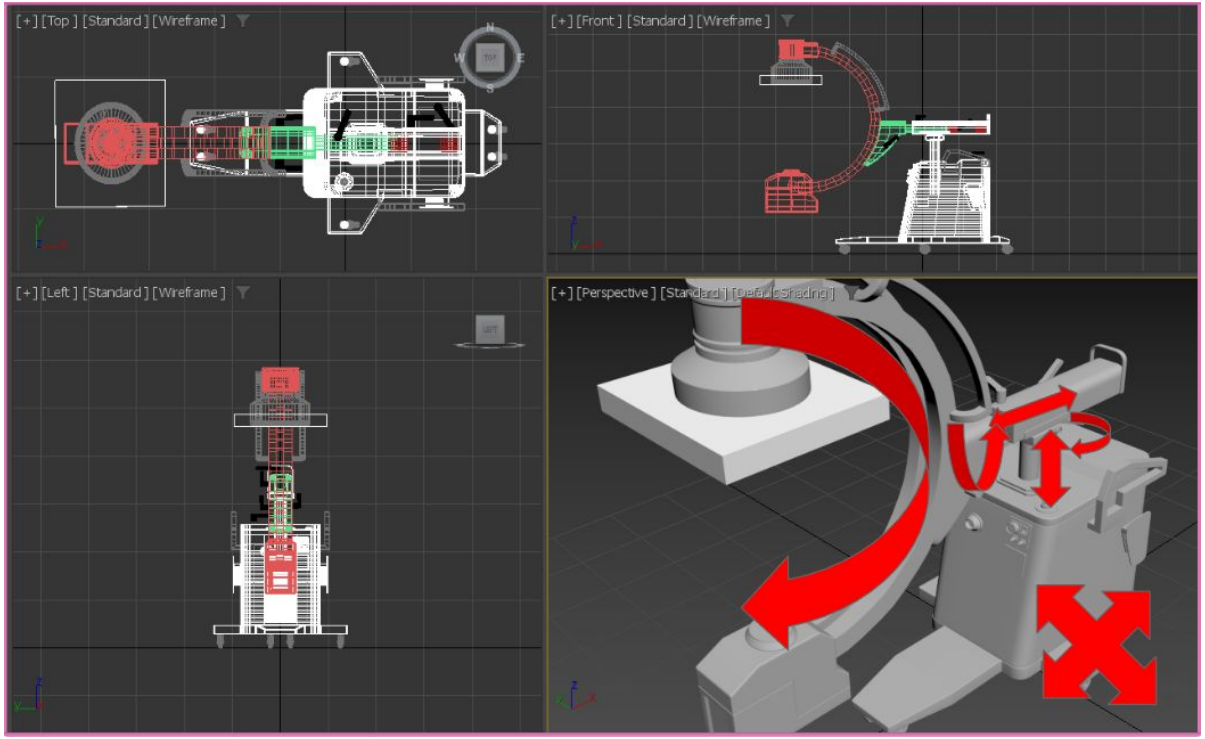


Figure: 7 DOF C-arm Model

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Current Approach–Model Design

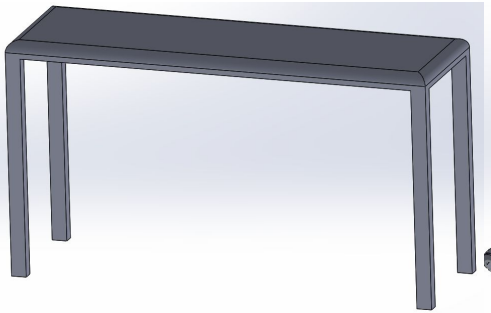


Figure : X-ray Table

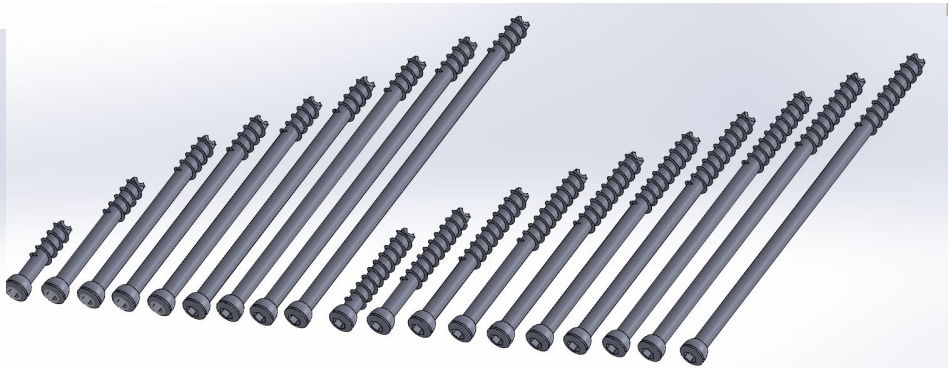


Figure : Screw Sets

Figure : Driver Sets

Figure : Kwire Sets

Current Approach-Interaction

1. Scene interaction
   a. Vibration feedback
   b. Audio feedback
   c. Tracked Joystick Controller
2. Tissue-tool interaction
   a. In bone:
      i. Disabled rotation
      ii. Enable move forward/backward.
      iii. High vibration(moving)
   b. In tissue:
      i. Enabled Pivot rotation
      ii. Enabled move forward/backward.
      iii. Low vibration(moving)

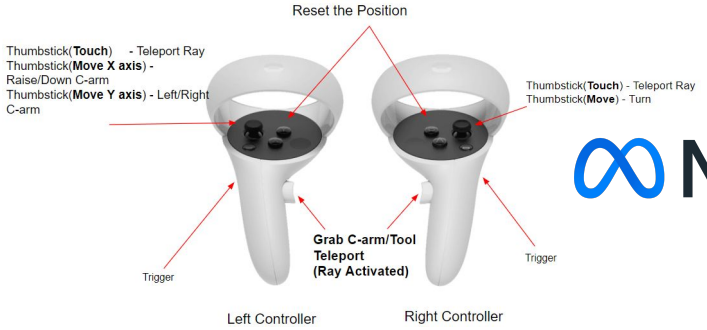


Figure: Joystick controller manual

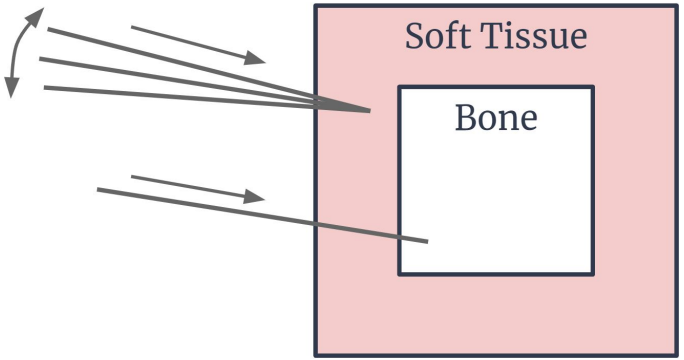
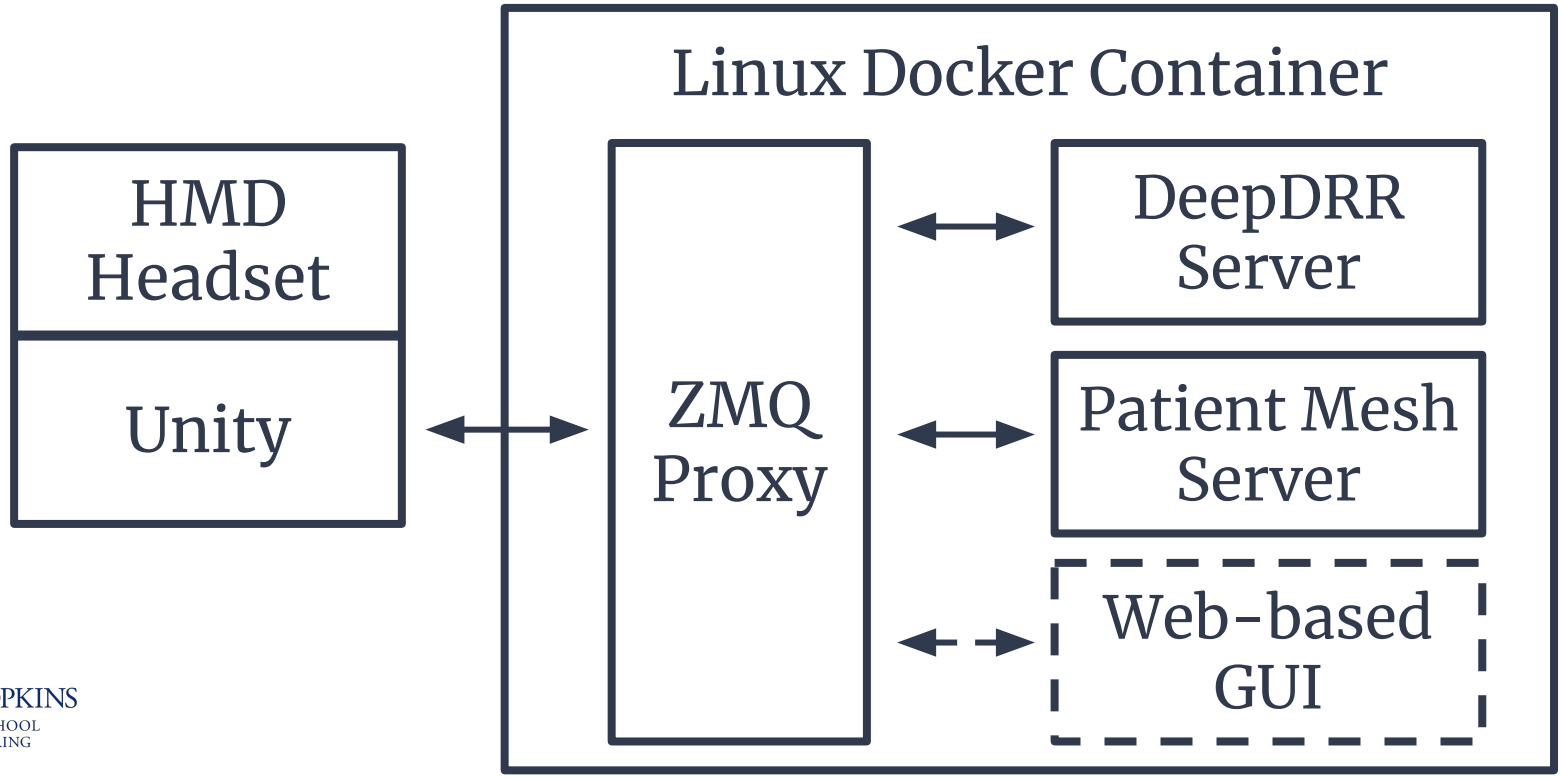


Figure: Insertion Simulation

Current Approach–DeepDRR ZMQ Server



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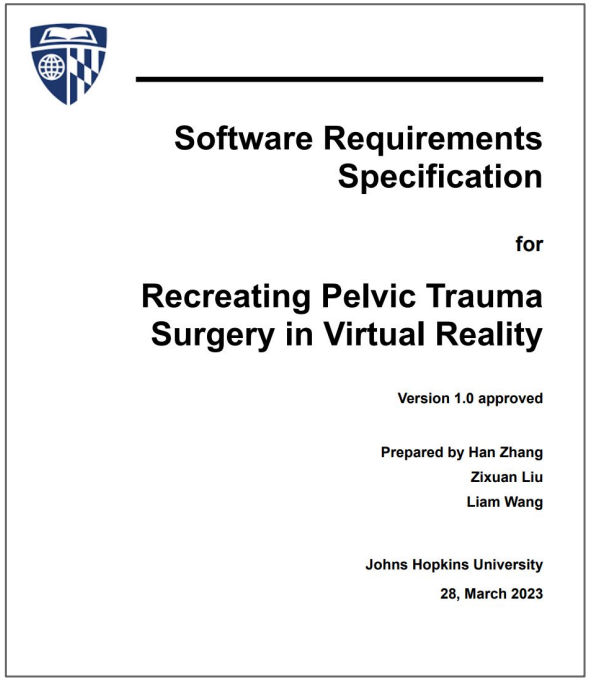
Documentation – Software Requirement Specification

- Software Requirement Specification (SRS)
  Concentrate on the functional and non-functional requirements
  - Functional Requirements
    - Patient Model Selection
    - C-arm Interaction
    - Surgical Tool Interaction
    - Real-time X-ray Simulation
    - Haptic Feedback
    - Cross-platform Compatibility
  - Non-functional Requirements
    - Timing and Capacity
    - Ease of use
    - Reliability and Robustness
  - External Interface Requirements



Software Requirements Specification

for

Recreating Pelvic Trauma Surgery in Virtual Reality

Version 1.0 approved

Prepared by Han Zhang
Zixuan Liu
Liam Wang

Johns Hopkins University

28, March 2023

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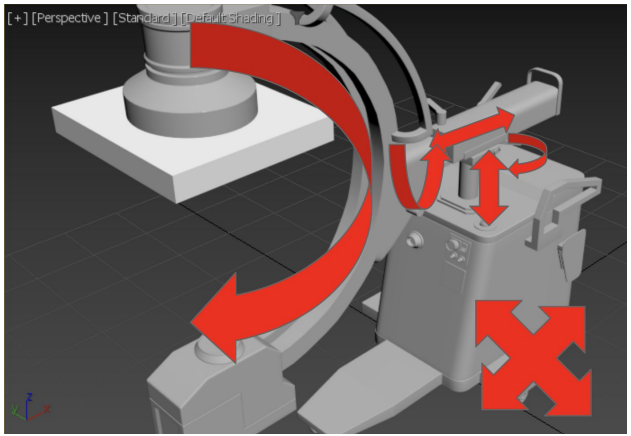
Test Management

- Unity unit test - Unity Test Framework (UTF)
  - For General:
    - Acquire the game object
    - Add a time-step
  - For C-arm:
    - Check the position/rotation error of the C-arm target component
  - For tools:
    - Check whether the drill/user's hand in VR grabs the adaptor or the K-wire

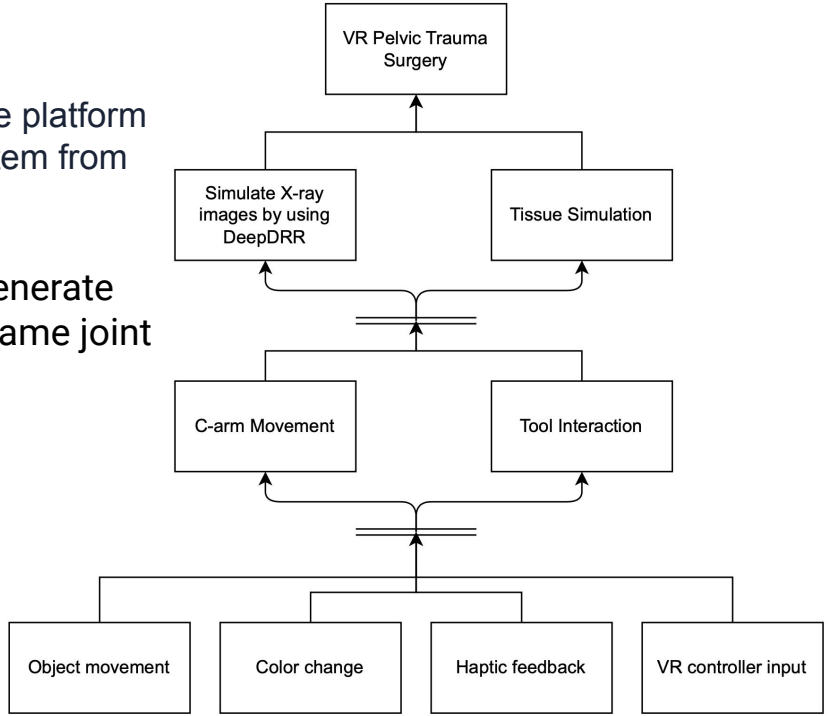


https://www.cgmodel.com/model/347633.html

Figure: C-arm Unit Test

Test Management

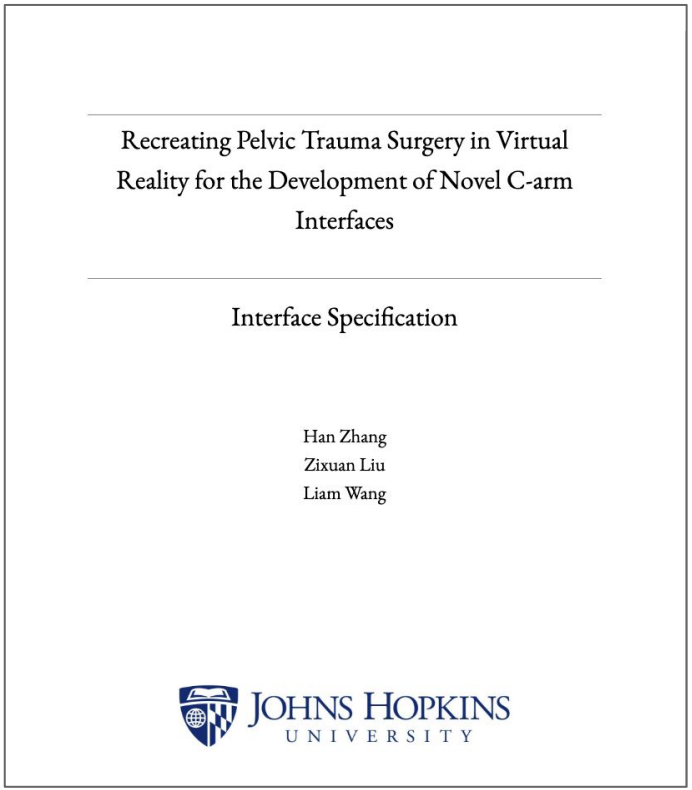
- Integration test - Bottom-up approach
  - Not big bang - as our project does not run in one platform
  - Not top-down - as we are implementing the system from simple
- C-arm pose/tool pose verification
  - Validate whether the simulated C-arm can generate identical X-rays as the real C-arm given the same joint angles



Interface Definitions

We are maintaining an interface specification document on our Wiki page containing:

- ➔ The network protocol interfaces between the Unity application, DeepDRR server, Patient Mesh server, and Web GUI
- ➔ The internal functional interfaces between components of the Unity application, including:
  - VR Interaction Scripts
  - C-arm kinematics simulation
  - K-wire tissue interaction scripts
  - DeepDRR Client
  - Patient Mesh Client



Recreating Pelvic Trauma Surgery in Virtual Reality for the Development of Novel C-arm Interfaces

Interface Specification

Han Zhang
Zixuan Liu
Liam Wang

JOHNS HOPKINS UNIVERSITY

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Responsibility Distribution

- Team members
  - Han Zhang
    - *Master's Student, BME Major, responsible for User Study, Unity interaction, and Tool model.*
  - Zixuan Liu
    - *Master's Student, CS Major, responsible for Tool Interaction, Verification Test and Documentation.*
  - Liam Wang
    - *Undergraduate Junior, BME & CS Major, responsible for DeepDRR Server/Client, Web GUI.*
- 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.

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Management Plan

- 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

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References

[1] D. R. Allen, C. Clarke, T. M. Peters, and E. C. S. Chen, “Development and evaluation of an open-source virtual reality C-Arm simulator,” *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–6, Dec. 2022, doi: 10.1080/21681163.2022.2152374.

[2] M. Unberath et al., “DeepDRR -- A Catalyst for Machine Learning in Fluoroscopy-guided Procedures,” *arXiv.org,* https://arxiv.org/abs/1803.08606v1 (accessed Mar. 13, 2023).

[3] A. L. Brazil, A. Conci, E. Clua, L. K. Bittencourt, L. B. Baruque, and N. da Silva Conci, “Haptic forces and gamification on epidural anesthesia skill gain,” *Entertainment Computing*, vol. 25, pp. 1–13, Mar. 2018, doi: 10.1016/j.entcom.2017.10.002.

[4] J. Moo-Young, T. M. Weber, B. Kapralos, A. Quevedo, and F. Alam, “Development of Unity Simulator for Epidural Insertion Training for Replacing Current Lumbar Puncture Simulators,” *Cureus*, vol. 13, no. 2, p. e13409, doi: 10.7759/cureus.13409.

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