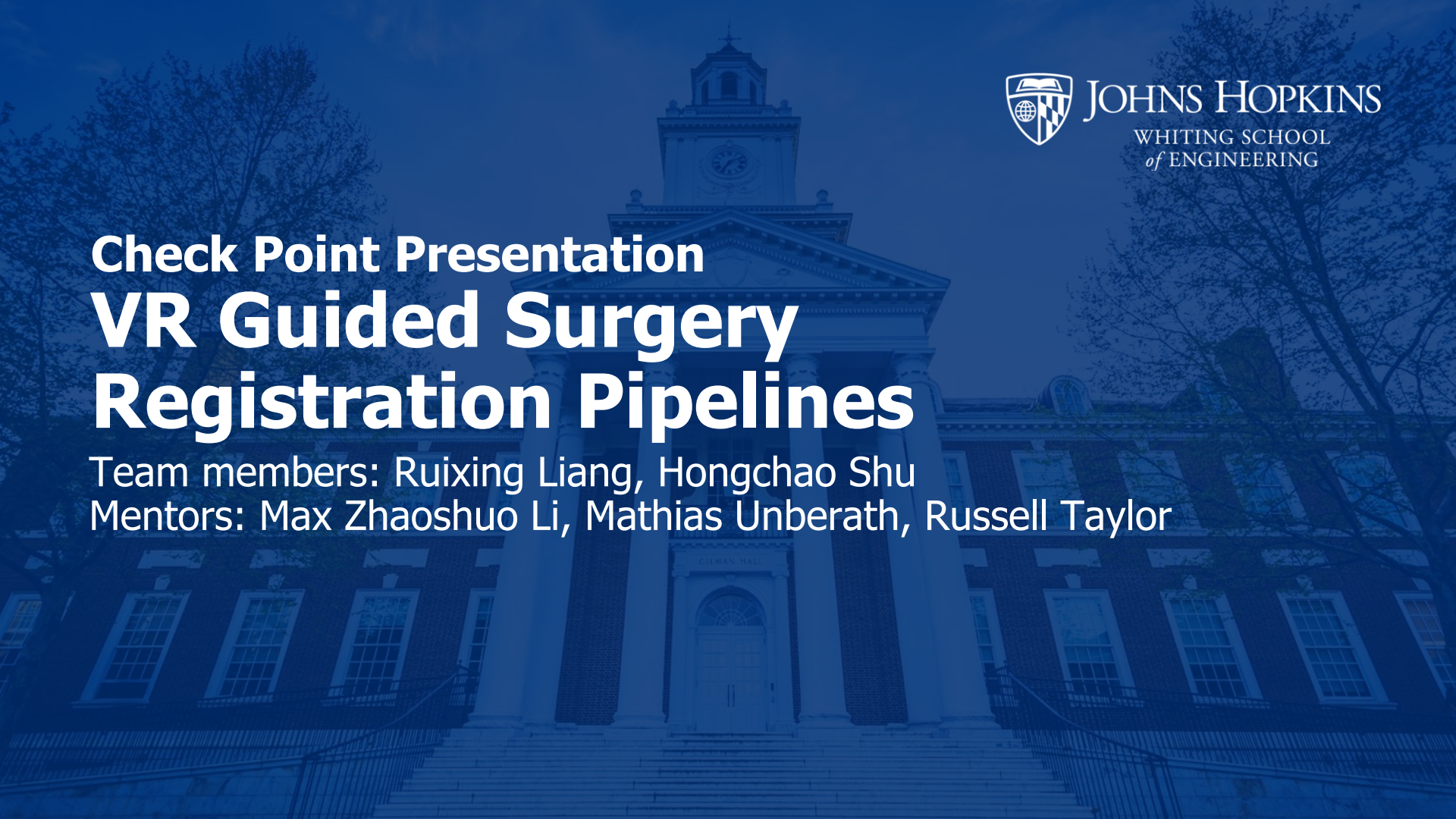


JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

Check Point Presentation

VR Guided Surgery Registration Pipelines

Team members: Ruixing Liang, Hongchao Shu
Mentors: Max Zhaoshuo Li, Mathias Unberath, Russell Taylor

Overview

On Mastoid Surgery For Navigation

Background

Registration And VR Integration For Data Generation

Goal

Deliverables Update
Development Status
Functional review
Test Document
Summary

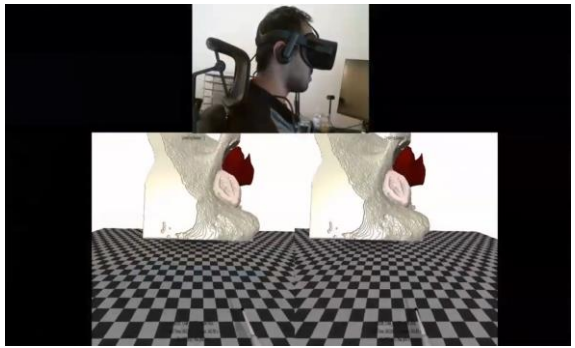
Process

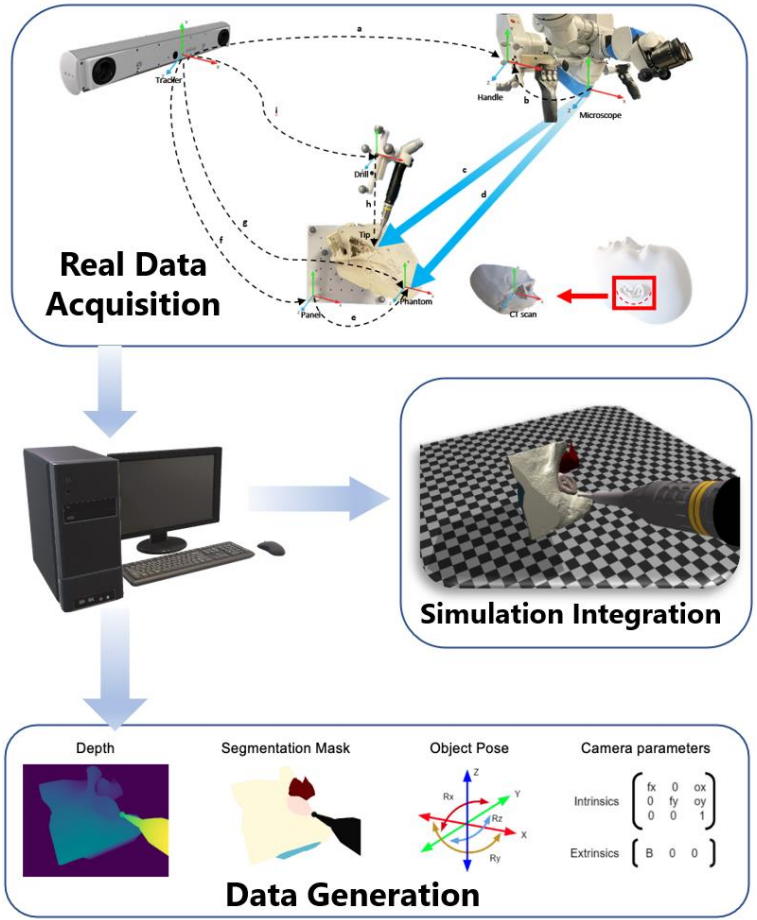
References

Reference

Goals Recap

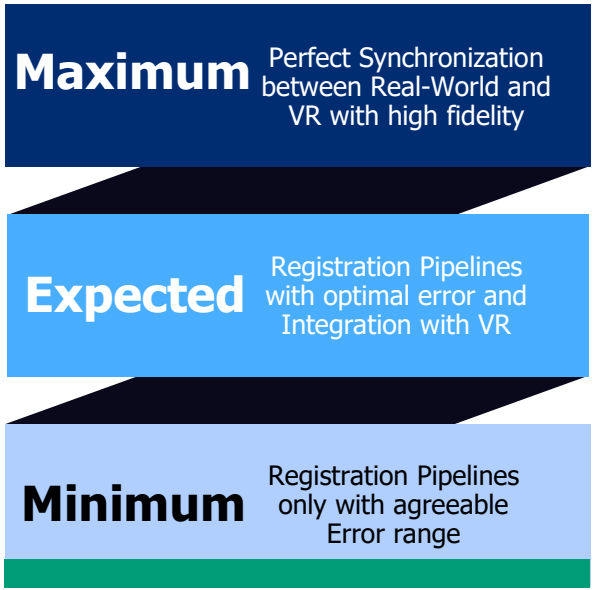
- Maintain accurate patient-to-tool registration for downstream applications
  - Integration of Virtual Reality and Real-world data to generate infinite and accurately-annotated images for Deep Neural Network training.





(A. Munawar et al. ,2021)

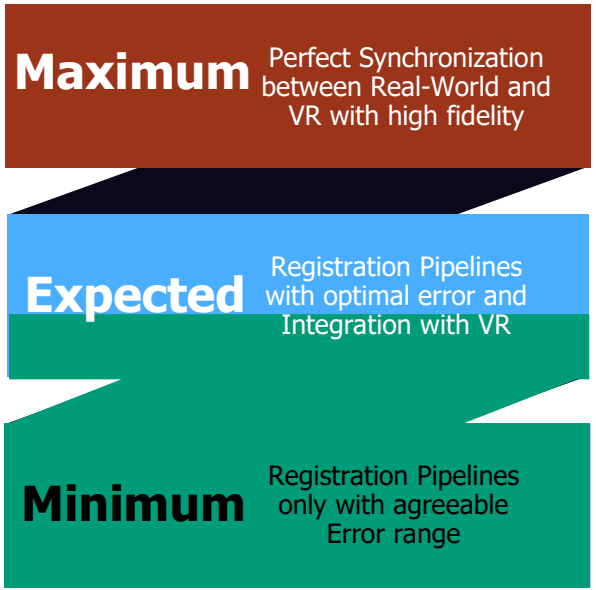
Deliverables



As part of VR guided surgery project, we are happy to develop the integration of all if possible.

- Minimal deliverables have been developed during the MICCAI submission process. Registration pipeline ready to work now.
- Expected deliverable will be integration of VR using refined version of registration.
- Maximum deliverable will be even possibly beyond the scope of this course but partial accomplishment could be within this term
- **Form: Documentations, Demo, Paper**
  Library of Codes for CIIS, and Data

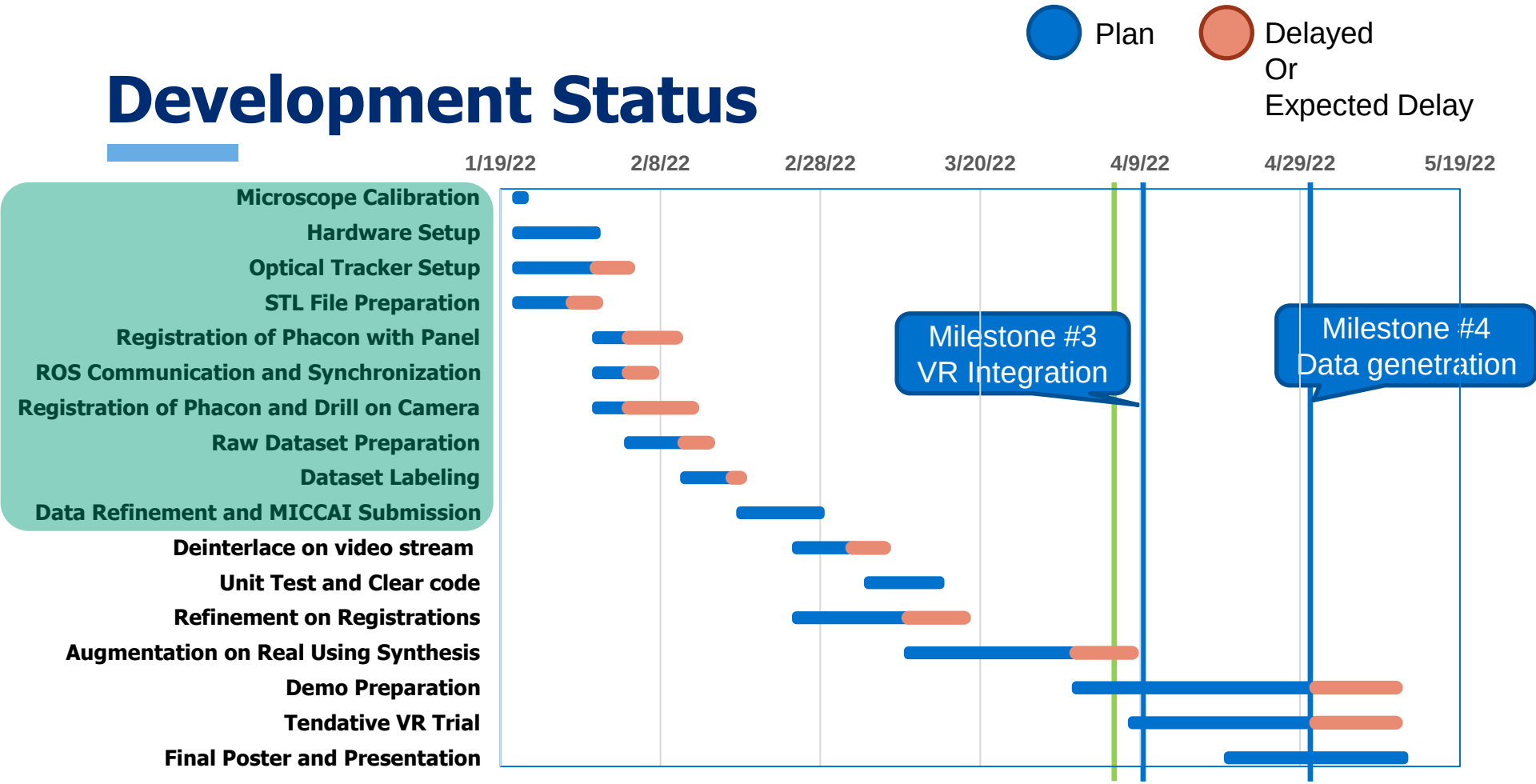
Deliverables



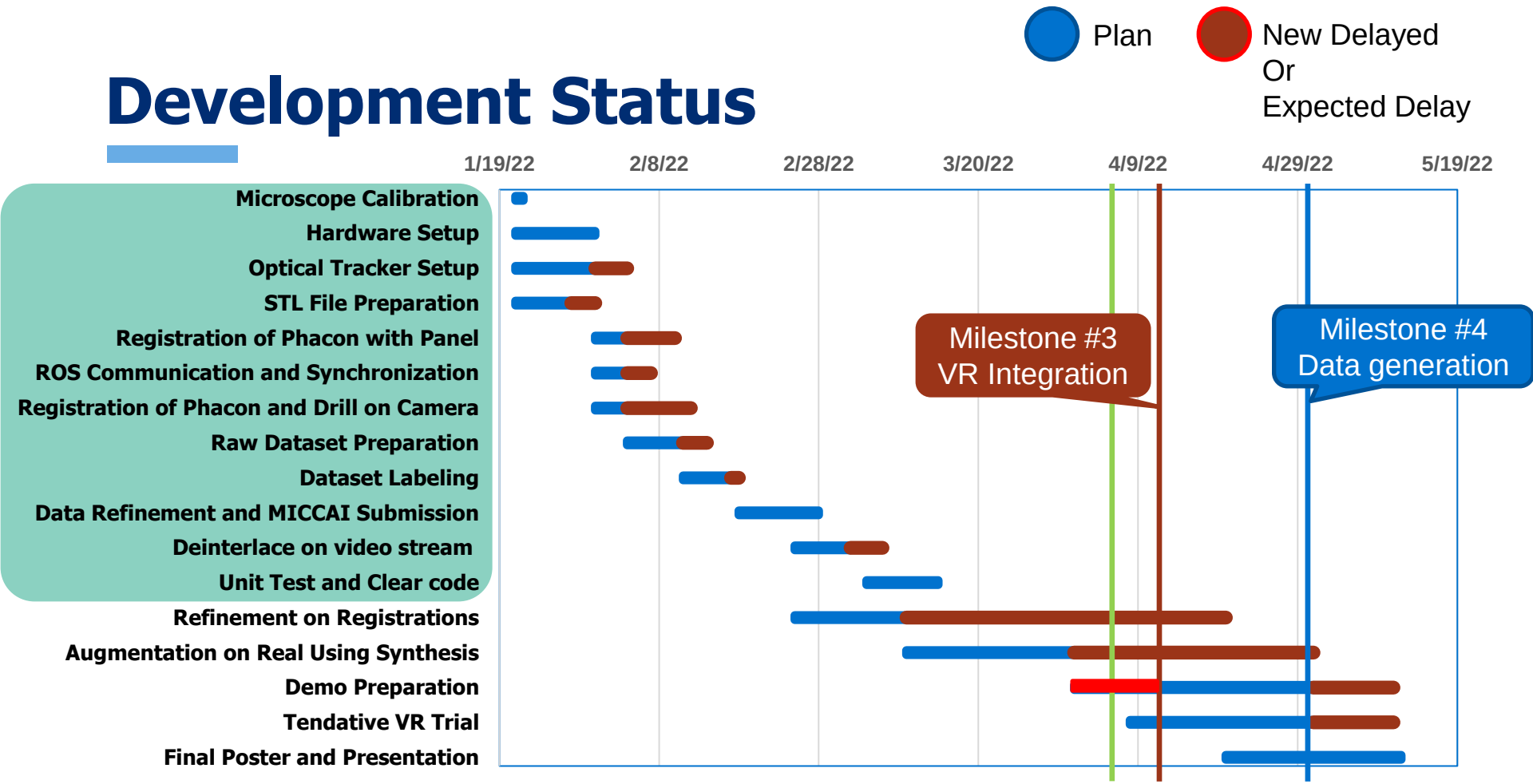
As part of VR guided surgery project, we are happy to develop the integration of all if the error evaluation pass.

- Minimal deliverables have been developed during the MICCAI submission process. Registration pipeline ready to work now.
- Expected deliverable will be integration of VR using refined version of registration.
- **Maximum deliverable will be achieved in summer instead of partially achieved this semester**
- **Form: Documentations, Demo, Paper**
  Library of Codes for CIIS, and Data

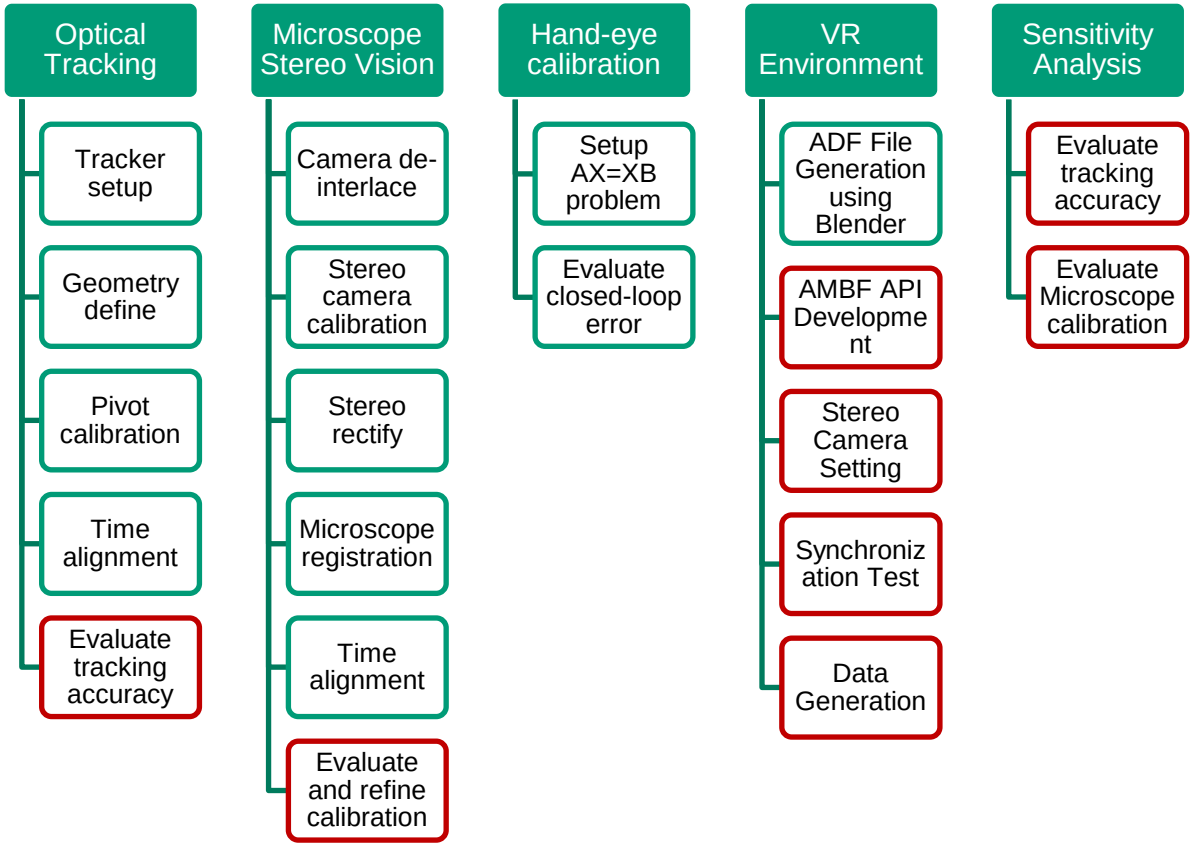
Development Status



Development Status

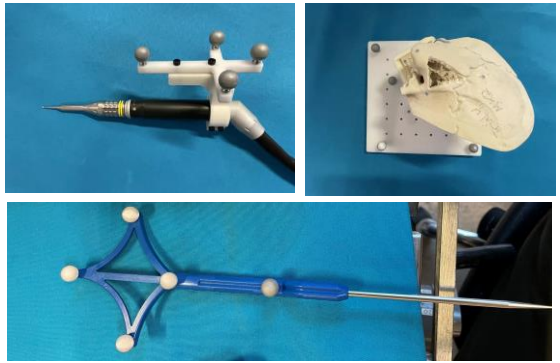


Technical Works

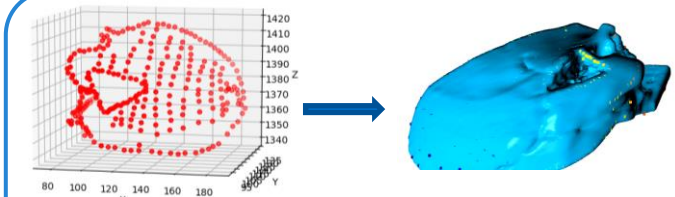


Optical Tracking

- Use the API to setup the Atracsys fusion-track 500
- Define geometry of optical sphere frames
  - Track every sphere, rebuild the geometry
- Pivot calibration
  - Implement pivot calibration method using poses
- Phantom registration
  - Fix Phantom on the panel
  - Build phantom registration pipeline
- Evaluate tracking accuracy
  - Design evaluation method involve Galen



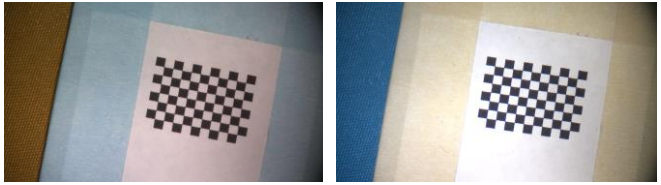
Optical frames



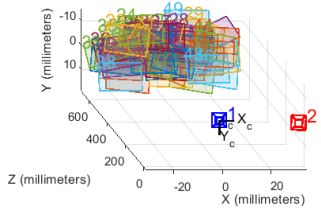
Phantom registration

Microscope Stereo Vision

- Stereo camera calibration
  - Build stereo calibration pipeline
- Rectify stereo images with intrinsic parameters
  - Implement stereo rectify method
- Camera registration
  - Inference the phantom with depth estimation Networks designed by Max
  - Derive the camera pose in tracker coordinate
- Timestamp synchronization
  - Build a synchronizer to align timestamp of all
- Camera deinterlace
  - Change to gstreamer deinterlace mode

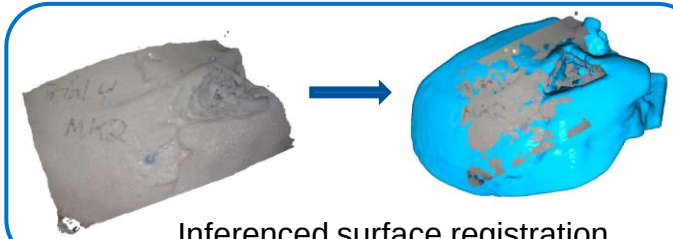


Camera calibration target



Calibration result

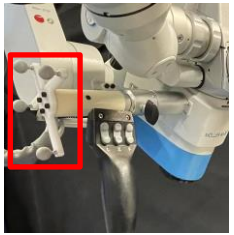
Rectify result

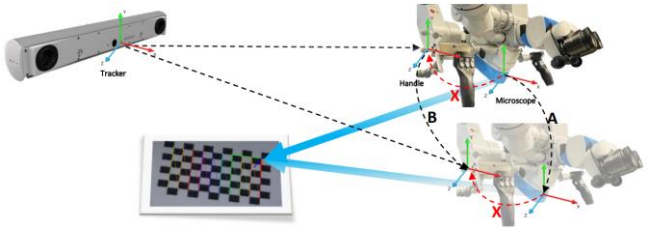


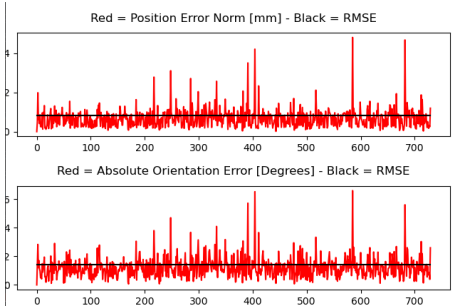
Inferenced surface registration

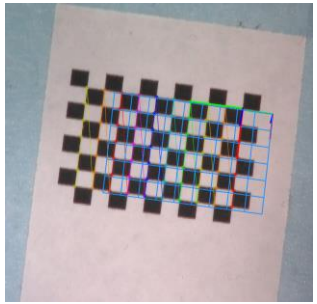
Hand-eye Calibration

- Set the AX=XB problem
  - Build traditional method to solve
  - Build dual-quaternion method to solve
  - Use a state-of-art hand-eye calibration library[1]
- Analysis closed-loop error
  - Build evaluation method for closed-loop reprojection error



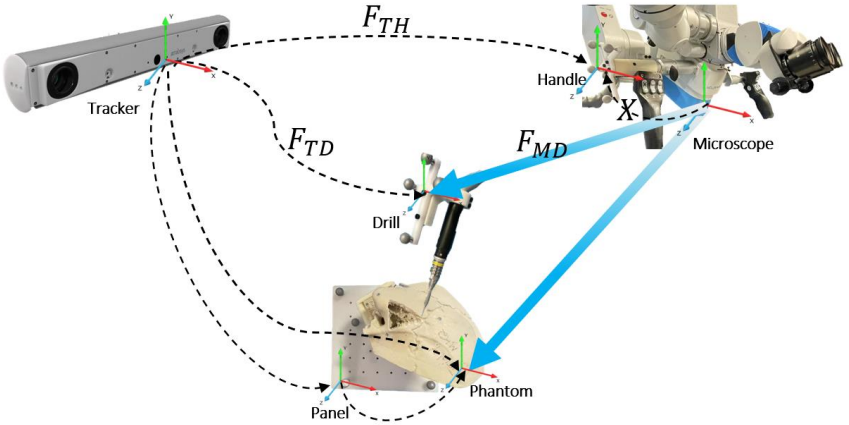






[1] Furrer, F., Fehr, M., Novkovic, T., Sommer, H., Gilitschenski, I., Siegwart, R. (2018). Evaluation of Combined Time-Offset Estimation and Hand-Eye Calibration on Robotic Datasets. In: Hutter, M., Siegwart, R. (eds) Field and Service Robotics. Springer Proceedings in Advanced Robotics, vol 5. Springer, Cham. https://doi.org/10.1007/978-3-319-67361-5_10

Sensitivity Analysis



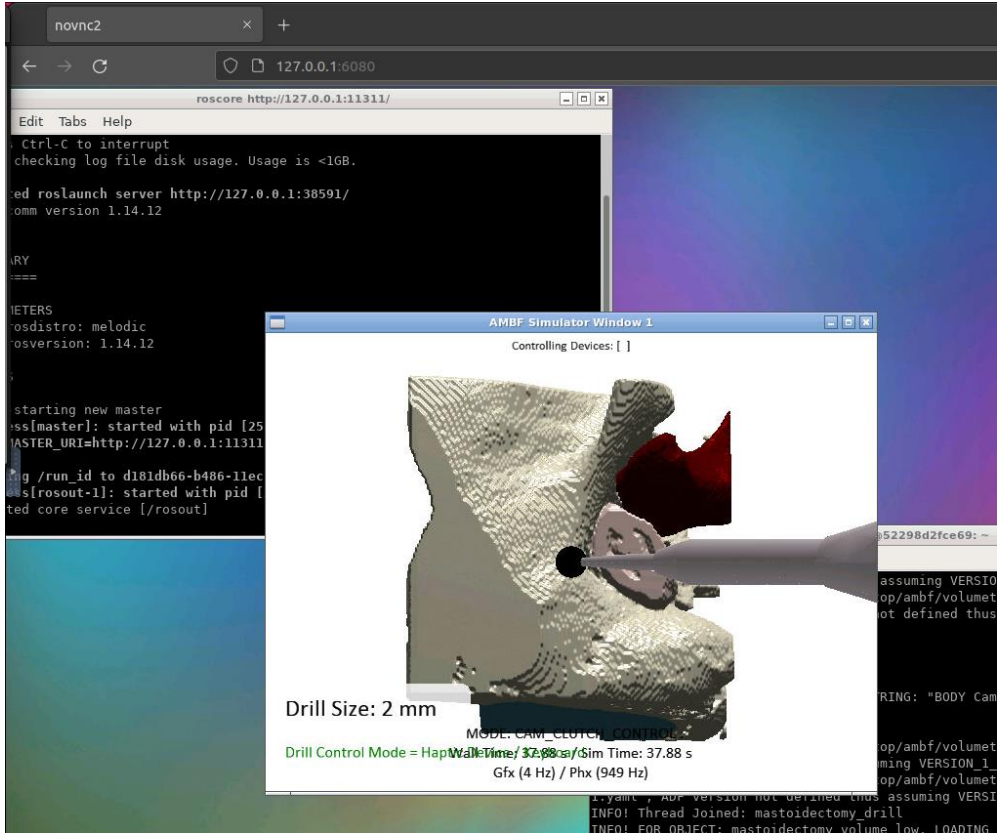
- Mathematical derivation of sensitivity
- Get the error range of tracker
  - Evaluation method involve Galen
- Get the error range of camera pose
  - Setup simulation environment of camera calibration

$$\alpha_{\vec{MD}} = \begin{bmatrix} I, & -R_{TD}^{-1}R_{TH}R_X^{-1}, & -R_{TD}^{-1}R_{TH} \end{bmatrix} \begin{bmatrix} \alpha_{\vec{TD}} \\ \alpha_{\vec{X}} \\ \alpha_{\vec{TH}} \end{bmatrix}$$

$$\varepsilon_{\vec{MD}} = \begin{bmatrix} I & , -R_{MD}^{-1}R_X^{-1}sk(R_{TH}^{-1}(t_{TH}-t_{TD})) & , -R_{MD}^{-1}sk(R_X^{-1}R_{TH}^{-1}(t_{TH}-t_{TD})) & , R_{MD}^{-1}R_X^{-1} & , R_{MD}^{-1} \end{bmatrix} \begin{bmatrix} \varepsilon_{\vec{TD}} \\ \alpha_{\vec{TH}} \\ \alpha_{\vec{X}} \\ \varepsilon_{\vec{TH}} \\ \varepsilon_{\vec{X}} \end{bmatrix}$$

VR Set Up

- Based on AMBF Framework
- For Cross Platform Application, Docker has been used with X11 Enabled for browser Visualization
- Build on Volumetric Drilling Plugin. In the end, could serve as a plugin to enable more modalities like microscope gstreamer and Optical Tracker Input



VR Set Up

- Blender has been used to create virtual pattern for validation on hand eye calibration
- Closed Loop Error Simulation Test to test in controlled manner
- Final Step: Data Generation

Key Test Documentation Summary

Function Names	Test Date/ Expected Date	Test Method	Standard	Status	Effect on milestones if not pass
Optical Tracking	1/31	Simulation & API	If successfully track	Pass	N/A
Microscope Time Difference	2/7	Manual Check	If within 50ms	Pass	N/A
Communication Synchronization	2/7	ROS Timestamp	ms Difference Allowed	Pass	N/A
Camera Deinterlace	3/3	Timer Check	ms Difference Allowed	Pass	N/A
CVAT Labeling Platform	2/11	Human Evaluation	Within reasonable range	Pass	N/A
Camera Calibration	1/22 (First) 3/11 (Issue)	Reprojection Error Covariance	Error within 0.5 pix Scatter like Gaussian	Not Pass	N/A
Optical Tracker Accuracy	4/10	Error in Transformation	Should be within	Panned	Limited in
VR simulation environment code	4/29	Mask Evaluation Error Map	Human Discretion (Absolute Difference not applicable)	Planned	Fail the expectation deliverable

Milestones

01 Hardware Setup

Accomplished on Jan 31st.
Huge credit to Anna

02 Initial Pipeline

Accomplished on Feb 14th.
Batches of data were collected and manually labeled and evaluated by Max

03 VR Integration

After verification of accuracy and error analysis
VR will be integrated and expected to be available on Apr 10th

04 Data Generation

Augmentation on the dataset harnessing the registration accuracy in ROS synthesis environment will be tested at the final stage of our project in Apr 24th

(If Integration is not ideal on VR Headset, alternative to use rviz for visualization of VR is still possible.)

(If the results of the data generated for training DNN perform worse or tie with existing solution, we may downgrade our deliverable to expected rather than Maximum)

References

- 1. L. C. French, M. S. Dietrich, and R. F. Labadie, "An estimate of the number of mastoidectomy procedures performed annually in the United States," Ear Nose Throat J **87**(5), 267–270 (2008).
- 2. F. Furrer et al., "Evaluation of Combined Time-Offset Estimation and Hand-Eye Calibration on Robotic Datasets," in Field and Service Robotics, M. Hutter and R. Siegwart, Eds., pp. 145–159, Springer International Publishing, Cham (2018) [doi:10.1007/978-3-319-67361-5_10].
- 3. C. R. Razavi et al., "Image-Guided Mastoidectomy with a Cooperatively Controlled ENT Microsurgery Robot," Otolaryngol Head Neck Surg **161**(5), 852–855, SAGE Publications Inc (2019) [doi:10.1177/0194599819861526].
- 4. V. M. E. | 2841 N. H. R. Owensboro and K. 42303 | Office:691-6161, "Mastoid Surgery," in Midwest Ear, Nose and Throat Head & Neck Surgery.
- 5. A. Munawar et al., "Virtual Reality for Synergistic Surgical Training and Data Generation," Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, 1–9 (2021) [doi:10.1080/21681163.2021.1999331].