CIS II VR Guided Surgery - Registration Pipelines

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1 Introduction

Real time and simultaneous tracking of both surgeon region of interest(ROI) and surgical tool is of great significance to computer assisted surgery. However, existing tracking solution is disruptive in current surgical workflow especially within the scope of our focus mastoid surgery. An urge to tailor a stereo video-based tracking for accurate surgical navigation system has been developing recently since the burgeon of large scale deep neural network (DNNs). Though researchers are craving for large quantity of good data with expert level of annotations for either semi- or supervised learning, they could never be satisfied simply using existing traditional algorithm based registration pipelines. It involves cascaded calculations and transformations which intuitively amplify the error throughout each step which has been evaluated in the first half of the project process. Therefore, we proposed a novel combination of real world data and generation of virtual reality annotations to refine and expedite the data generation process both in favor of better surgical training and preoperative plan but more importantly for overcoming the data scarcity issue existed wide-spread in DNNs training.

2 Background

Mastoidectomy is a common surgical procedure within otology with more than 30,000 60,000 patients go through this process. It involves drilling a hole in the mastoid bone and removing the infected air cells with extra attention to avoid nerves and other unwanted region.
For now, we have image-guided Mastoidectomy with an experimental cooperatively controlled robotic system, which needs no prior surgical experience, and decrease drilling time. To land the system in clinical use, a precise surgical navigation system is also needed.
Nowadays we mainly use two types of tracking system based on optical tracker or EM tracker. From intraoperative aspect however, it‘s hard to use the optical tracker to maintain a consistent surgical navigation system due to the line-of-sight problem, though the EM tracker doesn’t have this problem, it has relatively low precision within it‘s working volume.
The stereo video-based motion tracking system is all we need to setup a high precision, low latency, no interruption surgical navigation system. This system can be integrated with VR, which can be applied in surgical training and pre-surgery planning.

3 Technical Approach

In our work, the very first step is to calibrate the microscope.

1. We use the 2mm checkerboard to perform stereo calibration. Then we use the camera intrinsic parameters to undistort and rectify stereo phantom images.

Figure 1: Rectified phantom stereo image

We have two approaches to do phantom registration:

1. Use the calibrated pivot tool to sample some points, then using ICP registration.
2. Fix few fiducial markers to the phantom, take a CT scan of the phantom, then we do pivot calibration on those fiducials in a specific order, and we register the phantom to the 3D model directly.

To register the microscope, we mainly have two approaches:

1. Use the rectified stereo image to inference the depth image, then reproject the points in image to reconstruct phantom surface. Register the surface to the 3D model with ICP and drive the transformation from microscope to tracker.

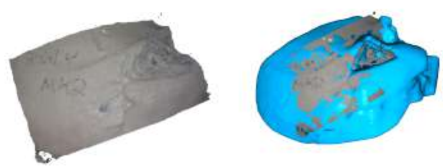

Figure 2: Inference surface registration

2. Mount marker frame on microscope handle, then perform hand-eye calibration to find transformation from tracker to microscope.

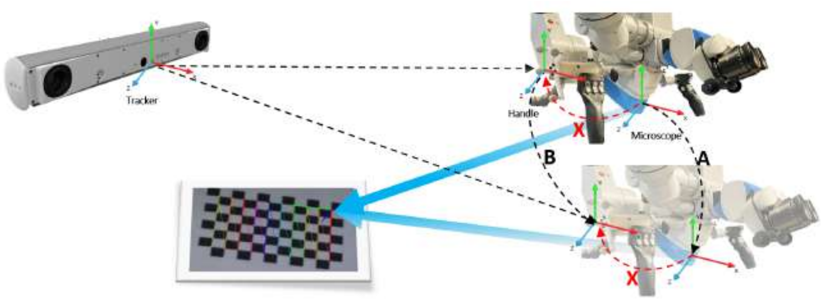

Figure 3: hand-eye calibration

The microscope and optical tracker are unsynchronized, thus requiring time alignment of measurements.

1. We use Rospy to subscribe the raw stream, and align the timestamp, then publish filtered topics.

Integrate refined registration pipelines with VR, generate ground truth data from simulation scenarios

1. We use VR simulation environment, take refined time-aligned registration data as input, the transformation between the tracker, microscope, drill and phantom in simulation scenario should be identical to those of real setup only with minimal error.

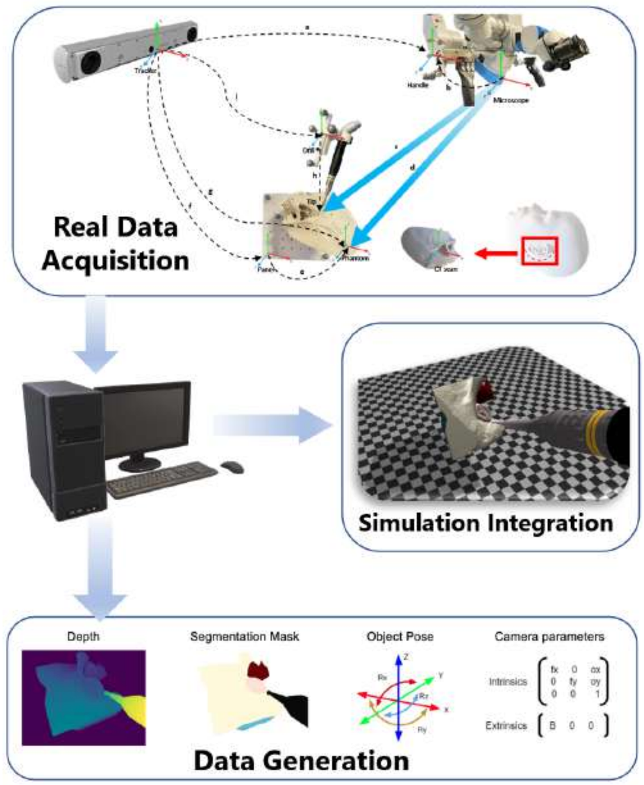

Figure 4: VR pipeline

4 Deliverables Statement

Three levels of deliverables are expected to be ready to share and present by the end of this semester in the form of documentations, paper, demo and library of codes with sampled data available.

1. Minimum deliverable is to get a registration pipeline stand by with agreeable error range. We are thrilled to announce that it was almost done along with MICCAI submission process.

2. Expected goal would be optimal registration in error range with integration in VR, in particular VR headset for better evaluation of the registration results.

3. maximal deliverable, we are considering proposing integration of real world data with simulation to generate infinite well annotated data with high fidelity. This will be evaluated by using both human subjectives and DNN training relative results.

5 Dependencies

Most of the required dependencies are available for us except of the VR headset.(See Figure5) Conflicts of usage will be resolved by reasonable distribution by negotiation like with Nick Greene to increase the productivity. If this happen with VR headset, same approach will be applied. If date we receive the VR headset is postponed, time of delay in development could be anticipated or even VR headset is not functional, we could still proceed without it. Since it is just an Interactive visualization tool.

Item Name	Expected Time	Contact	Shared with	Status	Effect on milestones if not met
Atracsys Fusion track 500	1/22	Nick Greene	Nick Greene	Fulfilled	N/A
HS Allegra 500 with Desktop	1/21	Anna Goodridge	N/A	Fulfilled	N/A
Optical marker * 13	1/22	Nick Greene	N/A	Fulfilled	N/A
Phacon	1/31	Anna Goodridge	N/A	Fulfilled	N/A
Pointer	1/23	Jonas Winter	Jonas Winter	Fulfilled	N/A
J&J Driller	1/31	Anna Goodridge	Jesse Haworth	Fulfilled	N/A
VR simulation environment code	2/28	Max Li	N/A	Fulfilled	N/A
VR Headset	Before 4/9	Max Li	TBD	Pending	Time Delay, or simulate on PC only

Figure 5: Dependencies

6 Milestones

Four primary milestones have been identified and addressed in detail in this section as following:

1. Hardware Set up: Set up the crucial components of the registration pipeline including: Microscope, Optical Tracker, Phacon, Driller and Camera Handle with marker. This has been accomplished on Jan 31th.

2. Initial Registration Pipeline: Batches of labeled data have been evaluated by Max. It was completed on Feb 14th.

3. VR Integration: After Verification and error analysis, VR is expected to be integrated into the pipeline symbolizing the connection of real world data with simulation motion. It is estimated to be available on Apr 10th.

4. Data Generation: After proper synchronization between the data flow from real world and simulation. This synthesized world will be evaluated to compared with direct real world data registration flow as baseline to validate our novel design of pipeline. This will be the final step to realize the maximal deliverable as well. This is projected to be realized in Apr 24th.

For the remaining two milstones, CV related issues will be assigned to Ruixing Liang, whereas robotics related issues will be solved by Hongchao Shu. Joint collaboration between us will be the primary when we are faced with difficulties.
Two alternatives here for our two milestones:

1. VR headset does not live up to our expectation, or simply it is not available to us somehow, we could still proceed without it like mentioned before in dependencies section.

2. If the results of the data generated for training DNN perform worse or tie with existing baseline registration generated data, we may downgrade our deliverable to expected level rather than Maximum.

7 Development Process Control

We have been evaluating the process by milestones and date constantly, decisions on the deliverable level have also been included during this evaluation process in last section. But illustration of the milestones relative checkpoints have been clearly annotated below. (See Figure6)

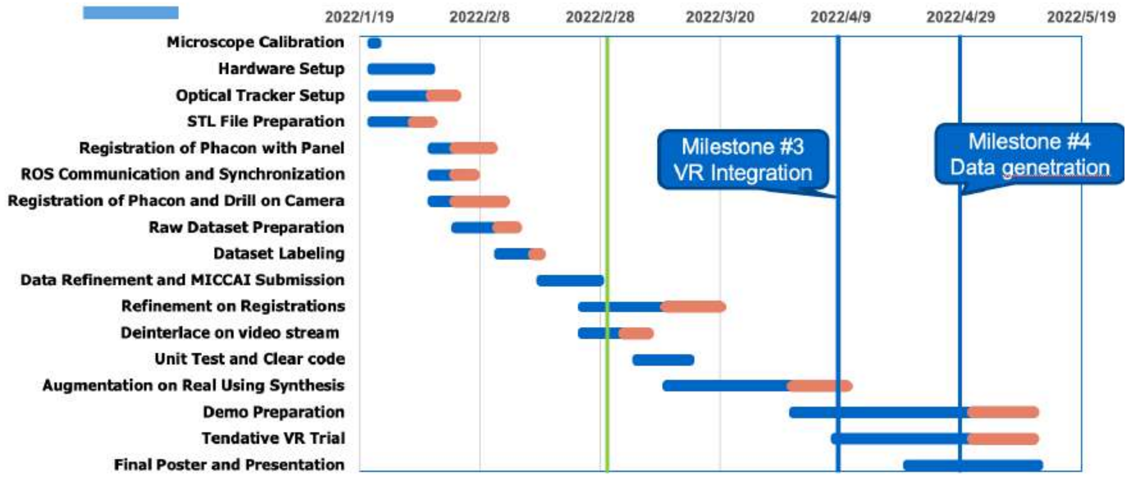

Figure 6: Gantt Schedule

Green line is today's line. Tasks before that were completed. Blue represents plan, pink represents delay or expected error in plan. For instance, Deinterlace and refinement are planned this week and next week moreover, if refinement is completed by March 20th, it could be seen as normal process because it is lot challenging than zero-to-one process in the early stage. If process go slower than expected, a sprint will be executed to speed up the development process. Since time delay are cascaded as we experienced in the early stage of this project. For instance, verification and refinement on registration results could potentially take more time than expected and in turn result in further delay in VR integration. So the expected delay are also illustrated here as cascaded way.

8 Management Plan

We will use github for code management; Communication between us and supervisor or other related personnel will be using Slack Email or Wechat. Weekly meeting have been carrying out since the start of this term as well. Development control would be complied with the gantt schedule and milestones evaluation to ensure the process of our project.

9 Reading List

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].