Evaluation of Various Sensing Modalities for Accurate Measurement of Neck Flexion Angle during Ear Surgery

Final Report

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1.Goal

Increasing evidence demonstrates that a surgeon's operating posture can contribute to chronic pain. Specifically, trapezius muscle fatigue has been shown to be highest when neck flexion exceeds 30°. This study sought to accurately measure the surgeon's neck flexion angle while performing ear surgery, comparing the postural ergonomics of traditional "heads down" surgery to that of "heads up" endoscopic surgery.

2.Background

Nowadays, there is increasing evidence suggesting that specific posture of surgeon while operating can contribute to discomfort, cervical musculoskeletal strain, and chronic pain. Postural neck pain can be caused by several factors. The persistent neck flexion, extended periods of static posture, and the long-time use of microscopes and magnifiers lead the microsurgeons to a particularly considerable risk to the pain mentioned above.

In this project, we are focusing on the surgeon's posture during ear surgery. There are two kinds of surgical sceneries: traditional case and endoscopic case. Traditional ear surgery includes microscopic and open surgery scenarios, as shown in **Figure 1 and 2**. In these scenarios, surgeons must bend their necks or their bodies to finish specific operations. This persistent neck flexion is the main factor that causes discomfort. However, as for endoscopic cases shown in **Figure 3**, surgeons can make full use of the monitors. It is easier for them to keep the correct upright posture most of the time.

Figure 1. microscopic surgery[1]

Figure 2. open surgery[2]

Figure 3. Endoscopic surgery[3]

[1] Figure 1 from https://oklahoman.com/gallery/articleid/3808606/
[2] Figure 2 from http://amandeepmedicity.org/specialities/bariatric-metabolic-surgery
[3] Figure 3 from http://www.tristonekidneyhospital.com/index.html
[4] Khansa I, Khansa L, Westvik TS, Ahmad J, Lista F, Janis JE. Work-related musculoskeletal injuries in plastic surgeons in the United States, Canada, and Norway. Plast Reconstr Surg. 2018;141(1):165e-175e.

3.Significance

Poor surgical ergonomics may lead to surgeon disability:

- A recent survey of plastic surgeons in the United States, Canada, and Norway showed that nearly two-third of respondents reported neck discomfort related to their occupation [1].
- Among laparoscopic, ophthalmic, and general surgeons surveyed, the reported prevalence of musculoskeletal symptoms in the neck and shoulders is as high as 87% [2].
- Dangers of Forward Head Posture (FHP) can be described as a "DOMINO EFFECT" [3]: Surgeons have their heads moving forward → shifting the center of gravity → upper body drifting backward → hips tilting forward. Therefore, FHP can not only cause neck pain but can also be a root cause of middle and lower back pain.

It is crucial and meaningful for us to investigate:

- The region of the neck flexion angle which the surgeon feels comfortable with while operating.
- The neck flexion angle data will be used to correct the new surgeons' posture, preventing chronic injury.
- The data which contributes to figuring out whether endoscopic surgery has more advantages than traditional surgery by comparison.

4. Method and Technical Approach

4.1 Project Workflow Overview

We hypothesize that neck flexion angle is greater than 30 degrees for a higher proportion of time during traditional open surgery, such as microscopic ear surgery, than during minimally invasive endoscopic surgery, such as endoscopic ear surgery.

1.Khansa I, Khansa L, Westvik TS, Ahmad J, Lista F, Janis JE. Work-related musculoskeletal injuries in plastic surgeons in the United States, Canada, and Norway. Plast Reconstr Surg. 2018;141(1):165e-175e.

2.Capone AC, Parikh PM, Gatti ME, Davidson BJ, Davison SP. Occupational injury in plastic surgeons. Plast Reconstr Surg. 2010;125(5):1555-1561.

3. Naresh-Babu, J et al. "Surgeon's Neck Posture during Spine Surgeries: "The Unrecognised Potential Occupational Hazard"." Indian journal of orthopaedics vol. 53,6 (2019): 758-762. doi: 10.4103/ortho.IJOrtho_677_18

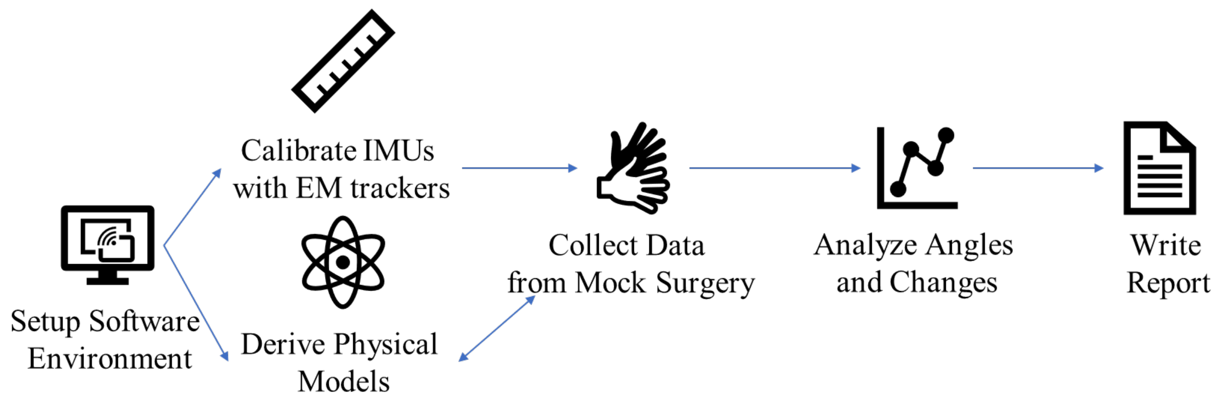


Figure 4. Project Workflow Overview

For this study, the workflow overview is illustrated above. Firstly, the software and the surgical simulation environments for data collection were arranged. Two Inertial Measurement Units (IMUs) were utilized, with one banded to the forehead and the other attached to the back as shown in **Figure 5**. Neck flexion angle was indicated by the pitch angle between the two IMUs. To confirm the accuracy of neck flexion measurements, the IMUs' pitch angle was calibrated against a known angle measured by an electromagnetic tracker (EM tracker), and a linear regression model is used to derive the calibration. Next, explained in 4.2, the mathematical model is derived to obtain accurate neck flexion angle from data collected by IMUs. In 4.3 the data is collected from both mock surgery and real surgery for analysis.

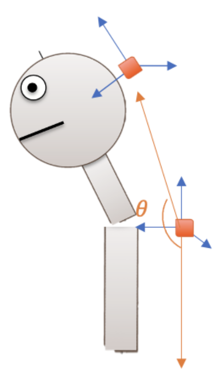


Figure 5. Measurement method

Figure 6. Inertial Measurement Units

4.2 Neck Flexion Angle Mathematical Model

The mathematical model for pitch angle calculation was derived using quaternion and rotation matrices as shown in the workflow (**Figure 7**). The quaternions of the IMUs were collected for both the reference posture (standing normally and neutrally for one minute) and in the operating posture. We converted the quaternions to Euler angles to calibrate the pitch component using the linear regression model mentioned above. Then, the calibrated Euler angles were converted into rotation matrices. For both IMUs, we calculated the difference rotation matrices between the reference position data and the surgical position data. Finally, the difference rotation matrix between the two IMUs was calculated and converted into Euler angles with X, Y, and Z components. The X component, or the pitch angle, was the neck flexion angle of our interest.

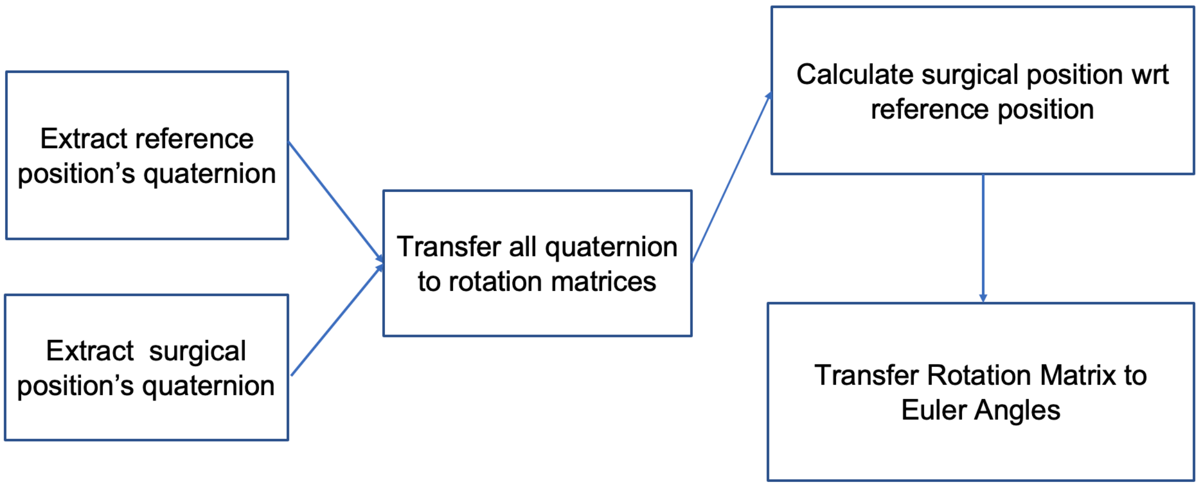


Figure 7. Neck Flexion Angle Model Workflow

The detailed calculation process for matrix transformation is illustrated below. We first define back and head IMU's rotation matrix in reference and surgical position with respect to world's coordinate system:

$\boldsymbol{R}_{BR}^{W}$: The **B**ack IMU's rotation matrix in **R**eference position w. r. t. **W**orld's coordinate system.

$\boldsymbol{R}_{HR}^{W}$: The **H**ead IMU's rotation matrix in **R**eference position w. r. t. **W**orld's coordinate system.

$\boldsymbol{R}_{B}^{W}$: The **B**ack IMU's rotation matrix in **S**urgical position w. r. t. **W**orld's coordinate system.

$\boldsymbol{R}_{H}^{W}$: The **H**ead IMU's rotation matrix in **S**urgical position w. r. t. **W**orld's coordinate system.

In Reference position: t*he Head* IMU w. r. t. the Back IMU :

$$\boldsymbol{R}_{HR}^{BR} = R_{W}^{BR} \cdot R_{HR}^{W} = (\boldsymbol{R}_{BR}^{W})^{-1} \cdot \boldsymbol{R}_{HR}^{W}$$

In surgical position: t*he Head* IMU w. r. t. the Back IMU :

$$\boldsymbol{R}_{H}^{B} = R_{W}^{B} \cdot R_{H}^{W} = (\boldsymbol{R}_{B}^{W})^{-1} \cdot \boldsymbol{R}_{H}^{W}$$

Surgical position $w.r.t.$ reference position:

$$\boldsymbol{R}_{final} = (\boldsymbol{R}_{HR}^{BR})^{-1} \cdot \boldsymbol{R}_{H}^{B} = \left(\boldsymbol{R}_{HR}^{W}\right)^{-1} \cdot \boldsymbol{R}_{BR}^{W} \cdot (\boldsymbol{R}_{B}^{W})^{-1} \cdot \boldsymbol{R}_{H}^{W}$$

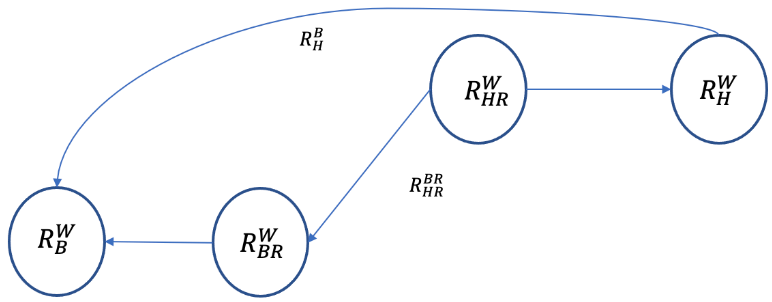


Figure 8. Neck Flexion Angle Matrix Transformation

4.3 Real Surgery Data Collection

We collected data for basic head movements, including turning the head in the X, Y and Z planes periodically, shaking yes no and rotating the head from shoulder to shoulder, to confirm the rationality of our algorithm. We then performed mock surgical procedures in a simulated operating room setting and conducted eggshell drilling experiment. Then we applied the same procedures to collect real surgery data with the assistance of medical students and surgeons in Johns Hopkins Outpatient Center. Twenty surgeries have been previously collected and six surgeries are newly collected. Excluding three surgeries which have no reference position to enable analysis, nineteen surgeries include microscopic operations, and seven surgeries include endoscopic operations. With these data we can conduct neck flexion angle study comparing two different scenarios.

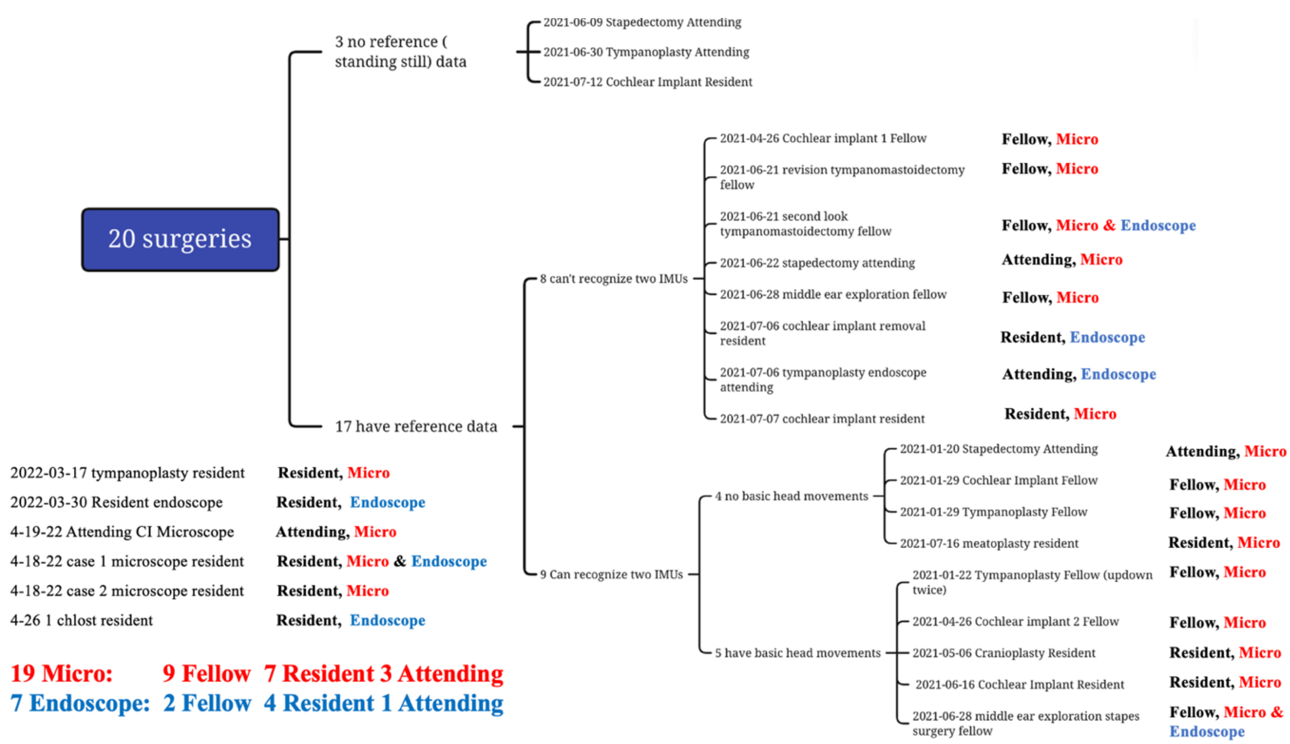


Figure 9. Surgical Data Collection Summary

4.4 Eggshell Drilling Experiment Setup

Figure 10. Eggshell Drilling Experiment Setup **Figure 11**. RGBD depth camera (in two positions)

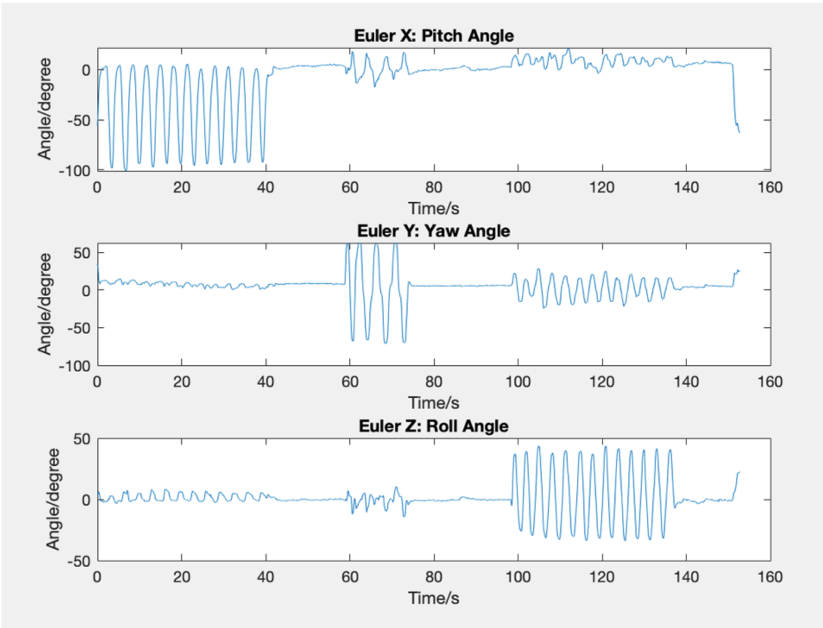
An eggshell drilling experiment has been conducted with the help of Dr. Deepa Galaiya. Two IMU were attached to her head and back and she was performing eggshell drilling as shown in **Figure 10.** The RGBD depth camera is utilized to record the surgery and assisted in surgical ergonomic analysis.

Figure 12. Eggshell Drilling Performed in Bad (left) and Good (Right) Ergonomics

Dr. Deepa Galaiya performed eggshell drilling as shown in **Figure 12**. With two intended ergonomics postures, we could analyze the difference of neck flection angle between bad and good ergonomics. The purpose of the mock eggshell drilling experiment is to validate our method of collecting surgical data from IMUs and rationality of algorithm.

5.Results and Discussion

5.1 Mock OR Data: Basic Head Movement



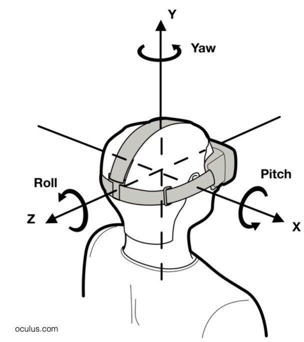


Figure 13. Neck Flection Angle of Basic Head Movement **Figure 14** IMU's Coordinate System

Figure 13 shows how the three Euler Angles change with time. (Note: the definitions of pitch angle, yaw angle, and roll angle are the same as the IMU's coordinate system defined in **Figure 14**.)

We first performed "shaking yes" with our head. The IMU managed to record the periodic pitch angle changes. Then it followed with "shaking no" which IMU records a periodic change mainly in yaw angle. Finally, "shoulder to shoulder" was performed and a periodic change in roll angle was observed. The yaw angle and pitch angle also varied in a periodic way but with a much smaller magnitude (less than 10 degree) while we performed "shoulder to shoulder", since our head control was not perfect, and the motion could not be complected purely in Euler Z direction.

Before surgeons start operations, they will perform the basic head movement "shaking yes no" and "shoulder to shoulder" to ensure the IMU is working properly. Data collected without clear basic movement will be considered unreliable. This process guarantees that analysis is based on correct IMU attachment and good Bluetooth connection.

5.2 Mock OR Data: Eggshell Drilling Experiment

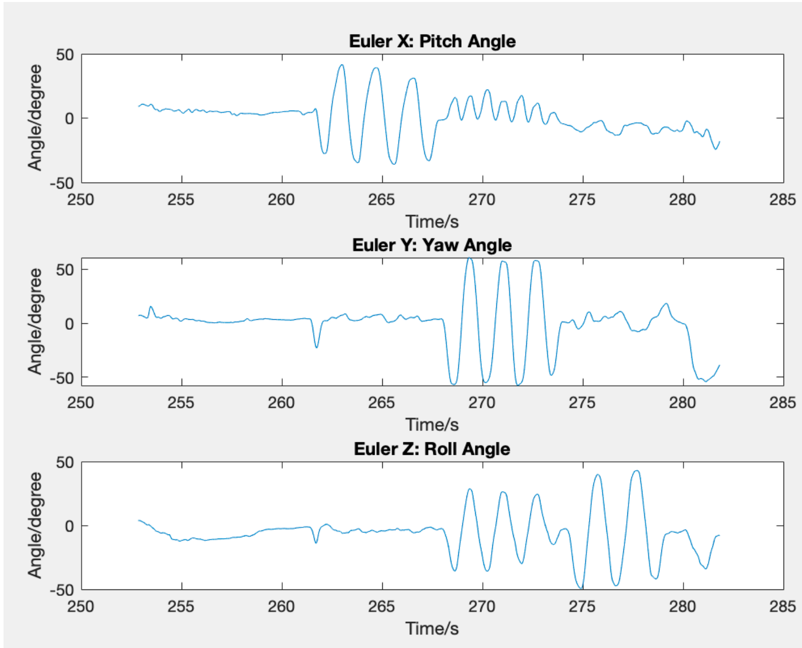


Figure 15. Neck Flection Angle of Basic Head Movement for Eggshell Drilling

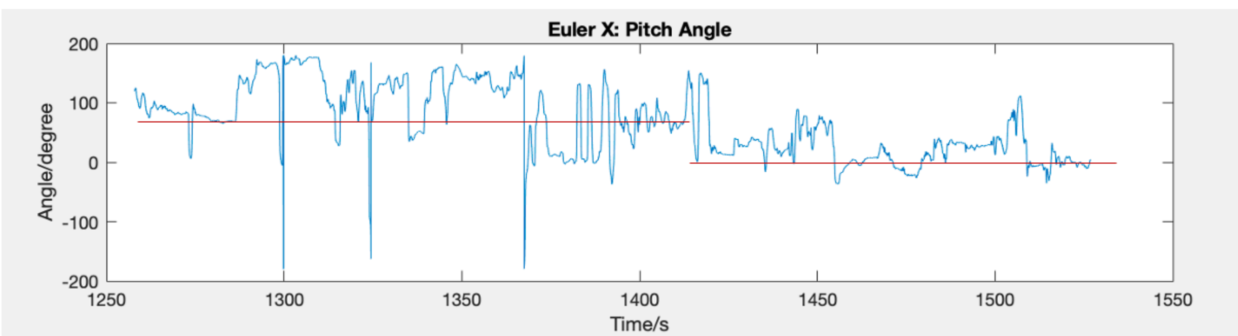


Figure 16. Neck Flection Angle During Eggshell Drilling

The basic head movement clearly presented the periodic changes in three Euler angles before we started eggshell drilling experiment. Then two periods of neck flection angle variation were recorded during the experiment. Dr. Deepa Galaiya first performed drilling in a bad ergonomic position as we could see the neck flection angles are around 50-100 degree; while the drilling performed in a good ergonomic position had angles maintaining around 0-30 degree. The results strongly support our theory that a larger neck flection angle persists in unfavorable ergonomics compared to a favorable one.

5.3 Real Surgery Data

Excluding unreliable surgery data, we collected eleven cases for the microscopic scenario and five cases for the endoscopic scenario. For each case, we selected the main operation periods for analysis. The standard deviation, maximum angle, minimum angle, and average angle for each case are presented in **Table 1 and 2** and summarized into boxplots for a better visualization **(Figure 17 & 18).**

Neck Flexion Angle (Microscopic Operation)

	Standard Deviation	Maximum Angle	Minimum Angle	Average Angle
6-21 fellow	23.6858	179.9907	-99.9377	33.9104
7-7 resident	25.1321	179.9548	0.0360	63.6222
1-20 attending	43.8492	179.9673	99.9354	37.3022
1-29 fellow	44.1300	113.2913	- 81.8749	- 1.0806
1-29 fellow	78.3454	179.9615	-179.9603	27.8957
7-16 resident	70.0834	179.9893	-69.9170	62.1623
1-22 fellow	40.0989	145.9878	-62.0530	28.8991
4-26 fellow	41.3543	179.9966	-89.1674	15.1450
4-18 resident	32.3590	157.1137	7.8004	50.4207
4-18 resident	29.5889	99.9992	-99.5939	29.7070
6-21 fellow	14.4043	82.5923	-46.4564	19.1340

Table 1. Neck Flexion Angle during Microscopic Operation

Neck Flexion Angle (Endoscopic Operation)

	Standard Deviation	Maximum Angle	Minimum Angle	Average Angle
4-18 resident	29.9462	155.3769	-179.9086	-14.4166
4-18 resident	30.3661	104.3274	-99.9913	-36.4381
6-21 fellow	37.9055	108.8314	-80.0874	10.8777
7-6 attending	50.0260	139.2365	-189.7597	2.3375
6-28 fellow	50.4250	179.9990	-179.9950	2.3059

Table 2. Neck Flexion Angle during Endoscopic Operation

Neck Flexion Angle Box Plot (Microscopic Operation)

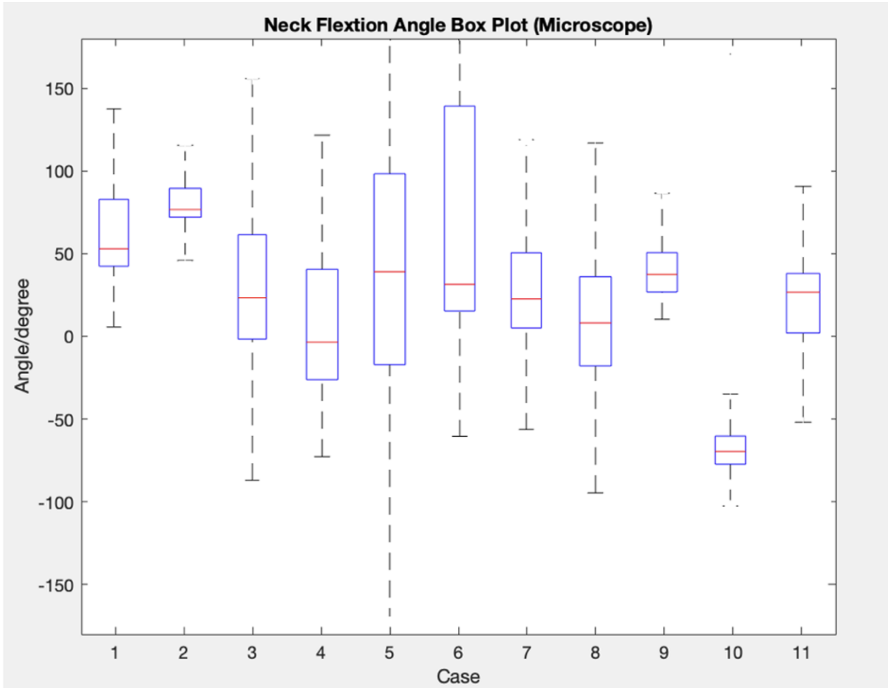


Figure 17. Neck Flexion Angle Boxplot during Microscopic Operation

Neck Flexion Angle Box Plot (Endoscopic Operation)

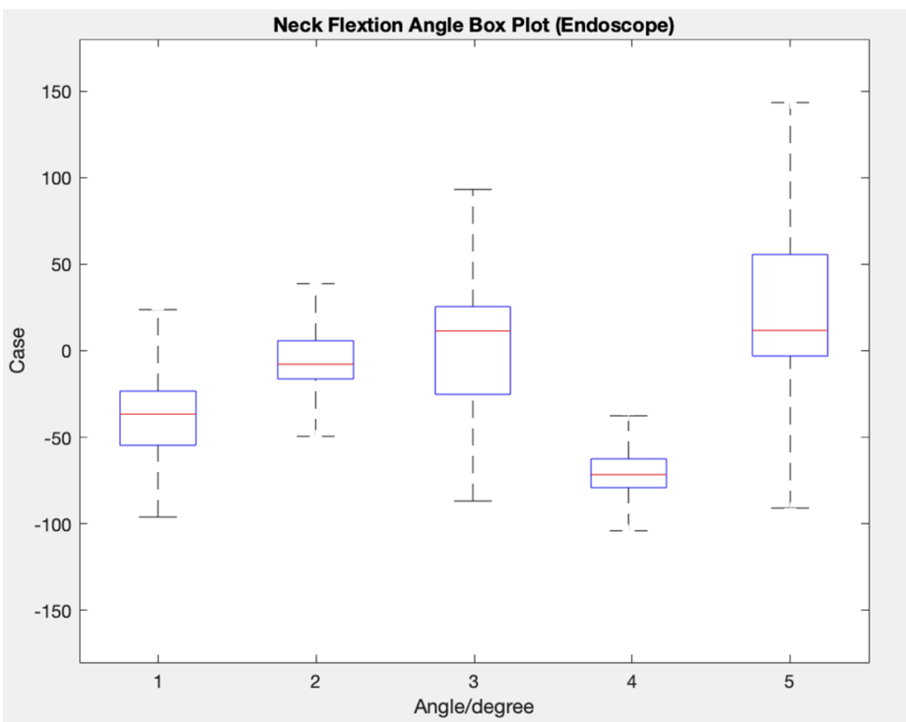


Figure 18. Neck Flexion Angle Boxplot during Endoscopic Operation

The histograms of neck flexion angle distribution are illustrated for each case. On the left figure, three Euler angles (Pitch, Yaw, and Roll) are all shown. On the right figure, the pitch angle is highlighted with a fitting curve. The results are separated into microscopic and endoscopic cases.

Neck Flexion Angle Distribution (Microscopic Operation)

2022-04-18 resident microscope L ear (operation period 1).

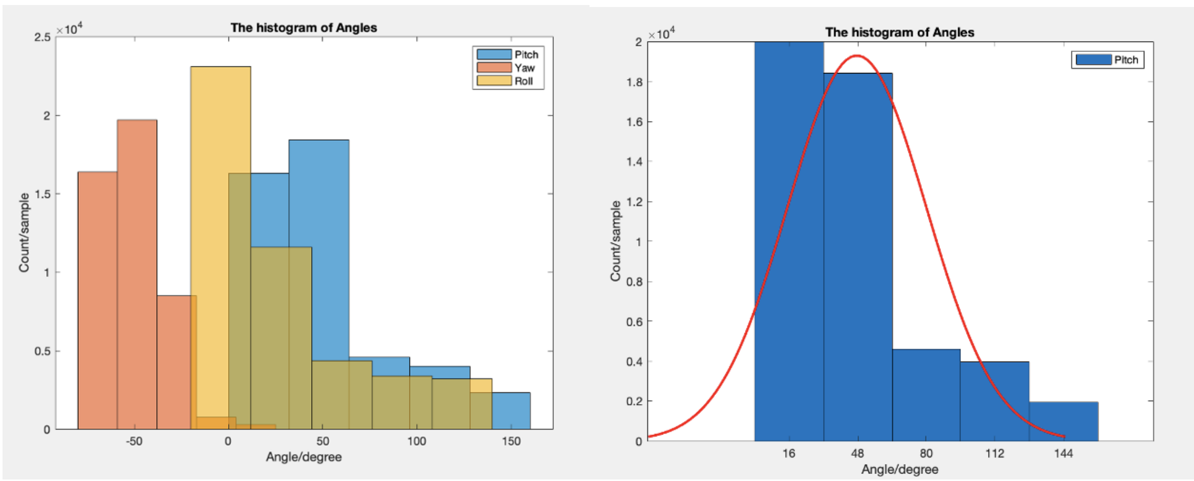


Figure 19. Neck Flexion Angle Distribution

2022-04-18 resident microscope L ear (operation period 2)..

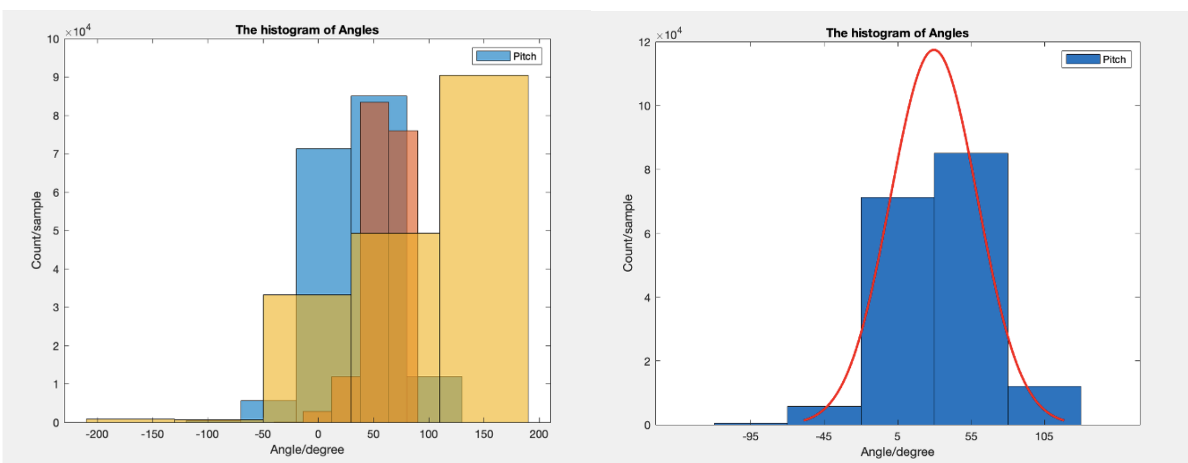


Figure 20. Neck Flexion Angle Distribution

2021-06-21 second look tympanomastoidectomy fellow

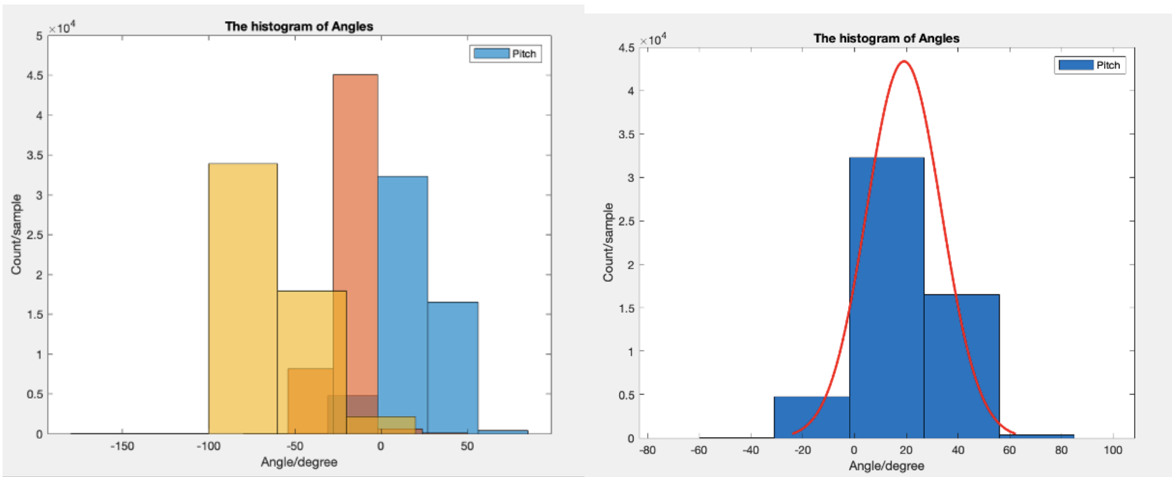


Figure 21. Neck Flexion Angle Distribution

2021-06-21 revision tympanomastoidectomy fellow

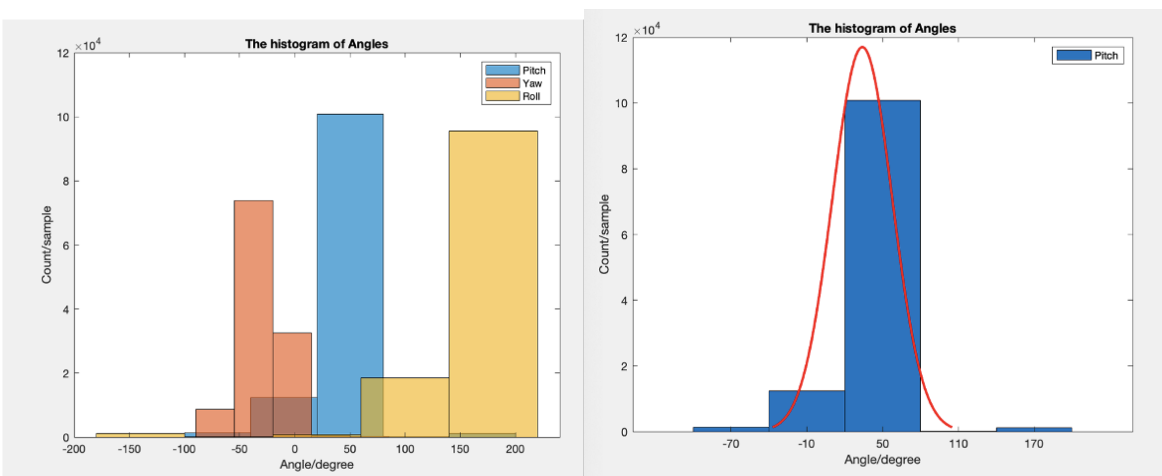


Figure 22. Neck Flexion Angle Distribution

2021-07-07 cochlear implant resident

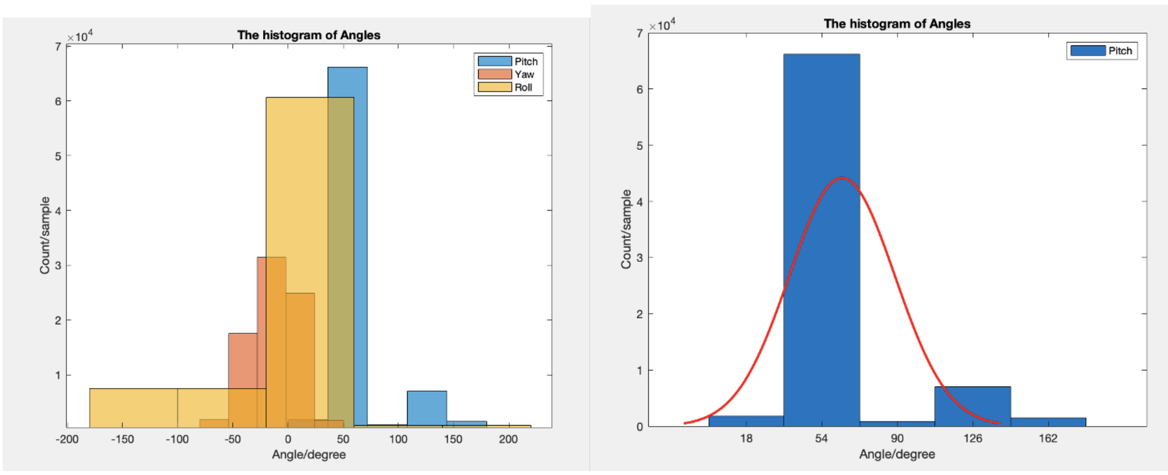


Figure 23. Neck Flexion Angle Distribution

2021-01-20 stapedectomy attending

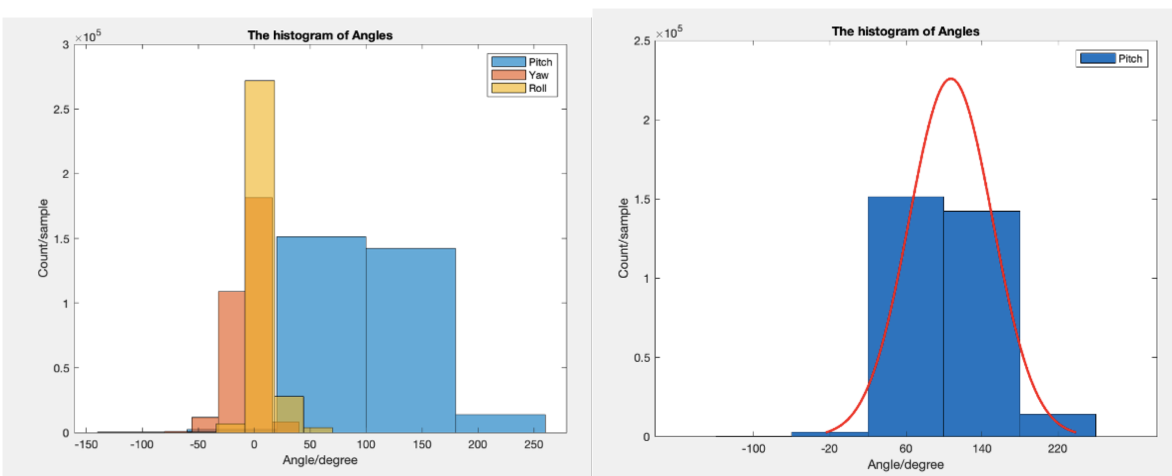


Figure 24. Neck Flexion Angle Distribution

2021-01-29 cochlear implant fellow

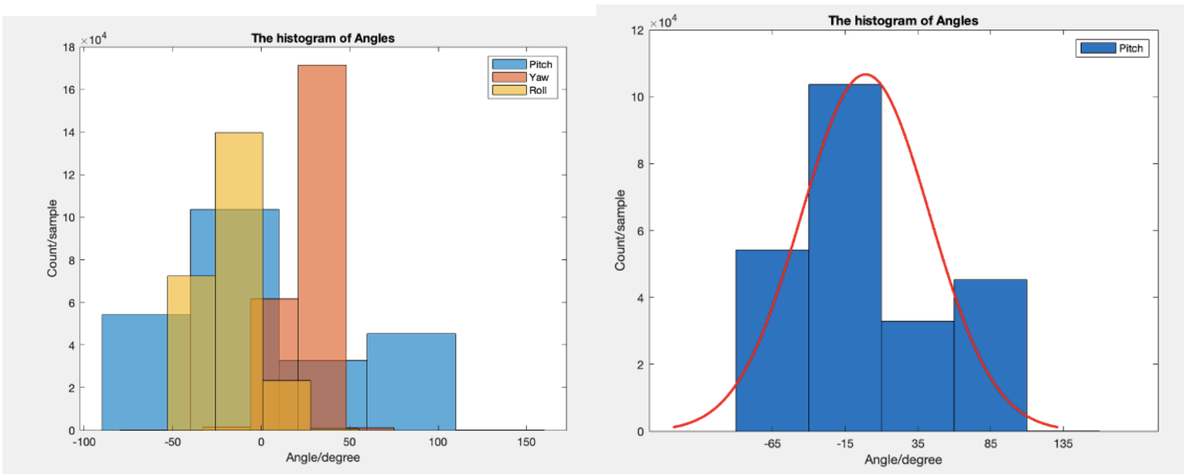


Figure 25. Neck Flexion Angle Distribution

2021-01-29 tympanoplasty fellow

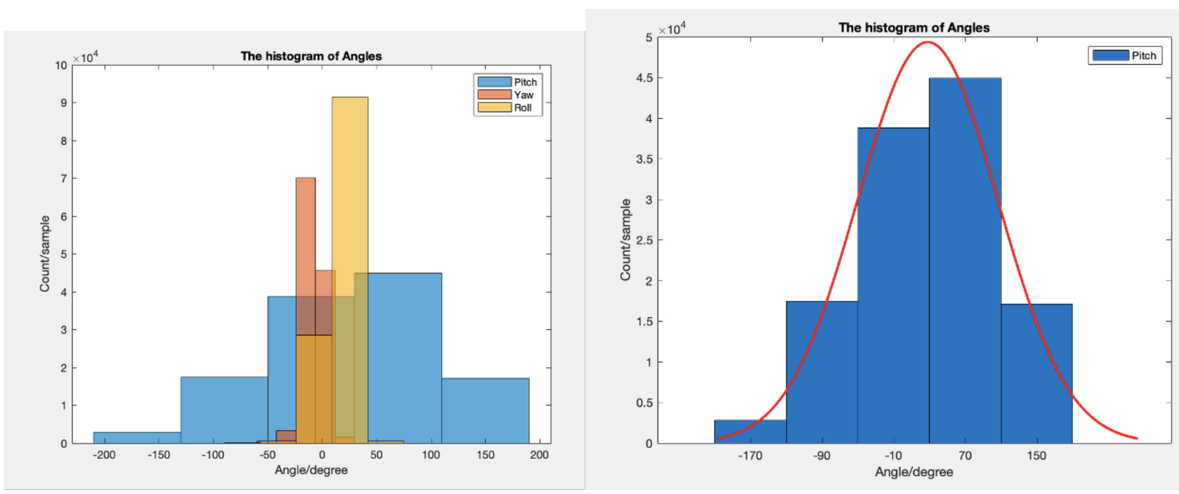


Figure 26. Neck Flexion Angle Distribution

2021-07-16 meatoplasty resident

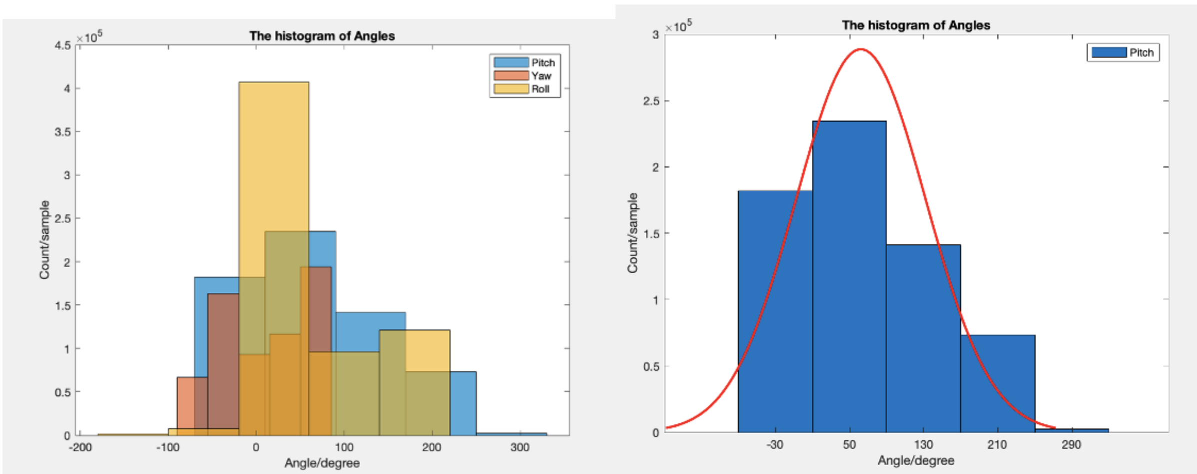


Figure 27. Neck Flexion Angle Distribution

2021-01-22 Tympanoplasty Fellow

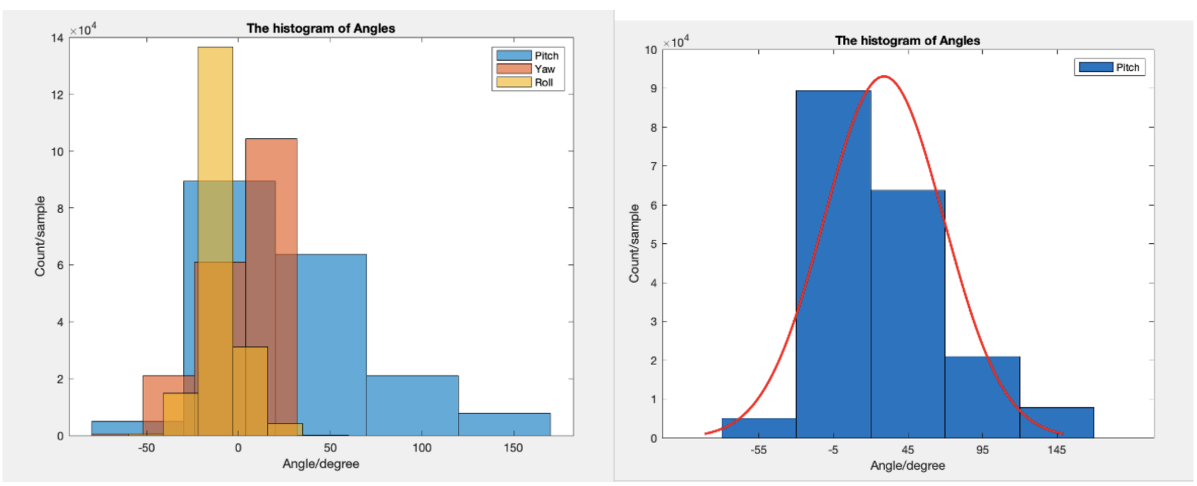


Figure 28. Neck Flexion Angle Distribution

2021-04-26 Cochlear implant 2 Fellow

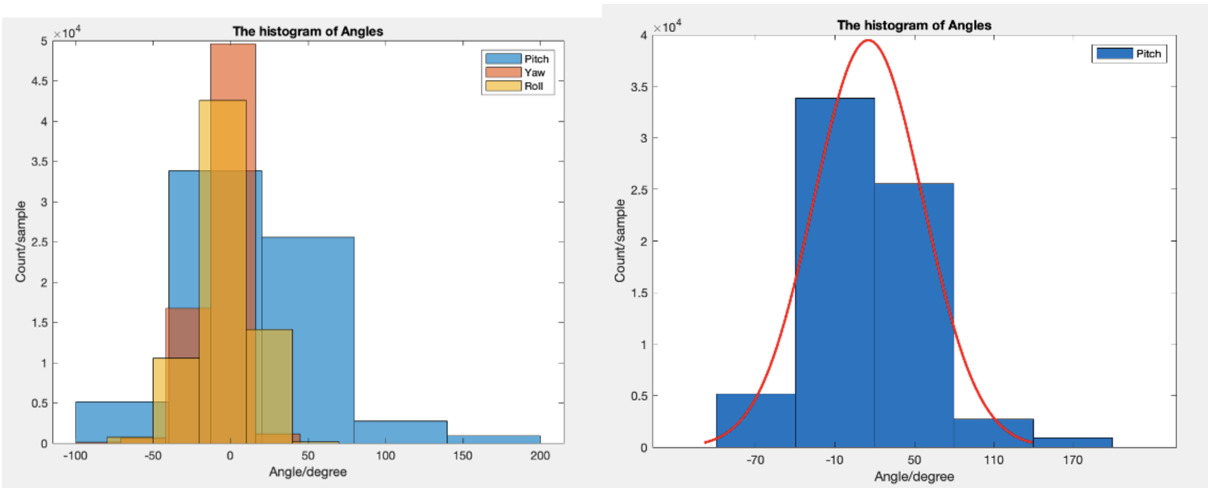


Figure 29. Neck Flexion Angle Distribution

Neck Flexion Angle Distribution (Endoscopic Operation)

2022-04-18 resident microscope L ear (operation period 1).

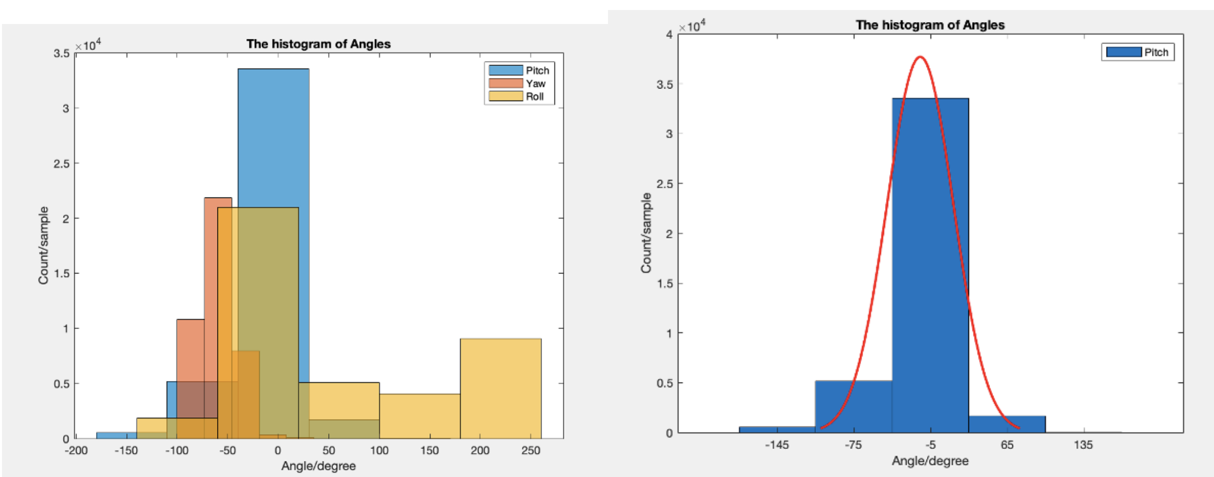


Figure 30. Neck Flexion Angle Distribution

2022-04-18 resident microscope L ear (operation period 2).

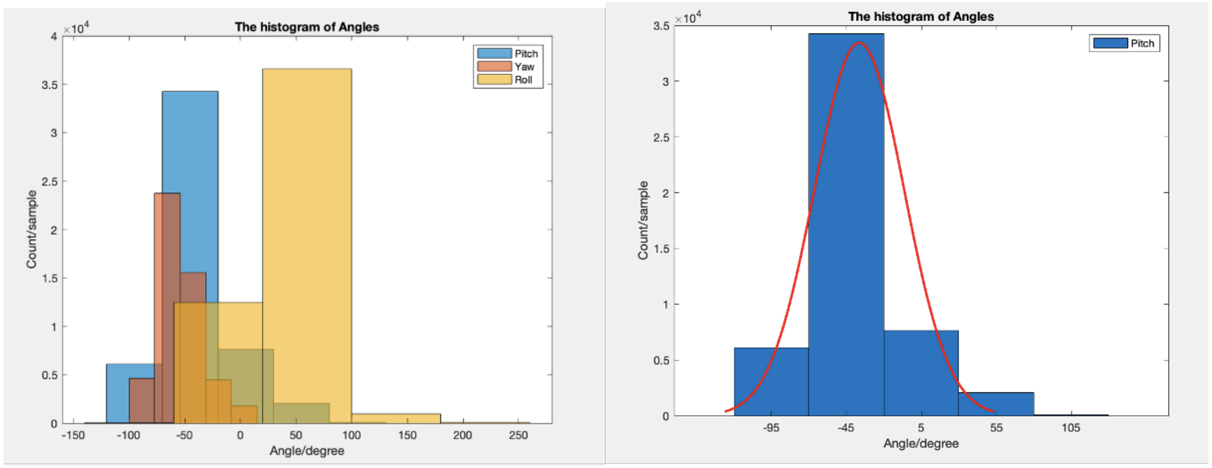


Figure 31. Neck Flexion Angle Distribution

2021-06-21 second look tympanomastoidectomy fellow

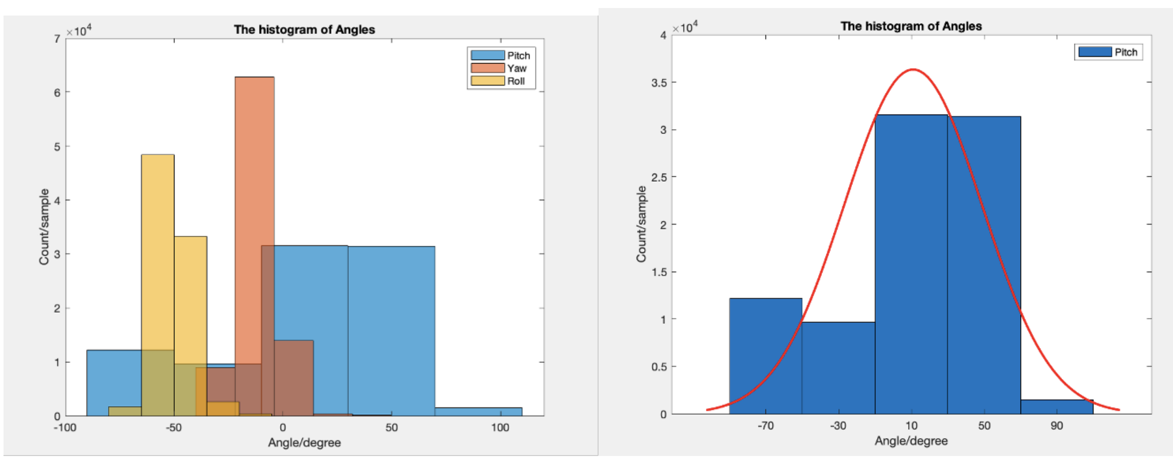


Figure 32. Neck Flexion Angle Distribution

2021-07-06 tympanoplasty endoscope attending

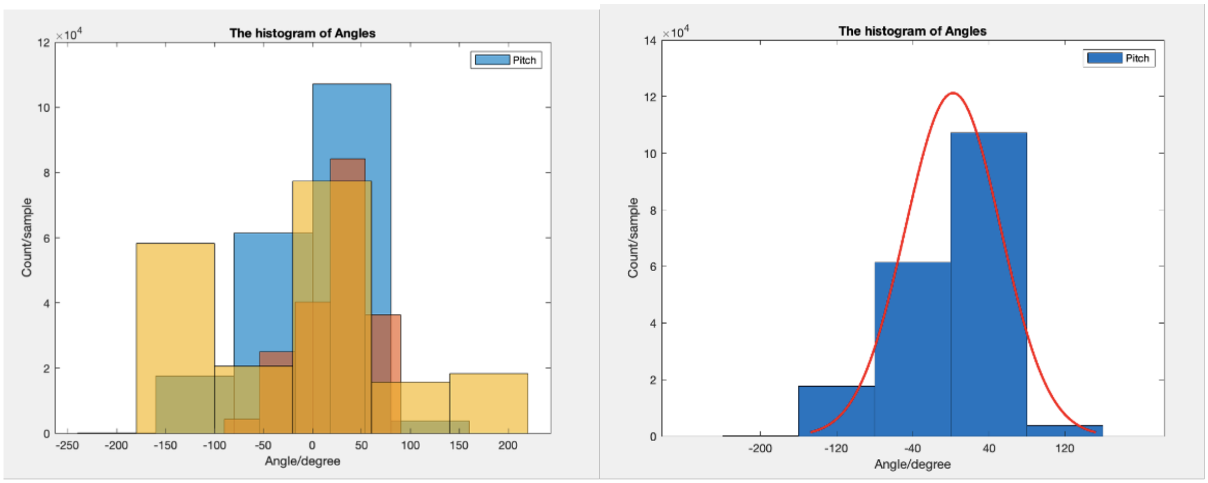


Figure 33. Neck Flexion Angle Distribution

2021-06-28 middle ear exploration stapes surgery fellow

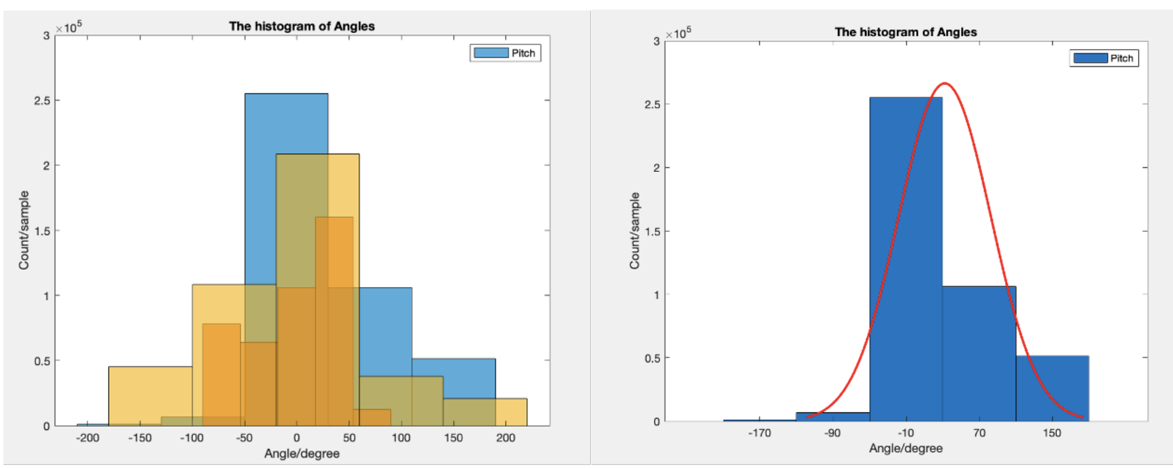


Figure 34. Neck Flexion Angle Distribution

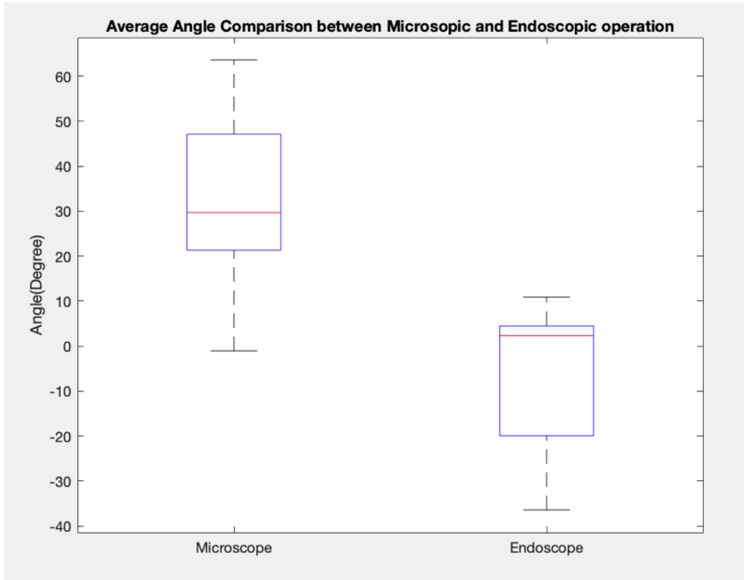


Figure 35. Average Neck Flexion Angle Boxplot Comparison

Average Neck Flexion Angle in Microscope Scenario: 33.3744°

Average Neck Flexion Angle in Endoscope Scenario: -7.0667°

From the surgical cases observed thus far, endoscopic surgery has a lower average neck angle compared to microscopic surgery. This is consistent with expectations because surgeons look more level during endoscopic surgery. There is relatively high variability in the average neck angle across surgical cases. This may be due to inconsistent placement of the IMUs on the surgeon's neck and back, variability in required neck flexion for different surgeries, and natural differences in posture across surgeons.

5.4 Drifting Problem:

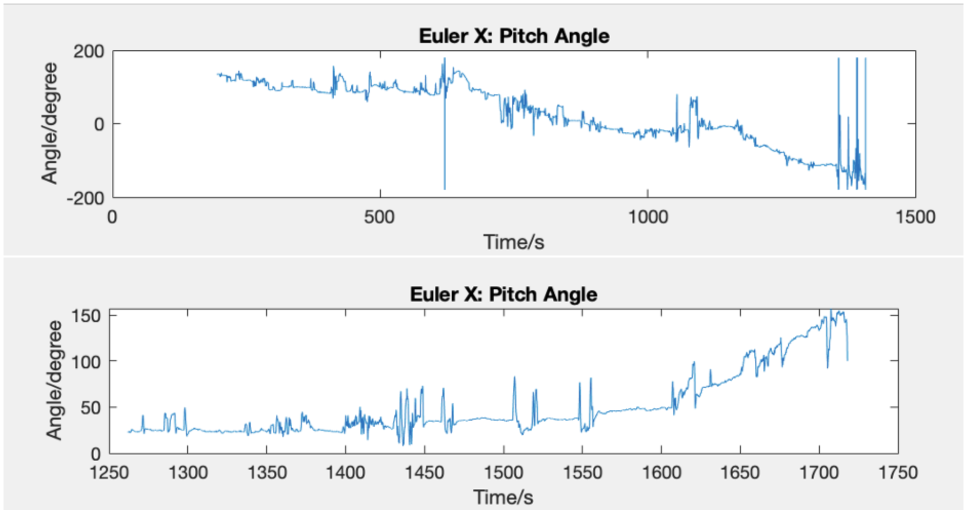


Figure 36. Observed Data Drift

As shown in the figures above, there is a gradual drift in the average pitch angle as the surgery progressed. This shift is sometimes positive and sometimes negative. The most probable cause for this drift is that the IMUs were not well secured on the surgeon's PPE. The IMUs may have been gradually sliding out of position as the adhesion from the surgical tape wore off or the surgeons' clothes shifted. To confirm this is the case, a stationary IMU test will be performed to check that the data collected by unmoving IMUs do not display a similar drift observed during the surgical cases. Looking forward to future surgical cases, the IMUs will be attached to the surgeon's scrubs instead of on the surgical gown and ensuring sufficient tape is used to prevent extraneous movement of the IMU. If these methods do not correct the drift, the team will explore options that will allow the IMUs to be fixed to the surgeon's body, finding a better adhesive, or designing another solution to keep the IMUs stationary.

5.5 Significance of Min/Max Metric:

Initially, one of the purposes of this study was to find the minimum and maximum neck angle of the surgeons during each case. This metric was important to determine the maximum strain put on a physician's neck during surgery. After completing the analysis of the existing surgical data, these metrics are less useful than initially hoped. The maximum and minimum angles were typically a result of noise and did not represent a physically relevant quantity. A way to combat this issue in the future may be to exclude outliers from being considered for the extreme neck angles, or denoise the IMU data to reduce large fluctuations in neck angle.

6. Conclusion

In a series by Lee, muscle fatigue levels of the right and left upper trapezius are the highest when neck flexion angle is at 50° and the lowest at 30°[1]. In traditional surgery, neck flexion angle is above 50° for a long time, implying that muscle fatigue level of trapezius is high. Compared with endoscopic cases, the neck flexion angle is near 10° for most of the time, implying that the risk of back pain is lower. It is obvious that the usage of endoscope will be beneficial for surgeons by avoiding the abnormal neck posture compared to the traditional surgery case.

The average neck flexion angle calculated using the IMUs was 33° for microscopic surgery and -7° for endoscopic surgery. Endoscopic surgery yields smaller neck angles compared to microscopic surgery; however, the values do not agree with what was expected based on prior literature. If one were to shift the angles received by the IMUs up by 17°, the numbers would match more closely. This indicates that our results agree with the literature in the differences between the two surgical scenarios but varies in the absolute measure of the angle, but endoscopic surgery may not guarantee that surgeon maintains an ergonomically favorable neck angle. Endoscopy monitors can be placed at varying positions relative to the surgeon depending on the surgical suite's design. This variability may explain the unreliability in the claim that endoscopic surgery neck angle is between 10 and 30°. To reap the ergonomic benefits of endoscopic surgery, the monitors and surgeon positions must be set up properly to ensure that minimal strain is placed on the surgeon's neck and decrease their risk of health complications. To avoid excessive consistent pressure on the neck, we suggest surgeon changing the posture regularly for at least 10s and further recommend surgeons to actively perform neck strengthening exercises daily, which will decrease the effect of FHP on surgeon's neck.

7. Future Work

One of the initial goals of this project was to compare neck angles of resident, fellow, and attending surgeons. During the semester, the team was able to analyze enough data to make initial comparisons between residents and fellows, however the sample of attendings observed is too small to make any meaningful comparisons. Future work will emphasize getting a larger pool from this surgeon population to make better comparisons between physicians at varying points in their careers.

Because of the existing concern about data drifting and mispairing over the surgery, data in later time of the surgery becomes unreliable when we are doing the analysis. Therefore, the initial plan of dividing the entire surgery into different phases and comparing the mean and standard deviation of each phase can't be implemented. We often obtain extremely large and discontinuous data in decomposition, fusion, and closure, the last three phases of a surgery. Furthermore, decompression and fusion are the most stressful phases affecting surgeon's neck on which we want to emphasize and analyze.

Main operation period within the first one or two hours of a surgery is analyzed in this project. In the future, improvement can be made to guarantee the validity of entire surgical data, so that different phases of a surgery can compared, and analysis can be done, for example the portion and time length of high neck flection angles in one surgery. We are also interested in time region which has larger neck flection angle and the according actions taken by surgeon. It is very educational to learn scenarios with higher ergonomic risk.

The current noise filter used in our analysis are a lowpass filter and a correction to baseline shifting, which impacts the real surgery data in a minor way. More testing and better method are expected to filter out noise that currently exists and reduces the accuracy of our result. Besides neck flexion angle, angles in other parts of the body such as back, elbow and shoulder are also effective to show operating stressfulness. Comparison between back angle, elbow angle and shoulder angle in both microscopic and endoscopic surgical scenarios can place more emphasis in surgical ergonomics, which can be a potential area that our future study explores.

Designing a wearable warning system can also be considered as a research direction in the future. When the neck flexion angle exceeds a certain value or surgeon keeps in a big neck flexion angle status for a long time, the system can remind the surgeon to adjust the position promptly.

8. Management Summary

Team Contributions

- Zihao：
  - Wrote codes for IMU differentiation and data analysis
  - Contributed to milestones outlined in *Milestone Summary*
- Millan:
  - Provided weekly updates at Dr. Taylor's research meeting
  - Contributed to milestones outlined in *Milestone Summary*
- Team
  - IMU Data Analysis
  - IMU Data differentiation
  - Provided weekly updates with Dr. Deepa Galaiya
  - Completed documentation and code in OneDrive folder
  - Completed weekly team member meetings

Milestone Summary

1. Linux and ROS Environment Configuration Finished (Zihao, Millan)
   - Planned Date: 2/22/22
   - Expected Date: 2/22/22
   - Status: Complete
2. Evaluation of IMU Calibration and Mathematical Model Finished (Zihao, Millan)
   - Planned Date: 3/2/22
   - Expected Date: 3/2/22
   - Status: Complete
3. First Measure in Mock OR and Analysis of the Data Finished (Millan)
   - Planned Date: 3/11/22
   - Expected Date: 3/11/22
   - Status: Complete
4. Data Analysis of Existing Surgical Measurement Finished (Zihao, Millan)
   - Planned Date: 3/27/22
   - Expected Date: 3/27/22
   - Status: Complete
5. Collect Mock OR Measurement from Eggshell Drilling Experiment Finished (Zihao, Millan)
   - Planned Date: 4/3/22
   - Expected Date: 4/3/22
   - Status: Complete

6. Data Analysis of Mock OR Measurement from Eggshell Drilling Experiment Finished (Millan)
    - Planned Date: 4/10/22
    - Expected Date: 4/10/22
    - Status: Complete
7. Data Analysis of New Surgical Measurement Among Various Surgery Scenarios Finished (Zihao)
    - Planned Date: 4/17/22
    - Expected Date: 4/17/22
    - Status: Complete
8. Documentation of Data Collection and Data Analysis Finished (Zihao, Millan)
    - Planned Date: 4/24/22
    - Expected Date: 4/24/22
    - Status: Complete
9. Final Report Paper Finished (Zihao, Millan)
    - Planned Date: 5/1/22
    - Expected Date: 5/1/22
    - Status: Complete

9. Deliverables

Minimum:

- ✓ Evaluation of the existing calibration steps, physical model
- ✓ Documentation of software setting, calibration steps, physical model (doc file)
- ✓ Data analysis and documentation of Mock OR experiment

Expected:

- ✓ Improvement to signal processing of measurement obtained from IMUs
- ✓ Data analysis and documentation of Eggshell Drilling experiment
- ✓ Data analysis report of real surgical scenarios

Maximum:

- ✓ Data analysis report of all possible scenarios
- ✓ Final Report

10. What we learned

We learn the matrix transformation and applying quaternion to calculate Euler angle in project. Besides that, collaboration with people in other fields to complete this interdisciplinary project is another important lesson. All the real surgical data are collected with the help of medical students and surgeons. Communicating with them and arranging time to teach them how to wear IMU, how to gather data, and what steps need to be followed contribute to every progress that we made in this project.

We also learn how to overcome technical difficulties. For example, we are struggling with the Bluetooth connection for a long time. The IMUs cannot connect stably when the EM tracker is connected at the same time. We only spent a half hour to collect the calibration data, but it took almost three hours to figure out the reason and solution before collecting. Maintaining a positive attitude and being patient are necessary in all research.

For management, it is beneficial for us to learn how to propose a detailed and thoughtful plan and divide a heavy workload into weeks at the beginning of a research. We never knew the importance of having a backup plan. Accidents happens like the collected data is not usable, and we need to make adjustment and have our plan B ready to deal with unexpected events promptly. Otherwise, all schedules would be postponed and greatly delay our progress.

Learning how to give an elevator pitch in one minute and perform a good presentation is also valuable for us during this semester. We believe our presentation skill and speaking in a natural way improves a lot from our project proposal presentation to our final presentation.

11. Acknowledgments

We would like to thank our mentors Dr. Russell Taylor and Dr. Deepa Galaiya for reviewing our work in weekly Galen group meeting and providing us with their guidance throughout the project period. We also appreciate Hyonoo Joo and Eric Formeister for helping us collecting real surgery data in Johns Hopkins Outpatient Center.

12. Reference

- Du, Y., Shih, C., Fan, S. et al. An IMU-compensated skeletal tracking system using Kinect for the upper limb. Microsyst Technol 24, 4317–4327 (2018).
- Islam, Tariqul, et al. "Comparison of complementary and Kalman filter based data fusion for attitude heading reference system." AIP Conference Proceedings. Vol. 1919. No. 1. AIP Publishing LLC, 2017.
- Won, Seong-hoon, William Melek, and Farid Golnaraghi. "Position and orientation estimation using Kalman filtering and particle filtering with one IMU and one position sensor." 2008 34th Annual Conference of IEEE Industrial Electronics. IEEE, 2008.

- Lakhiani C, Fisher SM, Janhofer DE, Song DH. Ergonomics in microsurgery. J Surg Oncol. 2018;118(5):840–844. doi:10.1002/jso.25197
- Vaisbuch Y, Aaron KA, Moore JM, et al. Ergonomic hazards in otolaryngology. Laryngoscope. 2019;129(2):370–376. doi:10.1002/lary.27496
- Wong K, Grundfast KM, Levi JR. Assessing work-related musculoskeletal symptoms among otolaryngology residents. Am J Otolaryngology. 2017;38(2):213–217. doi: 10.1016/j.amjoto.2017.01.013
- Wang R, Liang Z, Zihni AM, Ray S, Awad MM. Which causes more ergonomic stress: Laparoscopic or open surgery?. Surg Endosc. 2017;31(8):3286–3290. doi:10.1007/s00464-016-5360-5
- Zihni AM, Cavallo JA, Ray S, Ohu I, Cho S, Awad MM. Ergonomic analysis of primary and assistant surgical roles. J Surg Res. 2016;203(2):301–305. doi: 10.1016/j.jss.2016.03.058
- Nguyen NT, Ho HS, Smith WD, et al. An ergonomic evaluation of surgeons' axial skeletal and upper extremity movements during laparoscopic and open surgery. Am J Surg. 2001;182(6):720–724. doi:10.1016/s0002-9610(01)00801-7

13. Technical Appendices

13.1 Analytical Code

13.2 Code to Separate IMU Data

Table of Contents


```
% Revise items:
% 1. the address of ref/sur
% [reference's position's quaternion] part, length of Quat_A6 and Quat_A1
% [surgical position's quaternion] part, length of time_A6 and time_A1,
```

Read in

```
clear all; clc;close all;

%%%%%%%%%%% Need change:
%ref = table2array(readtable('/Users/zhenhu/Documents/JHU/CIS/Mock
 OR2/2021.3.25/Real Mock/ref2.csv'));
%sur = table2array(readtable('/Users/zhenhu/Documents/JHU/CIS/Mock
 OR2/2021.3.25/Real Mock/turn3.csv'));
data_total = table2array(readtable('/Users/zlin/Desktop/AnalyzeData/2021-01-22
 tympanoplasty fellow.csv'));

Error using readtable (line 498)
Unable to find or open '/Users/zlin/Desktop/AnalyzeData/2021-01-22
 tympanoplasty fellow.csv'. Check the path and filename or file permissions.

Error in Analyze (line 12)
data_total = table2array(readtable('/Users/zlin/Desktop/AnalyzeData/2021-01-22
 tympanoplasty fellow.csv'));
```

Read time of IMU starting, reference starting, operation starting

```
timeconvert = [3600,60,1];
totalstart_time = [8,13,24];
refstart_time = [8,13,37];
refend_time = [8,14,14];

surgstart_time = [8,44,06];
```

```
surgend_time = [9,1,59];

refstart = 100*sum(refstart_time.*timeconvert - totalstart_time.*timeconvert);
refend = 100*sum(refend_time.*timeconvert - totalstart_time.*timeconvert);
surgstart = 100*sum(surgstart_time.*timeconvert -
 totalstart_time.*timeconvert);
surgend = 100*sum(surgend_time.*timeconvert - totalstart_time.*timeconvert);

% IMU1 = table2array(readtable('IMU1.csv'));
% IMU2 = table2array(readtable('IMU2.csv'));
IMU1 = data_total(data_total(:,1)==1,:);
IMU2 = data_total(data_total(:,1)==2,:);

A6_ref = [IMU1(refstart:refend,1),IMU1(refstart:refend,16:19)];
A1_ref = [IMU2(refstart:refend,1),IMU2(refstart:refend,16:19)];
A6_sur = [IMU1(surgstart:surgend,1:2),IMU1(surgstart:surgend,16:19)];
A1_sur = [IMU2(surgstart:surgend,1:2),IMU2(surgstart:surgend,16:19)];

% ref = table2array(readtable('/Users/zlin/Desktop/refexp1.csv'));
% sur = table2array(readtable('/Users/zlin/Desktop/exp1.csv'));
% ref = sortrows(ref,1); sur = sortrows(sur,1);
```

Get the reference's position's quaternion

ref = [ref(:,1),ref(:,16:19)]; A6_ref = ref(ref(:,1)==1,:); A1_ref = ref(ref(:,1)==2,:);

```
%%%%%%%%%%% Need change:
% figure(1); plot(A6_ref)
% figure(2); plot(A1_ref)
Quat_A6 = A6_ref(200:1100,2:5); Quat_A1 = A1_ref(200:1100,2:5);

Quat_A6(:,2:4) = -Quat_A6(:,2:4); Quat_A1(:,2:4) = -Quat_A1(:,2:4); %
 conjugate
```

Average reference's position's quaternion

```
A6_quat = quaternion(Quat_A6);
A1_quat = quaternion(Quat_A1);

QA6_ref = compact(meanrot(A6_quat)); % The averaged quaternion of the A6 and
 1A
QA1_ref = compact(meanrot(A1_quat));
```

Get the surgical position's quaternion

sur = [sur(:,1:2) sur(:,16:19)]; A6_sur = sur(sur(:,1)==1,:); A1_sur = sur(sur(:,1)==2,:);

```
%%%%%%%%%%% Need change:
% figure(3); plot(A6_sur(:,(3:6)))
% figure(4); plot(A1_sur(:,(3:6)))
time_A6 = A6_sur(1:end-2,2);
QA6 = A6_sur(1:end-2,3:6); QA1 = A1_sur(:,3:6);
```

```
QA6(:,2:4) = -QA6(:,2:4); QA1(:,2:4) = -QA1(:,2:4);
```

Transfer all the quaternion to rotation matrix (using matlab toolbox)

reference

```
RA6 = quat2rotm(QA6_ref);
RA1 = quat2rotm(QA1_ref);

R_A6_A1_ref = RA1.' * RA6;
R_A1_A6_ref = R_A6_A1_ref.';

A6_RM0 = cell(size(QA6,1),1);
A1_RM0 = cell(size(QA1,1),1);

for i = 1:size(QA6,1)
    A6_RM0(i,1) = {quat2rotm(QA6(i,:))};
    A1_RM0(i,1) = {quat2rotm(QA1(i,:))};
end
```

Calculating the final rotation matrix

```
Rph = cell(size(QA6,1),1);
for i = 1:size(QA6,1)
    %Rph(i,1) = {RA1*A1_RM0{i,1}.'*A6_RM0{i,1}*RA6.'}; %according to Russ
    R_A6_A1_sur = A1_RM0{i,1}.' * A6_RM0{i,1};
    Rph(i,1) = {R_A1_A6_ref * R_A6_A1_sur};
end
```

Transfer the rotation matrix into Euler Angle

calculate the three small angel matrix

```
eul = zeros(size(QA6,1),3);
for i = 1:size(QA6,1)
    %eul(i,:) = rotate2euler(cell2mat(Rph(i,1)));
    eul(i,:) = rotm2eul(Rph{i,1},'ZYX');

end
```

eliminate data jumps

```
Angle_X = rad2deg(eul(:,3));
Angle_Y = rad2deg(eul(:,2));
Angle_Z = rad2deg(eul(:,1));

for i = 1:1:size(time_A6)
  %  if(Angle_X(i)<-160)
```

```
  %      Angle_X(i) = Angle_X(i)+180;
  %  end
    if(Angle_Y(i)<-160)
        Angle_Y(i) = Angle_Y(i)+180;
    end
    if(Angle_Z(i)<-160)
        Angle_Z(i) = Angle_Z(i)+180;
    end
end
```

Figures

```
figure(5)
subplot(3,1,1)
%A = rad2deg(eul(:,3));
plot(time_A6,Angle_X)
title('Euler X: Pitch Angle');xlabel('Time/s');ylabel('Angle/degree')


subplot(3,1,2)
plot(time_A6,Angle_Y)
title('Euler Y: Yaw Angle');xlabel('Time/s');ylabel('Angle/degree')

subplot(3,1,3)
%A = rad2deg(eul(:,1));
plot(time_A6,Angle_Z)
title('Euler Z: Roll Angle');xlabel('Time/s');ylabel('Angle/degree')
```

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```
%function [imu1 imu2]=sort_twoIMUs(data)

    %data = table2array(readtable('/Users/zlin/Desktop/2021-06-28 middle ear
 exploration fellow.csv'));
    data = table2array(readtable('/Users/zlin/Desktop/2021-06-21 revision
 tympanomastoidectomy fellow.csv'));

    imu1 = data(1,:);
    imu2 = data(6,:);
    sizeofdata = size(data);
    index = 2;
    while (index < sizeofdata(1))
        sizeimu1 = size(imu1);
        sizeimu2 = size(imu2);
        if (imu1(sizeimu1(1),3) == (data(index,3)-1)) && (imu2(sizeimu2(1),3)
 == (data(index,3)-1))
            e1 = sqrt((data(index,13)- imu1(sizeimu1(1),13))^2
 + (data(index,14)- imu1(sizeimu1(1),14))^2 + (data(index,15)-
 imu1(sizeimu1(1),15))^2);
            e2 = sqrt((data(index,13)- imu2(sizeimu2(1),13))^2
 + (data(index,14)- imu2(sizeimu2(1),14))^2 + (data(index,15)-
 imu2(sizeimu2(1),15))^2);
            if e1 < e2
                imu1 = [imu1(:,:);data(index,:)];
            elseif  e1 > e2
                imu2 = [imu2(:,:);data(index,:)];
            end
        elseif (imu1(sizeimu1(1),3) == data(index,3)-1)
           imu1 = [imu1(:,:);data(index,:)];
        elseif (imu2(sizeimu2(1),3) == data(index,3)-1)
           imu2 = [imu2(:,:);data(index,:)];
        end
        index = index + 1;
    end
    imu2(:,1) = 2;
    writematrix(imu1,'IMU1.csv');
    writematrix(imu2,'IMU2.csv')
%end
```

```
Error using readtable (line 498)
Unable to find or open '/Users/zlin/Desktop/2021-06-21 revision
 tympanomastoidectomy fellow.csv'. Check the path and filename or file
 permissions.

Error in sort_twoIMUs (line 5)
    data = table2array(readtable('/Users/zlin/Desktop/2021-06-21 revision
 tympanomastoidectomy fellow.csv'));
```

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