Tremor Reduction Assessment in Microlaryngeal Surgery

CIS II Spring 2020
Project Final Report
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I. Background

Microlaryngeal surgeries are surgical procedures performed to better maintain, restore, or enhance the human voice. Imprecise surgery (i.e. with hand tremor) can lead to suboptimal voice outcomes. Current treatments that are available cannot effectively restore scarred vocal folds. Therefore, it is extremely important for surgeons to avoid scarring in the first place by performing surgery with the highest precision possible. However, as it can be seen in figure 1(a), with instruments as long as 25cm going down the throat and laryngoscope to perform procedures on the vocal cords which are 1.25-1.7cm long for females and 1.75-2.5cm for males, it is difficult to maintain a completely steady hand. Thus, steady-hand robots such as the Galen Robot (shown in figure 1(b)) have been developed. Previous studies using JHU REMS robot and Galen Robot for "Operation Game" on phantom, Microsurgical anastomosis, and Laryngeal surgery have shown that the effects of hand tremor are eliminated when these robotic systems were used. However, quantitative assessment of tremor reduction is necessary in order to objectively compare the performance in free-hand surgery and robot-assisted surgery. With recently improved surgical microscope and video capture capability, we are able to collect higher quality videos which will allow more accurate tremor reduction assessment.

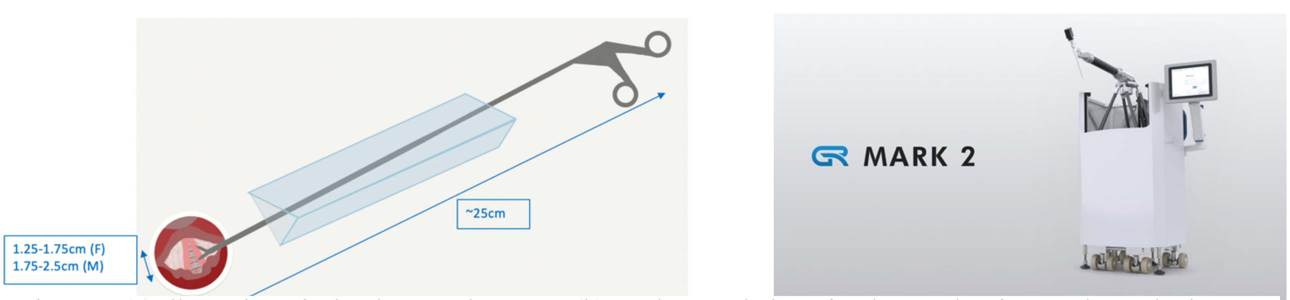


Figure 1: (a) Illustration of microlaryngeal surgery, (b) Product rendering of Galen Mark 2 from Galen Robotics Inc. Retrieved from https://www.artstation.com/artwork/W286BX

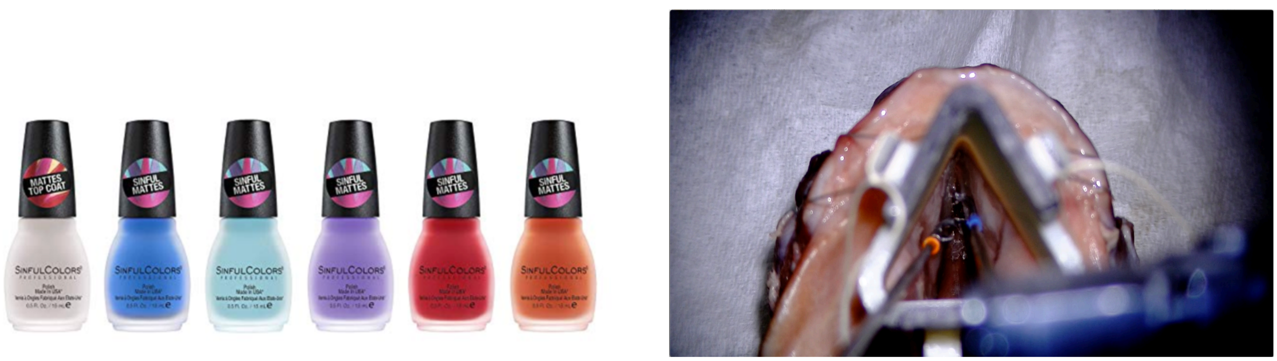
II. Project Goal

The goal of this project is to perform user study to assess the degree of tremor reduction in robotic microlaryngeal surgical procedures on cadaveric phantoms. The three specific aims are: 1) develop/adapt surgical tool tracking software using microscope video (with colored instruments), 2) conduct user study & reduce data, 3) write paper with surgeons. To meet the established aims, there are four main components in this project: experimental apparatus, user study, surgical tool tracking software, and data analysis (tremor reduction assessment).

III. Technical Approach

A. Experimental Apparatus

The instruments used in the microscope recordings were painted with easily distinguishable colored nail polish (shown in figure 1(a)), which makes tracking much easier than having marker-less instruments. Figure 1(b) shows an example frame with the colored instruments.



(a) (b)

Figure 2: (a) Nail polish used for coloring instruments. Image from: https://www.amazon.com/gp/product/B07NLL1G6W/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1 , (b) example frame showing colored instruments

B. User Study

Three surgeons participated in the user study. Short videos were recorded while the participants performed certain tasks such as retraction and cordotomy. A total of 19 videos (10 without pig cadavers and 9 with pig cadavers) were acquired. The Galen Robot was used in 9 out of these 19 videos. Specific information on each of the videos is shown in figure 3.

	A	B	C	D	E	F	G	H
1	path	filename	pig cadaver (o/x)	**left** (R/FH)	color	**right** (R/FH)	color	length (s)
2	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	DeepaTest01A.mov	x	FH	green	FH	blue	62
3	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	DeepaTest01B.mov	x	FH	green	FH	purple	19
4	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	DeepaTest02.mov	x	FH	blue	R	green	102
5	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	DeepaTest03A.mov	x	FH	purple	R	blue	53
6	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	DeepaTest03B.mov	x	FH	green	R	blue	35
7	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	DeepaTest04.mov	o	FH	orange	R	blue	170
8	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	DeepaTest05.mov	o	FH	orange	FH	green	61
9	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	DeepaTest06.mov	o	FH	green	R	blue	189
10	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	DeepaTest07.mov	o	FH	red	R	green	68
11	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	DeepaTest08.mov	o	FH	orange	R	blue	72
12	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	IoanTest01.mov	o	FH	green	R	blue	113
13	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	IoanTest02.mov	o	FH	green	R	green	62
14	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	IoanTest03.mov	o	FH	green	FH	green	28
15	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	Microscope_A.mov	x	FH	purple	FH	green	41
16	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	Microscope_B_1.mov	x	FH	purple	FH	green	35
17	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	Microscope_B_2.mov	x	FH	blue	FH	green	21
18	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	Microscope_B_3.mov	x	FH	purple	FH	blue	12
19	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	Microscope_B_4.mov	x	FH	green	FH	blue	7
20	/Users/suemincho/Research/Laryngeal_Tremor_Analysis/Spring2020/CIS2/Microscope_Videos	PeteTest02.mov	o	FH	red	FH	green	83

Figure 3: Data acquired from the user study

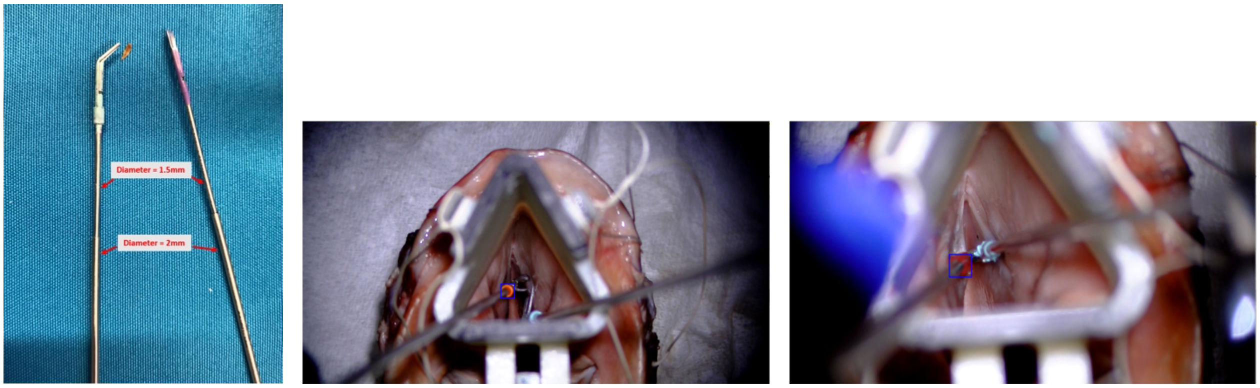
C. Surgical Tool Tracking Software

The performance of 7 different OpenCV trackers (CSRT, KCF, BOOSTING, MIL, TLD, MEDIANFLOW, MOSSE) in tracking colored surgical instruments were compared. The known strengths and weaknesses as well as the performance in microscope videos are shown in table 1. Based on the performance results, the CSRT (Discriminative Correlation Filter (with Channel and Spatial Reliability)) tracker was selected to be used for acquiring the surgical tool tracking data for this project. The code for implementing the OpenCV trackers was adapted and modified from https://www.pyimagesearch.com/2018/07/30/opencv-object-tracking/.

The frame number, midpoint of bounding box x coordinate, midpoint of bounding box y coordinate, left top corner of bounding box x coordinate, left top corner of bounding box y coordinate, width of bounding box, and height of bounding box were recording in the output csv file.

Tracking Algorithm	**CSRT** (Discriminative Correlation Filter (with Channel and Spatial Reliability))	**KCF** (Kernelized Correlation Filters)	**BOOSTING**	**MIL** (Multiple Instance Learning)	**TLD** (Tracking, learning and detection)	**MEDIANFLOW**	**MOSSE** (Minimum Output Sum of Squared Error)
Pros	- higher object tracking accuracy	- decent accuracy and speed	none	- better than BOOSTING - reasonable job under partial occlusion	- works the best under occlusion over multiple frames - tracks best over scale changes	- excellent tracking failure reporting - works well when motion is predictable and there is no occlusion	- very very fast
Cons	- slower fps throughput	- does not recover from full occlusion	- mediocre tracking performance - does not reliably know when tracking has failed	- does not report tracking failure reliably - does not recover from full occlusion	- too many false positives	- fails under large motion	- not as accurate - Reports failures well - model fails when there is too large of a jump in motion
Performance in Microscope Video	Best	Tracking fails for more than half of video	Not too bad	Slow and inaccurate	Very slow and very inaccurate	Only good when there is no light change or fast movement	Fast but loses tracking for about half of video

Table 1: Comparison of Different OpenCV Trackers



(a) (b) (c)

Figure 4: (a) picture of instruments with their measured diameters, (b) example frame with lower zoon, (c) example frame with higher zoom

Some approximations had to be made for pixel-to-mm unit conversion in the tracking data. In figure 4(a), OpenCV was used to measure the pixel-wise diameter for the known diameters (in mm). The 1.5mm and 2.0mm diameters were measured to be 18 pixels and 24 pixels respectively. The thickest colored part of the instrument is the region that is tracked and is calculated to be approximately 2.667mm. Because the level of zoom is different for each video (as can be seen in figure (b) and (c)), the pixel size of the selected initial ROI is measured and used for the pixel-to-mm unit conversion in the beginning of the tracking data acquisition.

D. Data Analysis

1. Economy of Motion Analysis

For the economy of motion analysis, the x and y trajectories of the tracking data, and the path of the instrument were plotted. With the x and y trajectories, the displacements of the x and y trajectories were calculated and plotted. Then, the first derivative, velocity, the second derivative, acceleration, and the third derivative, jerk were calculated and plotted as well. The total distances of the x and y trajectories were calculated to calculate the average instrument speed in the x and y directions.

The total Euclidean distance of the instrument path (example of instrument path shown in figure 5) was calculated by summing the Euclidean distance of all the consecutive points in the path. Then the instrument average speed was calculated by dividing the total Euclidean distance by the total time the instrument was tracked.

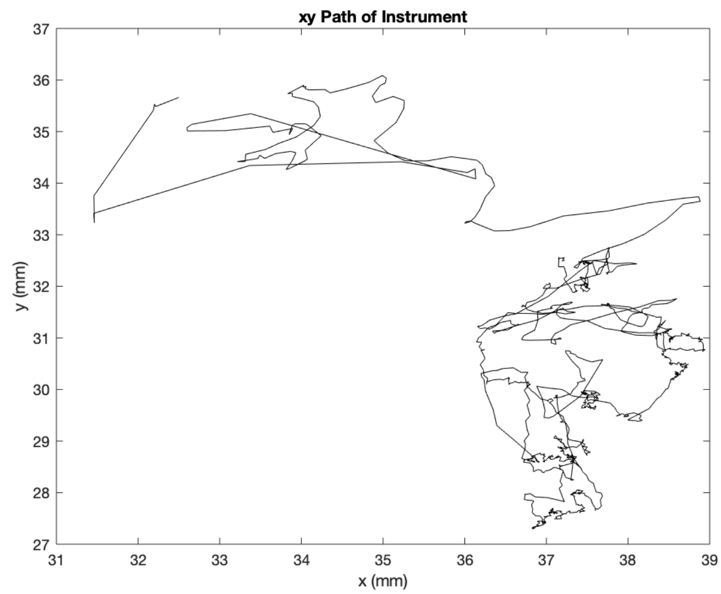


Figure 5: Tracked path of instrument

$$Euclidean\ Distance = \sqrt{\left(x(i+1) - x(i)\right)^2 + \left(y(i+1) - y(i)\right)^2}$$

$$Instrument\ Average\ Speed = \frac{Total\ Euclidean\ Distance\ of\ Instrument\ Path}{Total\ Time}$$

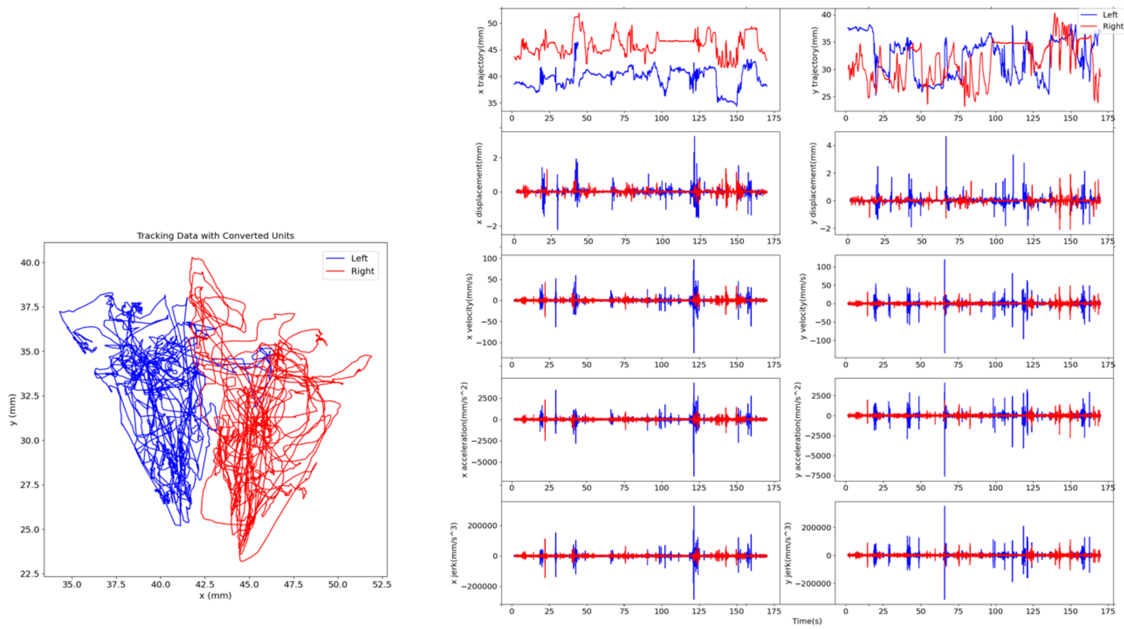
2. Frequency Analysis

For the frequency analysis, the x and y trajectories were analyzed. The trajectories were divided into significantly long continuous sections. The pwelch function in MATLAB was used for each section to return its power spectral density estimate. Then the average of these outputs was calculated and plotted.

IV. Results

A. Economy of Motion Analysis

Figure 6 shows the results of one microscope recording where a pig cadaver was used. The left (freehand) instrument data is in blue and the right (robot) instrument data is in red.



(a) (b)

Figure 6: (a) Tracked paths of both instruments (b) x, y trajectory, displacement, velocity, acceleration, and jerk of both instruments

Table 2 shows the results of robot and freehand instrument mean x, y average speed. The robot was always used in the right side, so the mean for the cases where the right instrument was freehand and the mean for all the cases where either left or right instrument was freehand were calculated separately.

	Robot	Freehand (only right)	Freehand (all)
	Mean ± SD		
x Speed (mm/s)	1.544 ± 0.55	2.837 ± 0.35	2.008 ± 0.71
y Speed (mm/s)	2.085 ± 0.80	3.103 ± 0.50	2.041 ± 0.80

Table 2: Results of robot and freehand instrument mean x, y average speed

	Robot	Freehand (only right)	Freehand (all)
	Mean ± SD		
Instrument Speed (mm/s)	**2.313 ± 0.80**	4.606 ± 0.66	3.090 ± 1.11

Table 3: Results of robot and freehand mean average instrument speed

Table 3 shows the results of robot and freehand mean average instrument speed. Like the instrument mean x, y average speed results, the mean for the cases where the right instrument was freehand and the mean for all the cases where either left or right instrument was freehand were calculated separately.

B. Frequency Analysis

Figure 7 shows an example result of the power spectral density of average sections of the instrument x and y trajectories. The left two plots show the results of the left instrument, which in this case was freehand, and the right two plots show the results of the right instruments, where the robot was used.

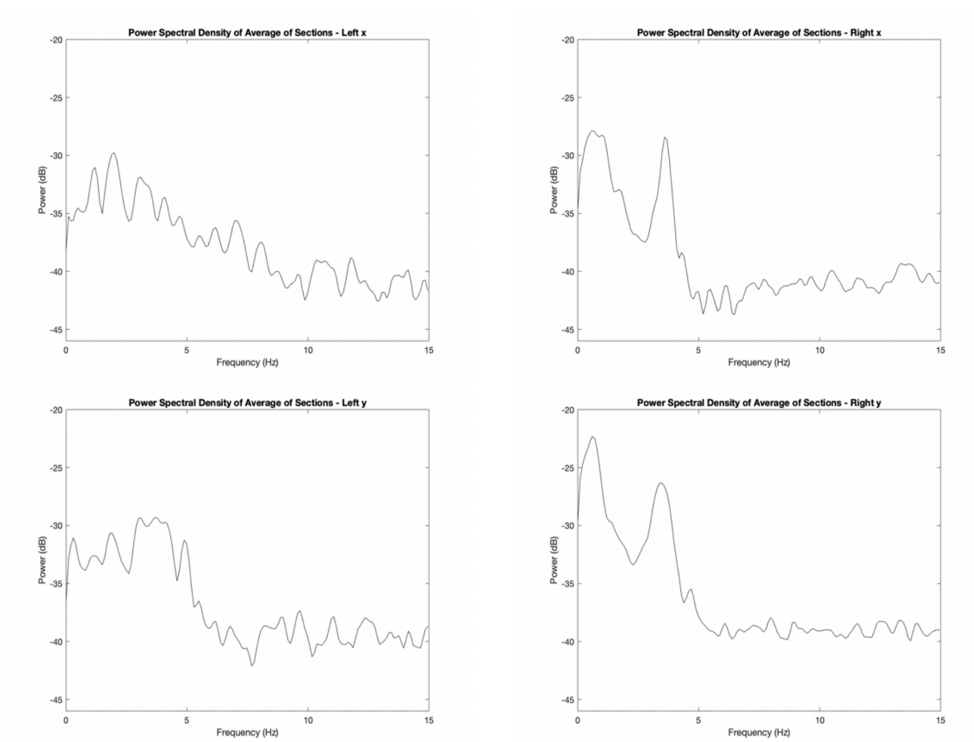


Figure 7: Example result of the power spectral density of average of sections of instrument x and y trajectories

In order to see the differences in the power of frequencies in range of tremor, a bandpass filter that passed the frequencies in between 5 and 14Hz was applied to the x and y trajectories. Figure 8 shows an example of the result of the power spectral density of instrument x and y trajectories. The left two plots are the results from the left (freehand) instrument, and the right two plots are results from the right (robot) instrument.

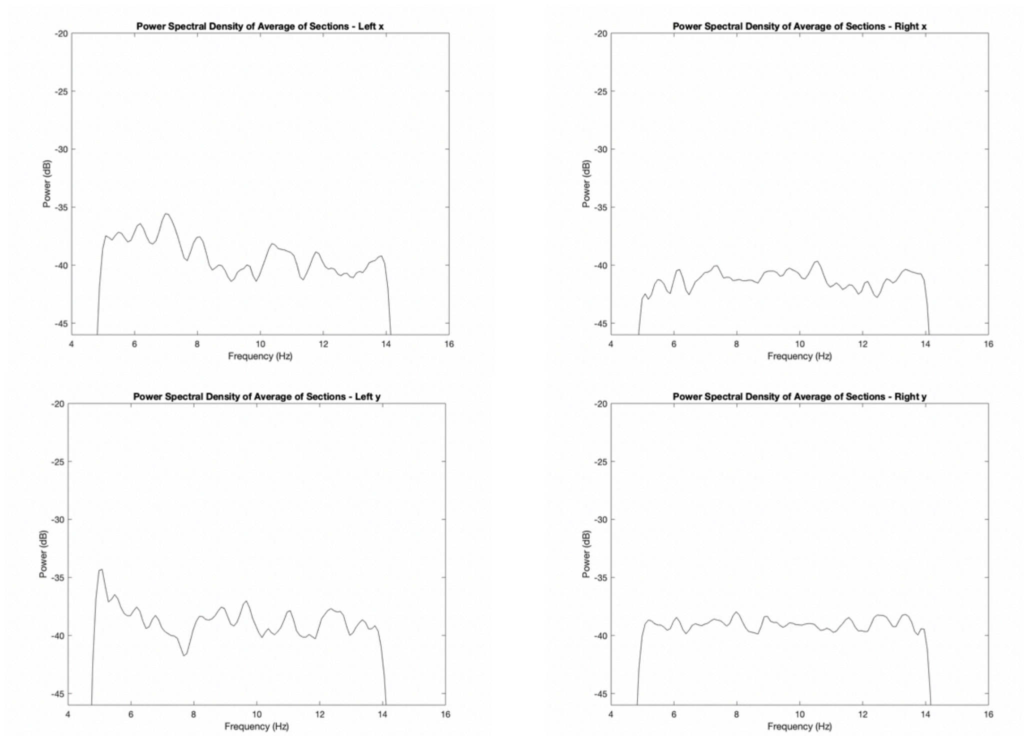


Figure 8: Example result of the power spectral density of instrument x and y trajectories after a bandpass filter was applied

V. Discussion and Conclusion

In this project, 1) a surgical tool tracking software was adapted which facilitated the acquisition of instrument tracking data, 2) a user study was conducted and experimental data was reduced which provided meaningful data for analysis, and 3) the acquired tracking data was analyzed which provided quantitative assessment results of tremor reduction in robotic microsurgical procedures.

The results of the economy of motion analysis show that using the robot generally reduces the effects of tremor. This is shown qualitatively in the plots of the x, y trajectories, displacement, velocity, acceleration, and jerk. It can be seen that the right (robot) instrument plots have fewer and smaller peaks compared to the left (freehand) plots. Also, the average of the mean x, y speeds of the instruments were calculated and compared. The robot has a lower mean average speed in the x-direction than both freehand (right only) and freehand (all) results. It also has a lower mean average speed in the y-direction than freehand (only right) but a higher mean average speed than freehand (all). The comparison of the mean average instrument speed shows that the robot has a lower average speed compared to both freehand (right only) and freehand (all) results.

However, the significance of these results is inconclusive, because the tasks that the instruments are performing are not taken into consideration. For instance, an instrument that is retracting will not have as much movement overall compared to one that is performing a cordotomy. Thus, having an annotation of the tasks being performed and analyzing based on task category will likely allow more accurate and significant results. For future study, further analysis in consideration of the annotations will be performed, and future user studies will be conducted in a more task-oriented systematic manner. Furthermore, considering the possibility of tremor being affected by gravity, movements in the z-direction will be analyzed by using stereo vision in the microscope recordings.

More quantitative assessments of the economy of motion analysis plots will be crucial in objectively comparing the results of freehand and robotic surgery. In a future study, a scoring method will be developed to give a score for acceleration, jerk, and also snap, which is the 4th derivative of displacement. Also, currently, it is difficult to know how the instrument is moving or the tracker is moving in which sections of the plots. It would be useful to develop a program that can visualize the tracking on the video and the corresponding location on the plots.

In the frequency analysis, the robot result shows a lower power than the freehand result in the frequency range of 5-7 Hz. The frequency range of hand or instrument tremor is reported differently in numerous studies. Thus, it will be informative to know the benchmark frequency range for instrument tremor in microlaryngeal surgery. For future study, the out-of-larynx (resting) tremor and in-larynx (performing procedure) tremor will be analyzed and use the results as a benchmark.

VI. Acknowledgements

Thank you, Professor Taylor, Balazs, Dr. Galaiya, Dr. Creighton, and Dr. Lina for your help throughout the project. With your help I was able to successfully finish my project without any major difficulties. Thank you, Professor Taylor, Dr. Galaiya, Dr. Creighton for your weekly feedback, thank you Balazs for the computer vision consultations, and thank you all for conducting the user study.

VII. Management Summary

A. Who did what?

As a one-person team, I did all of the technical work. A shortened version of the user study had to be conducted by my mentors due to the abrupt Covid-19 situation. Throughout the semester, I participated in weekly meetings and consulted with my mentors as needed.

B. Accomplished versus planned

The following table shows the deliverables for this project. I have accomplished all the minimum and expected deliverables that were planned. The maximum deliverable, which is the academic paper with surgeons, has not been completed, but it will be met by this summer.

Deliverables		**Date**	**Status**
Minimum	Experimental apparatus	03/15/2020	Met
	Documented code for surgical tool tracking software	03/25/2020	Met
Expected	Experimental data	04/07/2020	Met
	Documented code for tremor reduction assessment	04/07/2020	Delayed → Met
	Report	04/30/2020	Delayed → Met
Maximum	Academic paper	05/13/2020	On schedule

C. Next steps

I am planning on continuing the project in the summer and possibly next semester as well. I will write an academic paper with the surgeons with the results I got from this semester, and another with the results from an additional user study. The future user study will be more systematic with more participants. Also, I would like to develop a live plot and video program to help visualize the tracking on the video and the corresponding location on the economy of motion or frequency analysis plots.

D. Lessons Learned

One of the biggest lessons I learned was the importance of planning. By making a detailed weekly plan as well as thinking of all possible alternative plans, I believe there was not as many difficulties readjusting the project accordingly as there could have been.

VIII. References and Reading List

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IX. Technical Appendices

All of the relevant data, code, and documentation can be found in: https://drive.google.com/drive/folders/1_AckNOvGALFraMEArR5Kzc85FjVJfQZM?usp=sharing