JOHNS HOPKINS
UNIVERSITY

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

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Background

- Ear Surgery
  - Microscopic: looking through microscopes & standing over patient
  - Open surgery: looking down while operating
  - Endoscopic: looking straightforward at a monitor

Pictures from:
https://oklahoman.com/gallery/articleid/3808606/

http://amandeepmedicity.org/specialities/bariatric-metabolic-surgery

http://www.tristonekidneyhospital.com/index.html

Significance

- Poor surgical ergonomics may lead surgeon disability
  - –2/3 of surgeons reported neck discomfort related to their occupation[1]
  - –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]:
  - Head moves forward → shifting the center of gravity → upper body drifts backward → hips tilt forward
  - Hence, FHP can not only cause neck pain but can also be a root cause of mid/lower back pain.

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

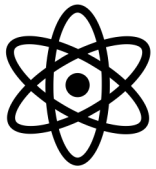
Goals

- Accurate Measurement of Neck Flexion Angle during Ear Surgery by using IMUs (Inertial measurement unit)
- Investigate and Compare Postural Ergonomics of Ear Surgeons during Microscopic and Endoscopic Scenarios.

Technical Approach

Calibrate IMUs
with EM trackers

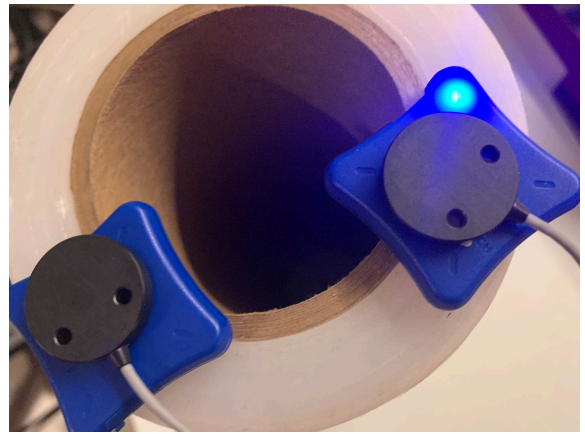
Setup Software
Environment



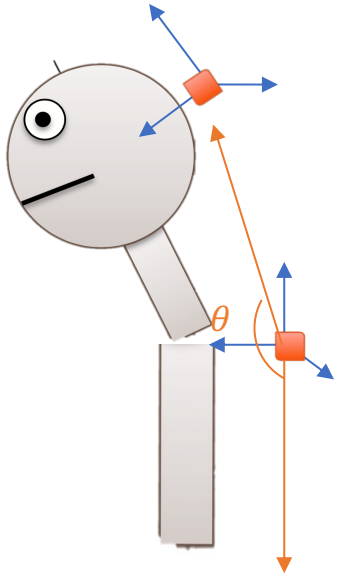
Derive Physical
Models

System: Linux & ROS
Package: lpms-imu;
ndi_tracker_ros

IMU: Inertial measurement unit
3-axis gyroscope
3-axis accelerometer
3-axis magnetometer



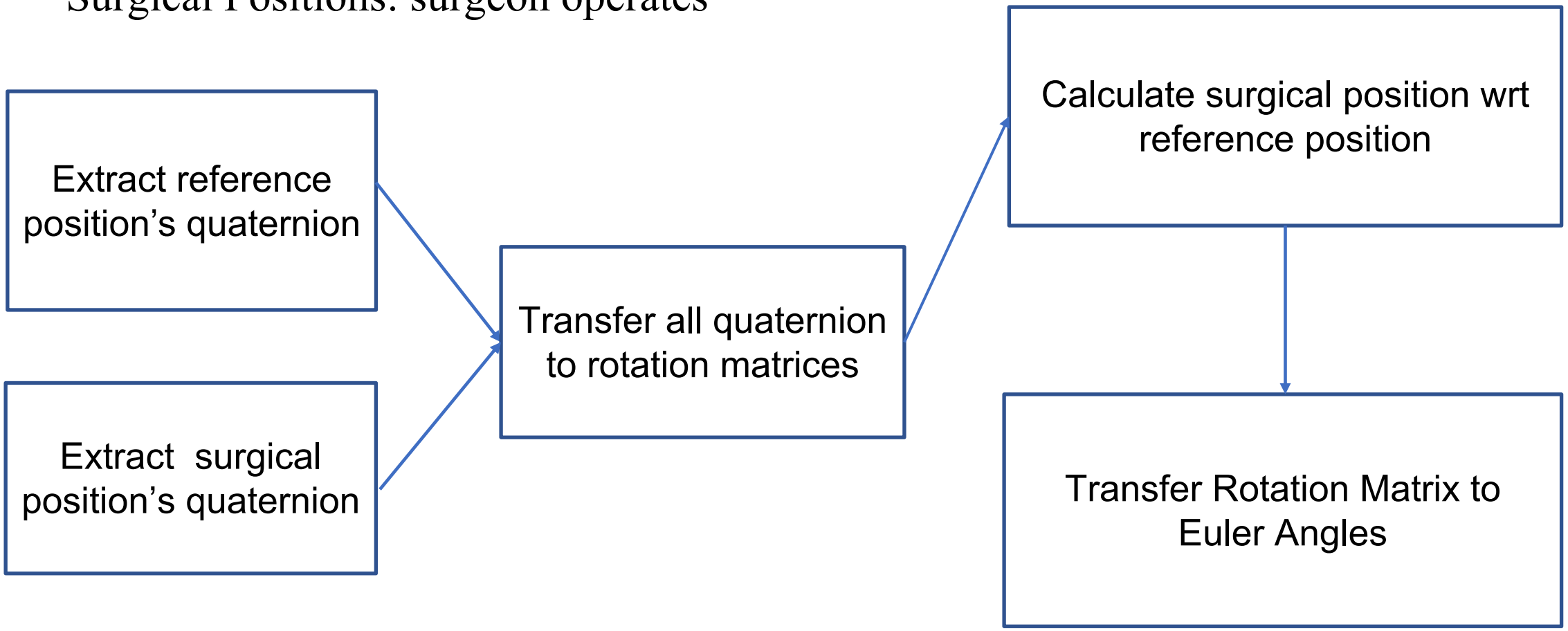
EM tracker: Electromagnetic tracker
-- External ground truth system



Right Lower Figure Edit from: https://stanford.edu/class/ee267/lectures/lecture10.pdf

Neck Flexion Angle Model

Reference Position: surgeon stands and stays unmoved
Surgical Positions: surgeon operates

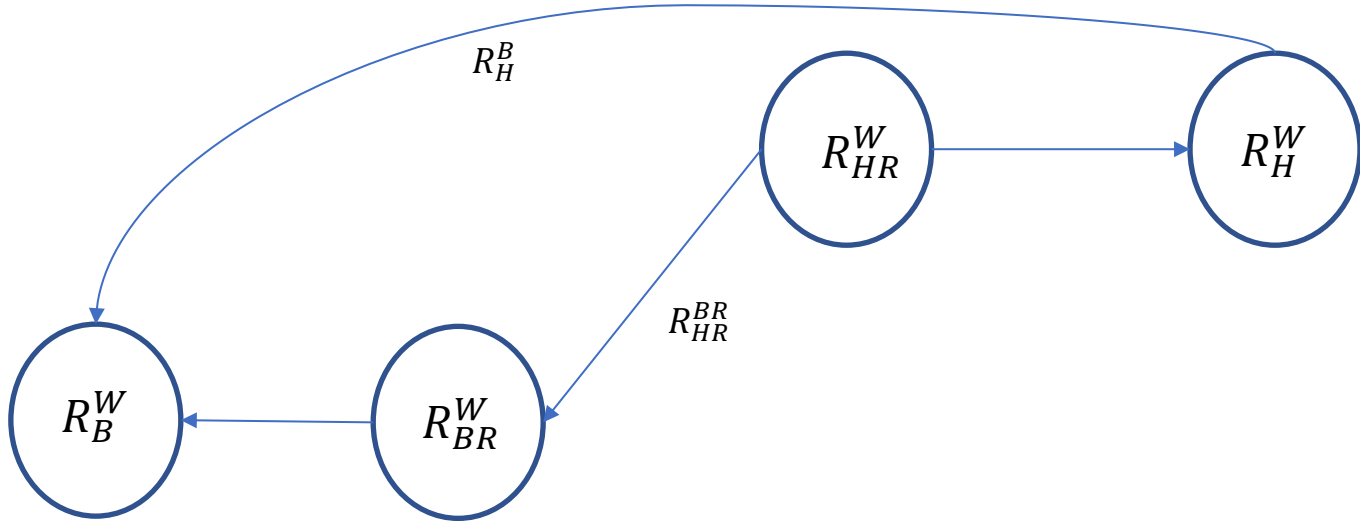


The mathematical formula

Superscript: the coordinate system that are w.r.t.

- $\boldsymbol{R_{BR}^{W}}$: 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 surgical position w. r. t. **W**orld's coordinate system.
- $\boldsymbol{R_{H}^{W}}$: The **H**ead IMU's rotation matrix in surgical position w. r. t. **W**orld's coordinate system.



Calculation Process:

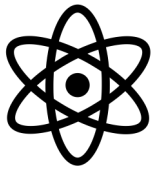
- In **R**eference position: the **H**ead IMU w. r. t. the **B**ack IMU : $\boldsymbol{R_{HR}^{BR}} = R_W^{BR} \cdot R_{HR}^W = (\boldsymbol{R_{BR}^{W}})^{-1} \cdot \boldsymbol{R_{HR}^{W}}$
- In surgical position: the **H**ead IMU w. r. t. the **B**ack IMU : $\boldsymbol{R_{H}^{B}} = R_W^B \cdot R_H^W = (\boldsymbol{R_{B}^{W}})^{-1} \cdot \boldsymbol{R_{H}^{W}}$

- **Surgical position w. r. t. reference position:** $\boldsymbol{R_{final}} = (\boldsymbol{R_{HR}^{BR}})^{-1} \cdot \boldsymbol{R_{H}^{B}} = \left(\boldsymbol{R_{HR}^{W}}\right)^{-1} \cdot \boldsymbol{R_{BR}^{W}} \cdot (\boldsymbol{R_{B}^{W}})^{-1} \cdot \boldsymbol{R_{H}^{W}}$

Technical Approach

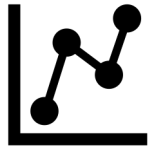
Calibrate IMUs with EM trackers

Setup Software Environment

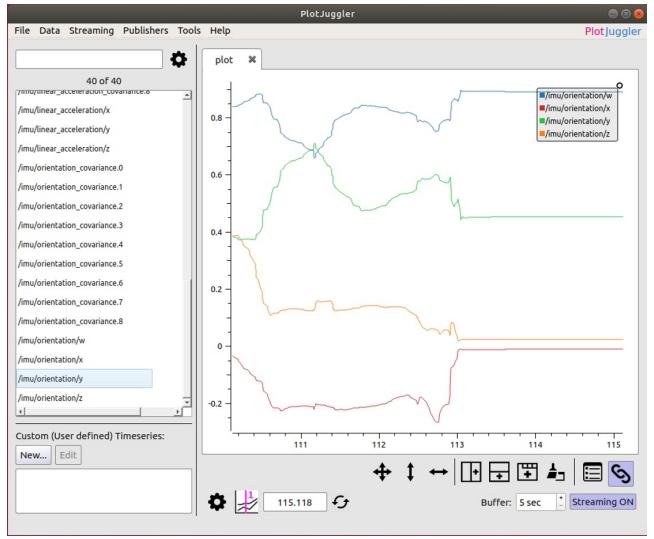


Derive Physical Models

Collect Data from Mock Surgery



Analyze Angles and Changes



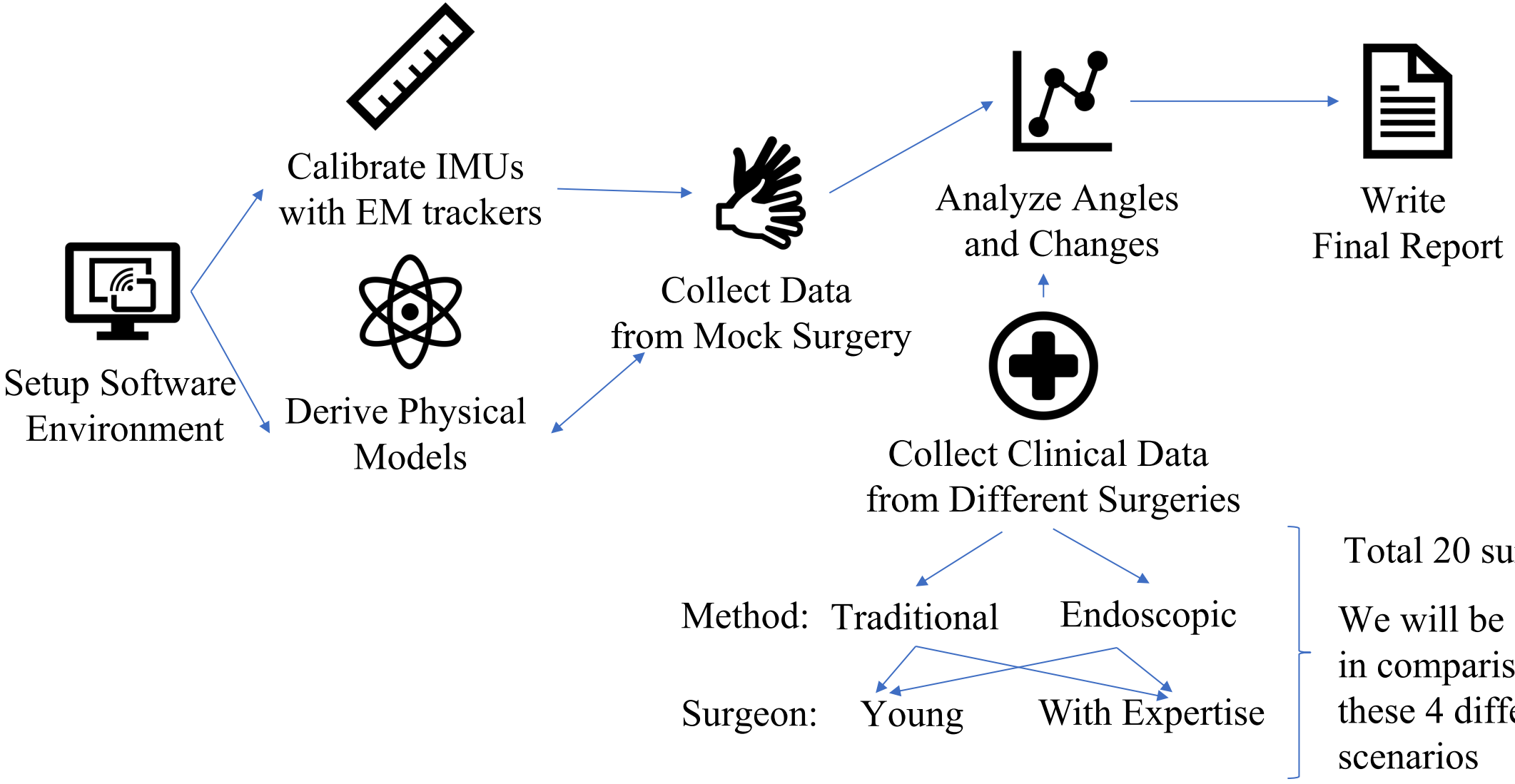
Data stores in rosbag file, and analyze using MATLAB

1. Signal processing, like Kalman filter, if needed
2. Calculate neck flexion angle from mathematical model

We will be interested in such data:

1. The largest angle, lowest angle, and average angle
2. Length of time when neck angle greater than 30°

Technical Approach



Deliverables

- Minimum:
  - Evaluation of the existing calibration steps, physical model
  - Data analysis report of surgical data collected from previous semester
  - Data analysis report of Mock OR experiment

- Expected:
  - Improvement to signal processing of measurement obtained from IMUs
  - Data analysis report of real surgical scenarios

- Maximum:
  - Clinical paper

Time schedule

	Feb,7 - Feb,13	Feb,14- Feb, 22	Feb,23- Mar, 2	Mar,3- Mar,11	Mar,12- Mar,20	Mar,21- Mar,27	Mar,28- Apr,3	Apr,4 - Apr,10	Apr,11- Apr,17	Apr,18- Apr,24	Apr,25- May,1	May,1- May,5
Set up the computer and document installation steps	✅	✅										
Evaluation of calibration and mathematical model of neck angle		✅	✅									
First measurement in Mock OR & First data analysis				☑								
Data analysis of existing measurement in real surgery scenarios				☑	☑	☑						
Collect mock surgery data from eggshell drilling experiments					☑	☑	☑					
Data analysis of mock surgery measurement						☑	☑	☑				
Data analysis of new measurement in real surgery scenarios						☑	☑	☑	☑			
Overall analysis and documentation of the difference between microscopic and endoscopic scenarios								☑	☑	☑		
Write clinical paper										☑	☑	☑

✅ : Finished ☑ : Planned

Milestones

Date	Detailed Description
February, 22	Linux and ROS environment configuration finished
March, 2	Evaluation of IMU calibration and mathematic model finished
March, 11	First measure in Mock OR and analysis of the data finished
March, 27	Data Analysis of existing surgical measurement finished
Apr 3	Collect Mock OR measurement from eggshell drilling experiment finished
Apr 10	Data Analysis of Mock OR measurement from eggshell drilling experiment finished
April, 17	Data Analysis of new surgical measurement among various surgery scenarios finished
April, 24	Documentation of data collection and data analysis finished
May, 4	Clinical paper finished

Dependencies

Dependencies	How to resolve	Alternative Plan	Date Expected	Date Needed
Computer with Linux & ROS	1. Our own computers for calibration 2. Another computer from CIIS lab	Use backup files in another computer	1. Feb, 14 2. Mar, 6	1. Feb, 19th (Solved) 2. Feb, 22th (Solved)
Two IMUs	Provided by Dr. Deepa Galaiya	Purchase two new IMUs	Feb, 7	Feb, 7 (Solved)
Eggshell drilling experiment data	Dr. Galaiya performs mock surgery in Mock OR	Assisted by other graduate students	Mar, 12	Mar, 21 (Not started)
Actual surgery data	Get data from Samuel who is responsible for collecting actual surgery data in medical school	Do all the measurement in Mock OR	Mar, 3	Mar, 21 (Not started)
MATLAB for data analysis Dropbox for data saving	Installation	Python Google drive	Mar, 1	Mar, 1 (Solved)

Project Management

- Attend the group meeting with Dr. Taylor weekly
- Regular weekly meeting with Dr. Deepa Galaiya
- Maintain communication via Email
- Documentation and code update in OneDrive folder

Reading List

- 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 diltering 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 Otolaryngol*. 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

Back up Slides

Calibration Method – Pitch angle calculation

- Average rotation of the elements of quaternions by using *meanrot* function in MATLAB
- Calculate flexion angle mathematically by using two quaternions
  - q_1: reference q_2: one of the eight different pitch angle samples
  - $Flexion\ angle = 2 * \text{atan}\,2(||q_1^* q_2(x,y,z)||, q_1^* q_2(w)) * \frac{\pi}{180}(degree)$

Flexion angle from EM tracker (degree)	Flexion angle from IMU 1A (degree)	Flexion angle from IMU A6 (degree)
26.6346	27.6527	27.6778
32.6116	33.3907	33.4102
37.8730	38.5087	38.4184
42.1996	42.6490	42.52
45.7238	46.0262	45.8209
48.4941	48.6611	48.4686
50.2905	50.4428	50.2339
52.8936	53.3970	53.1683

The detailed procedure

- Extract the reference position's quaternion and average using *meanrot function* from MATLAB
  - $Q_{head}^{ref}, Q_{back}^{ref}$
- Extract the surgical position's quaternion
  - $Q_{head}^{sur}, Q_{back}^{sur}$
- Transfer all quaternion to rotation matrices using *quat2rotm* function from MATLAB
  - $RM_{head}^{ref}, RM_{back}^{ref}, RM_{head}^{sur}, RM_{back}^{sur}$ which corresponds to *Rh2, Rs1, R2 and R1* in bubble diagram respectively
- Calculate the final rotation matrix using $\text{Rsh} = Rs1 \cdot R1^{-1} \cdot R2 \cdot Rh2^{-1}$
  - $Rsh = RM_{back}^{ref} \cdot (RM_{back}^{sur})^{-1} \cdot RM_{head}^{sur} \cdot (RM_{head}^{ref})^{-1}$
- Transfer rotation matrix Rsh into Euler Angles