Surgical Skills Analysis with Virtual Reality: Project Checkpoint

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Background

- Mastoidectomy Procedures
  - Highly precise surgery
  - Requires drilling of temporal bone
- Temporal Bone Simulators
  - Stereoscopic vision and haptic feedback
  - Automated metrics have limited results
- Objective technical assessment needed for OHNS

Methods/Aims

- Asynchronous Multibody Framework (AMBF)
  - Generate stereoscopic RBG data for training of computer vision algorithms
  - Determine features to be extracted/metrics needed from data collection stream
  - Calculation/validation of feature calculations
- Data collection from practicing surgeons/residents
  - Collect data from both experienced surgeons (attendings) and residents for training
- Generate/validate CNN to evaluate and predict surgical skill
  - Use data collected from AMBF simulator

Updated Deliverables

Minimum	Document/calculate metrics for extraction from data stream
	Update simulation data stream
Expected	Data collection from attending and resident users at JHMI
	Evaluate/document existing algorithms for surgical skill analysis
	Develop CNN for surgical skill analysis
Maximum	Conference Paper

Updated Dependencies

Main Dependencies	Sub Dependencies	Contact	Expected Date	Status	Notes
Dataset	IRB Training	Dr. Danielle Trakimas	02/15	Completed, 02/15	N/A
	Feature extraction from sample data	Max Li, Adnan Munawar	03/28	Completed, 04/09	N/A
	NEW: Validation of extracted features	Max Li, Adnan Munawar	04/04	Ongoing	Will use data already collected by one attending
	Data collection/labeling (attendings, N=6)	Dr Danielle Trakimas	04/11	Not started	Data collection will depend on time needed for validation
	Data collection/labeling (resident trainees, N=8)	Dr. Danielle Trakimas	04/17	Not started	
	Data collection/labeling (fellows, N=8)	Dr. Danielle Trakimas	04/24	Not started	N/A
Hardware	HTC VIVE Headset	Max Li	02/15	Completed, 02/15	N/A
	PHANToM Omni haptic device	Max Li	03/02	Completed, 02/28	Force update integrated
	Computer capable of running simulator	Adnan Munawar	02/15	Completed, 02/15	N/A
Computational Resources	GPU (depends on the algorithm for surgical skills analysis, may not be needed)	Professor Unberath Max Li	03/22	Obtained, 03/01	N/A

Project Timeline/Milestones

- February
  - Project Plan Presentation, formulate technical approach and deliverables
  - Set up simulator on lab computer
- March
  - Literature review of features/documentation of required metrics from data stream
  - Start coding features extraction scripts and incorporate required metrics into data stream
- April
  - Mid April
    - Finish coding/documentation of feature extraction scripts, validate scripts
    - NEW: Incorporate eye tracking for data collection purposes
  - End of April
    - Data collection from attendings, residents, trainees
    - Literature review of existing algorithms for surgical skill analysis, begin design of initial CNN architecture
- May
  - Finalize data collection/labelling, start work on initial CNN

Feature Extraction - Progress

Calculated skill metrics from simulation or video		
Category	Metrics	Description
Drill technique:	Basic kinematics	Distance, speed, acceleration
	Jerk	Time derivative of acceleration, measure of coordination[40]
	Curvature	Measure of change in direction or discrete movement[41]
	Orientation	Angle of drill shaft with respect to plane of bone
	Force*	Force exerted by drill on bone or anatomical structure
	Bur view	%SA of bur in view
	Efficiency	Volume of bone removed per time or distance
Bone removal:	Appropriate removal	Locations of bone with ≥0.83 probability of expert removal
	Inappropriate removal	Locations of bone with ≤0.17 probability of expert removal
	Coverage*	Thickness of bone over anatomical structure
	Exposure	%SA of structure without boney coverage
	Injury	%SA of structure injured or # of instances

Feature Extraction

Currently Have

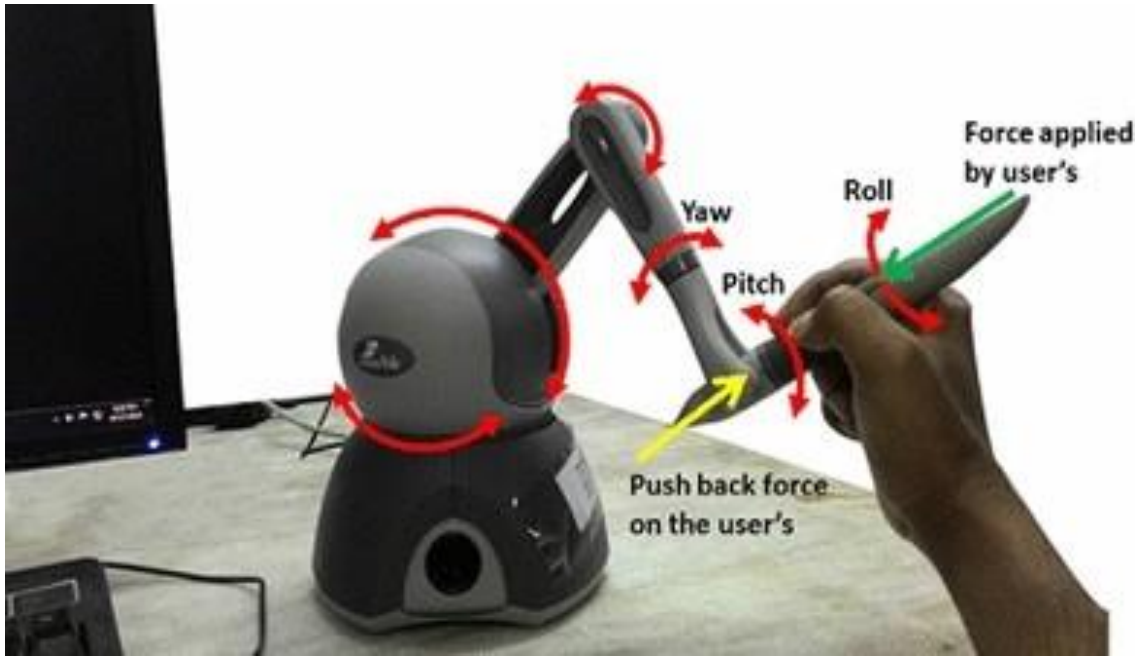
- Positional Data
  - Drill Location
  - Drill Orientation
- Time
- Stereoscopic Images
- Voxels Removed
- Depth Data
- Segmentation Map
- Pose of Volume
- Burr Change

Added/To Be Added

- Force Data (Haptic Feedback from Omni)
- Eye Tracking Data
- Phase Segmentation
  - This must be added manually by an expert after data collection.

Force Publishing

- Phantom Omni provides haptic feedback depending on substance being drilled
- **Approach:**
  - Create force message (geometric_msgs/Wrench)
  - Set up publisher in collision_publisher file
  - Call message in volumetric drilling file to get force data
  - Create subscriber in data_record python file to store data in output hdf5 file

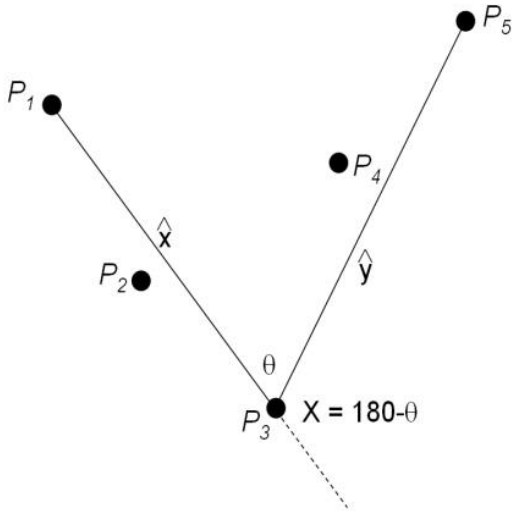


Eye Tracking

- Recommended by Dr. Creighton
- Pupil Labs VR Gaze Tracking Add-On
- Recordings of gaze while using simulator for potential analysis
- **Issues:**
  - VR device driver incompatible with Linux
  - Pupil software cameras not recognized by system
- **Potential Workarounds:** Use Windows for pupil software, port back to Linux when validated

Surgical Stroke Definition

- A set of points defining a continuous drilling motion
- From literature review, use k-cos method
  - Optimal parameter was identified to be k=6
- End of stroke defined as:
  - Abrupt change in direction of trajectory
  - Parameter k used to determine how far back in each direction of the stream to search for the "previous" point.
  - Modified algorithm to have at most one stroke started within each 2k interval.
- Calculate features per stroke as indicators of surgical skill



k-cos

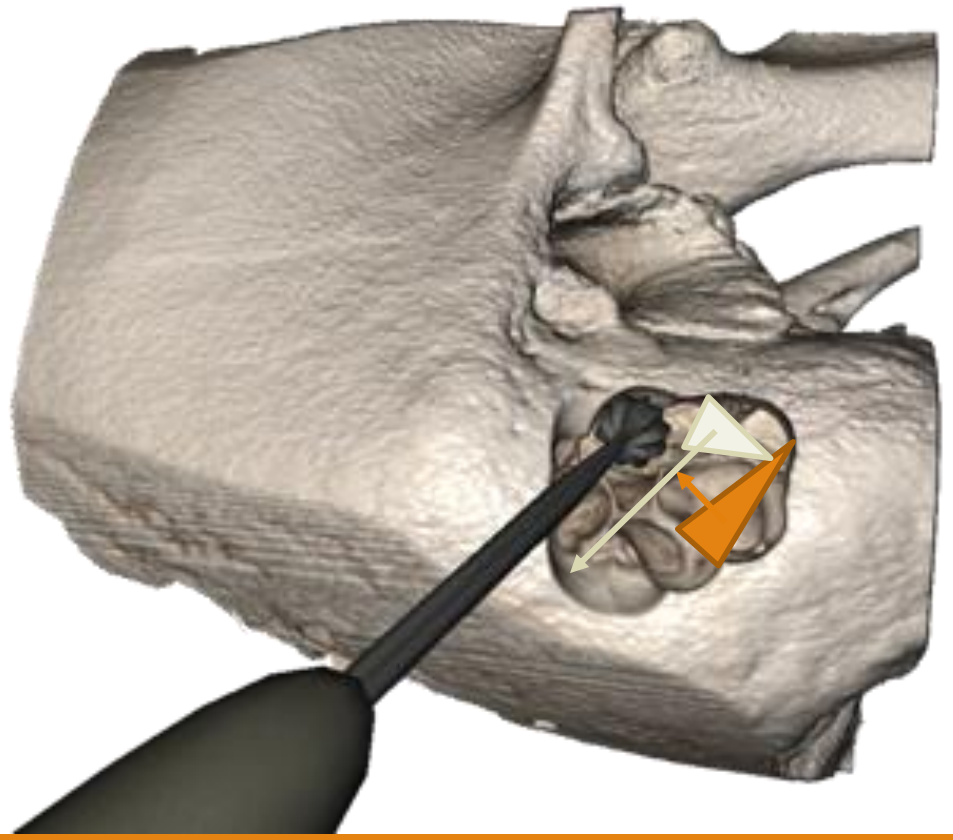
Wijewickrema, S., Piromchai, P., Zhou, Y., Ioannou, I., Bailey, J., Kennedy, G., & O'Leary, S. (2015). Developing effective automated feedback in temporal bone surgery simulation. Otolaryngology–head and neck surgery : official journal of American Academy of Otolaryngology-Head and Neck Surgery, 152(6), 1082–1088.

Velocity, Acceleration, Jerk, Curvature

1. Collect position data of drill
2. Preprocess using 2nd order Butterworth filter and FFT
3. Calculate numerical derivatives of position data
4. Find average value across each stroke
5. Report mean, median, and max values across strokes

$$\kappa(t) = \frac{\|\mathbf{r}'(t) \times \mathbf{r}''(t)\|}{\|\mathbf{r}'(t)\|^3}$$

Drill Orientation



- **Approach:** Find angle between drill and plane of bone at any time using removed bone
  - At timestamp, create vector using position and orientation of drill tip
  - Create plane using any 3 bone voxels removed at the nearest timestamp
  - Find complement of angle between drill vector and normal vector to plane
- **Issues:**
  - Drill tip is spherical, could potentially lead to incorrect angle depending on which voxels are removed
  - High variance in angles extracted

Ongoing Features

- Phase Segmentation
  - Upon the collection of data files from each simulator run, time point representing start of each procedure phase will be labeled manually by Dr. Trakimas

- Removal of Bone
  - Once attending procedure data is obtained, use probability of each voxel's removal from those procedures to represent appropriate and inappropriate removal of bone

Next Steps

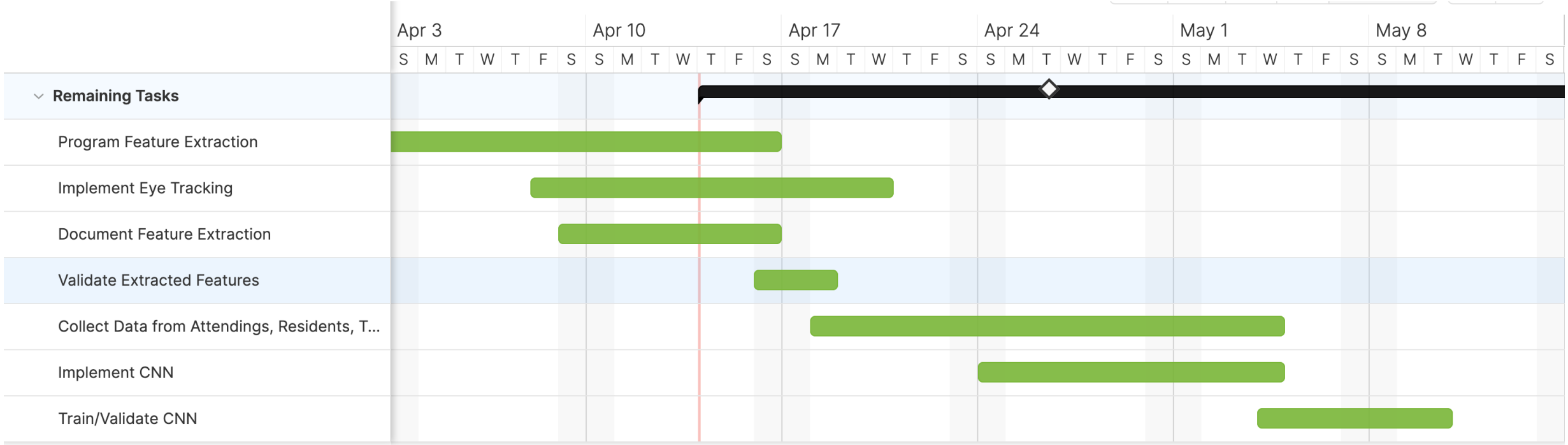
Documentation

- Provide detailed README of feature extraction and model code in a (public) GitHub repository including:
  - Appropriate usage
  - Software/hardware dependencies
  - Intended application
- Write final report detailing:
  - Location of source code
  - Theoretical and technical approaches used
  - Areas for future development

Future Work

- Finish validation of feature scripts
- Implement eye tracking software into simulation data stream
- Collect data from attendings/residents
- Plan initial CNN architecture

Next Steps (cont.)



Reading List

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Azari DP, Frasier LL, Quamme SRP, et al. Modeling surgical technical skill using expert assessment for automated computer rating. Ann Surg. 2019;269(3):574-581. doi:10.1097/SLA.0000000000002478

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