JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Building a Workflow for Cooperatively Controlled Robotic Mandibular Surgery

Group 15: Jesse Haworth

Mentors: Dr. Robin Yang, Dr. Francis Creighton, Dr. Russell Taylor, and Andy Ding

Clinical Motivation

- Mandibular Surgery [1]
  - Used to correct overextended jaw or receding chin
- Surgery involves cutting through the mandible
- The alveolar nerve in the mandible can be damaged during surgery [3]
- Nerve damage can lead to:
  - Numbness of the chin, lower lip, and lower teeth

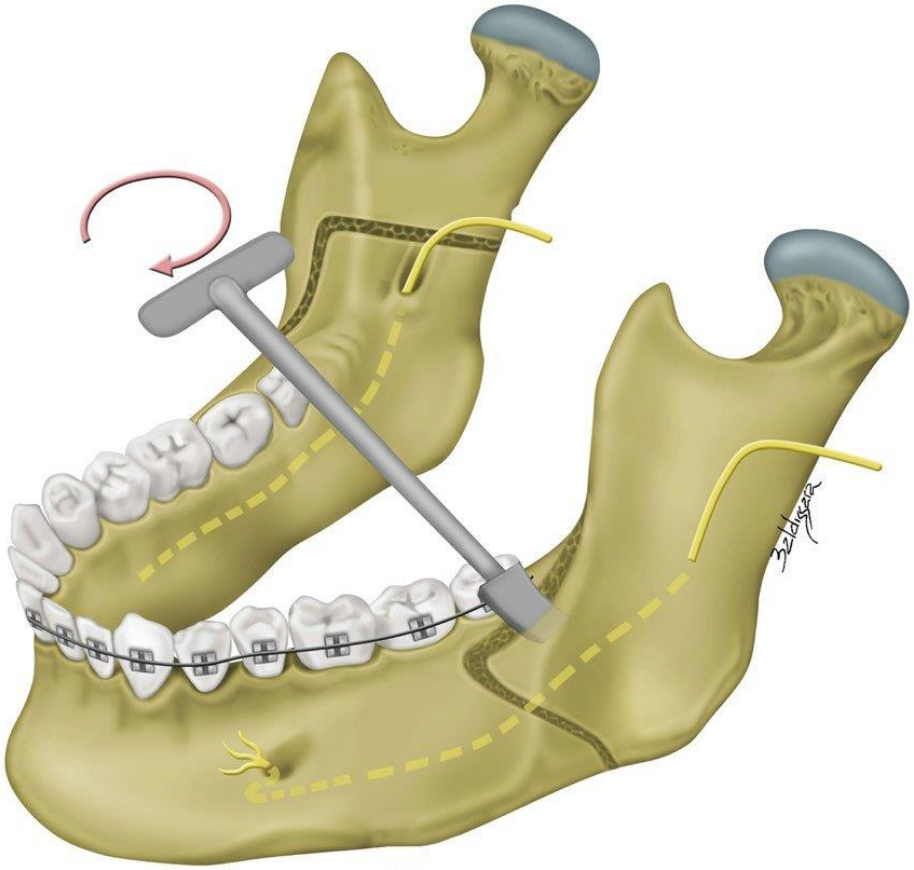
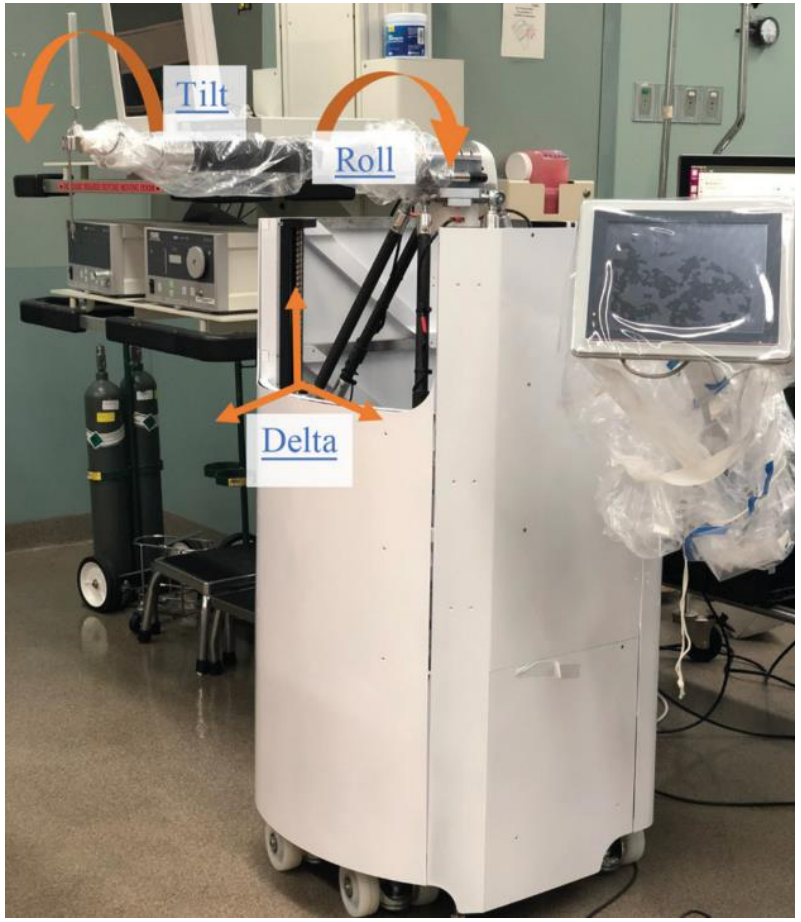


Image: [2]

Clinical Motivation

- Possible Solution: Virtual barriers enforced by a cooperative robot using segmented CT data
  - Reduces risk of facial nerve damage
  - Requires segmented CT data of the patient



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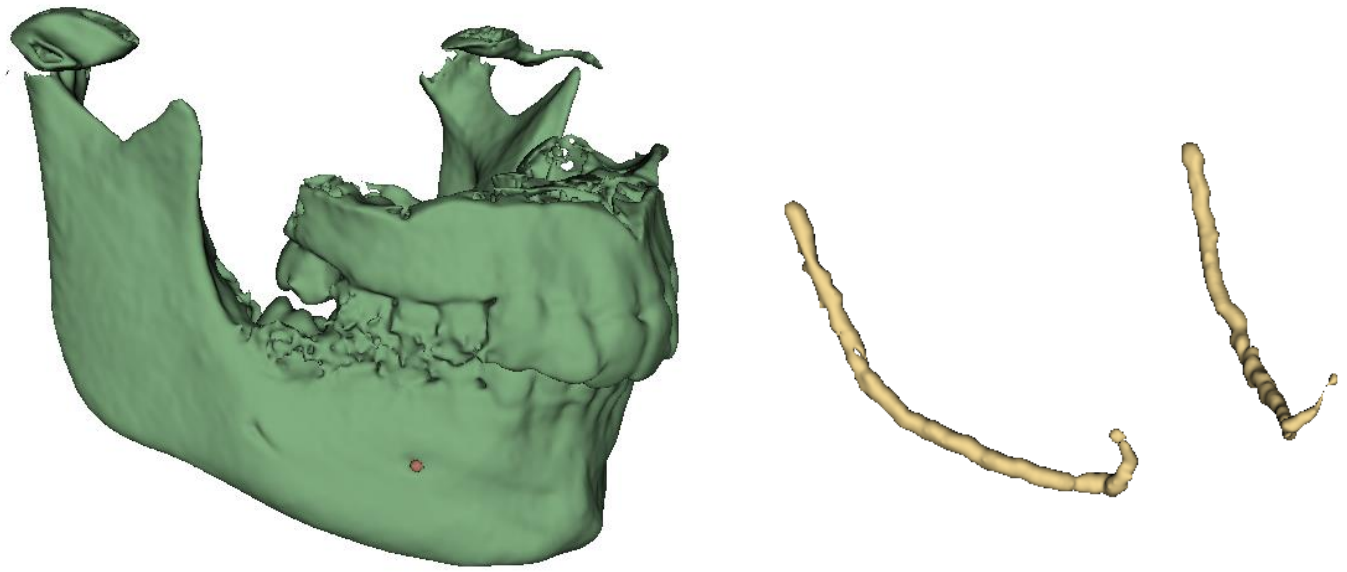
Project Vision

A cooperative robot workflow to enforce virtual barriers determined by segment CT data during mandibular surgery

Prior Work: Segmented CT Data

- 15 sets of patient CT scans have been segmented in 3D Slicer
  - Mandible
  - Right alveolar nerve
  - Left alveolar nerve



Prior Work: Virtual Fixtures

- Work has been done by Max Li and others [5] to develop a framework for automatically generating virtual fixtures from an STL file

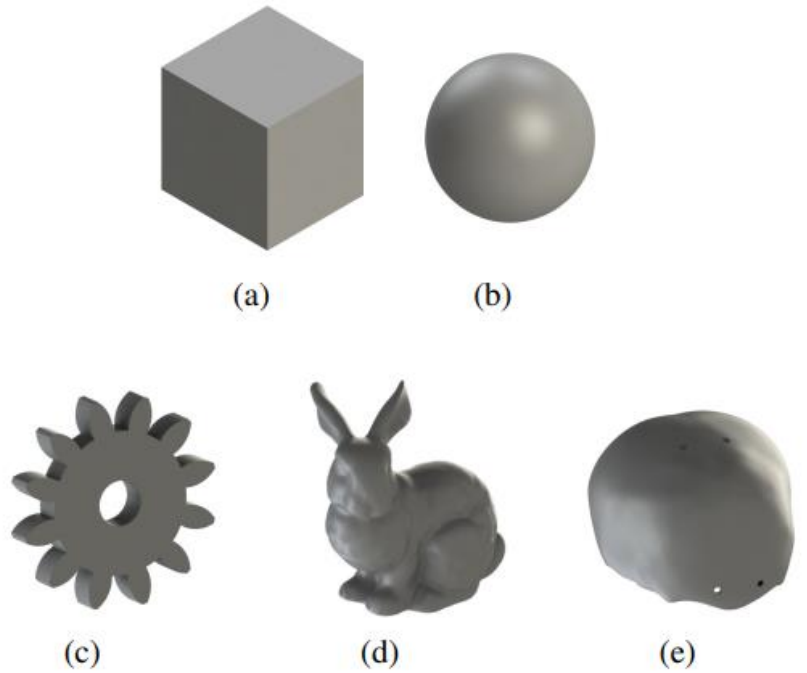


Fig. 6. Examples of the objects tested in simulation. (a) cube, (b) sphere, (c) gear, (d) Stanford bunny, (e) pediatric skull.

Image [5]

Goals and Significance

- Goals:
  - Establish a workflow for robot-assisted mandibular osteotomy with virtual barriers
- If successful:
  - This will be the first semi-autonomous robot-assisted mandibular osteotomy workflow
  - Improves procedure safety
  - Helps to pave the way for future cooperative robot procedures

Image: [4]

Technical Approach: General Setup

- Segmentation software: 3D Slicer
  - 15 models saved as NRRD files
- 3D Printing:
  - Software: GrabCAD, Simplify3D, Photon Workshop, Meshmixer
  - Machines: Stratasys F170, Flashforge Creator Pro, Creality CR-10, Anycubic Photon
  - Materials: ABS, PLA, Photopolymer Resin
  - Casting: Dental Stone
- Surgical Tool: J&J Drill Anspach EG1
- Robot: 5 DOF Galen Mark 2 in the mock OR
  - Additional software: ROS

Technical Approach: Strategy

- Machinable 3D printed materials and casted dental stone will be used to achieve a bone-like phantom
- Registration of the model to the robot coordinate system will be done using an optical tracking system and fiducials mounted on the teeth and drill
- Virtual Fixtures:
  - Identify critical anatomies
  - Use prior work (see Max Li's paper [5]) to enforce the virtual fixtures around critical anatomies

Key Deliverables

	Deliverable
Minimum	3D printed phantoms that are drillable and similar in feel to bone – Confirmed by clinical consultants
Expected	Demonstrable cooperative control robot-assisted mandibular osteotomy – Confirmed by clinical consultants
Maximum	Documentation and demonstration of virtual fixtures for robot-assisted mandibular osteotomy – Confirmed by clinical consultants

Timeline/Milestones

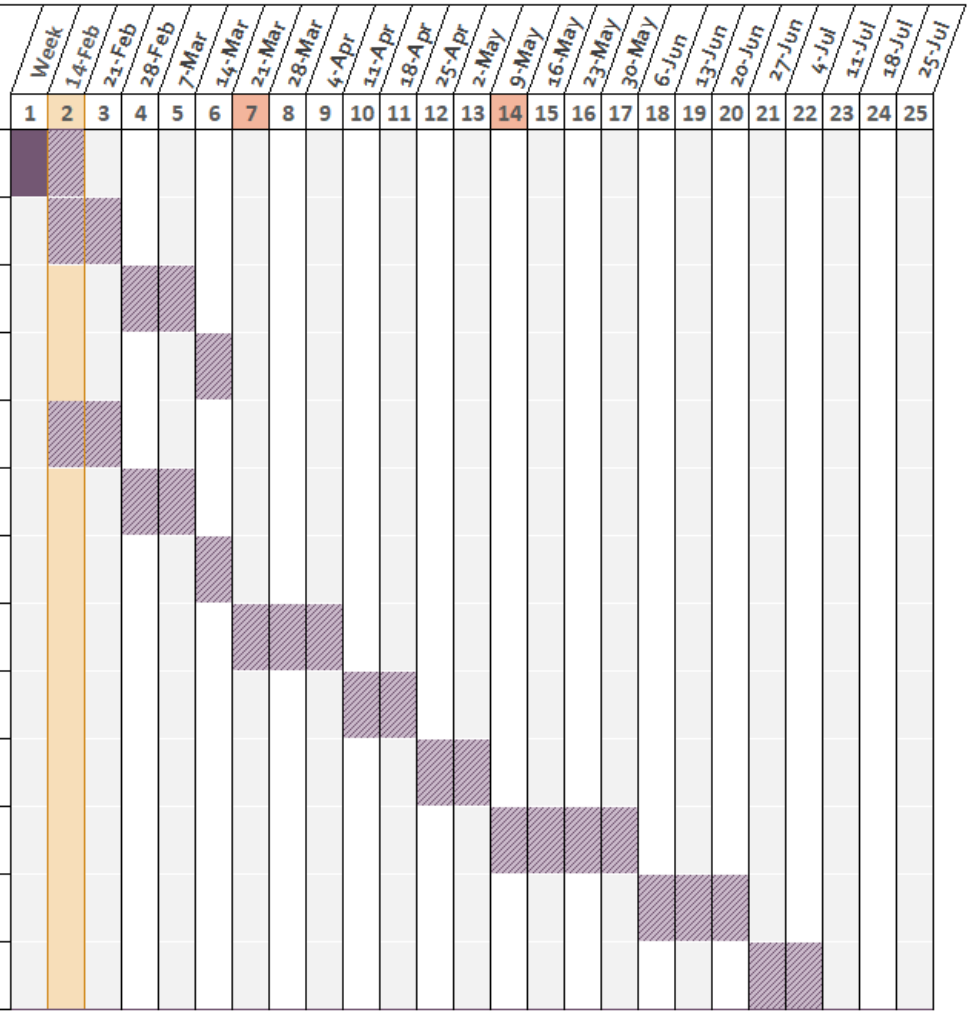
Milestones	Start	End
Mandible Phantoms	02/18	03/18
Galen configured for mandibular osteotomy	02/18	04/08
Registration with Galen	04/08	04/22
Virtual Fixtures Algorithm	05/13	06/03
Workflow Documentation	06/03	07/10

Dependencies

Dependency	Status	Fallback/Prevention	Need by	Effect
3D Printing Availability	Printer demand dependent	Personal 3D printers	Feb 28th	Delay in phantom creation
Mentor Feedback	Schedule dependent	Weekly meetings and early communication to avoid conflict	Mar 14th	Delay in phantom and Galen configuration
Drill and Drill Bits	Obtained	N/A	Feb 28th	Delay in Galen configuration
Galen accessibility	Schedule dependent	SharePoint calendar to schedule use	Throughout	Delay in all milestones
3D Segmentations suited for printing	In progress	Edit segmentations and use fewer models	Feb 21st	Delay in phantom creation
Dental stone for casting	Obtained	More can be acquired from Dr. Creighton	Feb 28th	Delay in phantom creation

Gantt Chart

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Project Plan and Webpage	1	2	1	2	50%
Prepare segmented models for printing	2	2	2	2	0%
Create phantom mandibles	4	2	4	2	0%
Gather phantom feedback from Dr. Yang and Dr. Creighton	6	1	6	1	0%
Gather tooling for mandibular procedure	2	2	2	2	0%
Setup Galen for procedure	4	2	4	2	0%
Gather Galen feedback from Dr. Yang and Dr. Creighton	6	1	6	1	0%
Modify Galen Setup based on feedback	7	3	7	3	0%
Develop mandible registration with the Galen	10	2	10	2	0%
Prepare Final Report and Poster	12	2	12	2	0%
Develop algorithm to enforce virtual barriers	14	4	14	4	0%
Pre and post op CT scans to measure effectiveness	18	3	18	3	0%
Create documentation for workflow	21	2	21	2	0%



Roles and Responsibilities

- **Team**:
  - Jesse Haworth – Responsible for all tasks
- **Mentors**:
  - Dr. Robin Yang – Clinical Lead
  - Dr. Francis Creighton – Clinical Consultant
  - Dr. Russell Taylor – Technical Consultant
  - Andy Ding – Technical Consultant

Management Plan

- **Meetings**:
  - Weekly meetings with Dr. Yang
  - Weekly Lab meetings
- **Communications**:
  - Email and Slack
- **File Sharing**:
  - SharePoint and email

Reading List

- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5392880/
- https://jscholarship.library.jhu.edu/bitstream/handle/1774.2/37927/OLDS-DISSERTATION-2015.pdf
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3805998/
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3094736/
- https://github.com/mli0603/PolygonMeshVirtualFixture
- https://journals-sagepub-com.proxy1.library.jhu.edu/doi/full/10.1177/0194599819861526

References

1. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5392880/
2. https://www.researchgate.net/figure/A-modified-Obwegeser-Dal-Pont-bilateral-sagittal-split-osteotomy-BSSO-technique-was_fig3_335848383
3. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3094736/
4. https://oralfacial.com/orthognathic-surgery-in-plantation-types/
5. https://github.com/mli0603/PolygonMeshVirtualFixture
6. https://journals-sagepub-com.proxy1.library.jhu.edu/doi/full/10.1177/0194599819861526