Validating and Improving Single-Stage Cranioplasty Prosthetics with Ground Truth Models

An expansion of single-stage cranial defect repairs and implants

Erica Schwarz, Willis Wang
Background

Team: Erica Schwarz, Willis Wang

Mentors: Mehran Armand, Chad Gordon, Ryan Murphy

Affiliations:

1. Applied Physics Laboratory: Research and Exploratory Development Department
2. Johns Hopkins University: Department of Mechanical Engineering
3. Johns Hopkins University School of Medicine: Department of Plastic and Reconstructive Surgery
4. Johns Hopkins University School of Medicine: Department of Neurosurgery
Introduction

- Cranioplasties are used to reconstruct the site of craniotomies and other cranial surgeries that remove sections of the skull.
- Due to risk of infection after such a procedure, creating a well-fitting prosthetic is important for increasing quality of life and risk management.
- Customized Cranial Implants (CCI) use CAD and CT scans to provide a full-thickness reconstructions which are used to replace the sections of the skull removed during operation.
Current Issues

- Creating a prosthetic that perfectly fits the operative hole requires the patient to be brought back to the operating room at a second date (two-stage surgery).
- A single-surgery solution where the implant is created manually can take considerable amount of time (10 - 80 minutes) and be inaccurate.
- New methods that use an overhead projector to aid manual implant creation are limited by complexity of implant.
- System has been developed for using 3D scanner to create a machined single-stage implant, but...

- **Effectiveness of using 3D scanners and point cloud models to completely capture defect shape and bevel is currently unknown.**
1. Use patient CT scan to create model of skull and ground truth defects of different shapes and complexities.
2. Fabricate physical representation of ground truth model.
3. Use a 3D scanner to make a point cloud representation of the defect site. A point cloud will be converted into a mesh of the defect through the patient’s skull that incorporates defect shape, depth, and bevel.
4. Process the defect mesh’s contours and register it to the defect model.
5. Validate and determine accuracy of mesh to defect fit.
Technical Summary

1. Use patient CT scan to create a patient-specific model of skull.
   a. Convert image stack into binary surface using lab program.

2. Create artificial defect using 3D modeling program.
   a. Subtract defined geometries from skull sections using Solidworks. Incorporate a range of bevels and shapes.
   b. 3D print defect and area surrounding it.

3. After ground truth defect is made, use a 3D scanner to make a point cloud representation of the defect site.
   a. Perform color and depth based segmentation of defect site.
   b. The point cloud will be converted into a mesh of the defect through the patient’s skull.

4. Process the mesh’s contours and register it to the oversized implant.
   a. Use a smoothing algorithm to eliminate noise and harsh angles on the interior wall of the defect.
   b. Find best fit of defect mesh’s surface to surface of patient CT scan model and evaluate accuracy

5. Using a fabrication device, cut the oversized implant into the form of the mesh.
   a. Mesh representation must be converted into a machining path
   b. Oversized implant must be registered to machine space
Technical Approach

Creating Single-Stage Cranioplasty Prosthetics
Deliverables

- **Minimum**
  - Segment and process point cloud of defect to create defect mesh
  - Register defect mesh to patient
  - Register mesh to oversized prosthetic

- **Expected**
  - Create ground truth models
  - Validate and improve process accuracy
  - Quantify accuracy of implant creation
  - Package process as Slicer module

- **Maximum**
  - Test process with cadavers
  - Register oversized prosthetic to UR5 machine
  - Define UR5 path for cutting fitted prosthetic
# Dependencies

<table>
<thead>
<tr>
<th>Status</th>
<th>Dependency</th>
<th>Description</th>
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<tbody>
<tr>
<td>Completed</td>
<td>Structure Sensor</td>
<td>Sensor to be used for scanning incision site. Provided by Dr. Armand.</td>
</tr>
<tr>
<td>Completed</td>
<td>iPad</td>
<td>iPad to use with structure sensor. Provided by Dr. Armand.</td>
</tr>
<tr>
<td>Completed</td>
<td>Software Repository</td>
<td>Provided by Ryan Murphy. Contains existing lab code, system, and test data.</td>
</tr>
<tr>
<td>Completed</td>
<td>Patient CT Scans</td>
<td>Will be used to create ground truth models. Provided by Ryan.</td>
</tr>
<tr>
<td>In Progress</td>
<td>3D Printer</td>
<td>Needed to fabricate ground truth models. DMC, BME Design Studio, or Shapeways.</td>
</tr>
<tr>
<td>In Progress</td>
<td>Operation Observation</td>
<td>Currently scheduling operation viewing to better motivate understanding of the problem.</td>
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# Timeline

<table>
<thead>
<tr>
<th>Date</th>
<th>Objective</th>
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<tbody>
<tr>
<td>2/22 - 4/25</td>
<td>Registration and Segmentation Development</td>
</tr>
<tr>
<td>3/14 - 5/02</td>
<td>Accuracy Testing</td>
</tr>
<tr>
<td>4/25 - 5/9</td>
<td>Procedure and UR5 Integration</td>
</tr>
</tbody>
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Creating Single-Stage Cranioplasty Prosthetics

Chart

- **Testing Data Production and Planning**
  - Dissect previous work's code
  - Process simple test data
  - Create test defects in Solidworks or Blender
  - 3D Print Skull with defect

- **Registration and Segmentation Development**
  - Configure iPad and Structure Sensor
  - Color-based segmentation
  - Depth-based segmentation
  - Register defect mesh to CT coordinates
  - Register defect mesh to oversized implant

- **Accuracy Testing**
  - Define metrics and process
  - Repeat trials with varied defect geometries

- **Procedure and UR5 Integration**
  - Complete modules for scanner communication
  - Streamline test procedure in mock operation
  - Convert mesh to coordinate codes
  - Register oversized implant to UR5
  - Program UR5 movement

**Timeline**

- **February**
  - 1
  - 8
  - 15
  - 22
  - 29

- **March**
  - 7
  - 14
  - 21
  - 28

- **April**
  - 4
  - 11
  - 18
  - 25

- **May**
  - 2
  - 9

**Background**

**Introduction**

**Proposed Solution**

**Technical Approach**

**Deliverables**

**Dependencies**

**Timeline**

**Management**

**Further Reading**
Management

The division of labor for this project will be distributed equally with both team members working on all components of the project. However, the primary responsibilities of the two members will be as follows:

- Erica Schwarz: Refining defect point cloud processing (i.e. smoothing and deleting outliers, simplifying geometry for later machining). Creating robust ground truth models from test data.
- Willis Wang: Refining segmentation method of incision point cloud. Researching best ways to compare fit of meshes to ground truth.

Team meetings will be weekly on Wednesday mornings with additional meetings planned based on the discussion during that time. Meetings with Ryan Murphy will take place weekly on Thursday mornings to review progress.


Questions?