Robotic Drilling for Single-Stage Cranioplasty

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The Biomechanical and Image Guided Surgical Systems Lab (BIGSS) at Johns Hopkins University is working to improve each patient's experience with craniofacial surgery. We have developed techniques to reduce the time and cost of craniofacial surgery, as well as improve the quality and durability of the facial implants that are used. One important technique that we have worked on is robotically cutting a skull implant in the operating room during surgery. By implementing this technique, the time spent in surgery will be drastically reduced and the fit of the implant will improve tremendously.

Crainioplasty is a procedure to treat and repair cranial defects using custom cranial implants (CCIs). It may be

Figure 1. Pre-operative design of an oversized implant.

needed for patients who have brain tumors, infected or cancerous bone, or birth defects. Single-stage CCI is when the bone is resected and the implant is placed in the same procedure. This is preferred because of cost, time, recourses, patient safety, and patient comfort. The implants used for single-stage CCI are based off of a preoperative CT scan in efforts to achieve a good match between the shape of the implant and the shape of the skull defect. Even when designing the implant based off of a preoperative CT scan, the surgeon often needs to revise the planned bone resection and therefore change the shape of the implant during surgery. Previous work in the BIGSS lab has involved using intraoperative navigation to identify the region of resected bone and guide the surgeon in modifying the implant. A cadaveric case study proved that this method results in good accuracy and fit with minimal time required for implant modification. The technique uses an oversized implant and preoperative surface model of the skull and of the implant. We now extend this technology to include robotic modification of the implant during surgery. We have implemented the control algorithm and proven that the robot can move in the path of the implant shape at a constant velocity. This technology will drastically decrease the operative time for single-stage cranioplasty.

Figure 2. Robot control logic diagram.

During surgery, the surgeon uses a digitizer to collect a set of three anatomical landmarks and then a registration is performed using the iterative closest point technique to map landmarks on the patient to landmarks on the CT scan. After the surgeon resects the bone, they use the digitizer to trace the outline of the resection on the skull. This is tracked by the Polaris optical tracker and provides the required implant shape. Then, this shape is transformed to the CT coordinate system. We used this shape when controlling the Universal Robot 5 through the open-source software 3D Slicer.

We developed an algorithm to move the robot with a constant velocity. We passed a vector with 6 values representing joint velocities to the UR5 API. In order to calculate these velocities, we used the starting and ending positions of the robot and calculated the inverse kinematics of both positions.

With a digitizer tip attached, the UR5 5 traced the outline of an implant cut from a previous case study in 53 seconds. In previous studies using the projection technique, the total time to cut the implant to the desired shape was 14 minutes and 58 seconds. Even though our robotic cutting technique hasn't yet been tested with a drill attached, it shows a very promising
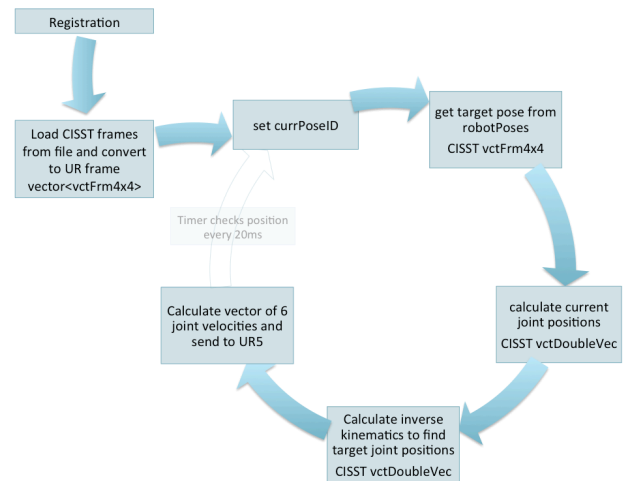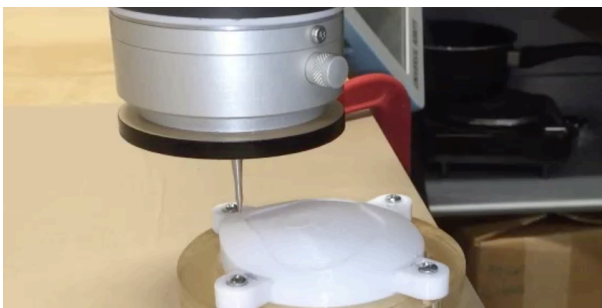

Figure 3. The UR5 in tracing the outline of an implant shape obtained by tracing

reduction in the time required to cut the implant to the correct shape.

       The BIGSS lab is working on creating a laser robot to perform the implant cut. This introduces many advantages regarding speed and sterility. The laser robot will be much smaller and will not require any physical contact to the implant in order to perform the cut. Overall, a robotic implementation of cutting the implant will drastically reduce the time spent on this step in the operating room. This will lead to reduced costs for the hospital, patient, and insurance companies.