Augmented Reality Assisted Orbital Floor Reconstruction

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Surgery background [1]

Orbital blowout fracture is deformity caused by significant blunt trauma to the orbital aperture, more commonly known as the eye socket. If a patient experiences blunt trauma from an object that is of larger size then the orbital aperture, then fractures can occur on the orbital floor and medial wall of the eye-socket. An image of the corresponding anatomy is shown below.

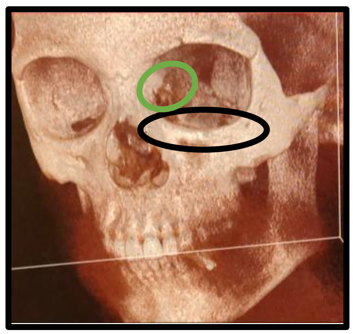

Figure 1: 3D CT Image of Patient with medial wall fracture. Medial wall is circled in green and orbital floor in black.

Orbital blowout fractures are common and account for about 40% of all facial fractures. This is primarily due to thinness of the orbital floor. Once the orbital has fractured, the bone will be displaced downward into the maxillary sinus [2]. As a result, the contents of the orbital aperture will herniate into the newly opened space. This can cause a variety of problems for the patient and can affect their ability to have proper ocular alignment which can result in difficulty of sight. This is known in the medical community as tropia. Tropia in patients with orbital blowout fracture tend to have constant upward or downward gaze [2].

To return orbital tissue from the maxillary sinus and into the eye socket as well as realign the eye, reconstruction of the orbit floor is necessary. The procedure involves the placement of an orbital implant that restores structure to the eye socket, preventing any orbital tissue from returning to the maxillary sinus and improving any previous tropia [2]. An image of an orbital implant is shown below.

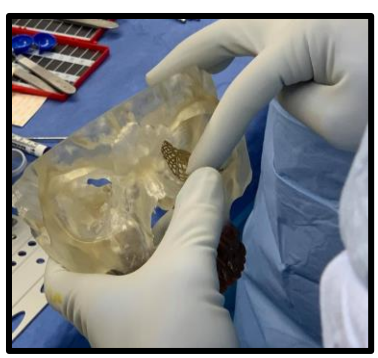

Figure 2: Image of implant being molded to a patient model.

The implant is of a relevant size necessary for restoring stability in the orbital aperture and no larger. In order to ensure proper fit in the eye socket, the surgeon may shape the implant multiple times before settling on a shape that is appropriate for the patient’s specific anatomy. If the implant is not flush with the orbital wall, it may cantilever during fixation and cause unnecessary damage to orbital tissue.

Importance and Relevance

Orbital floor reconstruction surgery is a long and arduous process, requiring significant attention from the surgeon and manipulation of delicate and complex structures in a tight, compact space. Due to the nature of the orbital floor bone and manner in which it may fracture, shattered bone fragments may be present scattered in the maxillary sinus and in other regions within the operative field. Below is a CT slice of a patient with orbital floor blowout [1].

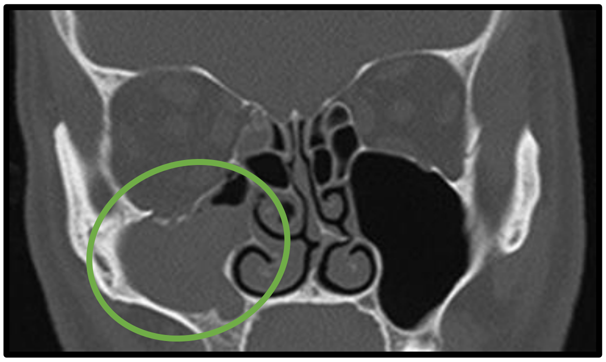

Figure 3: CT Slice of patient with orbital floor fracture and clearly visible herniated tissue into the maxillary sinus, circled [1].

The orbital aperture is a tightly confined space due to the fact that its primary purpose is to provide structure of the ocular system. As a result, a fracture in the orbital aperture is difficult access since it is within the compact space. Additionally, any incision made in order to access the tissue underneath is relatively small, giving surgeons limited visibility into the orbital aperture. As a result, it is difficult for surgeons to develop context and orientation of the anatomy once they have dissected along the orbital wall. This sense of orientation is necessary, as placement of the orbital implant plate requires precise shaping of the implant and identification of the posterior lip of fracture. The implant must rest on this bony structure into order to remain securely in place. Since the posterior lip is towards the backside of the orbital aperture, it can take surgeons multiple attempts before they feel confident that the implant is resting on the posterior wall as they struggle to see its location through the relatively small incision and following dissection.

This relative operative blindness is an indication of a clear need for improved surgical navigation and visualization techniques specific for orbital floor reconstruction. An augmented reality assisted orbital floor reconstruction system is proposed to resolve the problem of low visibility of the distal orbital wall during the procedure, so that misplacement may be avoided. The introduction of a head mounted display to provide navigation to surgeons in the orbital floor implant process would reduce operation time and increase surgeon confidence in secure implant placement.

Current Surgery Workflow

Current surgical process is compressed of three core phases. The surgical process begins with a dissection along the orbital bone in order to access the fracture area and the orbital aperture. The eye is pulled upward in order to get clear access to the orbital floor or medial wall. Once access is established, the fracture cavity is examined, and herniated tissue is slowly returned to its proper location. This process allows the fracture cavity to be exposed. The end of the first phase is characterized by the clearing of the fracture cavity and the removal of pieces of fractured bone.

The second phase of the surgery involves the stabilization of the orbital aperture by the introduction of an orbital plate. This phase of the surgery is an arduous process, taking up a significant portion of operation time. First, the orbital implant is shaped to the patient's specific anatomy by the surgeon's intuition of the operative field from the phase 1 process. Once the surgeon feels as though the implant is in the correct shape, they will attempt implantation. It is very rare for the implant placement to be perfect on the first try. The surgeon will take multiple attempts to shape the implant correctly and then place the implant in its proper place.

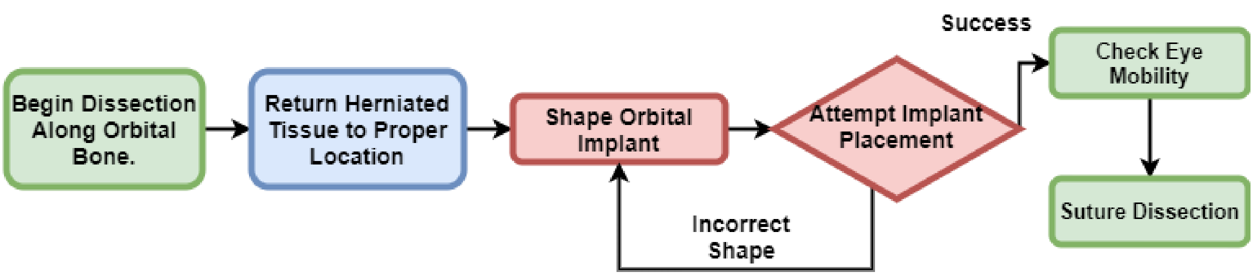

Figure 4: Current surgery workflow chart, green indicates a fast step, red indicates a time-limiting step and blue represents the in between.

Both parts of this phase are challenging and pose as non-trivial tasks for the surgeon. Implant placement is difficult due to the nature of the dissection and tight, compact space in which they are operating in. Additionally, the presence of delicate, complex anatomy in the area adds additional complexity to an already complicated process. Correct implant placement involves placing the implant's distal portion on the posterior edge of the fracture, this portion of bone is known as the posterior ledge. Having a clear visual of this ledge is difficult to achieve as the it is deep within the orbital aperture and the surgeons only line of sight is through the dissection. Finding the posterior ledge can take up a significant portion of operating time. Considering this process in conjunction with shaping the implant, it's clear that there is a need for surgical navigation that can provide guidance to surgeons during phase 2 of the surgery. A workflow of the proposed surgical navigation is shown in the deliverables section.

Phase 3 of the operation begins after the surgeon is confident with their placement of the orbital implant and its shape. Afterward, the surgeon will return the eye to its proper location and test eye mobility. Due to the invasive nature of the procedure in the eye socket, it is important to ensure that all ocular muscles are in their correct location and that the eye is able to move properly. Once the eye mobility is checked, the dissection and incision are sutured and closed up.

Deliverables

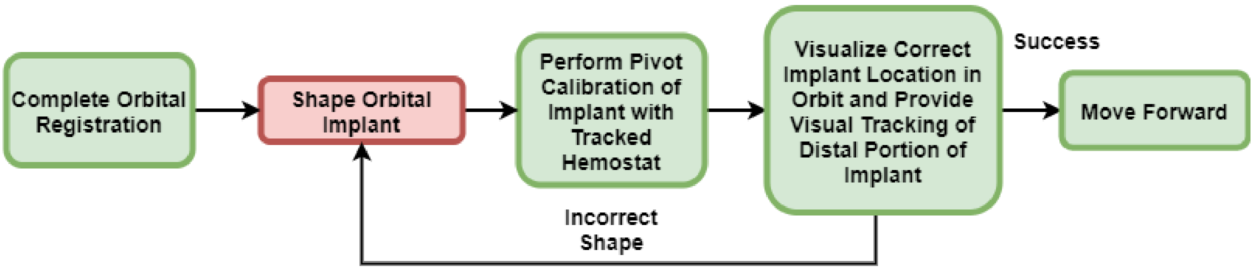

Figure 5: Proposed surgery workflow chart, green indicates a fast step, red indicates a time-limiting step and blue represents the in between.

The proposed system will add the procedures of registration and calibration. For the registration, process, some feature points on the patient will be collected and become the basis of the registration from the skull to CT mesh/model. The calibration will be conducted before the visualization of the implant. In order to have correct relative position of the implant in the visualization display frame, our initial proposal is to attach and lock the implant to the hemostat which is tracked by passive markers and Polaris. However, this may introduce complexities to the procedure. Thus, this will be a technical detail that will need to improve on by discussing with our clinical mentors.

Every time after the surgeon need to reshape the orbital implant manually, a new calibration will needed to be conducted.

The following deliverables are all expected before the end of the semester (final presentation).
Point/surface registration method for orbital socket

- Min: Target registration error (TRE) <4mm
- Expected: TRE <3mm
- Max: TRE <2mm

Calibration of implant with respect to tracked hemostat

- Min: Pivot Calibration of the distal edge of the implant (only model the distal edge)
- Expected: Use calibrated pointer to model the implant distal edge
- Max: Use calibrated pointer to model the entire implant

Visualize position of tracked implant with respect to CT

- Min: Visualization on 3D slicer (Open IGT link on client to update model)
- Expected: Visualization in AR system (Hololens)
- Max: A comparison between 3D slicer implementation and Hololens implementation

Preliminary system description

The project will be implemented using existing libraries (mostly from *cisst* software library). Some customizations will be made. The major components can be seen in the following chart.

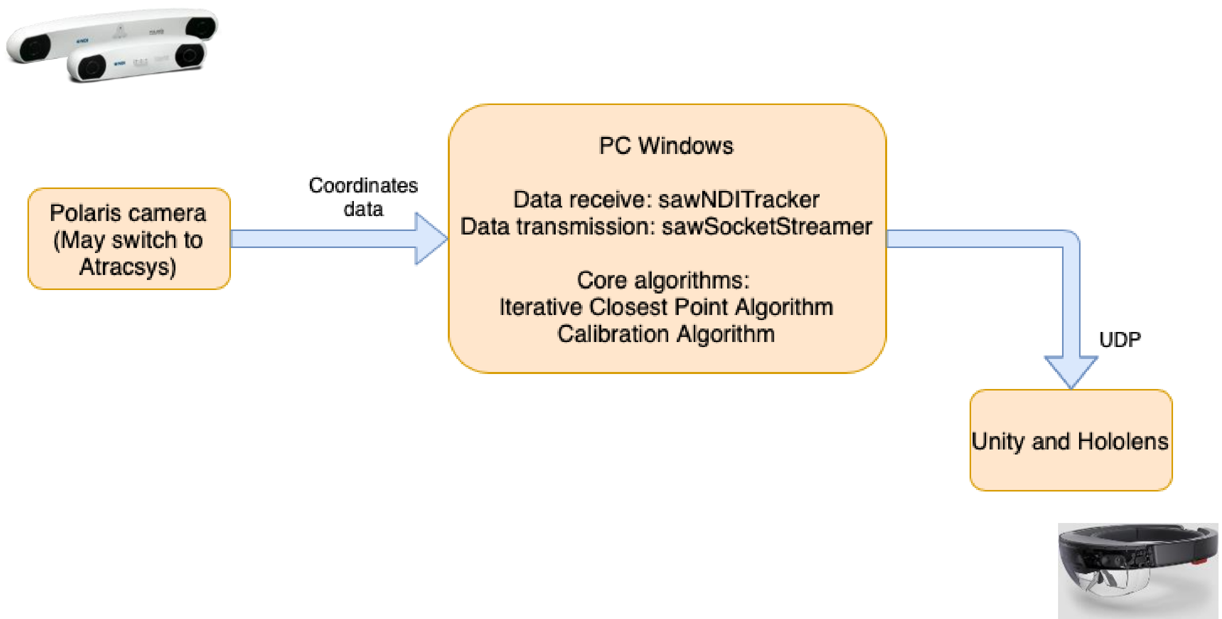

Figure 4. The proposed preliminary system components.

The data collection will be made through NDI Polaris camera and will be transmitted by *sawSocketStreamer* in the *cisst* software library. A Windows PC will be used to run the algorithms. The system may require more computers to run the Unity algorithm and registration/calibration algorithms separately.

Polaris camera is used to get the tracker coordinates by sawNDITracker. The data format and the way of use will be specified in the later work, because it will be largely dependent on the specifications of CISST libraries. For the registration process, the received coordinate data is the coordinates data of the passive trackers on a pointer, which will be used to collect the coordinate of the pointer tip. The pointer tip collects the point cloud which will be used for registration. Once a sufficient point cloud is collected, it will be sent along with the CT model data to Iterative Closest Point (ICP) algorithm. For the calibration process, the received Polaris data is again the coordinates of the passive trackers attached to the pointer. The pointer will be used to collect the coordinates of the distal edge (expected deliverable) or a complete point cloud (maximum deliverable) of the implant.

Unity and Hololens will be used to model and visualize the implant.

Dependencies

Dependencies	**Solution**	**Alternatives**	**Status**
Computer with Linux	Use Personal computers	Use LCSR Lab Computer	Resolved
Computer with Windows (HMD development)	Use Personal computers	Request Lab Computer	Resolved
Data Back-ups	Use Microsoft OneDrive	Use personal hard drive	Resolved
Learn Workflow from Surgeons	Shadow surgery in OR	Meet with Surgeons	Resolved
STL Files for Implants	Coordinate with Clinical Partners	Find Potential Online Source	Resolved
CT Scans of Skulls for Corresponding STL Files	Coordinate with Clinical Partners	Obtain other model from Dr. Kazanzides	3/15/20
Polaris Camera	Coordinate with Anton	Coordinate with Dr. Kazanzides	Resolved
Learn cisst Library ICP	Refer to Online Material	Work with Anton	3/1/20
Passive Rigid Body Pointer	Coordinate with Ehsan & Dr. Kazanzides	Coordinate with Peter	3/7/20
Installation of SAWSocketStreamer	Discuss with Anton	Discuss with Long	Resolved
Dependencies	Solution	Alternatives	Status
Learning Python Wrapper	Refer to Online Material	Seek mentorship from Anton and Ehsan	3/1/20
Hemostat	Coordinate with LCSR	Seek from Clinical Mentors	Resolved
Attachable Rigid Body for Polaris and Hemostat	Seek from Ehsan or Dr. Kazanzides	Coordinate with LCSR, Potentially Make Our Own.	3/15/20
Learn cisst Pivot Calibration	Read Online Material	Coordinate with Anton or Dr. Kazanzides	3/15/20
HoloLens	Coordinate with Ehsan	Coordinate with Dr. Kazanzides	4/15/20
Unity Installation and Hololens Set-up	Utilization of Online Resources	Help from Ehsan	4/1/20
OpenGL/3D-Slicer Installation and Set-up	Utilization of Online Resources	Coordinate with Dr. Kazanzides and Ehsan	4/1/20

Management plan

We have scheduled the regular biweekly mentor meetings and daily sprint group meetings. We will meet with our clinical mentors and technician engineer mentor when it's necessary. The detailed plan can be seen in the following list.

- Biweekly mentor meeting (Friday 3 pm.)
    - Weekly progress report
- Scheduled surgeon meetings
- Scheduled technician engineer meetings
- Daily sprint group meeting (3 or 4 meetings / week)
    - M: 12.00-15.00
    - TTh: 18.00-21.00
    - F: 15.00 - 18.00
- Weekend technical meeting
    - Saturday 15.30 - 19.30

Bibliography

[1] S. Grob, M. Yonkers and J. Tao, "Orbital Fracture Repair," *Seminars in Plastic Surgery,* vol. 31, no. 1, pp. 31-39, 2017.

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Reading List

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