# Projection Mapping in Surgery

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## Summary

The goal of this project is to develop a handheld prototype, consisting of a projector and depth camera, that can project patient data (e.g. CT/MRI scan) fixed onto patient body in real-time during surgeries.

## Background

Projection Mapping, also known as Spatial Augmented Reality (SAR), is a frequently used method to add and visualize textures on real world objects. Static projection mapping is common in many applications such as multimedia shows, where the camera, projector, and object on which to project are all not moving. Dynamic Projection Mapping, which can deal with projections on moving targets or with a moving projector on a static target, is still a challenge.

Virtual reality has recently been introduced to the field of medicine over the past few years. Physicians already use virtual technology for a variety of medical procedures. Conventional MRI or CT scans has the potential to reveal much information about a patient when used as a preoperative guide for surgeons to plan their surgery. However, inter-operative techniques that can assist surgeons to accurately perform a procedure by interacting with patient data in real-time is still a challenge.

Cranioplasty is a procedure to treat and repair cranial defects using CCIs (custom cranial implants). The implants are usually made in oversized profiles and require resizing of the CCI to make it fit onto a specific patient's skull. This resizing process is a challenging task for the surgeon just by relying on visual analysis and manual hand modification. Therefore, we believe it has great value and potential to use projection mapping and robotic technology to assist surgical procedures such as cranioplasty to make the whole process faster and more accurate.

## Technical Approach

### Overview

The proposed solution is to develop a novel approach to cranioplasty using projection mapping. This compact system will consist of a depth camera and projector, assisted by a computer to handle the computation and processing. Ideally, the system will be able to project patient data (eg. CT data, oversized implant model, etc.) onto the patient while the surgeon does not need to wear any external hardware as is needed for most AR systems. Specifically, as illustrated in Figure 1, our system consists of a portable projector and the Intel RealSense Depth camera that can move around the skull model while projecting patient data onto it and retrieving 2D and 3D image data. The main parts of our technical approach consist of 3D reconstruction of CT scans, calibration of the camera-projector system, and registration. The 3D reconstruction will simply be done using existing software such as 3D slicer, and the other parts of the technical approach will be explained in the subsections below.

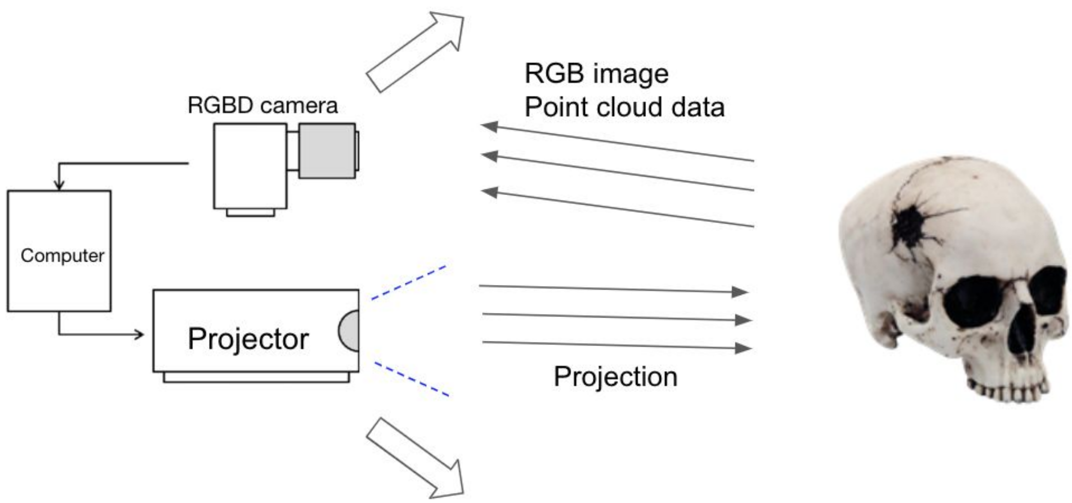


Figure 1: overview of projection mapping system

# Workflow

As illustrated in Figure 2, to summarize, before operating the camera-projector system, two steps need to be conducted. One is the calibration of the camera-projector system as noted by Huang et. al. The second step is to setup the marker-based registration through the pivot calibration and touching the anatomical landmarks.

During operation, the system needs to be able to first detect the patient markers and then perform registration. The program then needs to extract the visible view of the 3D model and transform it properly to match the pose of the actual skull model. And lastly, that transformed model needs to be projected onto the skull model. And as the system is moved by the user, these steps need to be conducted over and over again.

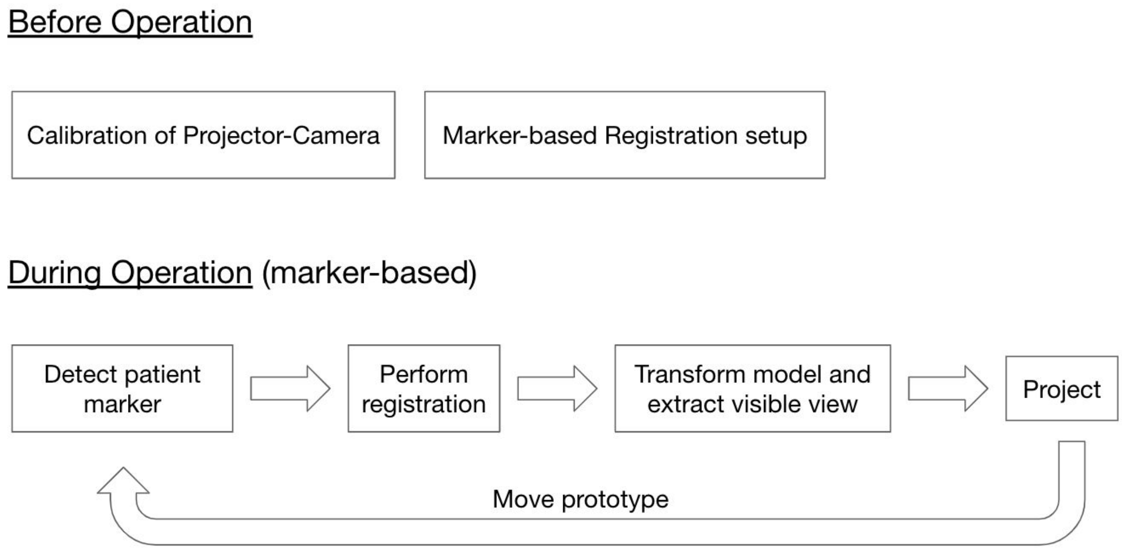


Figure 2: block diagram of system workflow

# Camera-Projector Calibration

In order to calibrate the camera and projector together, our procedure will build off the research done by Huang et. al. Figure 3 illustrates most of the calibration setup. There will be a checkerboard placed in front of the projector and camera, and there will also be structured light patterns projected onto the same surface as the checkerboard.

The first step would be to conduct a checkerboard calibration procedure in order to calibrate the camera. This will give us the intrinsic parameters of the camera along with the relative rotation and translation matrices between the calibration board pose and the camera. A homography between the calibration board pose and the camera image plane can then be calculated using formulas provided in their paper. The nodes in the structured light patterns then need to be undistorted and transformed to the calibration board model space. We can then perform a similar camera calibration procedure as in the first step but with the structured light nodes instead. We then know the transformations between the camera and the checkerboard as well as the projector and the checkerboard. This then allows us to find the transformation between the camera and the projector.

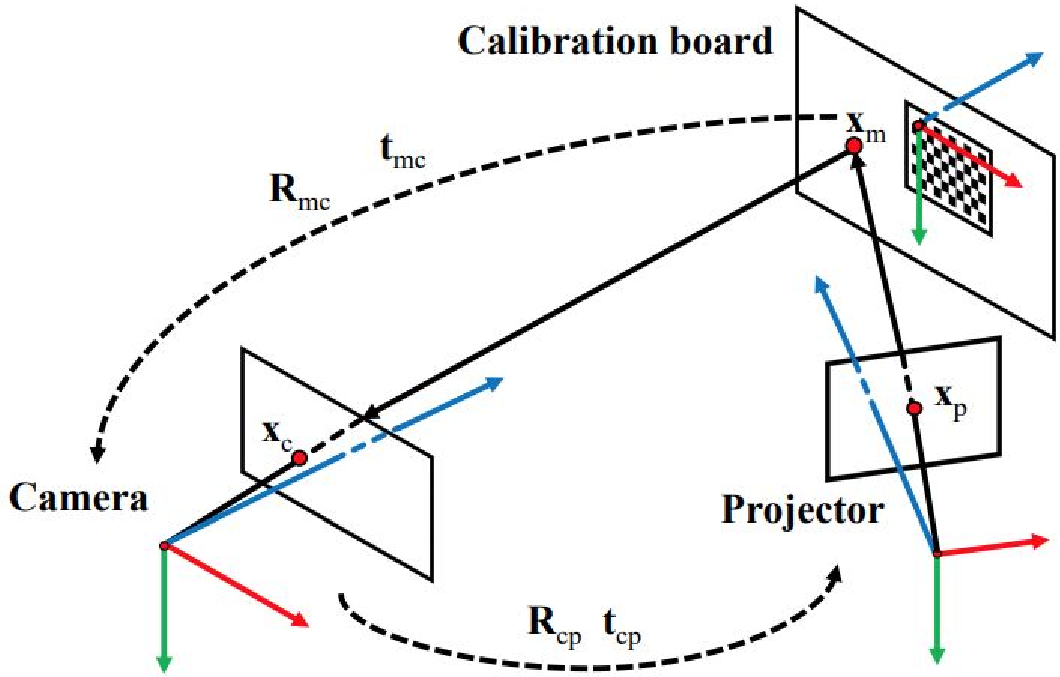

Figure 3: setup of camera-projector calibration [1]

## Marker-Based Registration

In order to determine what pose the actual skull model is in front of our camera-projector system, there needs to be some registration procedure that will be able to transform one set of points from the CT model to match the corresponding points on the skull model. In order to quickly achieve a fully working prototype, we have decided to first pursue a marker-based registration method.

As illustrated in Figure 4, we first need markers that are stationary relative to the skull model and also a tool with a marker on its end. The markers then need to be detected through the images retrieved from the RealSense camera. After detection, a pivot calibration needs to be performed to obtain the transformation from the marker on the tool to the end of the tool. The tool can then be used to touch anatomical landmarks on the skull model, and the location of these anatomical landmarks needs to be recorded. With these locations, we can perform an initial registration with the points of the same anatomical landmarks that can be detected on the CT model. After this initial registration while the camera-projector is moving, the location of the same anatomical landmarks of the skull model can be obtained because we are able to detect the location of the markers stationary relative to the skull model. Registration can then be performed while the system is moving to obtain the proper transformation of the CT model to project onto the skull model.

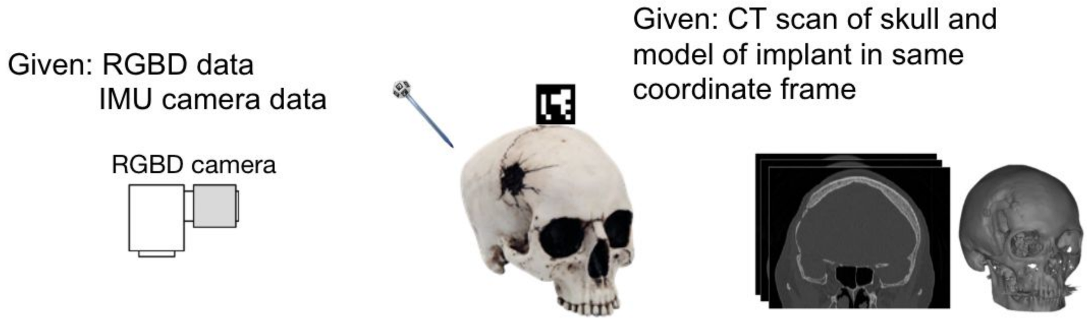


Figure 4: components of the marker-based registration

However, before diving into the registration procedure, we will first conduct an accuracy evaluation for the ArUco marker detection and pose estimation. The setup for this evaluation will consist of a checkerboard and a marker printed on the same surface. The camera will be calibrated, and the transformation between the checkerboard coordinate frame to the marker frame will be known. We can then compare the location of the marker using two methods to evaluate the pose estimation accuracy. The first will be through detecting marker directly from the RGB image of the RealSense camera, and the second method will be calculating the location of the marker using the checkerboard location that we have through the camera calibration. This accuracy can be evaluated at different poses, and the different poses can be created by rotating the checkerboard surface at different angles with respect to the camera.

## Markerless Registration

Another method under consideration is a markerless registration procedure. The underlying idea of this is that a subset of the point cloud data from the RealSense camera needs to be registered to a subset of the point cloud of the 3D model. For the point cloud data from the RealSense camera, there is unfortunately not a clear way to automate the process of segmenting the desired object. Most research focuses on systems where there is a static camera and a moving object or both a moving camera and a moving object. In these cases, methods such as optical flow can be used to subtract the background because the object relative to the camera moves in a different way than the background relative to the camera. However, in this situation, the camera is the only one moving, and therefore the desired object and the background move in the same manner relative to the camera. For the point cloud of the 3D model, we only want a subset because the correspondences of the points that are hidden from the point of view of the camera cannot be obtained from the RealSense camera. Because of this, we need to identify what points of the 3D model are immediately visible to the camera and use only those visible points in the registration process.

One idea to potentially help in identifying the object is utilizing object trackers built into OpenCV. These trackers allow the user to put a bounding box around the object in question before the tracking begins. And so if the program is able to identify where the object is in each frame with the help of the initial bounding box, we can eliminate all the points outside of the bounding box.


Figure 5: components of markerless registration

# Deliverables

- Minimum
  - Video showing ArUco markers are detected and output of their 3D location
  - Window display of aligned points with marker-based registration and text file with output stream of computed transformations
- Expected:
  - Window display of defect skull augmented with CT model
  - Python/C++ source code and documentation along with report of future work and recommendations
- Maximum:
  - Video of projection mapping also projecting oversize implant on defect skull
  - Visualization of point cloud data of defect area overlayed on CT skull model
  - Window display of aligned points with markerless registration and text file with output stream of computed transformations

# Activity Schedule

| | 2<br>18 | 2<br>25 | 3<br>4 | 3<br>11 | 3<br>18 | 3<br>25 | 4<br>1 | 4<br>8 | 4<br>15 | 4<br>22 | 4<br>29 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Develop and detect ArUco markers and locations | | | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Conduct accuracy evaluation for marker pose estimation | | | | | | | | | | | |
| Conduct marker-based registration with RealSense camera | | | | | | | | | | | |
| Calibrate projector-camera system | | | | | | | | | | | |
| Construct 3D model from CT scans | | | | | | | | | | | |
| Augment RGB image from Realsense with CT | | | | | | | | | | | |
| Write report, polish documentation | | | | | | | | | | | |
| Project implant to defect skull and gather point cloud data of defect area | | | | | | | | | | | |
| Develop markerless registration | | | | | | | | | | | |

# Milestones

To produce the above deliverables, these are the milestones I will reach at these certain dates:

- 2/22 - creation of marker tools and panels
- 2/23 - Python script to run ArUco marker detection and pose estimation with RealSense
- 3/2 - accuracy evaluation report of ArUco marker pose estimation
- 3/8 - Python script for marker-based registration with RealSense and all marker-related code will be documented
- 3/29 - 3D skull models reconstructed from CT scans
- 3/31 - camera-projector system will be calibrated
- 4/14 - video of projection mapping done on skull model and all calibration-related software/code will be documented
- 4/28 - projection mapping prototype will be complete
- 5/5 - Final report written and all code will be documented

# Dependencies

| Dependencies | Solution | Expected Date | Needed by |
|---|---|---|---|
| Computer | Personal laptop | Done | |
| Access to BIGGS Lab | Asking Professor Armand | Done | |
| Access to Intel RealSense SDK 2.0 | Downloaded from website | Done | |
| Access to Intel RealSense Camera | Bought | Done - Joshua | |
| Access to Open3D library and OpenCV | Installed | Done | |
| Access to projector | Currently have one, may upgrade | Done - Joshua | |
| Holding mechanism for projector and camera | Built by Joshua | Done | |
| Construct ArUco markers and marker tool | Build our own | 2/19 - Austin | 2/22 |
| CT scan reconstruction software (eg 3D slicer) | Seek advice from Professor Armand and lab mates | 2/22 - Austin | 3/15 |
| Obtain data (scans/models of skulls) | Currently have molds, need corresponding scans. Currently using heart model and 3D-reconstructed scan from structure sensor | 3/10 - Joshua | 3/15 |
| Interface with projector | Online research | 3/10 - Austin | 3/25 |

# Management Plan

Team meetings will be every Tuesday, and additional meetings will be planned as necessary. All project-related scans or models will be stored on OneDrive. All code will be kept in a private Github repository.

# Reading List


1. Yi Zhou, Shuangjiu Xiao, Ning Tang, Zhiyong Wei, and Xu Chen. 2016. **Pmomo: Projection Mapping on Movable 3D Object**. *In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16). ACM, New York, NY, USA, 781-790.* DOI: https://doi.org/10.1145/2858036.2858329
2. Thuong Hoang, Martin, Reinoso, Zaher Joukhadar, Frank Vetere, and David Kelly, 2017. **Augmented Studio: Projection Mapping on Moving Body for Physiotherapy Education**. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17). ACM, New York, NY, USA, 1419-1430*. DOI: https://doi.org/10.1145/3025453.3025860
3. Yuki Morikubo and Naoki Hashimoto. **Marker-less real-time tracking of texture-less 3D objects from a monocular image**. In *Proceedings of SIGGRAPH Asia 2017 Posters (SA '17). ACM, New York, NY, USA.* DOI: https://doi.org/10.1145/3145690.3145695
4. Yuki Morikubo, Eugene San Lorenzo, Daiki Miyazaki, and Naoki Hashimoto. **Tangible projection mapping: dynamic appearance augmenting of objects in hands**. In *Proceedings of SIGGRAPH Asia 2018 Emerging Technologies (SA '18). ACM, New York, NY, USA.* DOI: https://doi.org/10.1145/3275476.3275494
5. J.-P. Tardif, S. Roy, and J. Meunier. **Projector-Based Augmented Reality in Surgery without Calibration**. In *Proceedings of the 25th Annual International Conference of the IEEE MBS (Sept 2003), Cancun, Mexico, 548-551*.
6. Christoph Bichlmeier, Felix Wimmer, Sandro Michael Heining, and Nassir Navab. **Contextual Anatomic Mimesis: Hybrid In-Situ Visualization Method for Improving Multi-Sensory Depth Perception in Medical Augmented Reality**. In *Proc. ISMAR '07. 129-138*.
7. Bingyao Huang, Samed Ozdemir, Ying Tang, Chunyuan Liao, and Haibin Ling. **A Single-shot-per-pose Camera-Projector Calibration System for Imperfect Planar Targets**. In *Adjunct Proceedings of the IEE International Symposium for Mixed and Augmented Reality.* 2018.


References


1. Bingyao Huang, Samed Ozdemir, Ying Tang, Chunyuan Liao, and Haibin Ling. **A Single-shot-per-pose Camera-Projector Calibration System for Imperfect Planar Targets**. In *Adjunct Proceedings of the IEE International Symposium for Mixed and Augmented Reality.* 2018.