CIS II Project Plan Proposal
Motion Compensation and Evaluation of 3D Head Reconstruction

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Pediametrix Inc.

1 Goal

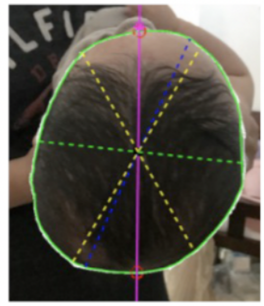
To be able to register the head of the patient using a 3D scanner, taking into account the motion of the head and there by be able to compensate for it to attain rigid registration to further use the registered points to generate a smooth mesh of the scan.

2 Background

It has been shown that over 20% of the babies have head deformities. These deformities are many times difficult to detect and often times, in later stage presents many challenges like difficult or expensive treatment, complications of delayed treatment and so on.

However, there aren't any specialised tools being used today to measure such deformities. Currently, the doctors use a measure tape to measure dimensions of baby head like the circumference and the diameter to measure quantities like Cranial Value Index - CVI and determine whether deformities are present or not.

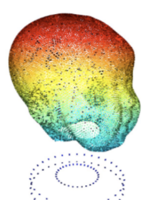
Pediametrix currentl uses 2D vision methods to automate measuring circumference and diameters and measures the CVI as shown below:

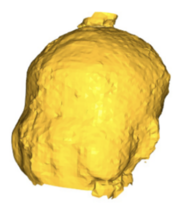


However, 2D methods are not able to capture in detail the topologoy of the head to fully scan and determine whether deformity is present or not. For e.g., 2D scans cannot contain information about the depth at a certain region.

Hence, a 3D scanner is used to scan the head in 3D and generate a 3D model to fully captures the detail which are not covered by 2D vision based techniques.

A 3D scanner is used to capture snapshots of the baby head from various directions and an ICP algorithm registers the points. After attaining the registration and thresholding to extract the points representing the head, a surface reconstruction algorithm is used to reconstruct a smooth mesh from the registered points as shown below:





The problem with the current pipeline is that it only works for static scans, i.e., it only works when head is not moving when taking scans. It also still produces artifacts when reconstructing surface because of certain outliers or the algorithm not being robust.

3 Technical Approach

3.1 Motion Compensation

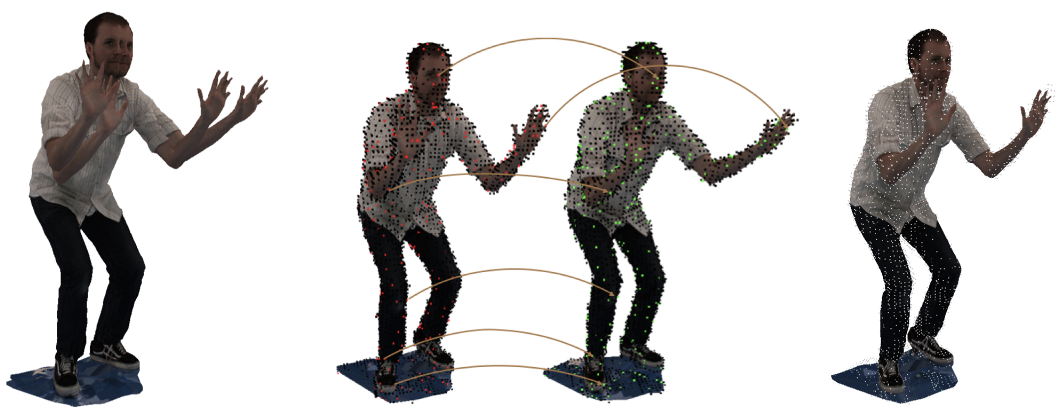
First, an algorithm to estimate and compensate for motion in scanning is to be developed and tested. For this, we are to take methods currently being researched.

The first one to test out is from Microsoft Inc.[1], using graph-based approached.

In this, the point clouds are first converted to octree data structure to have efficient structure of the data. Next, K-means is used to extract some points from data which represent the geometry accurately. Such geometry compression is done in each scan.

Next, attributes like position of the node or color, in their paper, is encoded in the node of the graph using Fourier transform and weigthed based on their distance from the node. This embeds all the necessary information in graph of that particular scan. All such scans have their corresponding graphs and thus the problem of estimating motion now becomes feature matching on these graphs.

This achieved using feature matching based on Mahalanobis distance and obtained motion is then propagated on all the point clouds using polynomial function for smoothing purposes. A test from their paper is as follows[1]:



(d) $\mathcal{I}_t + \mathcal{I}_{t+1}$ (e) Correspondence between $\mathcal{I}_t$ and $\mathcal{I}_{t+1}$ (f) $\mathcal{I}_{t,mc} + \mathcal{I}_{t+1}$

Figure: Graph-based approach[1]

Another approach, is to find an invariant feature in overlapping scans which can be detected and to register based on that invariant feature.

An idea proposed in [2] is to apply spherical Fourier transform to find such feature and match in different domain like the harmonic features for orientation. This paper also assumes minimum overlap. The coarser alignment based on such features is obtained on in transformed domain and fine tuned using ICP. An example scan of their method is given below:

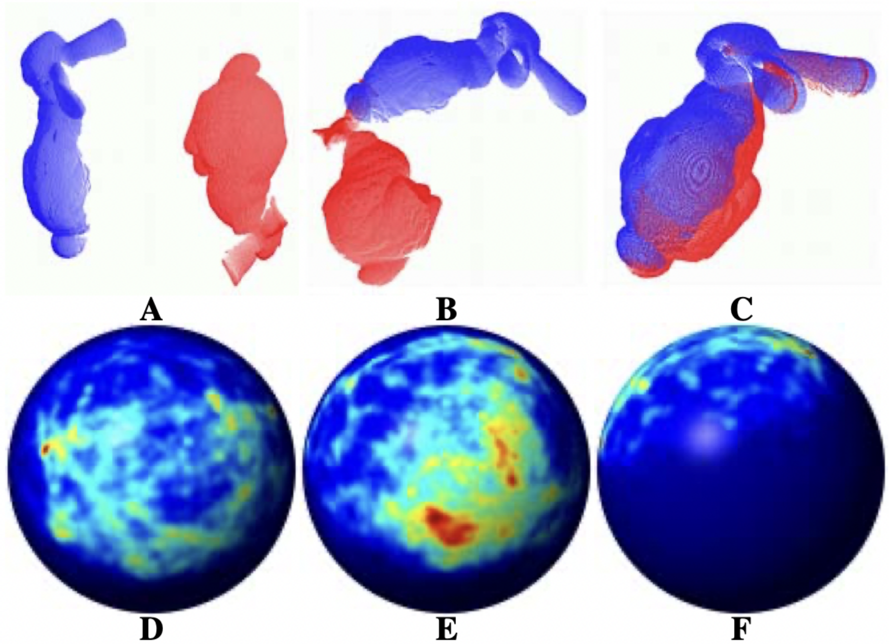


Figure: Transformed Base Domain approach[2]

Finally, the last method to explore uses Artificial Intelligence based approach. A neural network is modeled and trained on training data to detect, estimate and compensate for the motion. Some models are also trained just to measure the movement in consecutive scans, the output of which can be used in compensation, wihtout having to train the model on specialised situations or data.

Loop closure is also to be tested, to see it's impact on the final scan, as well as make sure it can account for the noisy data due to motion.

3.2 3D Reconstruction

Currently, an older method is used, Poisson's reconstruction to construct 3D model from the point clouds.

However, since it has been proposed, there are many variants and many newer algorithms have been proposed which need to be tested with the existing pipeline and tested thoroughly to check which algorithm works best with the data that we work with.

Some currently researched techniques includes Neural Networks, Genetic Algorithm, Particle Swarm Optimization, Differential Evolution and so on.

4 Deliverables

Minimum:

- Data collection at various stages
- Working pipeline for a few algorithmic approaches
- Accuracy Evaluation for both static and moving models:
  <2 mm average surface distance, ± 2.5

Expected:

- All of minimum deliverables
- Testing and documentation of more than 3 algorithms
- Accuracy Evaluation for both static and moving models:
  <2 mm average surface distance, ± 1.5

Maximum:

- All of expected deliverables
- Building a simulation environment and pipeline for data extraction for testing using CoppelliaSim software

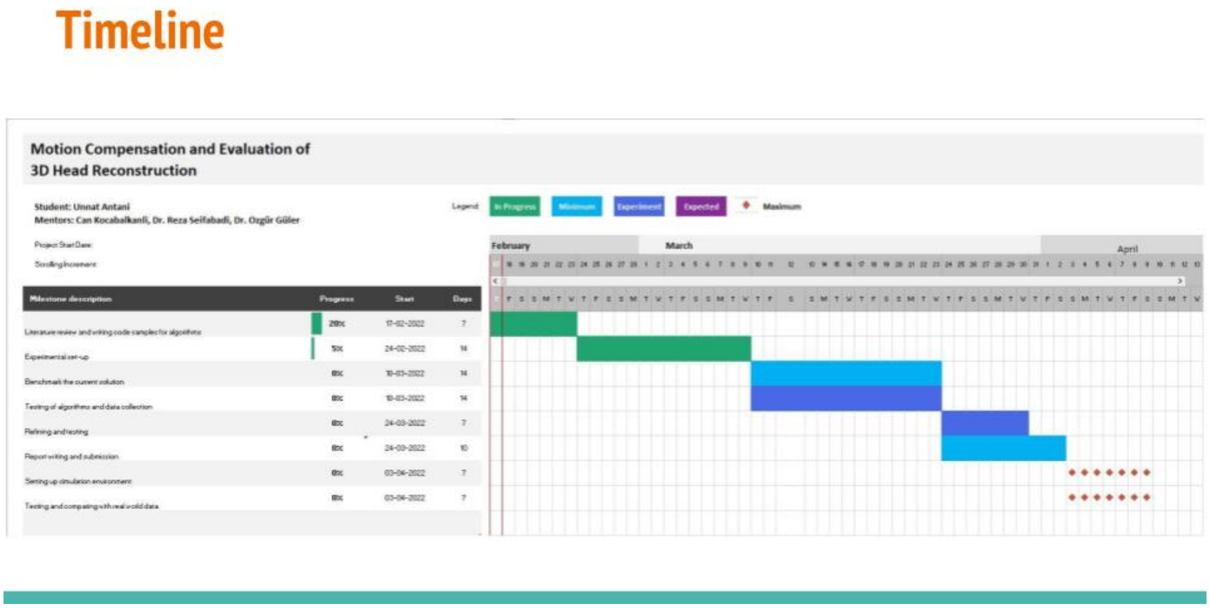
5 Dependencies

The dependecy table is as follows:

Dependency	Type	Expected	Impact
iPad	Hardware	Received	Delay in testing and deployment
Occipital Sensor	Hardware	Received	Delay in testing and deployment
Baby phantom head	Hardware	Received	Delay in testing and deployment
Aurora Sensor	Hardware	14 March, 2022	Delay in testing
Elliptical Motion Generator	Hardware	14 March, 2022	Delay in testing
AWS Access	Software	7 March, 2022	Delay in testing and deployment
Phantom 3D Models	Software	Received	Delay in testing and deployment
Source code	Software	Received	Delay in testing and deployment

The resolution of every delay is to create a simulation environment using CopelliaSim Software and conduct all the testing and data gathering from there.

6 Key Dates



7 Management Plan

- Weekly meeting with mentors on Tuesday
- Files and documents shared via drive
- Slack channel for discussion and file sharing
- Code and Version management via GitHub

8 Reading List

References

[1] Thanou, Dorina and Chou, Philip and Frossard, Pascal (2015) *Graph-Based Compression of Dynamic 3D Point Cloud Sequences*, IEEE Transactions on Image Processing.

[2] Makadia, A. and Patterson, A. and Daniilidis, K. (2006) *Fully Automatic Registration of 3D Point Clouds*, IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'06).

[3] Xuyan Zou and Hanwu He and Yueming Wu and Youbin Chen and Mingxi Xu (2020) *Automatic 3D point cloud registration algorithm based on triangle similarity ratio consistency*, IET Image Process.

[4] Gojcic, Zan and Litany, Or and Wieser, Andreas and Guibas, Leonidas and Birdal, Tolga (2021) *Weakly Supervised Learning of Rigid 3D Scene Flow*, IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR).