Augmented Reality for Orthopedic and Trauma Surgery

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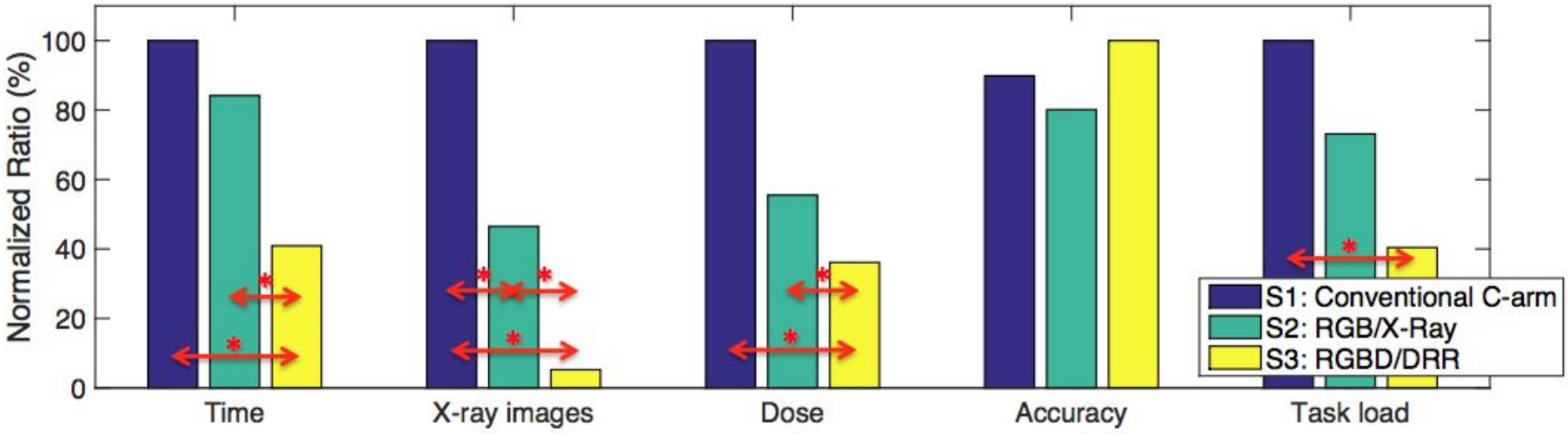
Project 6

Background

Orthopaedic surgeries are time intensive and require multiple images to ensure correct placement and direction of tools

Research has been done to create a manual calibration algorithm, that creates an intra-operative mixed-reality visualization

Minimizes: Time, X-ray images, Radiation Dosage, Task load



Objective

Automate the calibration process between CBCT scanner and RGBD camera.
Create standalone program with minimal dependencies.

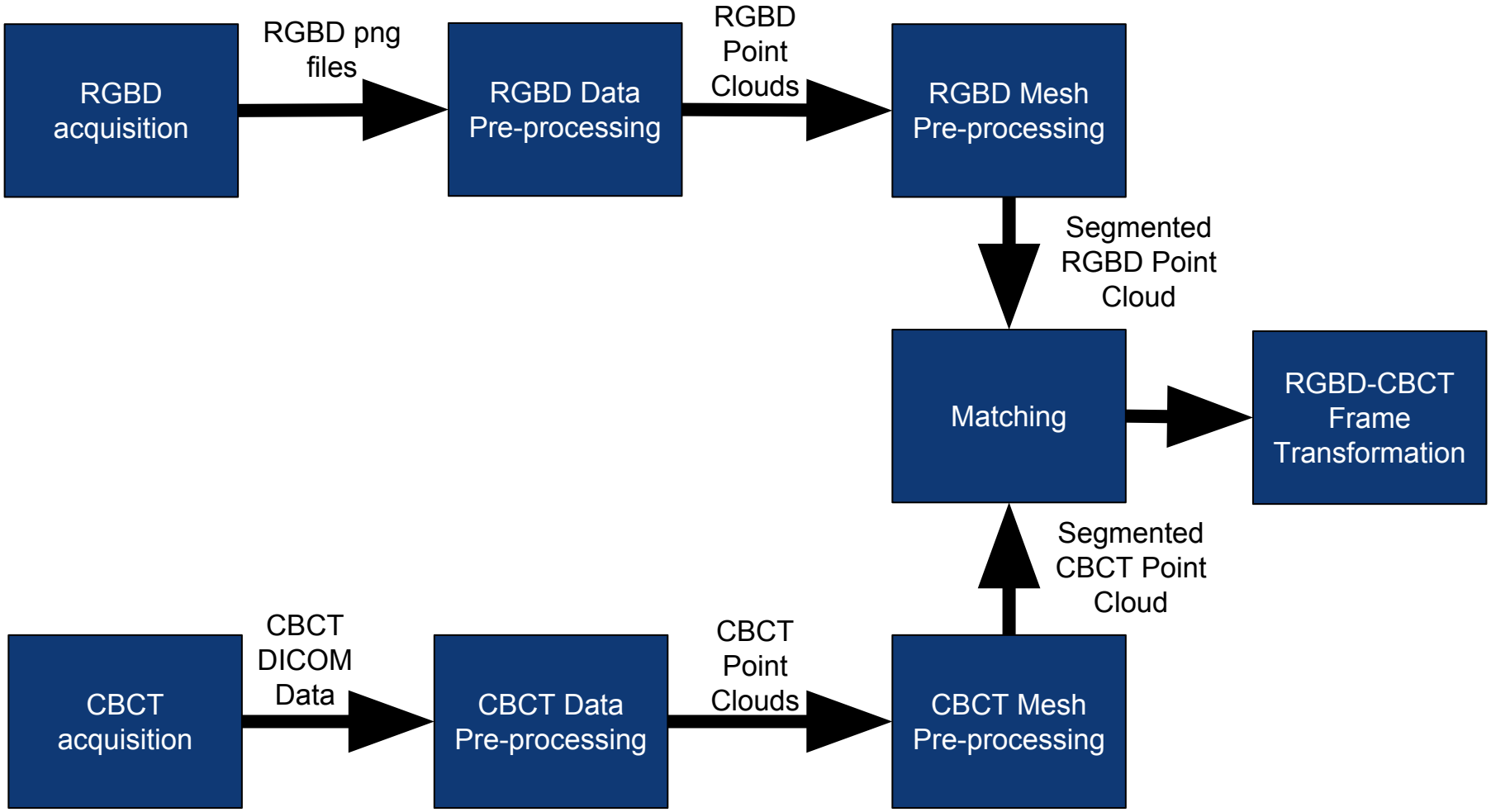
Manual Calibration Steps:

CBCT and RGBD Data Pre-processing - Done in ImFusion SDK
- KinFu generates the surface and export as point clouds
- Segmentation on CBCT and export meshes

Mesh Pre-processing- Done in MeshLab
- Create improved phantom
- Extract the useful point clouds in KinFu and MeshLab

Point Cloud Matching - Done in PCL
- Transform the point clouds to PCL pcd format
- FPFH for initialization, ICP for registration

Information Flow



Deliverables

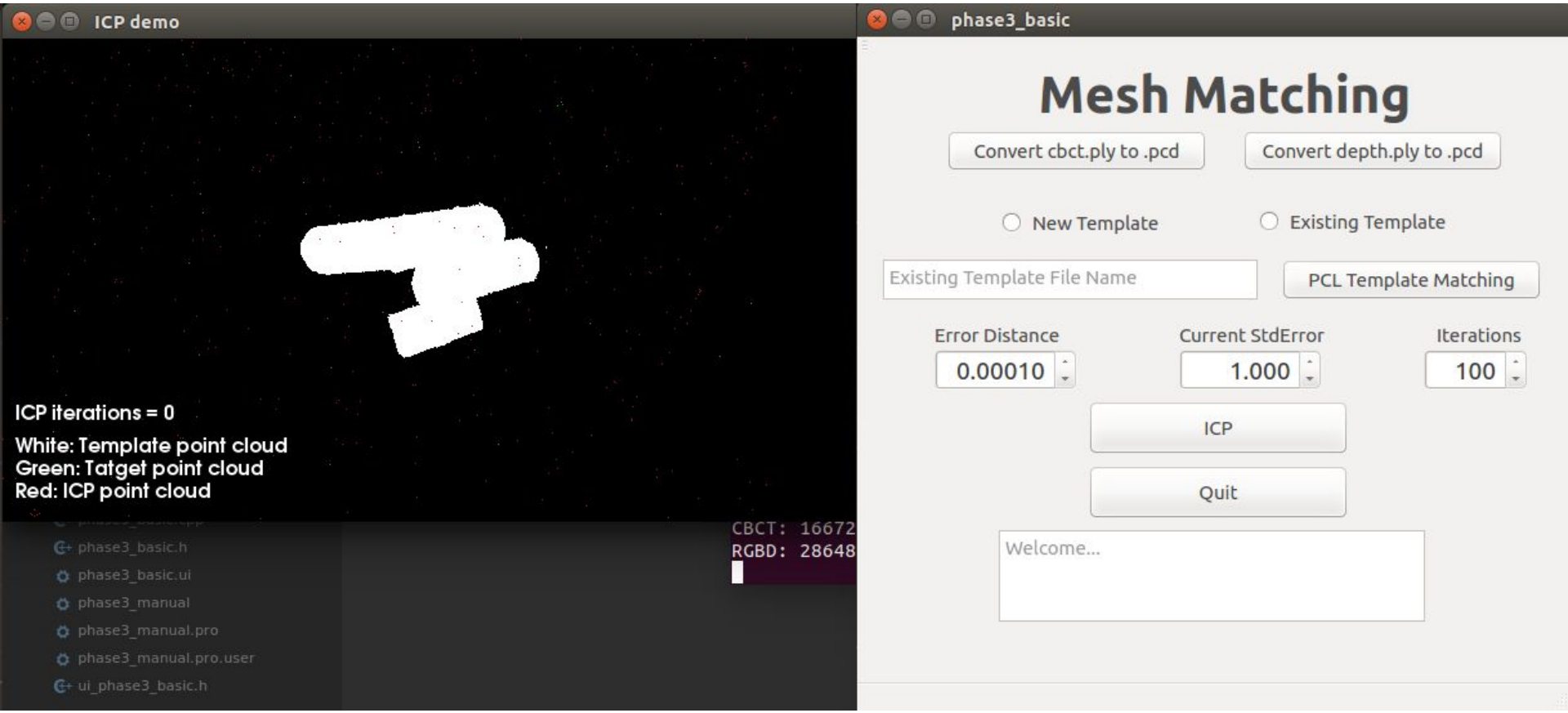
- **Minimum:** (COMPLETED: 03/04/2016)
  - Mentor meetings
  - Understand manual calibration
  - Develop automated calibration
  - Automated Matching of CBCT-RGBD
- **Expected:** (IN PROGRESS: 04/15/2016)
  - Automated CBCT Data Pre-processing
  - Automated RGBD Data Pre-processing
  - RGBD and CBCT Point Cloud Processing
- **Maximum:** (04/29/2016)
  - Research improved algorithm
  - Present Implementation
  - Implement (Not sure if will achieve, but hopeful)

Completed Milestones - Matching

Objective: Create an automated algorithm in PCL to take a post-processed CBCT and RGBD point cloud and complete registration

- Created a GUI to run this process (on next slide)
- GUI Inputs:
  - CBCT PLY File Input (Processed Point Cloud)
  - RGBD PLY File Input (Processed Point Cloud)
  - Convergence Criteria:
    - Max Iterations
    - Error
    - Distance between subsequent errors
- Outputs timestamped file with registration
  - P_RGBD = F * P_CBCT

Screenshot


ICP demo
ICP iterations = 0
White: Template point cloud
Green: Tatget point cloud
Red: ICP point cloud
CBCT: 16672
RGBD: 28648
phase3_basic.h
phase3_basic.ui
phase3_manual
phase3_manual.pro
phase3_manual.pro.user
ui_phase3_basic.h
phase3_basic
Mesh Matching
Convert cbct.ply to .pcd
Convert depth.ply to .pcd
New Template
Existing Template
Existing Template File Name
PCL Template Matching
Error Distance
0.00010
Current StdError
1.000
Iterations
100
ICP
Quit
Welcome...

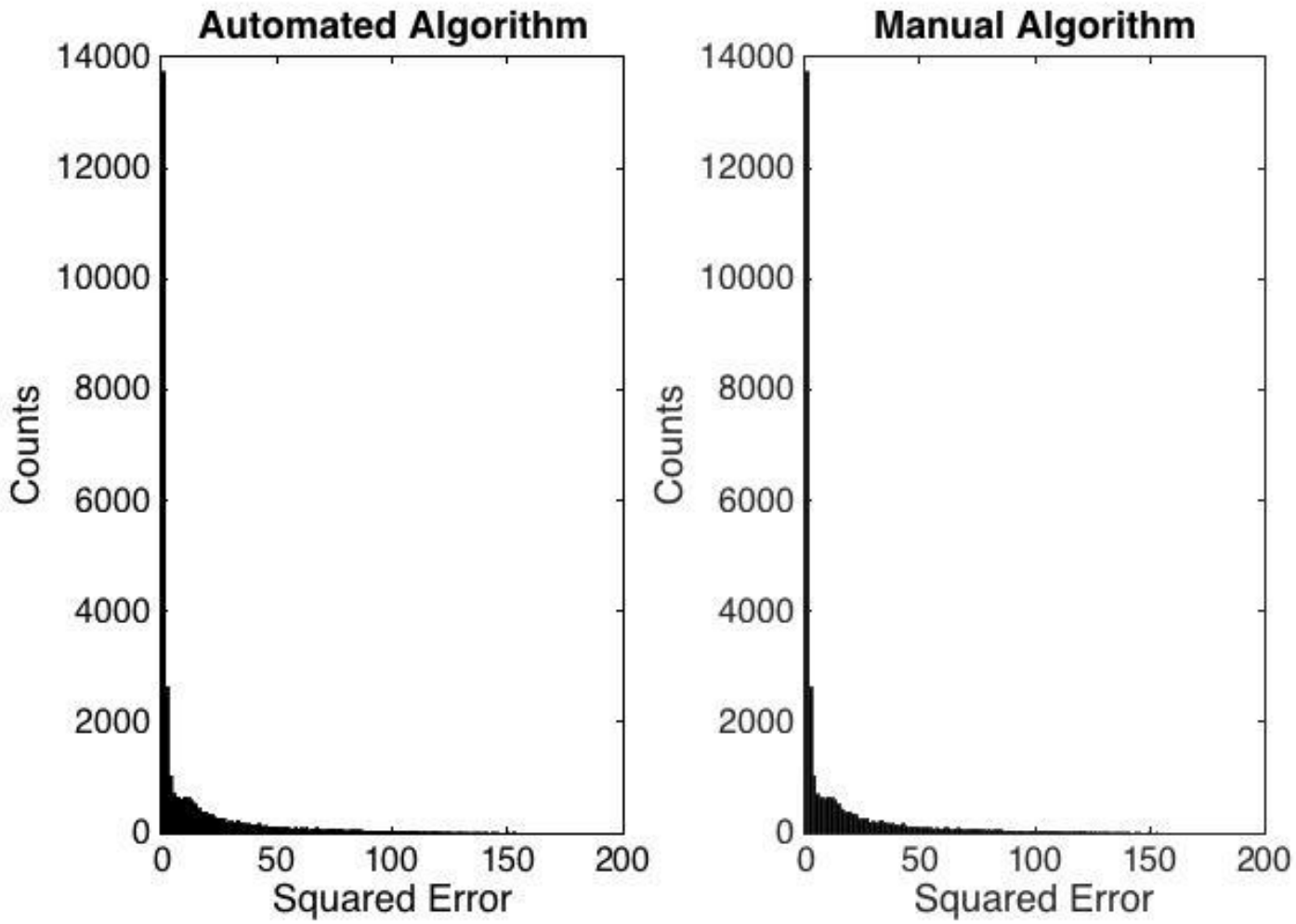
Mathematical Approach - Convergence

- Runs existing matching algorithm given by Sing Chun and Bernhard
- CREATED: Automated convergence criteria
  - Was previously a manual step-by-step ICP
- Converge ICP on:
  - Fitness Score (sum of squared errors)
  - Asymptote
  - Reach max iterations
- Issue: Unequal point clouds and outliers - PCL Nearest Neighbor

$$Fitness = \sum_{matched\ points} (p_{CBCT} - p_{RGBD})^2$$

P_CBCT = 3D CBCT point on mesh
P_RGBD = 3D RGBD point on mesh
Matched using PCL KD-Tree

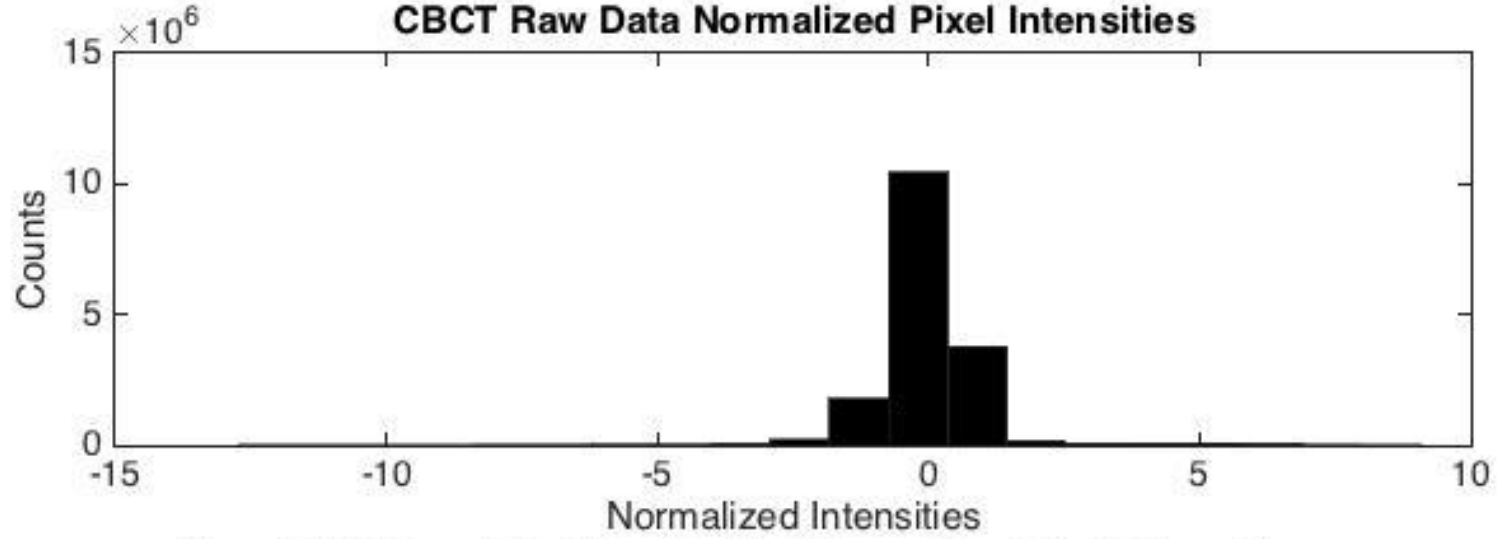
Comparison of Nearest Neighbor Squared Distance between RGBD and Transformed CBCT

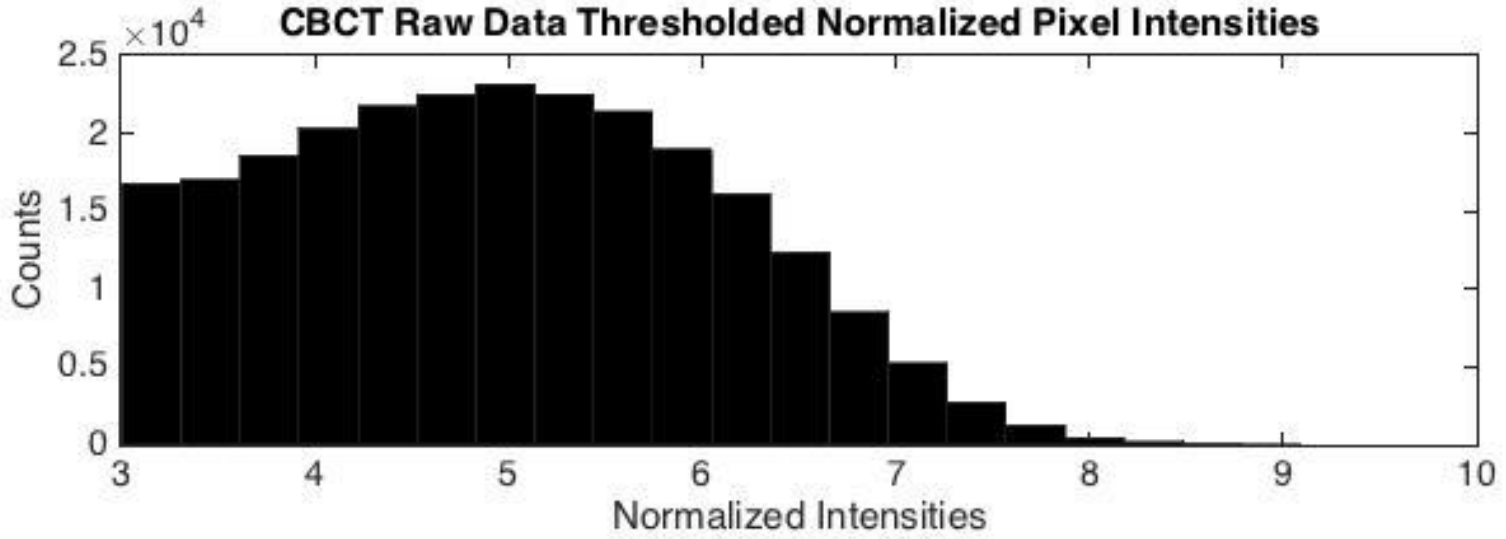


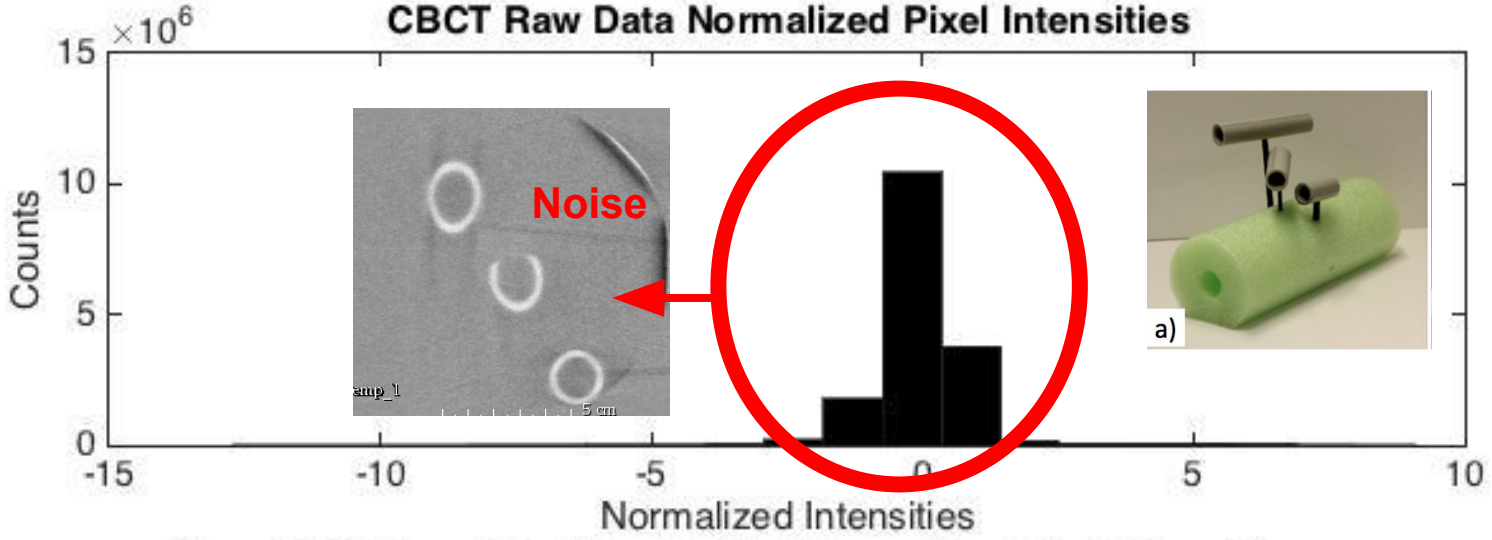
Completed Milestones - CBCT Data Pre-Processing

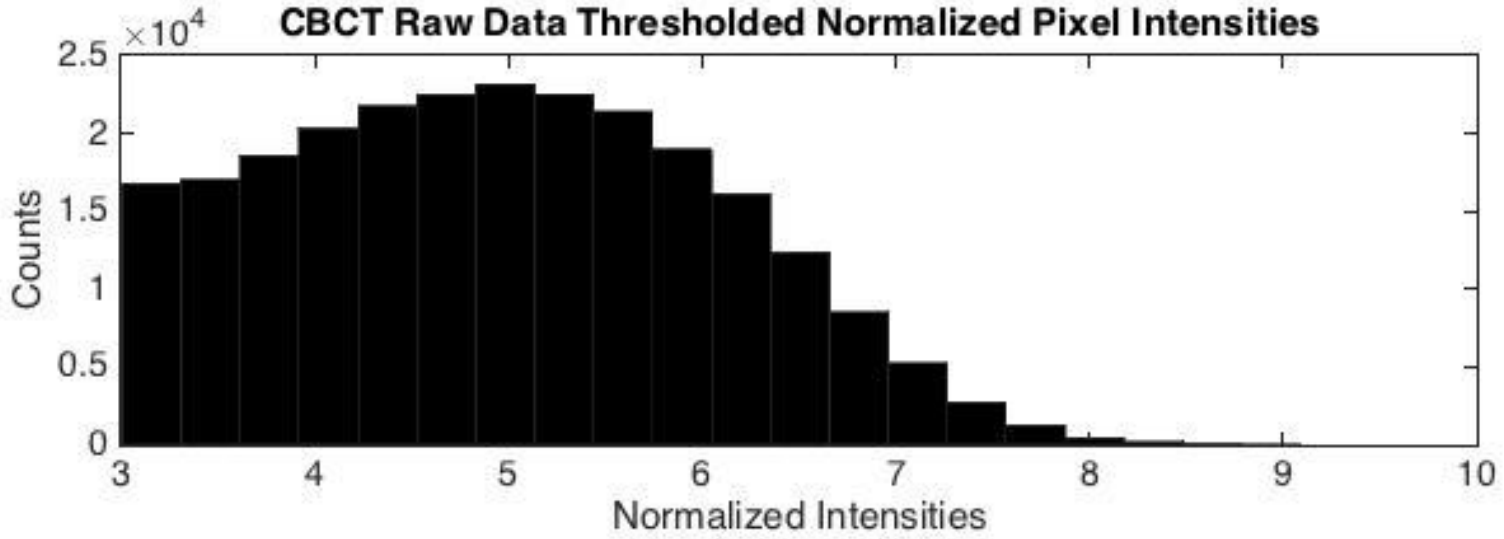
Objective: Take DICOM Data and make point cloud with high intensity inputs

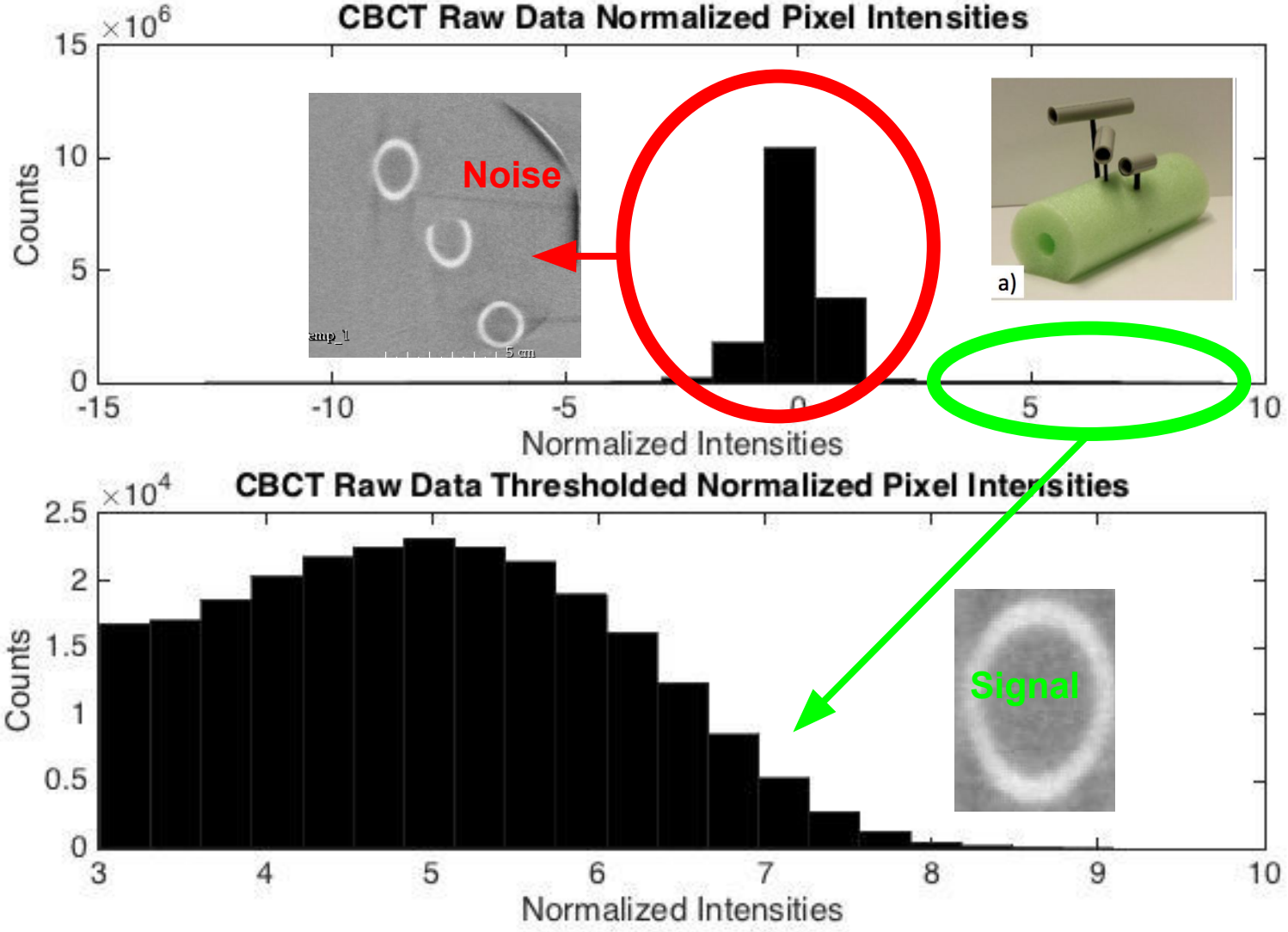
- Combine into a single file object using ITK
- Normalize the intensity data (next slides)
- Threshold to remove unwanted data (next slides)
- Save into an output a file that can be read by PCL
- GUI Inputs:
  - DICOM Folder
  - Threshold Range (Will explain on next slide)
    - Low standard deviation away from mean
    - High standard deviation away from mean


CBCT Raw Data Normalized Pixel Intensities
×10^6
15
10
5
0
Counts
-15
-10
-5
0
5
10
Normalized Intensities

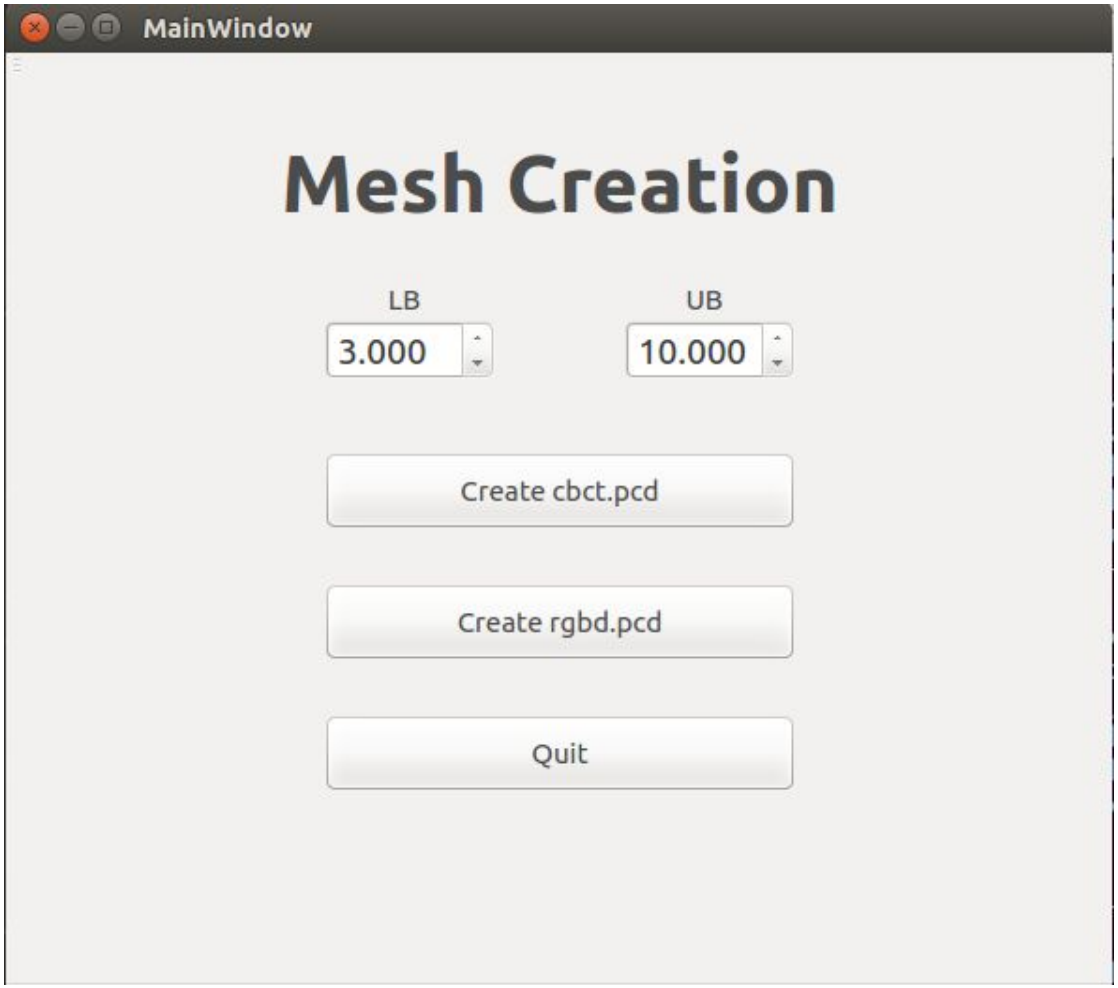

CBCT Raw Data Thresholded Normalized Pixel Intensities
×10^4
2.5
2
1.5
1
0.5
0
Counts
3
4
5
6
7
8
9
10
Normalized Intensities


CBCT Raw Data Normalized Pixel Intensities
×10^6
15
10
5
0
Counts
-15
-10
-5
0
5
10
Normalized Intensities
Noise
a)


CBCT Raw Data Thresholded Normalized Pixel Intensities
×10^4
2.5
2
1.5
1
0.5
0
Counts
3
4
5
6
7
8
9
10
Normalized Intensities


CBCT Raw Data Normalized Pixel Intensities
×10^6
Counts
Normalized Intensities
Noise
a)
CBCT Raw Data Thresholded Normalized Pixel Intensities
×10^4
Counts
Normalized Intensities
Signal

Screenshot


MainWindow
Mesh Creation
LB
3.000
UB
10.000
Create cbct.pcd
Create rgbd.pcd
Quit

Current Milestone - RGBD Data Pre-Processing

Objective: Take RGB and Depth .png files and make .pcd point cloud.

Combine into a single .pcd file using PCL.

- Combine pairs of corresponding RGB and Depth .png files into point clouds.
- Remove null points and outliers using PCL filters.
- Compile all the point clouds into one mesh.
- In progress - select PCL filters and use KinFu plugin to create mesh

Challenges

- Compilation using CMake with PCL, ITK, and VTK, resolved after much troubleshooting with building libraries and locating dependencies.

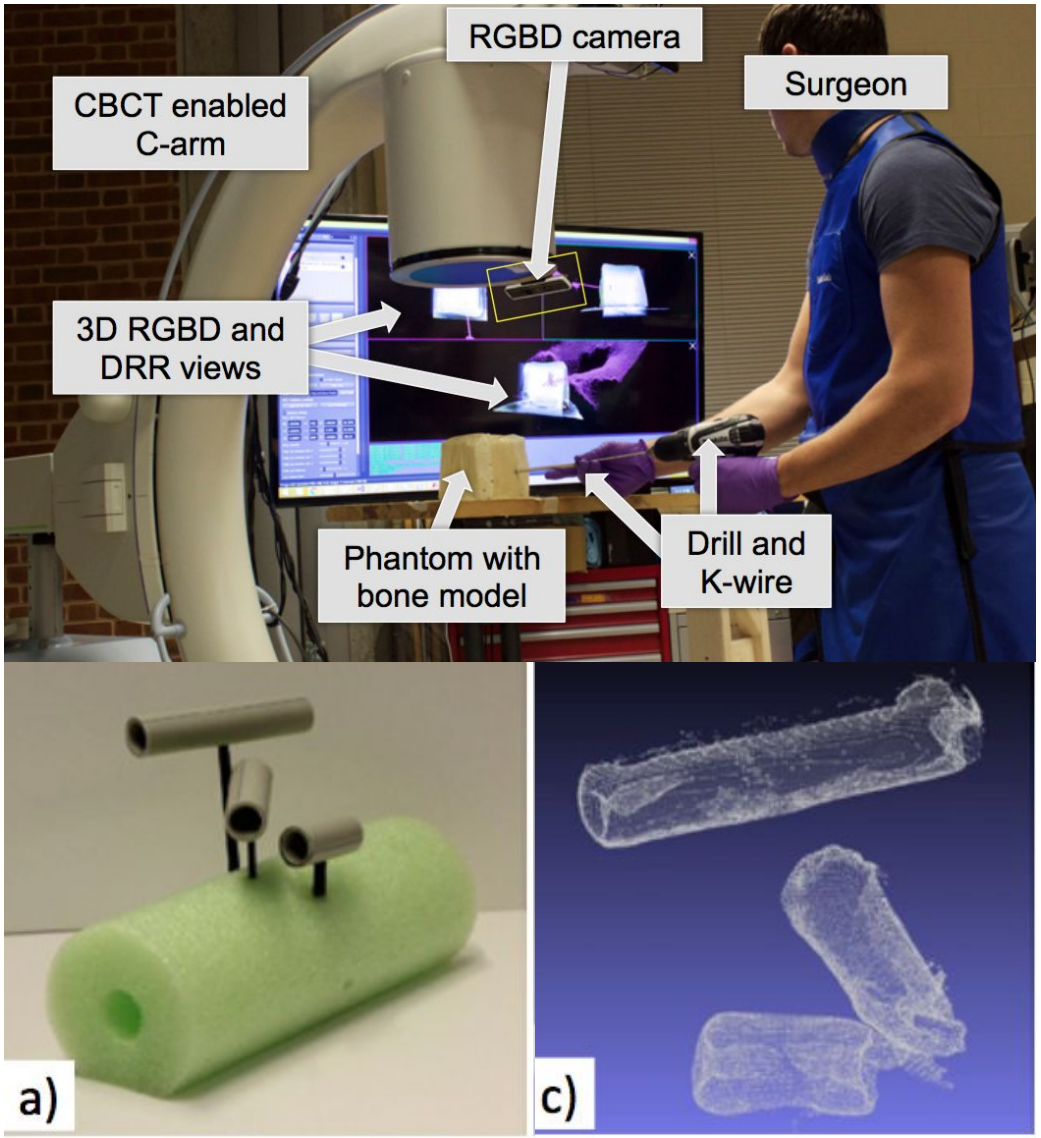
- Pre-processing step uses MeshLab which is an application, not a library, thus difficult to automate. Resolved by not using MeshLab and possibly improving the phantom to reduce pre-processing steps required.

- File formats from the different third-party applications, resolved by not using the third-party applications and maintaining direct compatibility with PCL. Currently working on manipulating file formats from .png to .pcl.

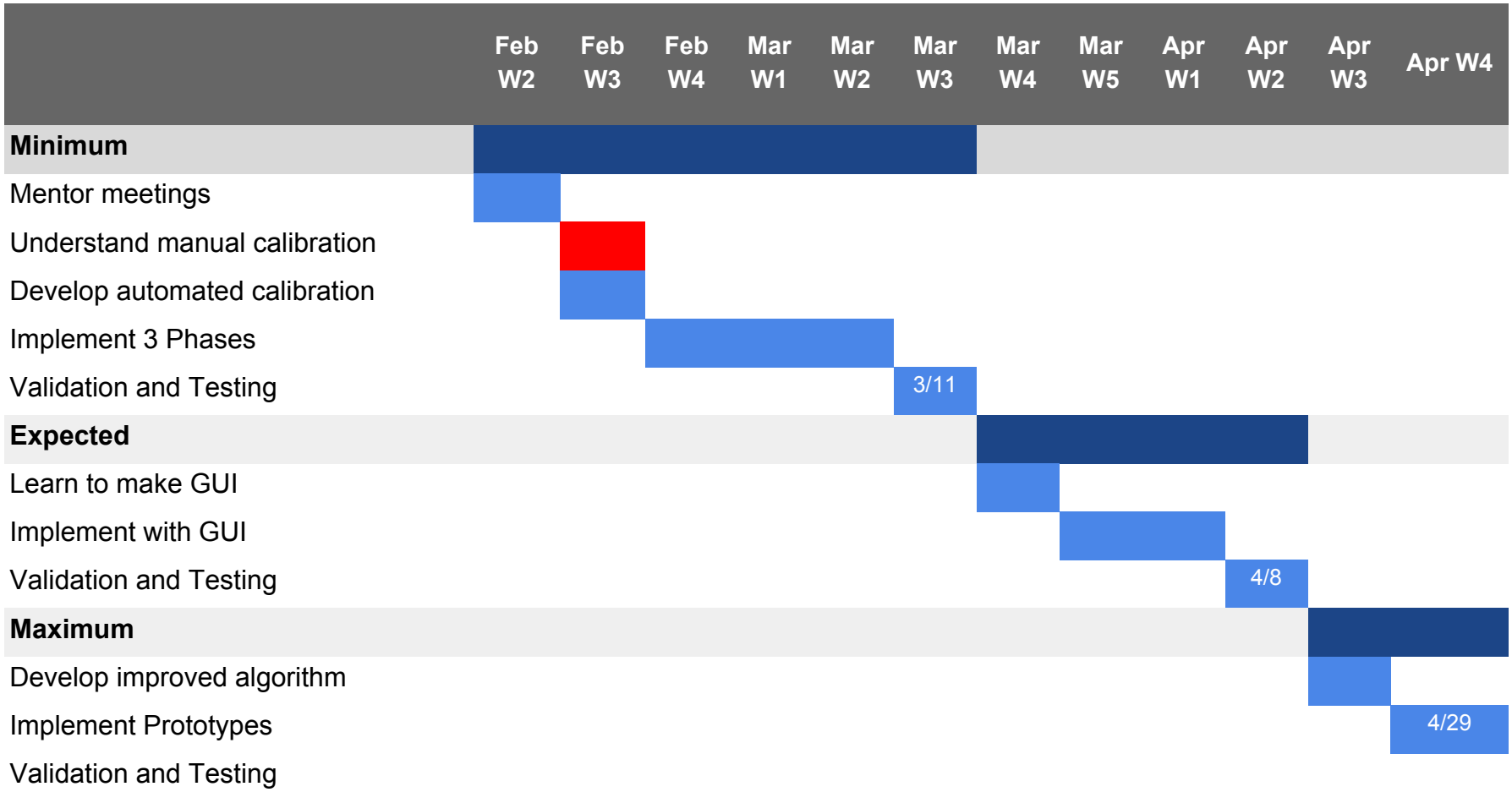
Dependencies

<u>Met</u>
Data: Created
Workspace: Mock OR
Technology: CBCT, RGBD
Software:MeshLab/PCL/ImFusion
Phantoms: Created and cheap
Code Backup: Bitbucket
Operating system
Data backup

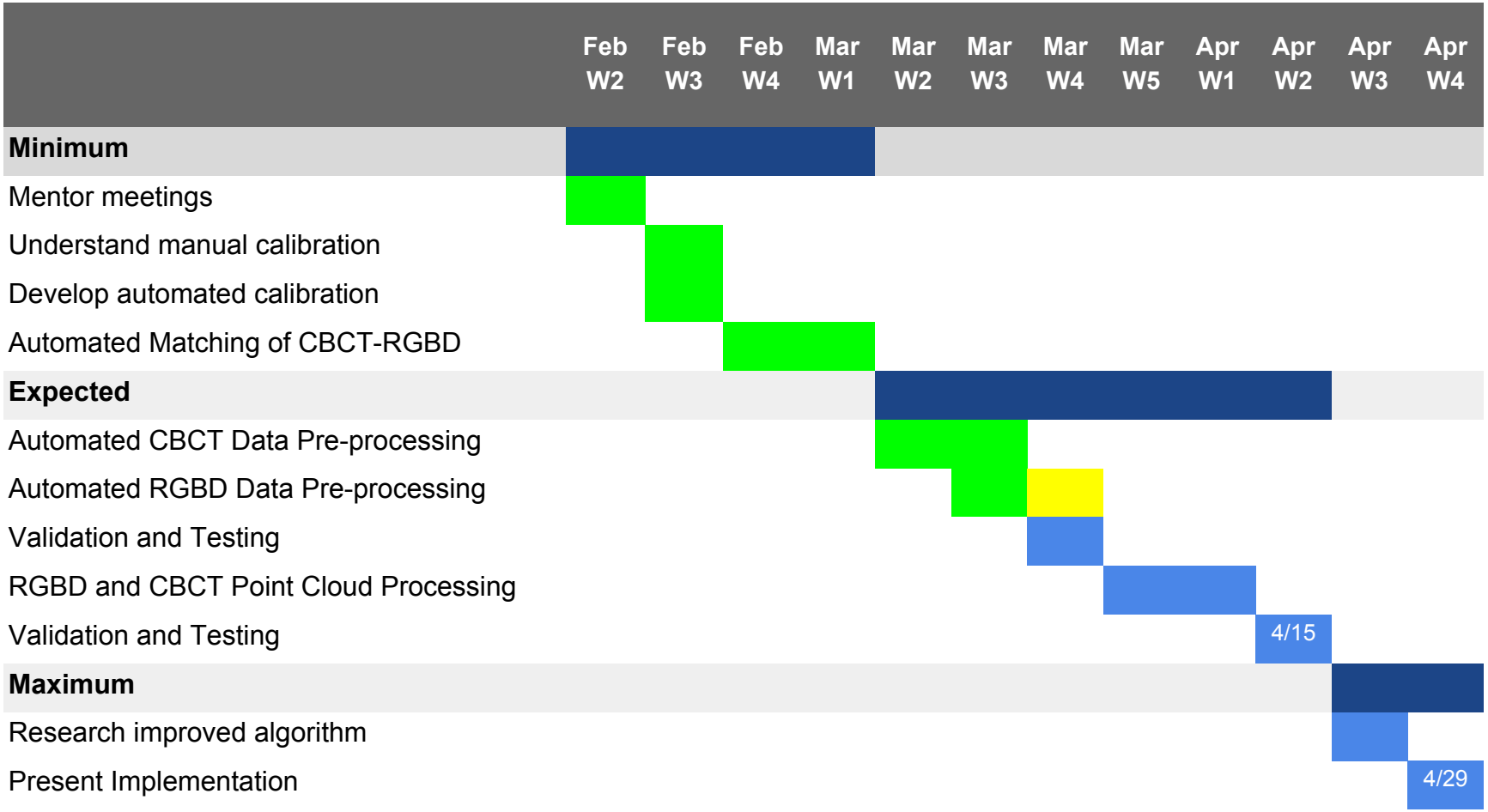
<u>Unmet</u>
Clinician input
Radiation Safety (potentially)



Old Timeline



New Timeline



Questions?

Reading List (Extended on Wiki)

Fischer M, Fuerst B, Lee SC, Fotouhi J, Habert S, Weidert S, Euler E, Osgood G, Navab N. Pre-Clinical Usability Study of Multiple Augmented Reality Concepts for K-Wire Placement. International Journal of Computer Assisted Radiology and Surgery / International Conference on Information Processing in Computer-Assisted Interventions (IPCAI), Heidelberg, June 2016.

Kojcev R, Fuerst B, Zettining O, Fotouhi J, Lee SC, Taylor R, Sinibaldi E, Navab N. Dual-Robot Ultrasound-Guided Needle Placement: Closing the Planning-Imaging-Action Loop. International Journal of Computer Assisted Radiology and Surgery / International Conference on Information Processing in Computer-Assisted Interventions (IPCAI), Heidelberg, June 2016

Lee SC, Fuerst B, Fotouhi J, Fischer M, Osgood G, Navab N. Calibration of RGBD Camera and Cone-Beam CT for 3D Intra-operative Mixed Reality Visualization. International Journal of Computer Assisted Radiology and Surgery / International Conference on Information Processing in Computer-Assisted Interventions (IPCAI), Heidelberg, June 2016.

Rusu RB, Blodow N, Beetz M. 2009. Fast point feature histograms (FPFH) for 3D registration. In Proceedings of the 2009 IEEE international conference on Robotics and Automation (ICRA'09). IEEE Press, Piscataway, NJ, USA, 1848-1853.

Rusu RB, Cousins S. 3D is here: Point Cloud Library (PCL). IEEE International Conference on Robotics and Automation (ICRA), Shanghai, China, May 2011.

Schroeder W, Martin KM, Lorensen WE. 1998. The Visualization Toolkit (2nd Ed.): An Object-Oriented Approach to 3D Graphics. Prentice-Hall, Inc., Upper Saddle River, NJ, USA.

Yoo TS, Ackerman MJ,Lorensen WE, Schroeder W, Chalana V, Aylward S, Metaxas D, Whitaker R. Engineering and Algorithm Design for an Image Processing API: A Technical Report on ITK - The Insight Toolkit. In Proc. of Medicine Meets Virtual Reality, J. Westwood, ed., IOS Press Amsterdam pp 586-592 (2002).