

# ESE580 Final Project: Structure from Motion

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## RANSAC to reject outliers



Figure 1: RANSAC matches shown across images 1 and 4

The Fundamental Matrix:

$$F = \begin{bmatrix} -0.0000 & 0.0000 & -0.0089 \\ -0.0000 & 0.0000 & 0.0032 \\ 0.0131 & -0.0021 & -0.9999 \end{bmatrix}$$

Number of Inliers:

images 1 and 2. Percent inliers = 1.000000  
images 1 and 3. Percent inliers = 0.996711  
images 1 and 4. Percent inliers = 0.980851  
images 2 and 3. Percent inliers = 1.000000  
images 2 and 4. Percent inliers = 0.999068  
images 3 and 4. Percent inliers = 0.999564  
images 3 and 5. Percent inliers = 1.000000  
images 3 and 6. Percent inliers = 1.000000  
images 4 and 5. Percent inliers = 1.000000  
images 4 and 6. Percent inliers = 1.000000  
images 5 and 6. Percent inliers = 0.934351

## Triangulation and Initial Camera Poses

The Essential Matrix:

$$E = \begin{bmatrix} -0.0578 & 0.7054 & 0.0416 \\ -0.7503 & 0.0334 & -0.6579 \\ 0.0019 & 0.7012 & 0.0938 \end{bmatrix}$$

4 Possible Camera Poses:

$$C_1 = \begin{bmatrix} -0.7052 \\ 0.0562 \\ 0.7068 \end{bmatrix}$$

$$R_1 = \begin{bmatrix} -0.0659 & 0.0533 & -0.9964 \\ 0.0026 & -0.9986 & -0.0536 \\ -0.9978 & -0.0061 & 0.0657 \end{bmatrix}$$

$$C_2 = \begin{bmatrix} -0.7052 \\ 0.0562 \\ 0.7068 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} -0.0659 & 0.0533 & -0.9964 \\ 0.0026 & -0.9986 & -0.0536 \\ -0.9978 & -0.0061 & 0.0657 \end{bmatrix}$$

$$C_3 = \begin{bmatrix} 0.7052 \\ -0.0562 \\ -0.7068 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.9948 & 0.0849 & -0.0559 \\ -0.0765 & 0.9876 & 0.1374 \\ 0.0669 & -0.1324 & 0.9889 \end{bmatrix}$$

$$C_4 = \begin{bmatrix} -0.7052 \\ 0.0562 \\ 0.7068 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0.9948 & 0.0849 & -0.0559 \\ -0.0765 & 0.9876 & 0.1374 \\ 0.0669 & -0.1324 & 0.9889 \end{bmatrix}$$

Camera Pose Configurations 3D Visual:

## Nonlinear Triangulation

Linear Triangulation compared to Nonlinear Triangulation:

Projections of Triangulations onto the Image:

## PnP RANSAC

Camera Poses and Number of Inliers: Camera 2:

$$C_2 = \begin{bmatrix} -0.1561 \\ -0.0225 \\ 0.2433 \end{bmatrix}$$

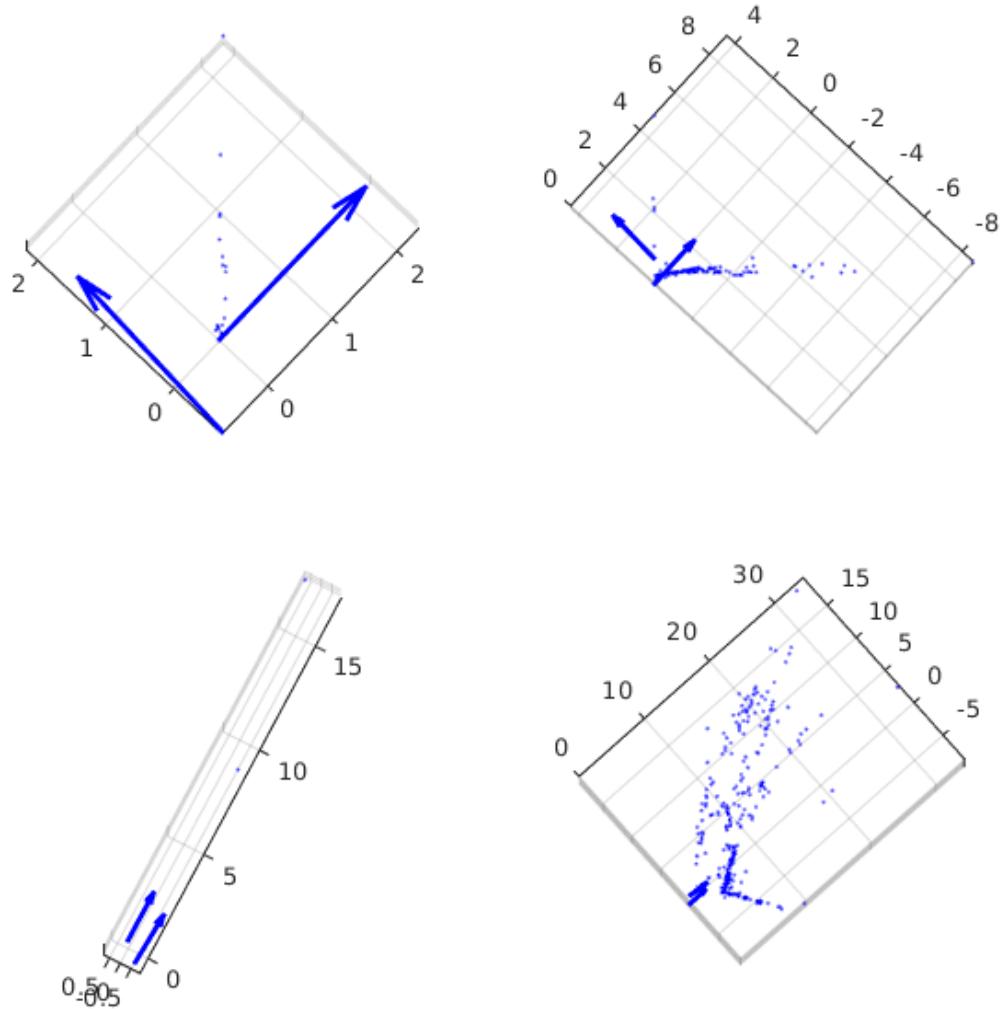


Figure 2: This visual shows the 4 camera poses with triangulated 3D points. Camera pose 4 was chosen.

$$R_2 = \begin{bmatrix} 0.9740 & 0.0639 & -0.2173 \\ -0.0264 & 0.9849 & 0.1714 \\ 0.2250 & -0.1612 & 0.9609 \end{bmatrix}$$

Kept 198 inliers of 198 Nonlinear PnP Points.

Camera 3:

$$C_3 = \begin{bmatrix} -0.4751 \\ 0.0077 \\ 0.4020 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.9986 & 0.0475 & -0.0231 \\ -0.0431 & 0.9851 & 0.1664 \\ 0.0306 & -0.1652 & 0.9858 \end{bmatrix}$$

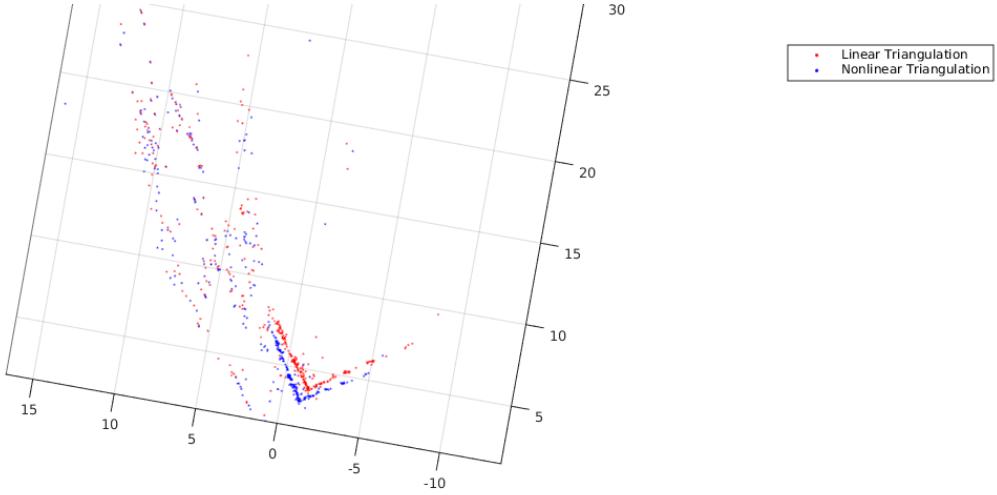


Figure 3: This visual shows non-linear and linear triangulation on the same plot. Top view.

Kept 661 inliers of 717 Nonlinear PnP Points.

Camera 5:

$$C_5 = \begin{bmatrix} -0.8299 \\ 0.0783 \\ 0.9752 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0.9655 & -0.0208 & -0.2595 \\ 0.0601 & 0.9877 & 0.1446 \\ 0.2533 & -0.1552 & 0.9548 \end{bmatrix}$$

Kept 385 inliers of 421 Nonlinear PnP Points.

Camera 5:

$$C_5 = \begin{bmatrix} -1.1776 \\ 0.0628 \\ 1.1814 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0.9610 & 0.0534 & -0.2713 \\ -0.0066 & 0.9853 & 0.1706 \\ 0.2764 & -0.1622 & 0.9473 \end{bmatrix}$$

Kept 478 inliers of 640 Nonlinear PnP Points.

Added Camera in 3D Reconstruction:

## Nonlinear PNP

2D Projection of 3D Points using Linear PNP and Nonlinear PNP Transforms:

## Bundle Adjustment

The Final Bundle: I was able to reconstruct all 6 cameras and 9971 points.

2D Reprojections of 3D Points onto each Camera/Image:

3D Point Cloud Colored by Camera:

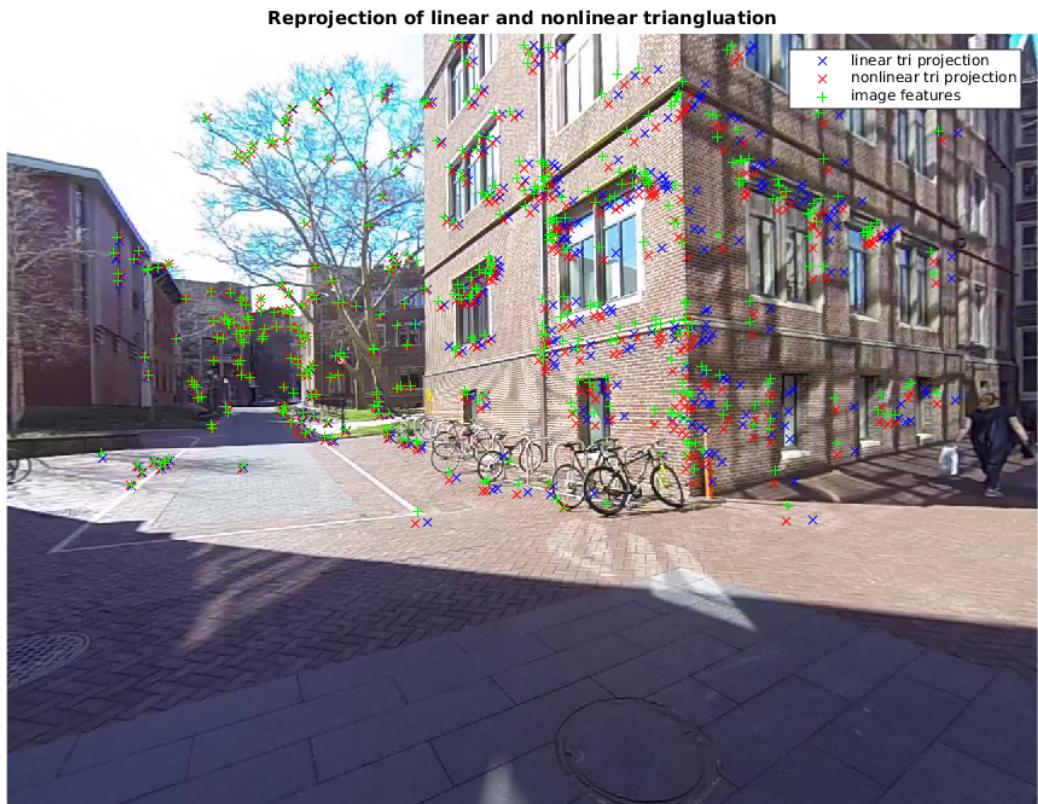


Figure 4: This image shows the noticeable difference between non-linear and linear triangulation. It is more apparent in the right of the image.

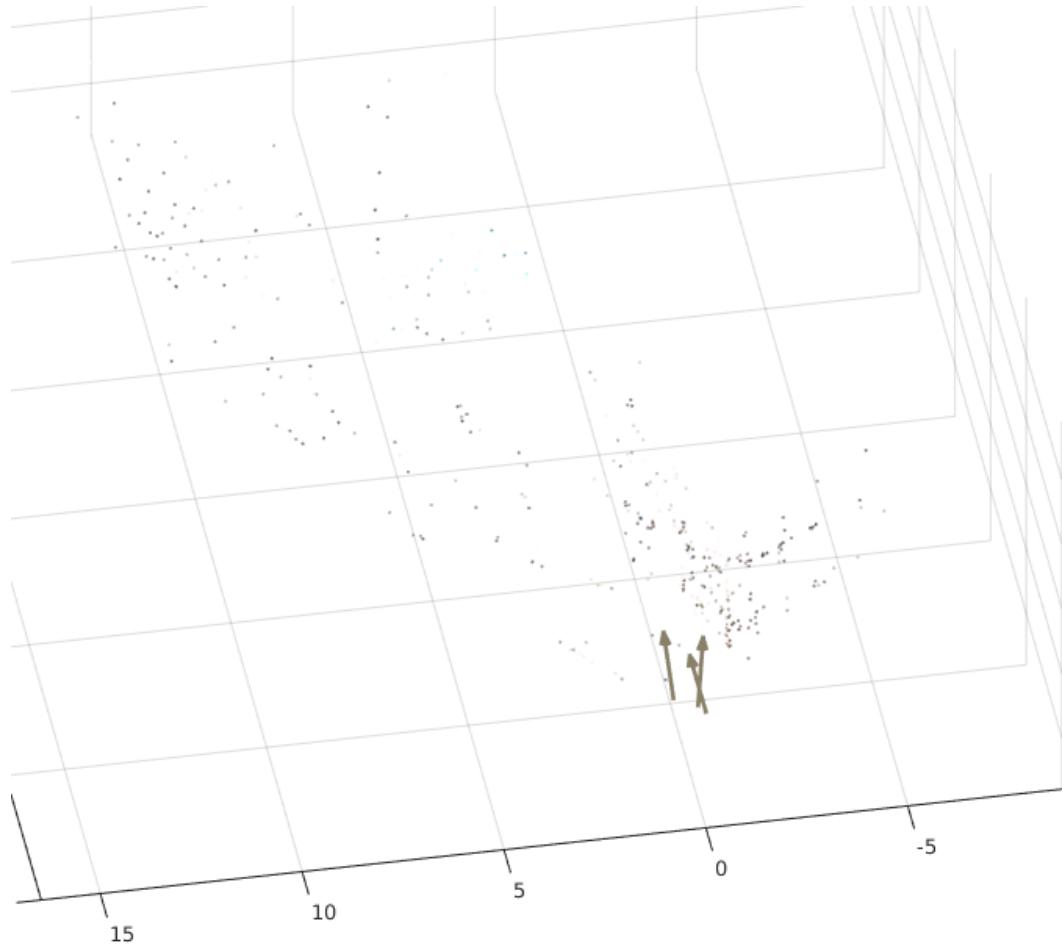


Figure 5: The cameras are shown as gray arrows. Notice they all point toward the structure starting to form.



Figure 6: This image is a zoomed in image to show to projection errors. Notice the nonlinear PnP points are closer to to actual feature that the linear PnP points

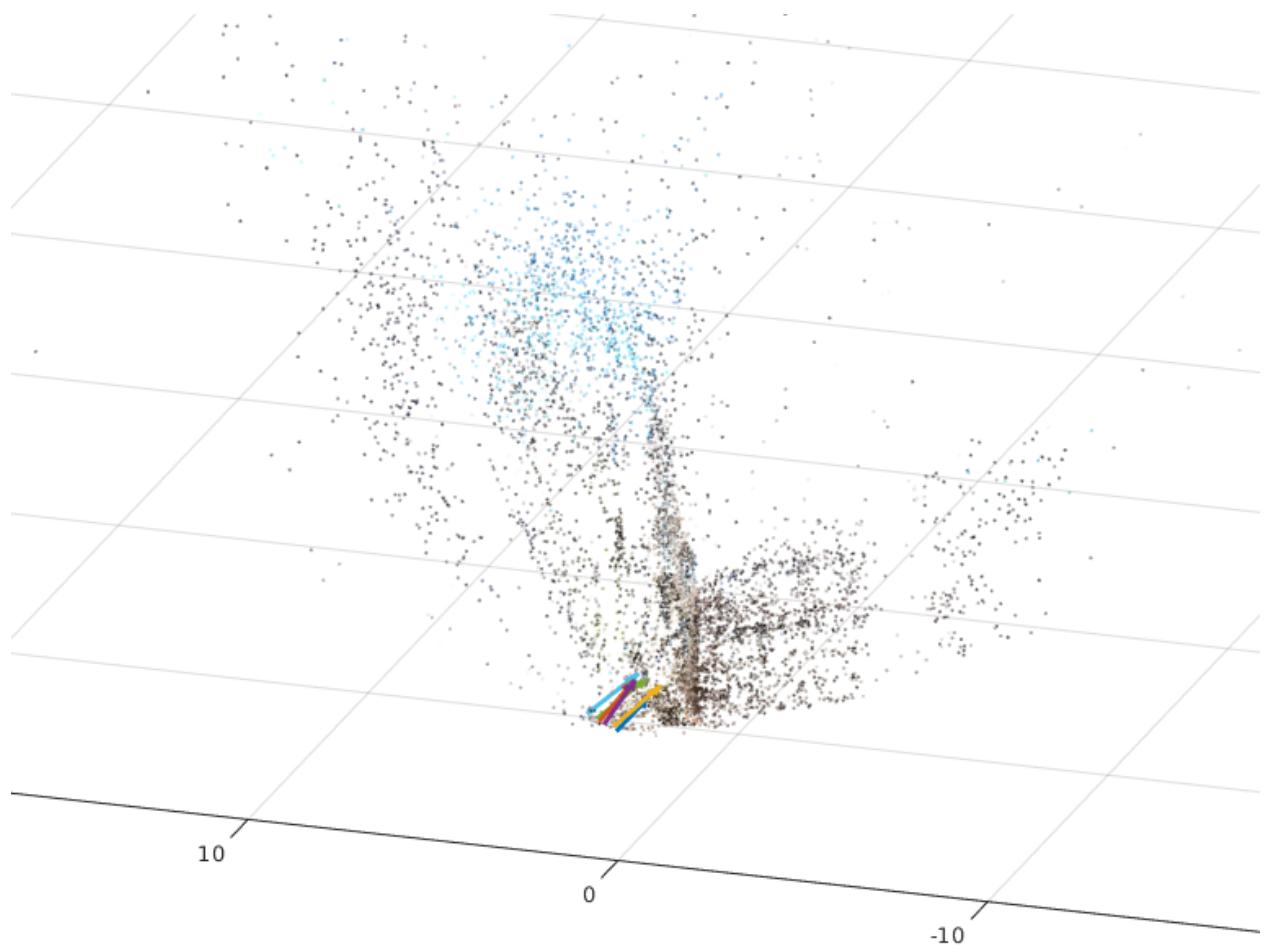


Figure 7: This plot shows the final point cloud reconstruction with the colors mapped from the original images

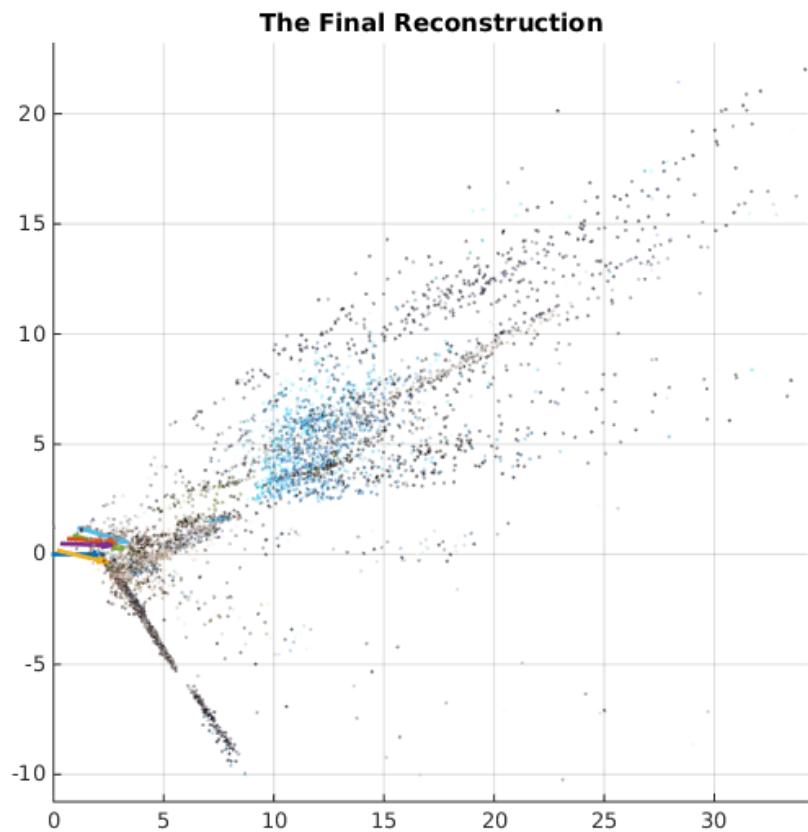


Figure 8: This plot shows the final point cloud reconstruction with the colors mapped from the original images. top view.



Figure 9: 3D structure projection onto image 1

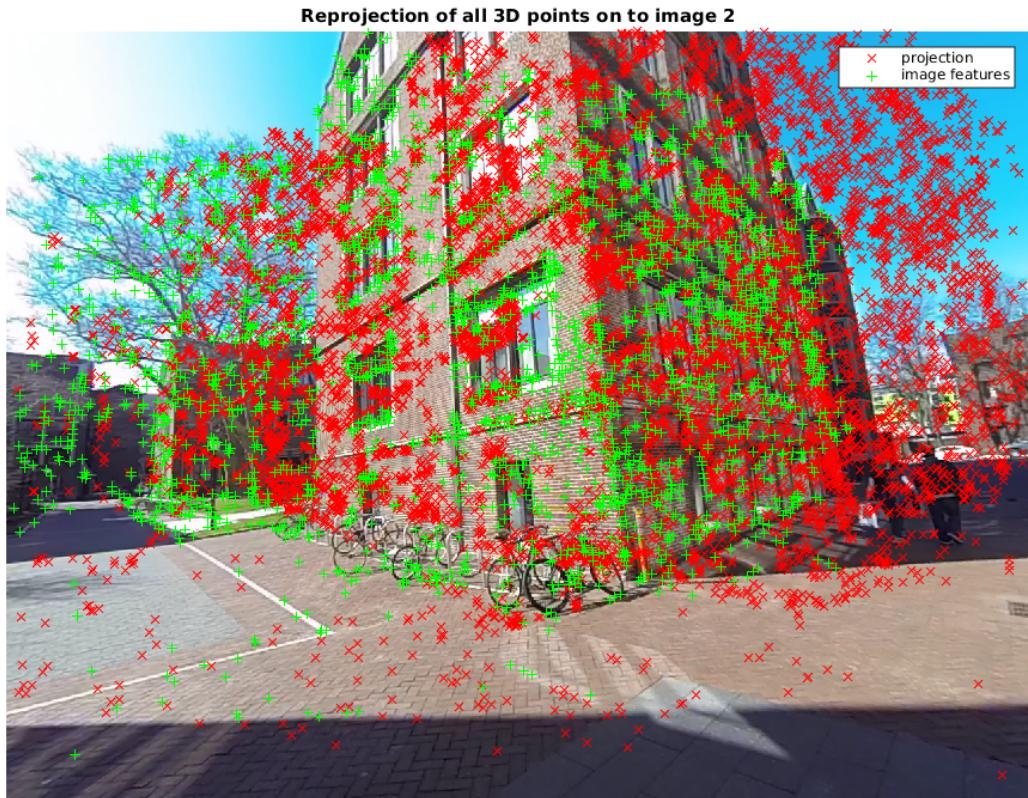


Figure 10: 3D structure projection onto image 2

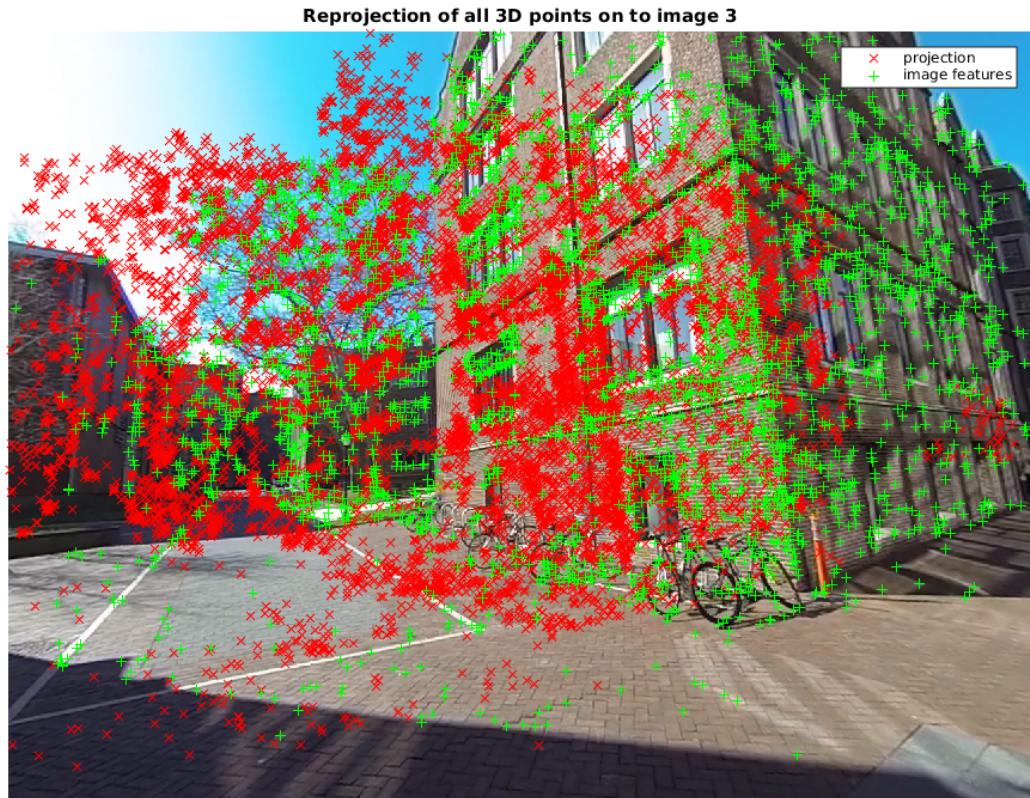


Figure 11: 3D structure projection onto image 3

**Reprojection of all 3D points on to image 4**

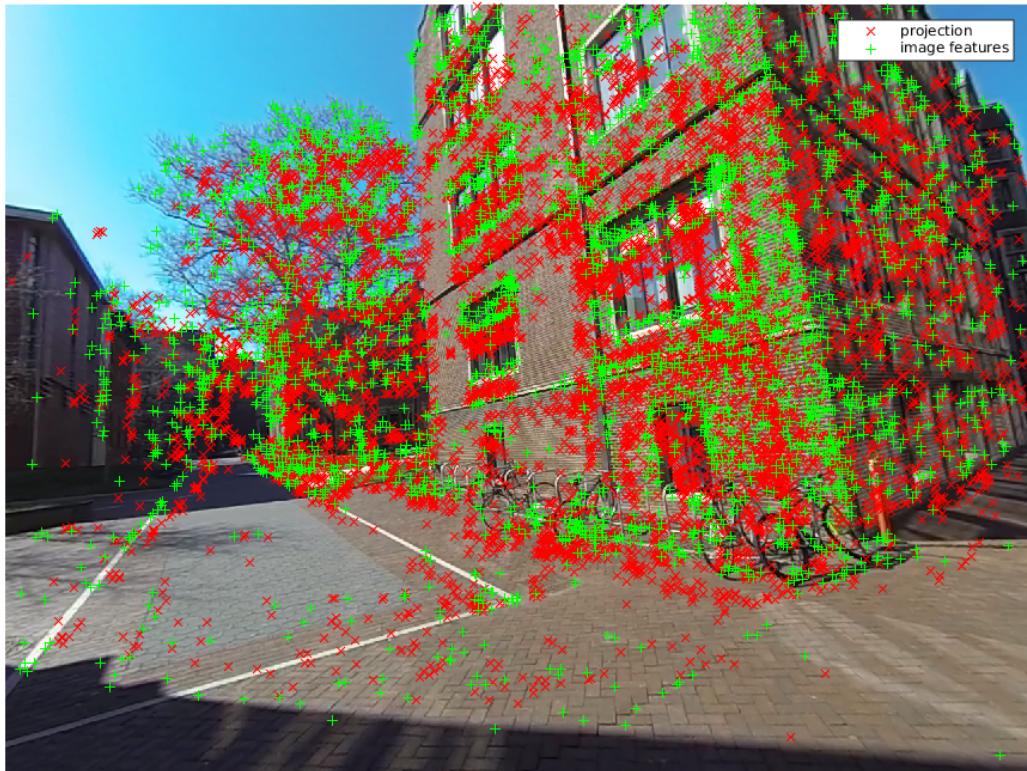


Figure 12: 3D structure projection onto image 4

**Reprojection of all 3D points on to image 5**

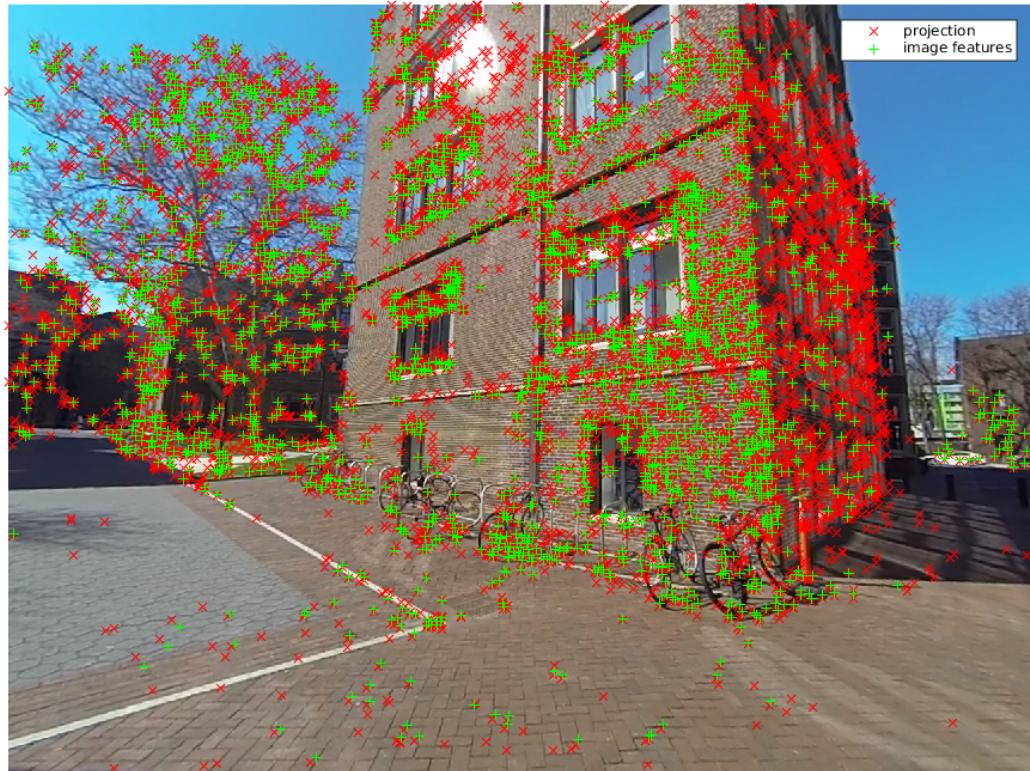


Figure 13: 3D structure projection onto image 5

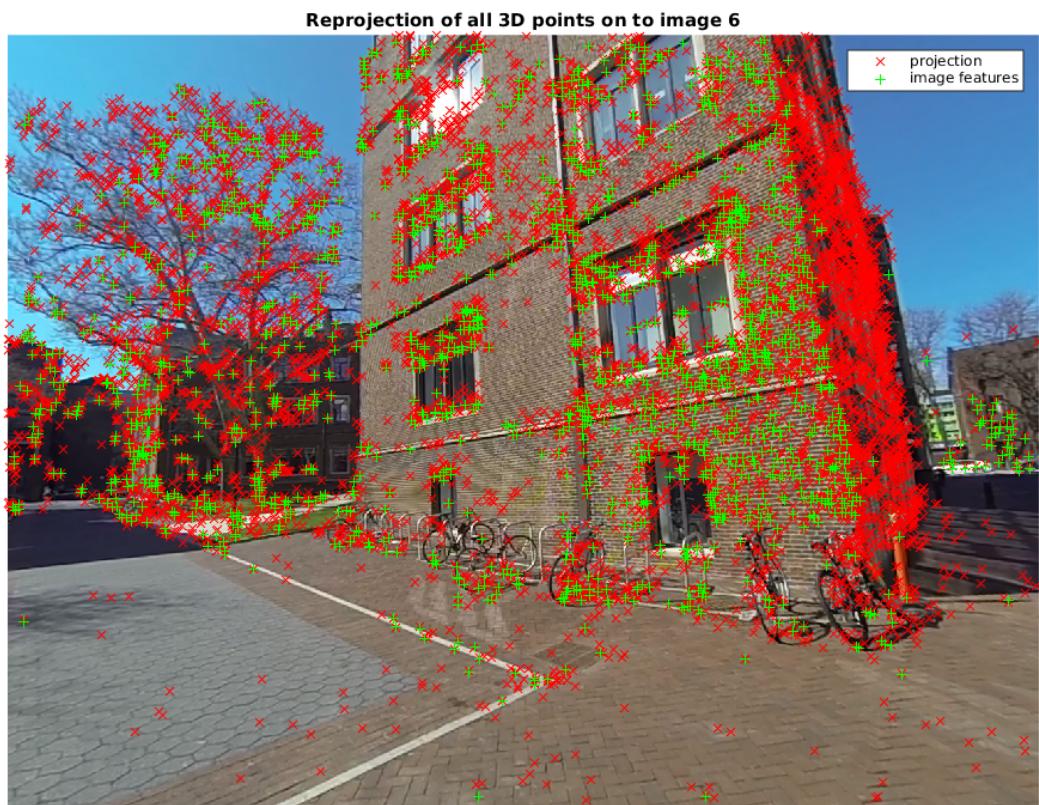


Figure 14: 3D structure projection onto image 6

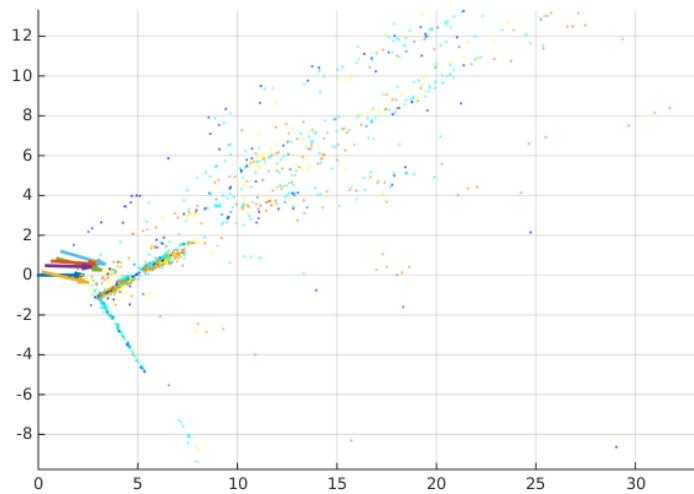


Figure 15: This plot shows which points were added by which camera. The point color matches the corresponding camera color.

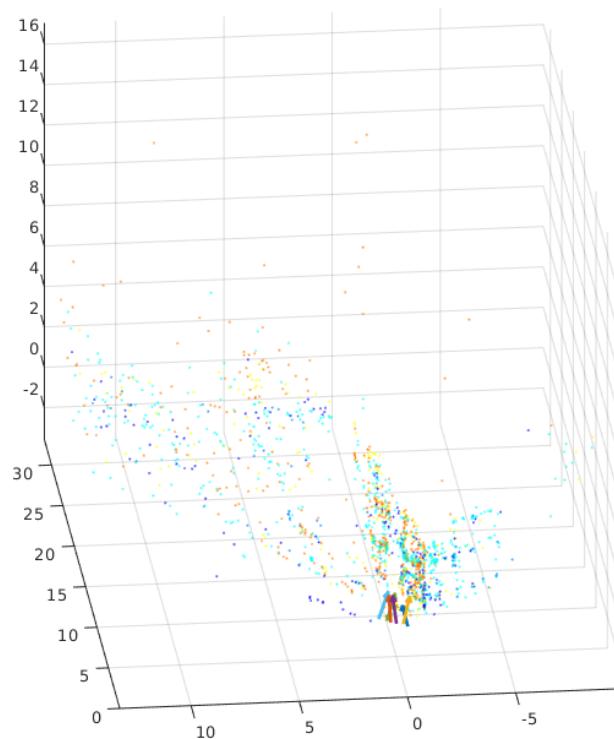


Figure 16: This plot shows which points were added by which camera. The point color matches the corresponding camera color.