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2022561

CV - A2

Date 4/4/25

Q1)

$$v = \begin{bmatrix} 3 \\ -1 \\ 4 \end{bmatrix}$$

1. $$R_1 = \begin{bmatrix} \cos(-\pi/6) & 0 & \sin(-\pi/6) \\ 0 & 1 & 0 \\ -\sin(-\pi/6) & 0 & \cos(-\pi/6) \end{bmatrix} = \begin{bmatrix} \sqrt{3}/2 & 0 & -1/2 \\ 0 & 1 & 0 \\ 1/2 & 0 & \sqrt{3}/2 \end{bmatrix}$$

2. $$R_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\pi/4) & -\sin(\pi/4) \\ 0 & \sin(\pi/4) & \cos(\pi/4) \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1/\sqrt{2} & -1/\sqrt{2} \\ 0 & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}$$

3. $$R_3 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

4. $$t = \begin{bmatrix} 1 \\ 0 \\ -2 \end{bmatrix}$$

1) Overall Transformation Matrix $= R = R_3 \cdot R_2 \cdot R_1$

$$R = \begin{bmatrix} 0.866 & 0 & -0.5 \\ 0.354 & -0.707 & 0.612 \\ 0.354 & 0.707 & 0.612 \end{bmatrix}$$

2) Rotated Vector $v_r = R \cdot v = \begin{bmatrix} 0.598 \\ 4.217 \\ 2.803 \end{bmatrix}$

Translated Rotated vector ~~v~~

$$v' = \begin{bmatrix} 1.598 \\ 4.217 \\ 0.803 \end{bmatrix}$$

Origin is now mapped to $\begin{bmatrix} 1 \\ 0 \\ -2 \end{bmatrix}$.

3) We know from Rodrigues' formula,

Rotation Angle $\theta = \cos^{-1}\left(\dfrac{\text{trace}(R) - 1}{2}\right)$

and Rotation Axis $\hat{r} = \dfrac{1}{2\sin\theta}\begin{bmatrix} R_{32} - R_{23} \\ R_{13} - R_{31} \\ R_{21} - R_{12} \end{bmatrix}$

$\therefore \quad \theta = \cos^{-1}(0.5855) = 53.65^\circ$

$\sin\theta = 0.9227$

0.6145

and $\hat{r} = \begin{bmatrix} 0.819 \\ -0.530 \\ 0.219 \end{bmatrix}$

$\therefore$ Original vector is rotated by 53.65° around the axis pointing in dirn $\begin{bmatrix} 0.819 \\ -0.530 \\ -0.219 \end{bmatrix}$ (before transformation)

4) Rodrigues Formula,

$$R' = I + (\sin\theta)N + (1-\cos\theta)N^2$$

$$N = \begin{bmatrix} 0 & 0.219 & -0.530 \\ 0.219 & 0 & -0.819 \\ 0.530 & 0.819 & 0 \end{bmatrix} \qquad N^2 = \begin{bmatrix} -0.329 & -0.434 & -0.179 \\ -0.434 & -0.719 & 0.116 \\ -0.179 & 0.116 & -0.952 \end{bmatrix}$$

$$\therefore \cancel{R =} \begin{bmatrix} \cancel{0.798} & \cancel{-0.469} \\ & \\ & \end{bmatrix} \qquad R' = \begin{bmatrix} 0.798 & -0.064 & -0.599 \\ 0.469 & -0.558 & 0.684 \\ 0.379 & 0.826 & 0.515 \end{bmatrix}$$

The matrices are coming out to be similar, rounding off has resulted in mismatch in values.

Date

(Q2) $x = K[R|t]X$

Intrinsic Matrix of Camera $C_1 \to K_1$
" " " " $C_2 \to K_2$

C_2 related to C_1 by Pure Rotation R

$\therefore$ For C_1: $x_1 = K_1 X$

$\therefore$ For C_2: $x_2 = K_2 R X$

$\because$ 3D Pt X is the same,

$\therefore$ $x_1 = K_1 \cdot R^T \cdot K_2^{-1} \cdot x_2$

$\therefore$ $x_1 = H \cdot x_2$

where Homography $\boxed{H = K_1 \cdot R^T \cdot K_2^{-1}}$

Report

Q3) Camera Calibration:

1) Here are the intrinsic Camera Parameters:

```
Intrinsic Camera Matrix:
[[956.00078429   0.         368.87920071]
 [  0.         956.79138954 648.83734178]
 [  0.           0.           1.        ]]
Focal Lengths: fx = 956.0007842949757, fy = 956.791389536468
Principal Point: (cx, cy) = (368.8792007144458, 648.8373417773257)
Skew Parameter: s = 0.0
Reprojection Error: 0.0749840389967154
```

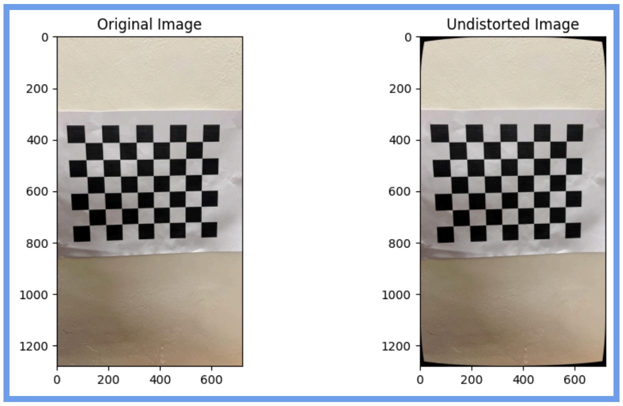
2) Image 1 Parameters:

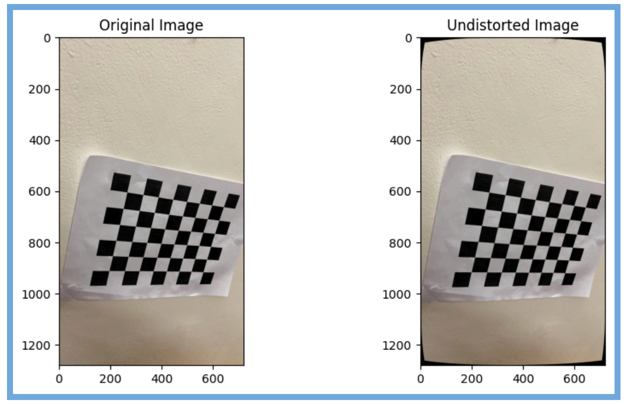
```
Image 1 Extrinsic Parameters:
Rotation Matrix:
[[ 0.99696999  0.01389194 -0.07653662]
 [-0.02499172  0.98896302 -0.14603959]
 [ 0.07366311  0.14750987  0.98631363]]
Translation Vector:
[[-3.93535601]
 [-3.57746406]
 [14.6559933 ]]
```

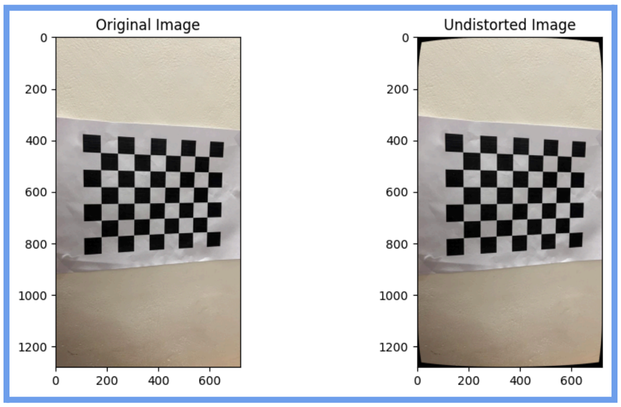
Image 2 Parameters:

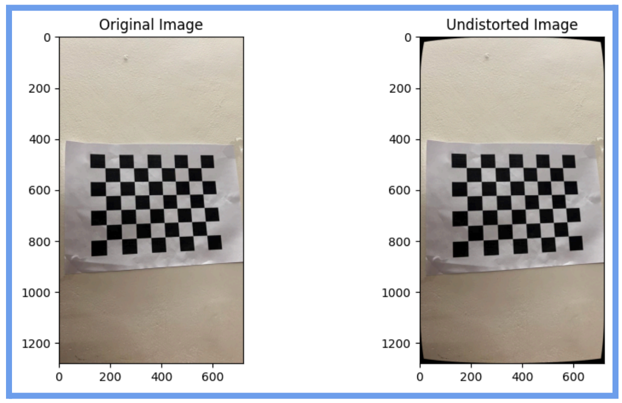
```
Image 2 Extrinsic Parameters:
Rotation Matrix:
[[ 0.89020699 -0.24204968 -0.38593196]
 [ 0.12308779  0.94345588 -0.30779928]
 [ 0.43861249  0.22650155  0.86966438]]
Translation Vector:
[[-1.49384997]
 [-0.61957713]
 [13.90226389]]
```

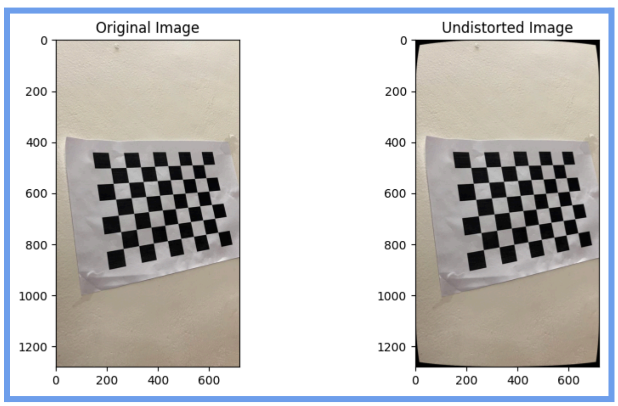
3) Observation: The straight lines near the edges of the original images appear curved due to radial distortion. After applying the distortion coefficients, the lines become straighter, confirming the effectiveness of the calibration.



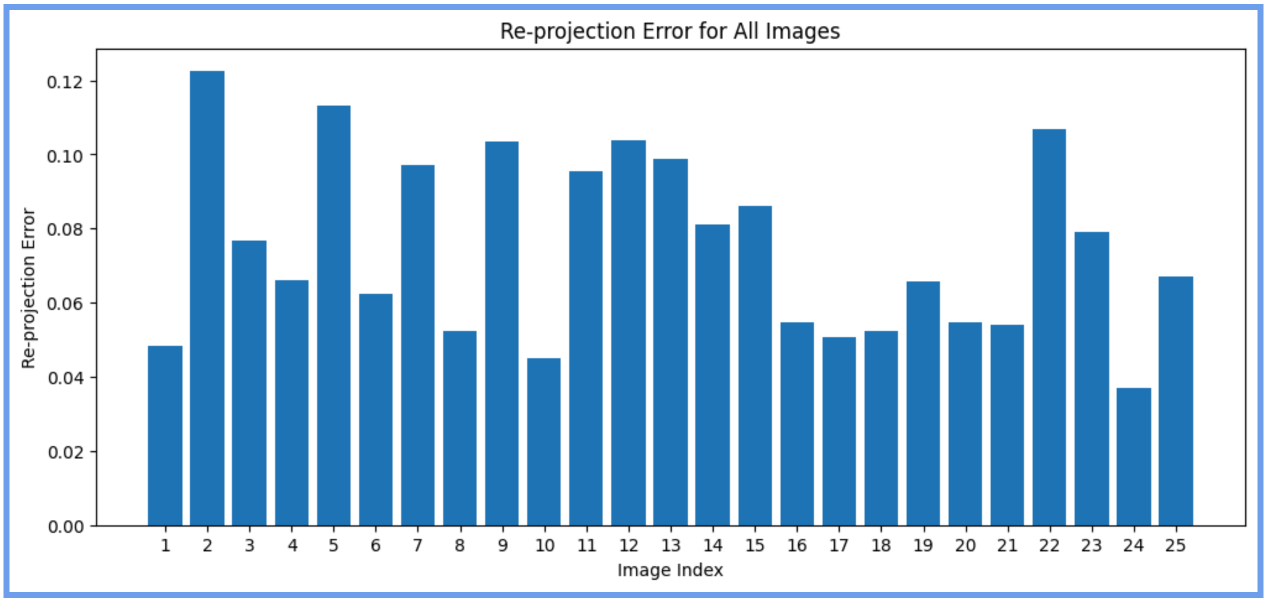




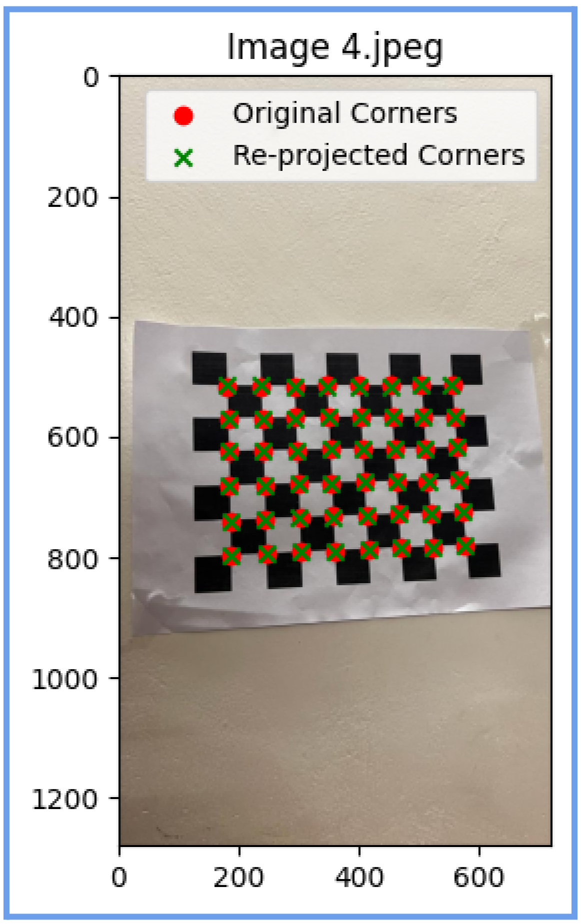


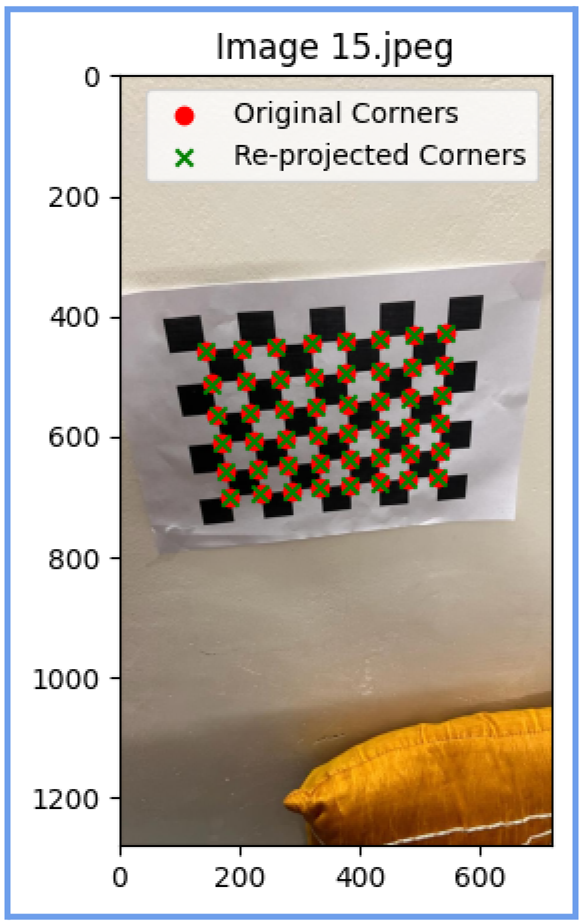


4) Re-projection Error: Mean: 0.0749840389967154, Std Deviation: 0.023955528050868088



5) Reprojection error is computed by projecting the 3D object points onto the image plane using the estimated camera parameters and comparing the projected points with the actual detected image points. The error is measured using the L2 norm and averaged across all points in the image.





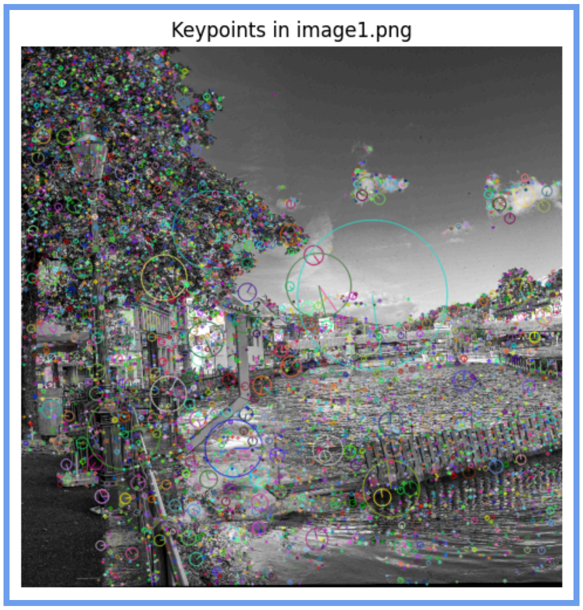
6) Checkerboard Normals:

```
Checkerboard Plane Normal for Image 1: [-0.07653662 -0.14603959  0.98631363]
Checkerboard Plane Normal for Image 2: [-0.38593196 -0.30779928  0.86966438]
Checkerboard Plane Normal for Image 3: [-0.27056215 -0.09590634  0.95791341]
Checkerboard Plane Normal for Image 4: [-0.16539831  0.16256005  0.97273718]
Checkerboard Plane Normal for Image 5: [-0.39754136  0.19241687  0.8971826 ]
Checkerboard Plane Normal for Image 6: [-0.08367022 -0.12463017  0.98866911]
Checkerboard Plane Normal for Image 7: [-0.10263293 -0.3992648   0.91107305]
Checkerboard Plane Normal for Image 8: [ 0.18869084 -0.0635797   0.97997622]
Checkerboard Plane Normal for Image 9: [0.45477004 0.40255344 0.79444001]
Checkerboard Plane Normal for Image 10: [-0.02246341  0.12531375  0.99186282]
Checkerboard Plane Normal for Image 11: [-0.39772862 -0.1859554   0.8984612 ]
Checkerboard Plane Normal for Image 12: [-0.34642613 -0.52644259  0.77643231]
Checkerboard Plane Normal for Image 13: [0.35757467 0.40151073 0.84316635]
Checkerboard Plane Normal for Image 14: [ 0.04557336 -0.32149957  0.9458124 ]
Checkerboard Plane Normal for Image 15: [-0.12740019 -0.50540701  0.85342425]
Checkerboard Plane Normal for Image 16: [0.0721908  0.2191962  0.97300643]
Checkerboard Plane Normal for Image 17: [-0.09641282  0.20028712  0.97498187]
Checkerboard Plane Normal for Image 18: [-0.14472038  0.07615594  0.98653752]
Checkerboard Plane Normal for Image 19: [-0.10791441 -0.08528209  0.99049556]
Checkerboard Plane Normal for Image 20: [-0.13523564 -0.10519423  0.98521343]
Checkerboard Plane Normal for Image 21: [-0.09660202 -0.27261729  0.9572606 ]
Checkerboard Plane Normal for Image 22: [-0.35940232  0.02047743  0.93295801]
Checkerboard Plane Normal for Image 23: [-0.16481441 -0.36095723  0.91790309]
Checkerboard Plane Normal for Image 24: [ 0.03593768 -0.10987577  0.99329542]
Checkerboard Plane Normal for Image 25: [-0.22306011  0.07011957  0.9722795 ]
```

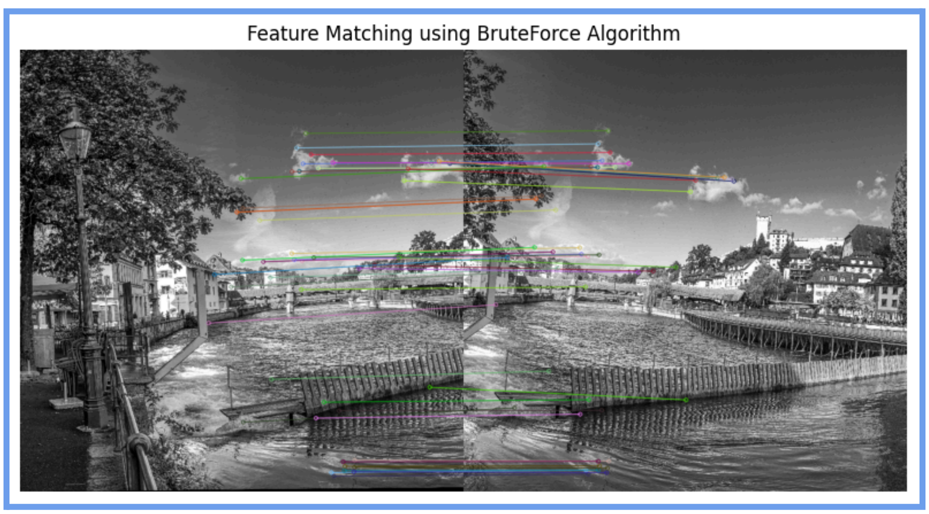
Q4) Panorama Generation:

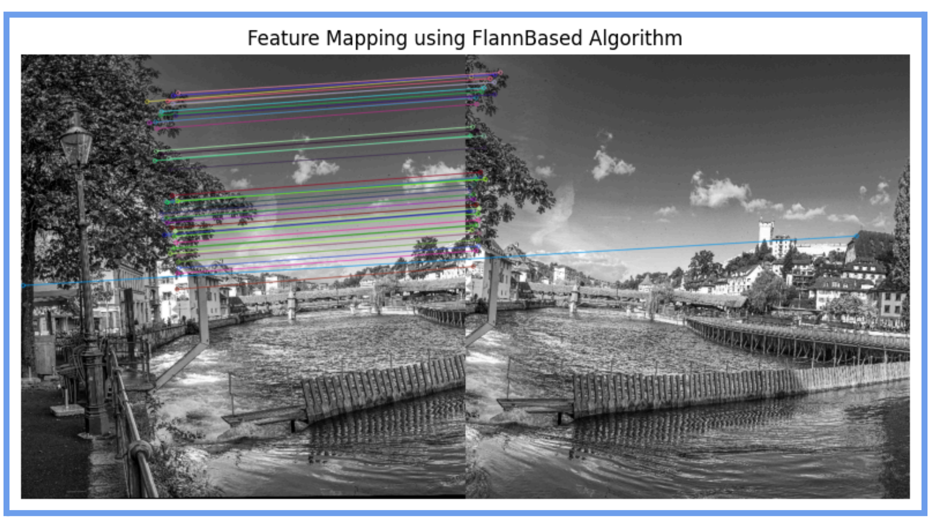
Since the images belong to different clusters primarily based on color similarities (e.g., blue sky and orange sky), a Color Histogram will naturally be a better clustering feature than Visual Bag of Words, which focuses more on detecting keypoints and textures rather than the global color distribution.

1) Keypoints in Image 1 and 2:



2) Brute Force and Flann Based Matching:

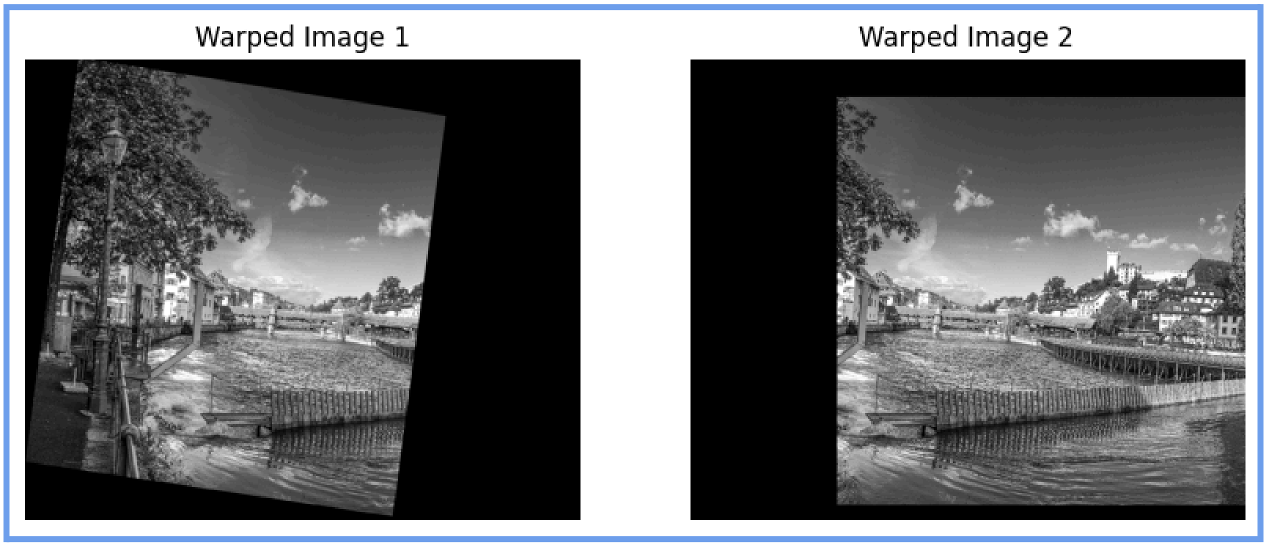




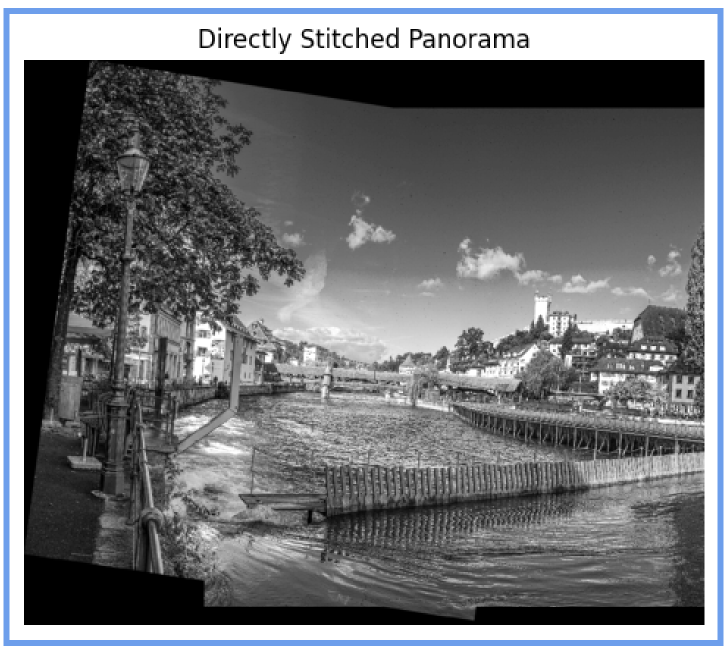
3) Homography Matrix:

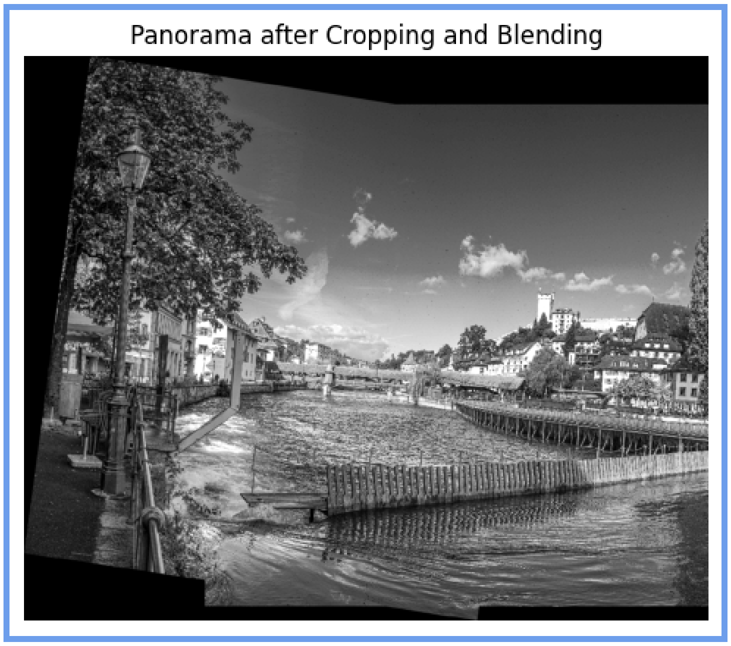
```
array([[ 8.99134087e-01, -1.31531656e-01, -1.64406566e+02],
       [ 1.43371278e-01,  9.90809456e-01, -6.95088198e+01],
       [ 3.91882263e-08,  5.19780356e-07,  1.00000000e+00]])
```

4) Warped Images:



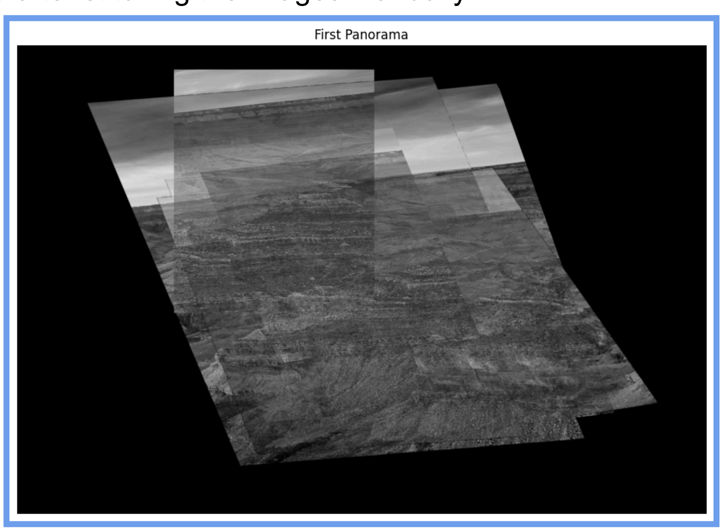
5) Panorama Images:



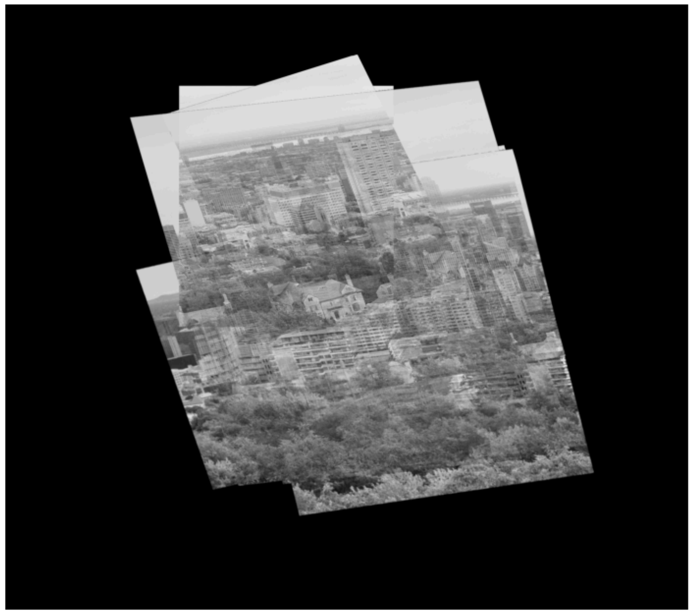


6) Ideal Panoramas that should be constructed:

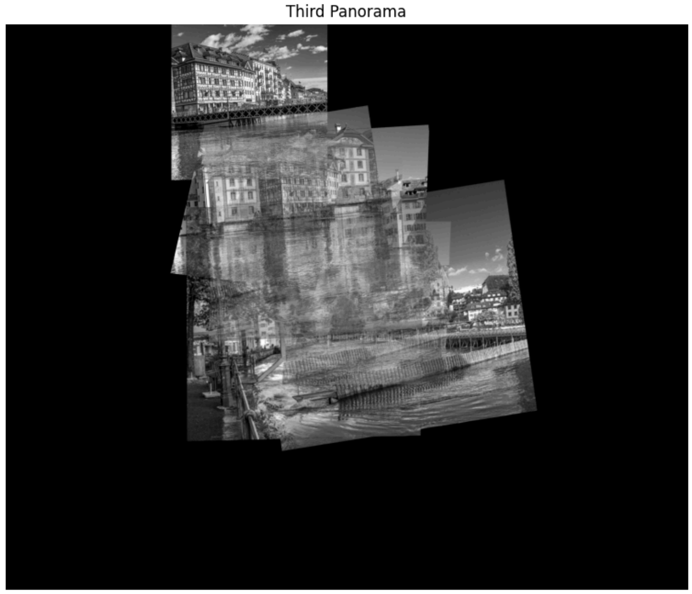
Panoramas obtained after stitching the images manually:



Second Panorama



Third Panorama



This must be because after obtaining the base image by stitching the first two images, the matchings formed between the new images and the base image are more confident for the points denoting the sky or the river, causing the panoramas to be formed as such.