1 Problem

In this assignment, I developed a image stitching system which can stitch multiple images in order to create a single panoramic image. Program implemented in Python 3.

2 Image Stitching Procedure

2.1 Select Common Points on Images

As it is told in the description, I have used matplotlib.pyplot.ginput to get corresponding points between images.

2.2 Homography Estimation

I calculated H matrix by calculating SVD of matrix A which is given below:

$$A = \begin{bmatrix} x_1 & y_1 & 1 & 0 & 0 & 0 & u_1x_1 & u_1y_1 & u_1 \\ 0 & 0 & 0 & x_1 & y_1 & 1 & v_1x_1 & v_1y_1 & v_1 \\ & & & & \vdots & & & & \\ x_N & y_N & 1 & 0 & 0 & 0 & u_Nx_N & u_Ny_N & u_N \\ 0 & 0 & 0 & x_N & y_N & 1 & v_Nx_N & v_Ny_N & v_N \end{bmatrix}$$

Matrix A holds the equality:

$$\begin{bmatrix} x_1 & y_1 & 1 & 0 & 0 & 0 & u_1x_1 & u_1y_1 & u_1 \\ 0 & 0 & 0 & x_1 & y_1 & 1 & v_1x_1 & v_1y_1 & v_1 \\ & & & & \vdots & & & & \\ x_N & y_N & 1 & 0 & 0 & 0 & u_Nx_N & u_Ny_N & u_N \\ 0 & 0 & 0 & x_N & y_N & 1 & v_Nx_N & v_Ny_N & v_N \end{bmatrix} \times \begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_{N-1} \\ h_N \end{bmatrix} = \mathbf{0}$$

The estimation of h given by singular vector which corresponds to least singular value, so $h \approx V_N$.

I have used numpy's svd algorithm to calculate h. Given h,

$$H = \begin{bmatrix} h_1 & h_2 & h_3 \\ h_4 & h_5 & h_6 \\ h_7 & h_8 & h_9 \end{bmatrix}$$

Additionally, to calculate a robust transformation matrix, I have also normalized all input points before calculate H, such that average length of points is $\sqrt{2}$ and average of points is $(0, 0)$.

By given transformation matrix T_1 and T_2 such that

$$T_2x' = H'T_1x$$
$$x' = T_2^{-1}H'T_1x$$
$$H = T_2^{-1}H'T_1$$

2.3 Image Warping

Image warping is changing the domain of the image function, rather than filtering. Let say we have transformation matrix H, which transforms domain of image-1 to the domain of image-2, then warping corresponds to finding $g(x')$. So,

$$g(x') = f(H(x))$$

where f is the input image of warping function and g is the output function. There are 2 major methods to calculate output image: Forward and backward transformation. I used backward transformation, which aims to find output image's pixels by transforming its index back to input image by using inverse transformation matrix H^{-1}.

$$H^{-1}x' = x$$

After finding all corresponding x, we can set $g(x)$. But result of inverse transformation can be placed between pixels on input image. So, I have used nearest-neighbour interpolation from "scipy" library.

In this assignment, first I have calculated borders for output image by forward transformation of corner points of input image. Then, I have calculated range for output image. By using H^{-1}, I have calculated all the corresponding points of the points in the range calculated, then I have assigned points of output image to corresponding input image pixel.

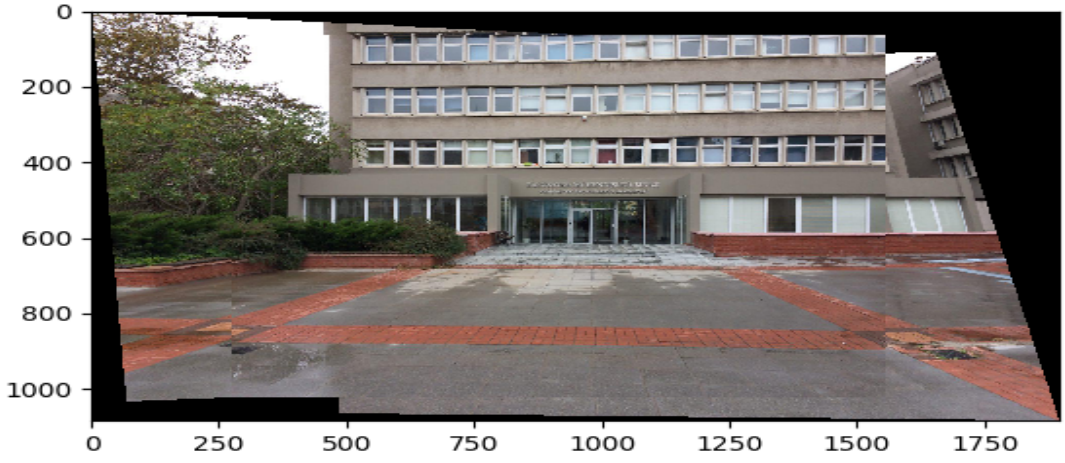
2.4 Image Blending

For blending all the images, first I have transformed the domain of all the images into middle one's domain. Then by warping all these images, I have calculated range for all of these. After all, I merged them into new big image. On the overlapping points, I have used a basic strategy that if overlapping pixel is zero in of the intersecting images, I have used the other one, and if both are non-zero, I used the average of them.

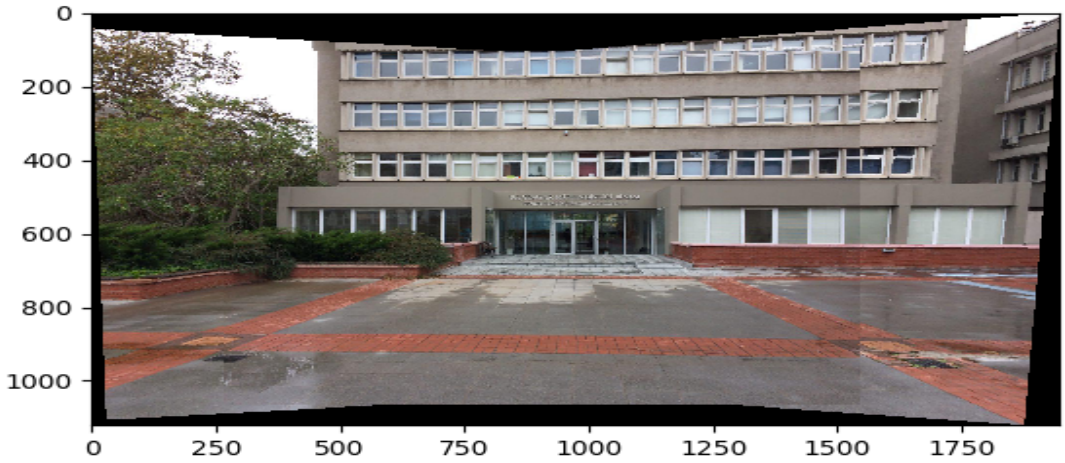
3 Experiments

3.1 Number of Points

I have experimented on both 5 and 12 corresponding points.



(a) Result for 5 correspondence points



(b) Result for 12 correspondence points

As we can observe that choosing more correspondence points results better. It is obvious that for above equation 5 points would be enough but more points are resulting better.

3.2 Point Selection

3.2.1 Without Normalization

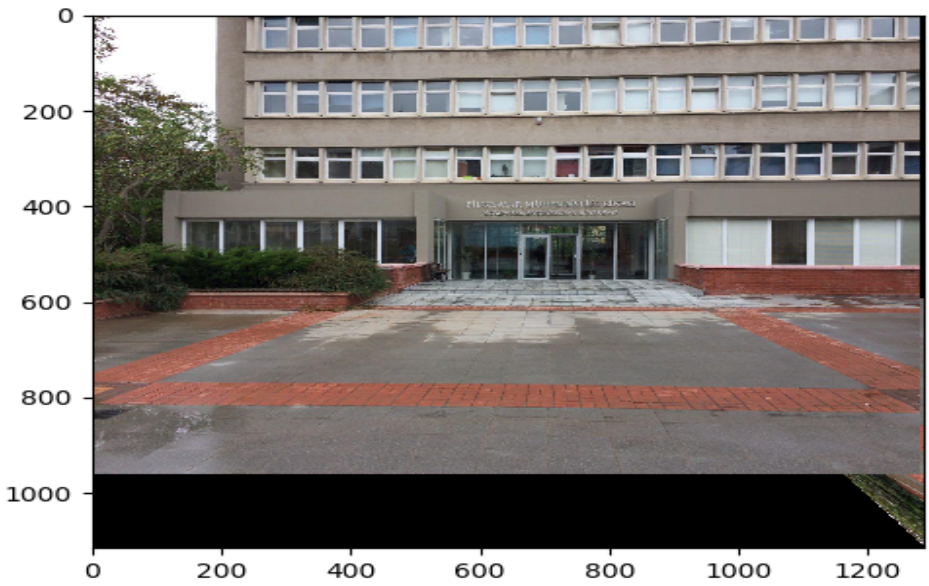


Figure 2: 3 wrong points are selected out of 12

3.2.2 With Normalization

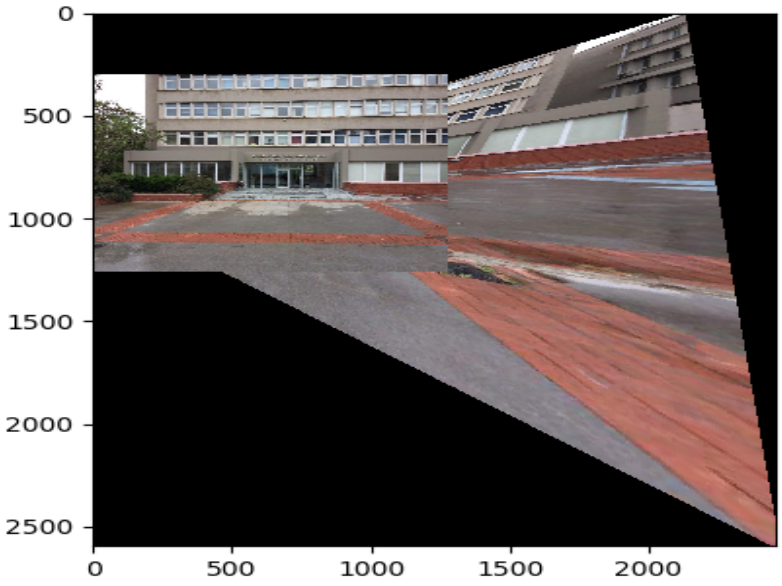


Figure 3: 3 wrong points are selected out of 12

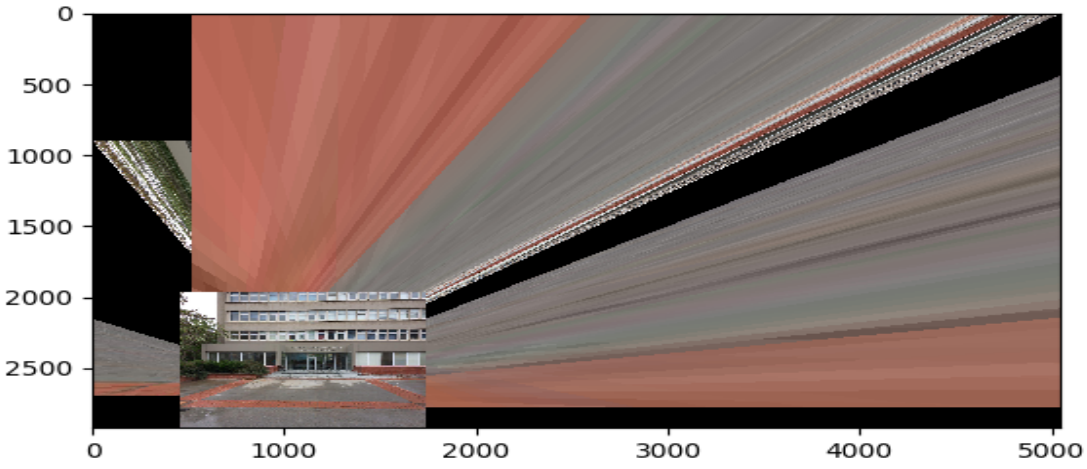
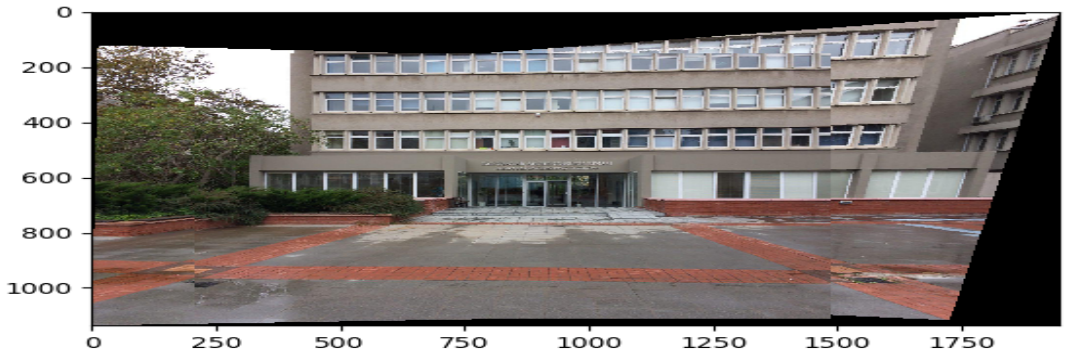


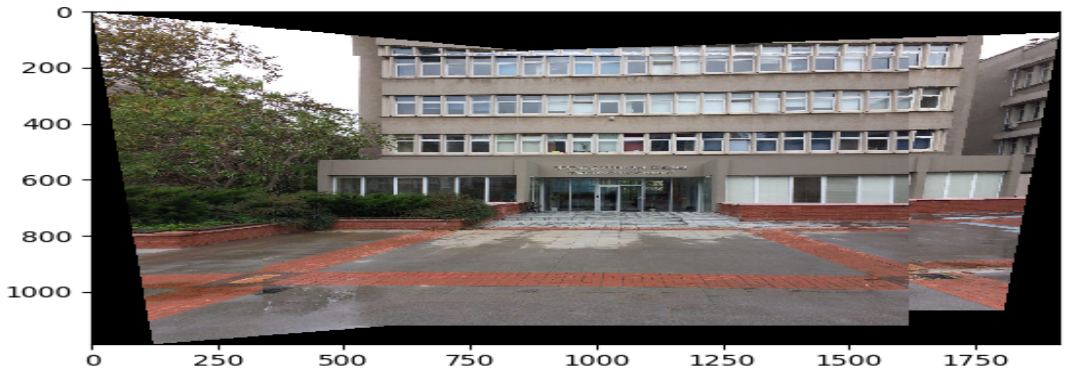
Figure 4: 5 wrong points are selected out of 12

3.3 Noisy Points

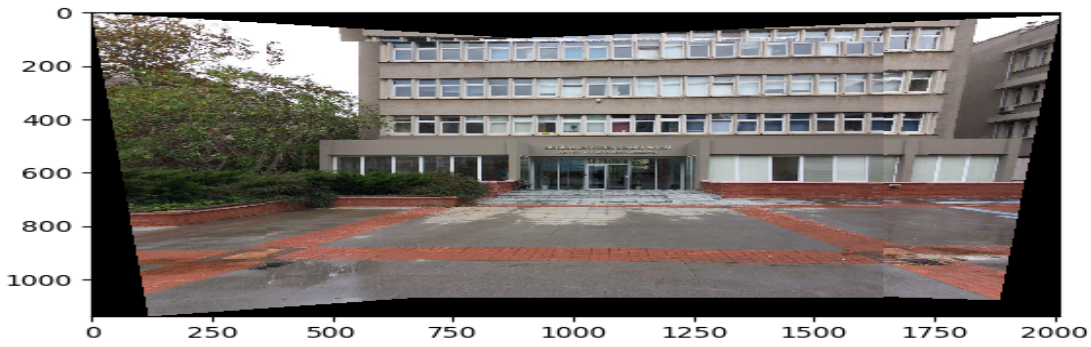
3.3.1 Normalized



(a) Gaussian Noise with variance 1



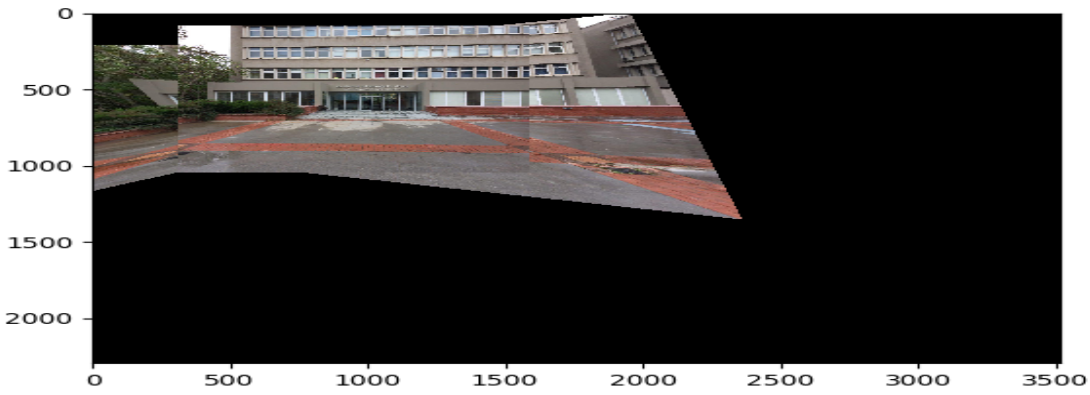
(b) Gaussian Noise with variance 5



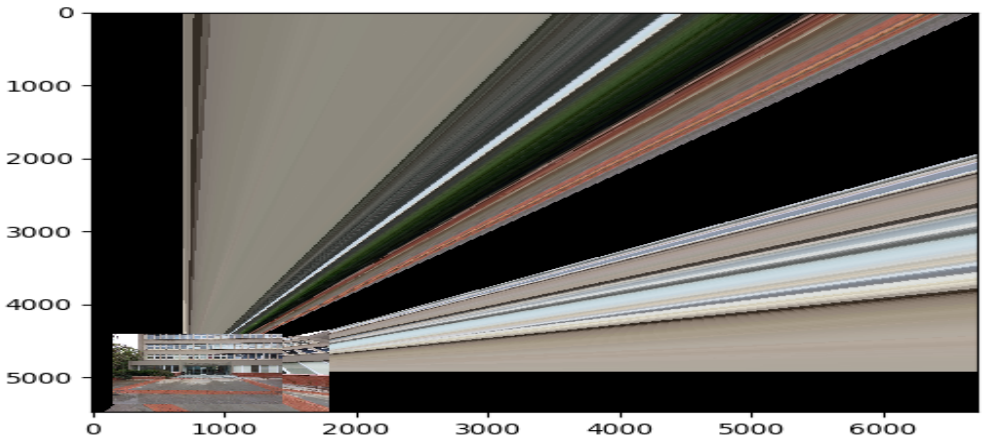
(c) Gaussian Noise with variance 10

So, as we can observe since normalizing is used, gaussian noise won't be so problematic.

3.3.2 Unnormalized



(a) Gaussian Noise with variance 1

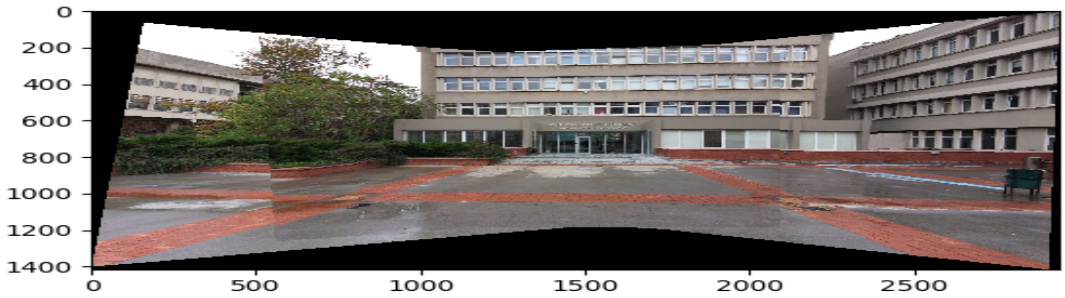


(b) Gaussian Noise with variance 5

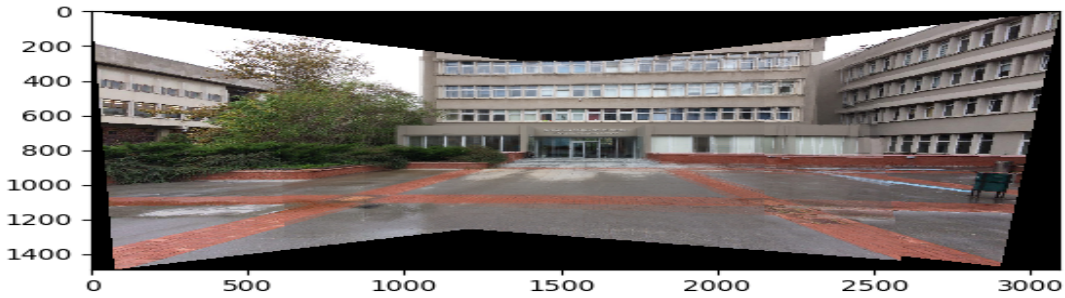
In unnormalized version, Gaussian noise would effect results even with little noise.

3.4 Stitching All

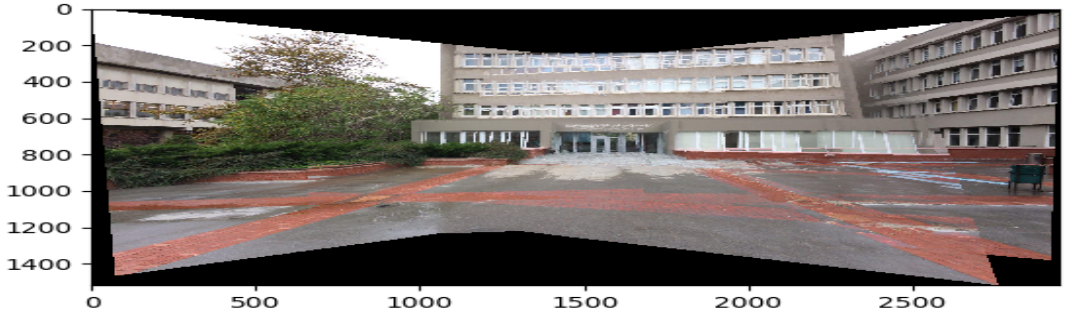
I have tried 3 different approach to handle overlapping pixels when blending all five images. In one of them I added images directly but in a natural way that gives priority to the middle image, in the second one, I averaged overlapped pixels, and lastly I set maximum intensity for each color channel. Results follows,



(a) All images blended directly top of each other



(b) Overlapping pixels are averaged



(c) Set it to max intensities