Spring 2023

Project 4 Report

Perception for autonomous robots

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Course code:
ENPM 673

Contents

1 Problem 1

This problem consists of 4 sub tasks -

1. Calibration.
2. Rectification.
3. Correspondence.
4. Compute Depth Image

1.1 Calibration Pipeline

This pipeline assumes that the input images have already been preprocessed and that the camera intrinsics are given. The pipeline is designed to calibrate the cameras by estimating the essential matrix, which is a fundamental matrix that takes into account the camera intrinsics.

1. Compare the two images in each dataset and select a set of matching features by using the ORB feature extractor.
2. horizontally stacking these points and finding the A matrix
3. Estimate the Fundamental matrix using the features obtained in the previous step and by performing SVD on A.
4. Use the RANSAC method for best Fundamental matrix estimation.
5. Estimate the Essential matrix E from the Fundamental matrix F by accounting for the calibration parameters(K1,k2).
6. Decompose E into a translation T and rotation R.

1.2 Rectification Pipeline

After the fundamental matrix has been computed. The goal of this pipeline is to rectify the images so that they can be easily compared and used for stereo vision. By making the epipolar lines horizontal, it becomes much easier to search for corresponding points between the two images. The homography matrices H1 and H2 are used to map the original image coordinates to the rectified image coordinates, and they can be used later on to reconstruct the 3D scene.

1. Apply perspective transformation to both images using cv2.warperspective to make sure the epipolar lines are horizontal.
2. Compute the homography matrices H1,H2 for both the images, respectively to rectify the images.
3. Plot the epipolar lines on both images, along with feature points.
4. Overlay the original points on top of the rectified images to visualize any distortions that were corrected by the rectification process.

1.3 Correspondence Pipeline

For the task of correspondence, which involves finding corresponding points between two stereo images. The pipeline should include steps for applying matching windows, calculating disparity, rescaling the disparity, and saving the resulting images as grayscale and color heat maps.

1. For each pixel on an epipolar line, define a matching window centered around it.
2. Compute the similarity metric between the corresponding pixels in the matching windows of the left and right images using sum of squared differences (SSD).
3. Choose the pixel with the best similarity metric as the match for the pixel on the epipolar line.
4. Calculate the disparity for each pixel by subtracting the x-coordinates of the matching pixel in the left and right images.
5. Normalize the disparity values to be in the range of 0-255.
6. Convert the normalized disparity values to grayscale, and save the resulting image.
7. Create a color heat map by mapping the grayscale values to a color scale such as jet or rainbow.
8. Save the color heat map image.

1.4 Image depth Compution Pipeline

For computing a depth image from a disparity map. The pipeline should include steps for converting the disparity values to distance, computing depth values, normalizing the depth values, and saving the resulting images as grayscale and color heat maps.

1. Load the disparity image obtained from the correspondence step.
2. Convert the disparity values from pixel offsets to distances using the camera calibration parameters and the baseline distance between the cameras.
3. Compute the depth value for each pixel by taking the reciprocal of the distance, i.e. depth = 1/distance.
4. Normalize the depth values to be in the range of 0-255.
5. Convert the normalized depth values to grayscale, and save the resulting image.
6. Create a color heat map by mapping the grayscale values to a color scale such as jet or rainbow.
7. Save the color heat map image.

2 Results

Following are the results of applying the above pipelines to the given 3 datasets

2.1 Chess room

1. Best Fundamental matrix $\begin{bmatrix} 6.32930326 \times 10^{-8} & 1.01763381 \times 10^{-7} & -1.51820078 \times 10^{-4} \\ 9.27532193 \times 10^{-7} & 1.36277877 \times 10^{-6} & -1.89988294 \times 10^{-3} \\ -4.77931804 \times 10^{-4} & -7.10523372 \times 10^{-4} & 9.99997817 \times 10^{-1} \end{bmatrix}$

2. Essential matrix $\begin{bmatrix} -0.42368624 & 0.23974036 & -0.87087302 \\ 0.5877528 & 0.80399827 & -0.06912413 \\ 0.06301574 & 0.03044201 & 0.05524765 \end{bmatrix}$

3.

4. Essential matrix $\begin{bmatrix} -0.54253871 & -0.83938721 & 0.03287643 \\ -0.46602642 & 0.26819304 & -0.84314404 \\ 0.6989071 & -0.47275956 & -0.53668172 \end{bmatrix}$,
$\begin{bmatrix} -0.54253871 & -0.83938721 & 0.03287643 \\ -0.46602642 & 0.26819304 & -0.84314404 \\ 0.6989071 & -0.47275956 & -0.53668172 \end{bmatrix}$,
$\begin{bmatrix} 0.63558528 & 0.76573148 & -0.09842078 \\ 0.386514 & -0.20525095 & 0.89915459 \\ 0.66831002 & -0.60953044 & -0.42642042 \end{bmatrix}$,
$\begin{bmatrix} 0.63558528 & 0.76573148 & -0.09842078 \\ 0.386514 & -0.20525095 & 0.89915459 \\ 0.66831002 & -0.60953044 & -0.42642042 \end{bmatrix}$

5. Translation vectors $\begin{bmatrix} 0.06778439 & -0.05792477 & 0.99601707 \end{bmatrix}$, $\begin{bmatrix} -0.06778439 & 0.05792477 & -0.99601707 \end{bmatrix}$

6. Estimated R : $\begin{bmatrix} -0.54253871 & -0.83938721 & 0.03287643 \\ -0.46602642 & 0.26819304 & -0.84314404 \\ 0.6989071 & -0.47275956 & -0.53668172 \end{bmatrix}$

7. Estimated C : $\begin{bmatrix} 0.06778439 & -0.05792477 & 0.99601707 \end{bmatrix}$

Figure 1: chess Matches

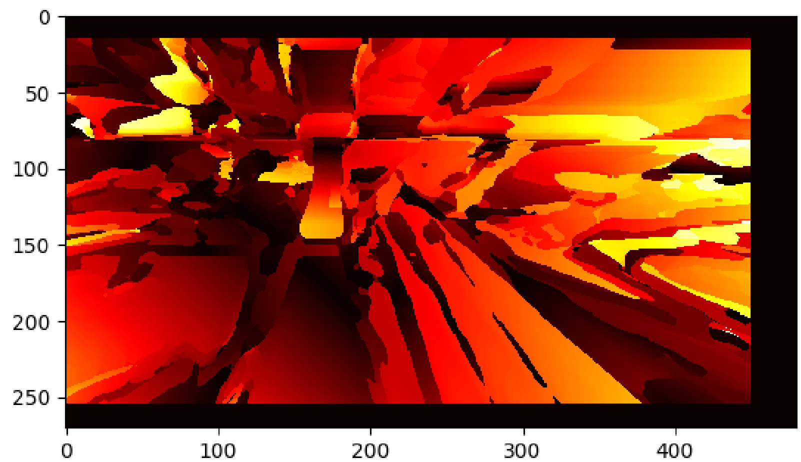

Figure 2: chess depth image heat map

2.2 Ladder room

1. Best Fundamental matrix $\begin{bmatrix} 1.55825274e-07 & 1.09377252e-06 & -1.19356287e-03 \\ -1.91907728e-07 & 1.61993024e-07 & 2.72430184e-05 \\ 8.82401673e-05 & -1.13356856e-03 & 9.99998641e-01 \end{bmatrix}$
2. Essential matrix $\begin{bmatrix} 0.24263696 & 0.9215656 & -0.08504698 \\ -0.91005182 & 0.23422764 & 0.323263 \\ 0.03256149 & -0.30960147 & -0.01191557 \end{bmatrix}$
3. Rotation matrices[R1 R2 R3 R4]

$$\begin{bmatrix} 0.96568628 & -0.257426 & -0.03437813 \\ 0.25840206 & 0.96563795 & 0.02777978 \\ 0.02604559 & -0.03570993 & 0.99902274 \end{bmatrix},$$

$$\begin{bmatrix} 0.96568628 & -0.257426 & -0.03437813 \\ 0.25840206 & 0.96563795 & 0.02777978 \\ 0.02604559 & -0.03570993 & 0.99902274 \end{bmatrix},$$

$$\begin{bmatrix} -0.7711028 & 0.25679027 & 0.5826313 \\ -0.18377875 & -0.96588176 & 0.18247685 \\ 0.60961122 & 0.03363315 & 0.79198672 \end{bmatrix},$$

$$\begin{bmatrix} -0.7711028 & 0.25679027 & 0.5826313 \\ -0.18377875 & -0.96588176 & 0.18247685 \\ 0.60961122 & 0.03363315 & 0.79198672 \end{bmatrix}$$

4. Translation vectors $\begin{bmatrix} 0.29087999 \\ 0.11155329 \\ 0.95023402 \end{bmatrix}$, $\begin{bmatrix} -0.29087999 \\ -0.11155329 \\ -0.95023402 \end{bmatrix}$, $\begin{bmatrix} 0.29087999 \\ 0.11155329 \\ 0.95023402 \end{bmatrix}$, $\begin{bmatrix} -0.29087999 \\ -0.11155329 \\ -0.95023402 \end{bmatrix}$

5. Estimated R : $\begin{bmatrix} 0.96568628 & -0.257426 & -0.03437813 \\ 0.25840206 & 0.96563795 & 0.02777978 \\ 0.02604559 & -0.03570993 & 0.99902274 \end{bmatrix}$

6. Estimated C : $\begin{bmatrix} 0.29087999 & 0.11155329 & 0.95023402 \end{bmatrix}$

Figure 3: Ladder Matches

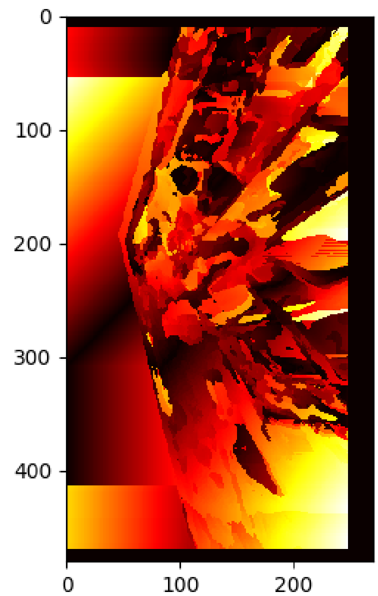

Figure 4: Ladder depth image heat map

2.3 Art room

1. Best Fundamental matrix $\begin{bmatrix} 1.89543398e-07 & 3.67308141e-07 & -3.73872292e-04 \\ 1.43357071e-06 & 1.46232115e-06 & -2.04375669e-03 \\ -6.46190773e-04 & -7.91339467e-04 & 9.99997320e-01 \end{bmatrix}$

2. Essential matrix $\begin{bmatrix} -0.57825406 & 0.81547166 & -0.01683029 \\ 0.81189676 & 0.57260272 & -0.02979988 \\ 0.07891864 & 0.07852077 & -0.00360783 \end{bmatrix}$,

3. Rotation matrices[R1,R2,R3,R4] $\begin{bmatrix} 0.81578594 & 0.57824063 & -0.01144895 \\ 0.57481059 & -0.8084411 & 0.12655343 \\ 0.06392253 & -0.10982149 & -0.99189372 \end{bmatrix}$,

$\begin{bmatrix} 0.81578594 & 0.57824063 & -0.01144895 \\ 0.57481059 & -0.8084411 & 0.12655343 \\ 0.06392253 & -0.10982149 & -0.99189372 \end{bmatrix}$,

$\begin{bmatrix} -0.81523783 & -0.57708578 & 0.04857241 \\ -0.57156947 & 0.81527004 & 0.09296831 \\ -0.09325032 & 0.04802877 & -0.99448359 \end{bmatrix}$,

$\begin{bmatrix} -0.81523783 & -0.57708578 & 0.04857241 \\ -0.57156947 & 0.81527004 & 0.09296831 \\ -0.09325032 & 0.04802877 & -0.99448359 \end{bmatrix}$

4. Translation vectors $\begin{bmatrix} -0.01857273 & -0.10982592 & 0.9937773 \\ 0.01857273 & 0.10982592 & -0.9937773 \\ -0.01857273 & -0.10982592 & 0.9937773 \\ 0.01857273 & 0.10982592 & -0.9937773 \end{bmatrix}$

5. Estimated R : $\begin{bmatrix} 0.81578594 & 0.57824063 & -0.01144895 \\ 0.57481059 & -0.8084411 & 0.12655343 \\ 0.06392253 & -0.10982149 & -0.99189372 \end{bmatrix}$

6. Estimated C : $\begin{bmatrix} -0.01857273 \\ -0.10982592 \\ 0.9937773 \end{bmatrix}$

Figure 5: Artroom Matches

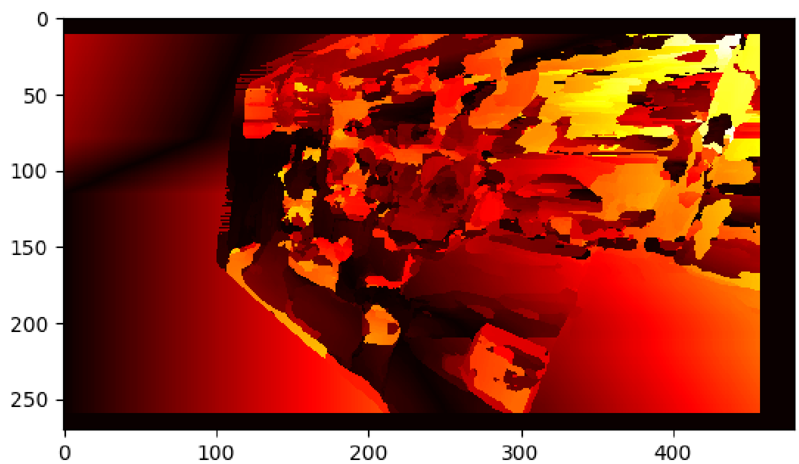

Figure 6: Artroom depth image heat map

3 Problems Encountered and solutions

Following road blocks were found during the entire process of completing the project:

1. 1.1 - In the camera calibration part getting rid of the outliers was difficult and estimating the fundamental matrix was tricky. The extraction of R and C was straight forward as the link to the CMSC course as well as lecture notes made it easier to extract all of them [R,C]. To get the correct estimate of the R,C triangulation condition was slightly difficult to execute as i was facing several array dimension issues during that process
2. 1.2 - Rectification was a straight forward process but I was not able to execute it and make the epipolar line horizontal for some reason. the warping did not go as planned
3. 1.3 - Correspondence finding formula was given and the concept of sliding a window and using SSD was clear but as the previous process was messed up it did not produce the desired results.
4. 1.4 - Computing depth heat map to my surprise did produce a result but unfortunately I don't think it is an optimal solution to the given problem as the entire process was interlinked.

4 References

1. https://cmsc733.github.io/2022/proj/p3/fundmatrix
2. https://courses.cs.washington.edu/courses/cse455/09wi/Lects/lect16.pdf
3. https://medium.com/analytics-vidhya/camera-calibration-with-opencv-f324679c6eb7
4. https://learnopencv.com/introduction-to-epipolar-geometry-and-stereo-vision/