CSCI 5561: Assignment #3

Stereo Reconstruction

1 Submission

- Assignment due: Oct 25 (11:59:59pm) Please check the dates
- Individual assignment
- Submission through Canvas.
- List functions to submission:
  - `compute_F`
  - `triangulation`
  - `disambiguate_pose`
  - `compute_rectification`
  - `dense_match`
- Do not change function interface (e.g. arguments and return values) in your code submission. Besides, please also keep their shapes consistent with that specified in this handout. If you really want to customize the functions for your convenience, you can add keyword arguments with default values at the back.
- Comment out visualization code snippets inside those functions before submission.
- Please also submit a summary write-up (up to 2 pages, in pdf format) with resulting visualizations and brief descriptions.
- Please place the code (i.e. hw2.py, DO NOT RENAME) and summary write-up into THE SAME FOLDER, compress it, and submit the compressed file.
- DO NOT SUBMIT THE PROVIDED IMAGE AND DATA
- The code must be run with Python 3 interpreter.
- Required python packages:
  - `numpy`: `https://pypi.org/project/numpy/`
  - `matplotlib`: `https://pypi.org/project/matplotlib/`
  - `opencv`: `https://pypi.org/project/opencv-python/`

  (Note) Use numpy array to represent matrices and vectors for this homework.
- You are not allowed to use computer vision related package functions unless explicitly mentioned here. Please consult with TA if you are not sure about the list of allowed functions.

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2 Overview

In this assignment, you will implement a stereo reconstruction algorithm given two views of a scene. We will focus on the geometric aspects od stereo and cover image processing components (In particular, SIFT features and matching) later in the class. For now, we will take correspondences as given.

(a) Left image (b) Right image

Figure 1: In this assignment, you will implement a stereo reconstruction algorithm given two images.

For your submission, you will fill each function and submit your code such that the skeletal code in `hw2.py` can run through and produces a stereo disparity map.

First, start by visualizing the correspondences. The correspondences between the two images are given in `correspondence.npz`, by matching SIFT features. You can use the provided `visualize_find_match` function to visualize the correspondences as shown in Figure 2.

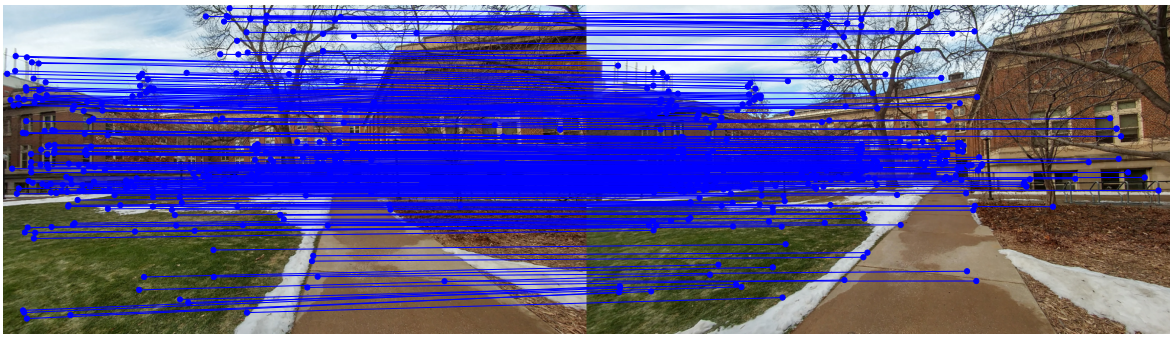

Figure 2: Correspondences between left and right images.

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3 Fundamental Matrix Computation

Figure 3: Given matches, you will compute a fundamental matrix to draw epipolar lines.

```
def compute_F(pts1, pts2):
  ...
  return F
```

Input: `pts1` and `pts2` are $n \times 2$ matrices that specify the correspondence.
Output: `F` $\in \mathbb{R}^{3\times3}$ is the fundamental matrix.
Description: `F` is robustly computed by the 8-point algorithm within RANSAC. Note that the rank of the fundamental matrix needs to be 2 (SVD clean-up should be applied.). You can verify the validity of fundamental matrix by visualizing epipolar line as shown in Figure 3.

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(Note) Given the fundamental matrix, you can get camera poses using the PROVIDED function:

```
def compute_camera_pose(F, K)
  ...
  return Rs, Cs
```

This function computes the four sets of camera poses given the fundamental matrix where `Rs, Cs` are python lists of rotation matrices (3×3) and camera centers (3×1) respectively (represented in the world coordinate system) and `K`$\in \mathbb{R}^{3\times3}$ is the PROVIDED intrinsic parameter. These four configurations can be visualized in 3D using PROVIDED function `visualize_camera_poses` as shown in Figure 4. Note that the camera pose and centers are recovered from the essential matrix and it is up to scale.

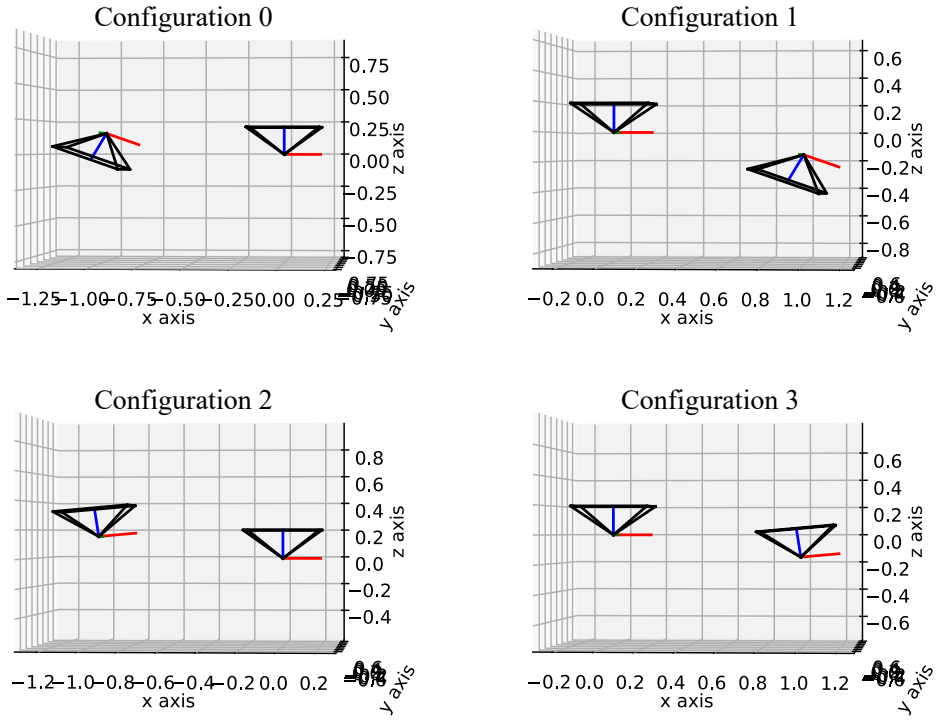

Figure 4: Four configurations of camera pose from a fundamental matrix.

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4 Triangulation

Given camera pose and correspondences, you will triangulate to reconstruct 3D points.

```
def triangulation(P1, P2, pts1, pts2)
  ...
  return pts3D
```

Input: `P1` and `P2` are two camera projection matrices ($\mathbb{R}^{3\times4}$). `pts1` and `pts2` are $n \times 2$ matrices that specify the correspondence.
Output: `pts3D` is $n \times 3$ where each row specifies the 3D reconstructed point.
Description: You can use a linear triangulation method, i.e.,

$$\begin{bmatrix} \begin{bmatrix} \mathbf{u} \\ 1 \end{bmatrix}_\times \mathbf{P}_1 \\ \begin{bmatrix} \mathbf{v} \\ 1 \end{bmatrix}_\times \mathbf{P}_2 \end{bmatrix} \begin{bmatrix} \mathbf{pts3D} \\ 1 \end{bmatrix} = \mathbf{0}$$

(Note) Use PROVIDED function `visualize_camera_poses_with_pts` to visualize 4 sets of camera poses with reconstructed 3D point cloud as shown in Figure 5.

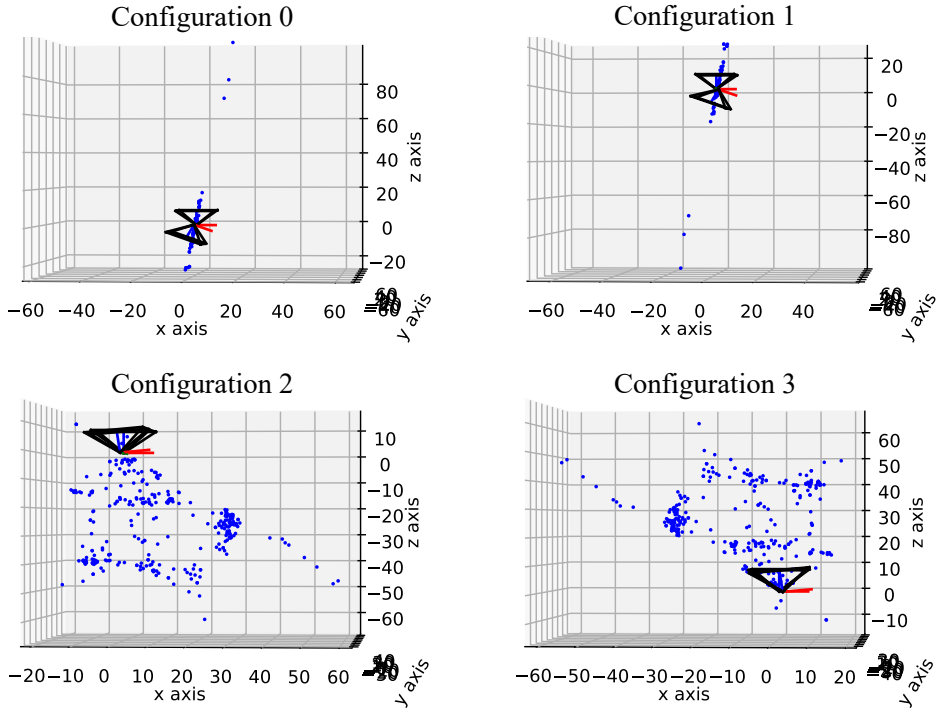

Figure 5: You can visualize four camera pose configurations with point cloud.

5 Pose Disambiguation

Given four configurations of relative camera pose and reconstructed points, you will find the best camera pose by choosing the configuration which leads to the most number of triangulated points in front of both cameras.

```
def disambiguate_pose(Rs, Cs, pts3Ds)
  ...
  return R, C, pts3D
```

Input: `Rs, Cs, pts3Ds` are python lists of rotation matrices, camera centers and 3D reconstructed points respectively
Output: `R`, `C`, `pts3D` are the best camera rotation, center, and 3D reconstructed points.
Description: The 3D point must lie in front of the both cameras. In Figure 5, configuration 3 produces the maximum number of valid points, and therefore it is the best configuration.

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6 Stereo

(a) Rectified image 1 (b) Rectified image 2

Figure 6: Stereo rectification.

Given the disambiguated camera pose, you will implement dense stereo matching between two views based on given correspondences, i.e. on dense SIFT.

```
def compute_rectification(K, R, C)
  ...
  return H1, H2
```

Input: The relative camera pose (`R` and `C`) and intrinsic parameter `K`.
Output: `H1` and `H2` are homographies ($\mathbb{R}^{3\times3}$) that rectify the left and right images such that the epipoles are at infinity.
Description: Given the disambiguated camera pose, you can find the rectification rotation matrix, $\mathbf{R}_{\text{rect}}$ such that the x-axis of the images aligns with the baseline. Find the rectification homographies for both cameras according to $\mathbf{H} = \mathbf{K}\mathbf{R}_{\text{rect}}\mathbf{R}^{\mathsf{T}}\mathbf{K}^{-1}$ where $\mathbf{R}$ is the rotation matrix of the camera. The rectified images are shown in Figure 6. This rectification sends the epipoles to infinity where the epipolar line becomes horizontal.

As shown in the skeletal code, function `cv2.warpPerspective` is then applied to warp original images to get rectified image pair.

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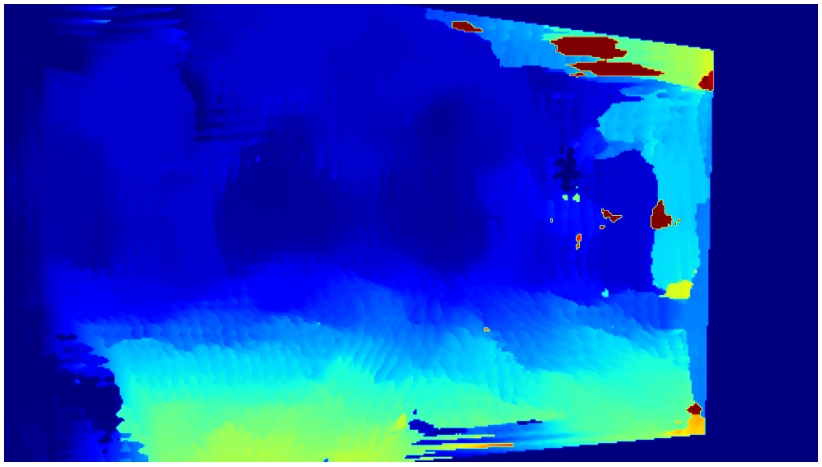

Figure 7: Visualization of stereo match.

```
def dense_match(img1, img2, desp1, desp2)
  ...
  return disparity
```

Input: two gray-scale rectified images in `uint8` format and their dense SIFT descriptors. `img1, img2` $\in \mathbb{R}^{H\times W}$, `desp1, desp2` $\in \mathbb{R}^{H\times W\times 128}$, where H and W are the image height and width.

Output: disparity map `disparity` $\in \mathbb{R}^{H\times W}$ where H and W are the image height and width.

Description: Compute the dense matches across all pixels. Given a pixel, $\mathbf{u}$ in the left image, sweep along its epipolar line, $\mathbf{l}_\mathbf{u}$, and find the disparity, d, that produces the best match, i.e.,

$$d = \arg\min_i \|\mathbf{d}^1_\mathbf{u} - \mathbf{d}^2_{\mathbf{u}-(i,0)}\|^2 \quad \forall i = 0, 1, \cdots, N$$

where $\mathbf{d}^1_\mathbf{u}$ is the dense SIFT descriptor at $\mathbf{u}$ on the left image and $\mathbf{d}^2_{\mathbf{u}+(i,0)}$ is the SIFT descriptor at $\mathbf{u} + (i, 0)$ (i pixel displaced along the x-axis) on the right image. The disparity map can be visualized using PROVIDED function `visualize_disparity_map` as shown in Figure 7.

(Note) Pre-computed dense SIFT descriptors are given in `dsift_descriptors.npz`.