

EE 5271: Assignment #2

Registration

1 Submission

- Assignment due: March 06, 2026 (11:59pm)
- Individual assignment
- Submission through Canvas.
- You will complete Registration.py that contains the following functions:
 - `find_match`
 - `align_image_using_feature`
 - `warp_image`
 - `align_image`
 - `track_multi_frames`

The code archive is provided with the assignment on Canvas.

- The function that does not comply with its specification will not be graded (no credit).
- The code must be run with Python 3 interpreter.
- 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.
- Place code and a two-page summary write-up with resulting visualization (in pdf format; more than 2 pages will be automatically returned.) into a folder, compress it, and submit.

EE 5271: Assignment #2

Registration

2 Sift Feature Extraction

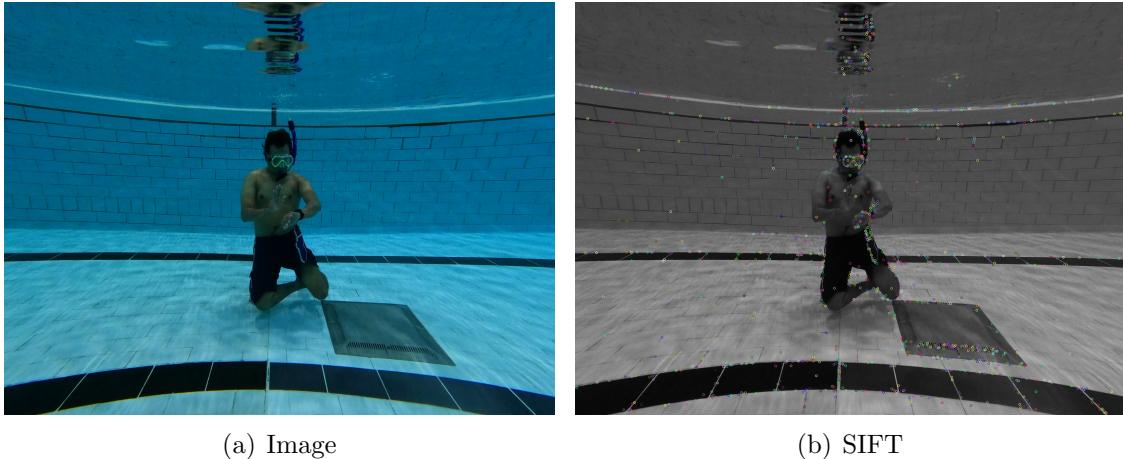


Figure 1: Given an image (a), you will extract SIFT features using OpenCV.

One of key skills to learn in computer vision (and software development in general) is the ability to use other, open-source code, which allows you to not reinvent the wheel. We will use OpenCV library for SIFT features extraction given your images.

(Note) You will use this library only for SIFT feature extraction and its visualization. All following visualizations and algorithms must be done by your code. Using OpenCV, you can extract keypoints and associated descriptors as shown in Figure 1. SIFT is now included with the *core* OpenCV library, as the patent for the algorithm expired in 2020. But older version of OpenCV will not have it in the core library, so please make sure you have a recent version of OpenCV.

(SIFT visualization) Use OpenCV to visualize SIFT features with scale and orientation as shown in Figure 1 (OpenCV may use different colors to visualize). You may want to follow the following tutorial:

https://docs.opencv.org/4.x/da/df5/tutorial_py_sift_intro.html

EE 5271: Assignment #2

Registration

3 SIFT Feature Matching

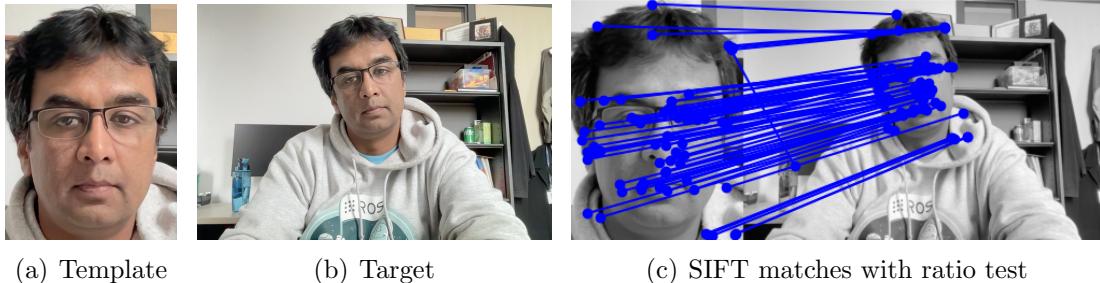


Figure 2: You will match points between the template and target image using SIFT features.

The SIFT is composed of scale, orientation, and 128 dimensional local feature descriptor (integer), $\mathbf{f} \in \mathbb{Z}^{128}$. You will use the SIFT features to match between two images, I_1 and I_2 . Use two sets of descriptors from the template and target, find the matches using nearest neighbor with the ratio test. You may use `NearestNeighbors` function imported from `sklearn.neighbors` (You can install `sklearn` package easily by "pip3 install -U scikit-learn").

```
def find_match(img1, img2):  
    ...  
    return x1, x2
```

Input: two input gray-scale images with uint8 format.

Output: x_1 and x_2 are $n \times 2$ matrices that specify the correspondence.

Description: Each row of x_1 and x_2 contains the (x, y) coordinate of the point correspondence in I_1 and I_2 , respectively, i.e., $x_1(i, :) \leftrightarrow x_2(i, :)$.

(Note) You can only use the SIFT module of OpenCV for the SIFT descriptor extraction. You need to implement the matching with the ratio test yourself.

EE 5271: Assignment #2

Registration

4 Feature-based Image Alignment

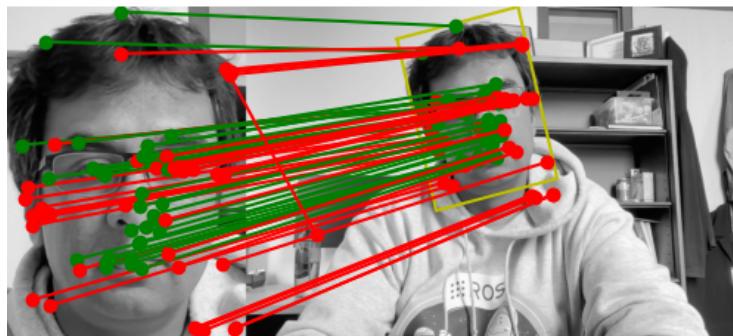


Figure 3: You will compute an affine transform using SIFT matches filtered by RANSAC. Red: outliers; Green: inliers; Yellow: the boundary of the transformed template.

(Note) From this point, you cannot use any function provided by OpenCV, except for purely visualization purposes.

The noisy SIFT matches can be filtered by RANSAC with an affine transformation as shown in Figure 3.

```
def align_image_using_feature(x1, x2, ransac_thr, ransac_iter):  
    ...  
    return A
```

Input: x_1 and x_2 are the correspondence sets ($n \times 2$ matrices). ransac_thr and ransac_iter are the error threshold and the number of iterations for RANSAC.

Output: 3×3 affine transformation.

Description: The affine transform will transform x_1 to x_2 , i.e., $x_2 = Ax_1$. You may visualize the inliers and the boundary of the transformed template to validate your implementation.

EE 5271: Assignment #2

Registration

5 Image Warping

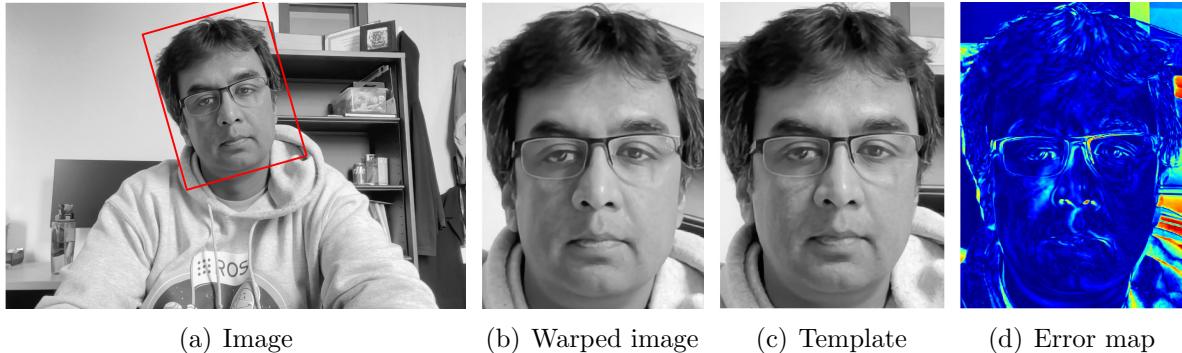


Figure 4: You will use the affine transform to warp the target image to the template using the inverse mapping. Using the warped image, the error map $|I_{\text{tpl}} - I_{\text{warp}}|$ can be computed to validate the correctness of the transformation where I_{tpl} and I_{warp} are the template and warped images.

Given an affine transform A , you will write a code to warp an image $I(x) \rightarrow I(Ax)$.

```
def warp_image(img, A, output_size):  
    ...  
    return img_warped
```

Input: I is an image to warp, A is the affine transformation from the original coordinate to the warped coordinate, $\text{output_size}=[h,w]$ is the size of the warped image where w and h are the width and height of the warped image.

Output: img_warped is the warped image with the size of output_size .

Description: The inverse mapping method needs to be applied to make sure the warped image does not produce empty pixels. You are allowed to use `interp1` function imported from `scipy.interpolate` for bilinear interpolation (`scipy` package can be easily installed through "pip3 install scipy" if you have not installed it yet).

(Validation) Using the warped image, the error map $|I_{\text{tpl}} - I_{\text{warp}}|$ can be computed to validate the correctness of the transformation, where I_{tpl} and I_{warp} are the template and warped images.

EE 5271: Assignment #2

Registration

6 Inverse Compositional Image Alignment

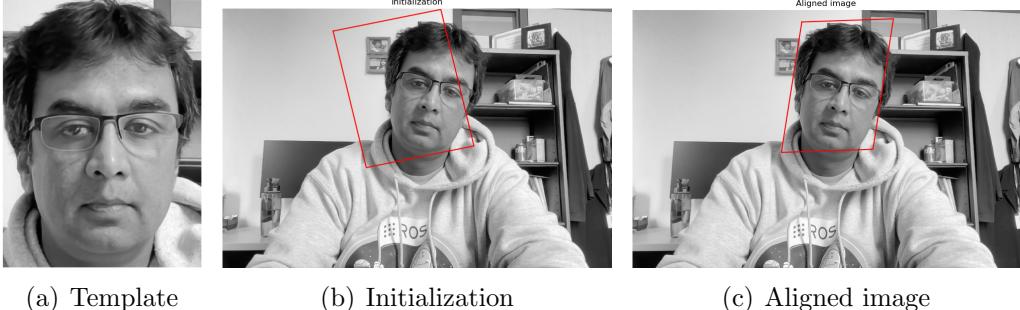


Figure 5: You will use the initial estimate of the affine transform to align (i.e., track) next image. (a) Template image from the first frame image. (b) The second frame image with the initialization of the affine transform. (c) The second frame image with the optimized affine transform using the inverse compositional image alignment.

Given the initial estimate of the affine transform A from the feature based image alignment (Section 4) as shown in Figure 5(b), you will track the next frame image using the inverse compositional method (Figure 5(c)). You will parametrize the affine transform with 6 parameters $p = (p_1, p_2, p_3, p_4, p_5, p_6)$, i.e.,

$$W(x; p) = \begin{bmatrix} p_1 + 1 & p_2 & p_3 \\ p_4 & p_5 + 1 & p_6 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = A(p)x \quad (1)$$

where $W(x; p)$ is the warping function from the template patch to the target image.

$x = \begin{bmatrix} u \\ v \\ 1 \end{bmatrix}$ is the coordinate of the point before warping, and $A(p)$ is the affine transform parametrized by p .

```
def align_image(template, target, A):
    ...
    return A_refined
```

Input: gray-scale template `template` and target image `target`; the initialization of 3×3 affine transform A , i.e., $x_{tgt} = Ax_{tpl}$ where x_{tgt} and x_{tpl} are points in the target and template images, respectively.

Output: `A_refined` is the refined affine transform based on inverse compositional image alignment

Description: You will refine the affine transform using inverse compositional image alignment, i.e., $A \rightarrow A_{refined}$. The pseudo-code can be found in Algorithm 1.

Tip: You can validate your algorithm by visualizing their error map as shown in Figure 6(a). Also you can visualize the error plot over iterations, i.e., the error must decrease as shown in Figure 6(b).

EE 5271: Assignment #2

Registration

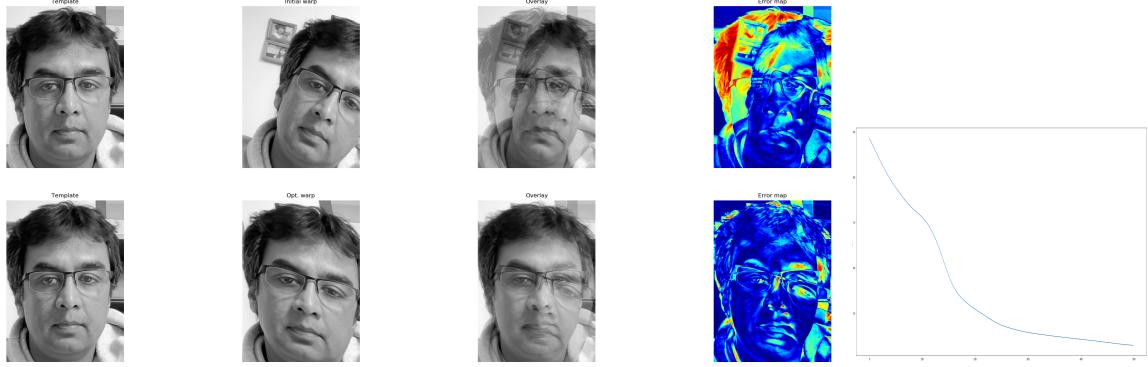


Figure 6: Left to right, top to bottom: Template images of the first frame, warped image based on the initialization of the affine parameters, template image is overlaid by the initialization, error map of the initialization, repeated template images of the first frame, optimized warped image using the inverse compositional image alignment, template image is overlaid by the optimized warped image. (h) Error map of the optimization. (i) An error plot over iterations.

Algorithm 1 Inverse Compositional Image Alignment

```

1: Initialize  $p = p_0$  from input  $\mathbf{A}$ .
2: Compute the gradient of template image,  $\nabla I_{\text{tpl}}$ 
3: Compute the Jacobian  $\frac{\partial W}{\partial p}$  at  $(x; 0)$ .
4: Compute the steepest decent images  $\nabla I_{\text{tpl}} \frac{\partial W}{\partial p}$ 
5: Compute the  $6 \times 6$  Hessian  $H = \sum_x \left[ \nabla I_{\text{tpl}} \frac{\partial W}{\partial p} \right]^T \left[ \nabla I_{\text{tpl}} \frac{\partial W}{\partial p} \right]$ 
6: while True do
7:   Warp the target to the template domain  $I_{\text{tgt}}(W(x; p))$ .
8:   Compute the error image  $I_{\text{err}} = I_{\text{tgt}}(W(x; p)) - I_{\text{tpl}}$ .
9:   Compute  $F = \sum_x \left[ \nabla I_{\text{tpl}} \frac{\partial W}{\partial p} \right]^T I_{\text{err}}$ .
10:  Compute  $\Delta p = H^{-1}F$ .
11:  Update  $W(x; p) \leftarrow W(x; p) \circ W^{-1}(x; \Delta p) = W(W^{-1}(x; \Delta p); p)$ .
12:  if  $\|\Delta p\| < \epsilon$  then
13:    break
14:  end if
15: end while
16: Return  $\mathbf{A}_{\text{refined}}$  made of  $p$ .

```

EE 5271: Assignment #2

Registration

7 Putting Things Together: Multiframe Tracking

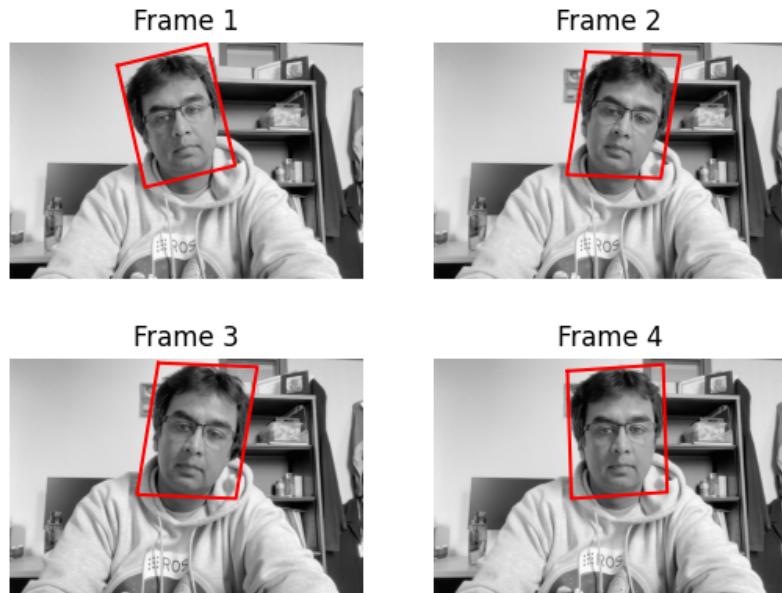


Figure 7: You will use the inverse compositional image alignment to track 4 frames of images.

Given a template and a set of consecutive images, you will (1) initialize the affine transform using the feature based alignment and then (2) track over frames using the inverse compositional image alignment.

```
def track_multi_frames(template, img_list):  
    ...  
    return A_list
```

Input: template is gray-scale template. img_list is a list of consecutive image frames, i.e., $\text{img_list}[i]$ is the i^{th} frame.

Output: A_list is the set of affine transforms from the template to each frame of image, i.e., $A_{\text{list}}[i]$ is the affine transform from the template to the i^{th} image.

Description: You will apply the inverse compositional image alignment sequentially to track over frames as shown in Figure 7. Note that the template image needs to be updated at every frame, i.e., $\text{template} \leftarrow \text{warp_image}(\text{img}, A, \text{template.shape})$.