Programming Assignments 3 and 4 – 601.455/655 Fall 2021

Score Sheet (hand in with report) Also, PLEASE INDICATE WHETHER YOU ARE IN 601.455 or 601.655

(one in each section is OK)

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Email	
Other contact information (optional)	
Signature (required)	I (we) have followed the rules in completing this assignment suryansh _____ _____

Grade Factor		
Program (40)		
Design and overall program structure	20	
Reusability and modularity	10	
Clarity of documentation and programming	10	
Results (20)		
Correctness and completeness	20	
Report (40)		
Description of formulation and algorithmic approach	15	
Overview of program	10	
Discussion of validation approach	5	
Discussion of results	10	
TOTAL	100	

CIS-PA4

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1 Mathematical Approach

1.1 Calculation of d_k

$F_{a,k}$ and $F_{b,k}$ are calculated by point cloud to point cloud registration

$$\vec{d_k} = F_{B,k}^{-1} \bullet F_{A,k} \bullet \vec{A_{tip}}$$

$$F_{A,k} \bullet \vec{A_{tip}} = R_{A,k} \bullet \vec{A_{tip}} + P_{A,k}$$
$$F_{B,k}^{-1} = [R_{B,k}^T, -R_{B,k}^T \bullet P_{B,k}]$$

1.2 Calculation of c_k

$$\vec{c_k} = F_{reg} \bullet d_k$$
$$\vec{c_k} = R_{reg} \bullet d_k + P_{reg}$$

1.3 Calculation of s_k

$$\vec{s_k} = F_{reg} \bullet d_k$$
$$\vec{s_k} = R_{reg} \bullet d_k + P_{reg}$$

2 Algorithm

2.1 Standard ICP algorithm

Iterative Closest point algorithm is the two step process of computing the F_{reg} or T In the first step we compute the correspondences between two scans and in second step Compute a transformation which minimizes distance between corresponding point.
For ICP the input and output are
Input - Two point-clouds: A = a_i and B = b_i Initial transformation T_0
Output -The correct transformation T, which aligns A and B

$T \leftarrow T0$;
while *not converged* **do**
  for $i \leftarrow 1$ *to* N **do**
    $c_k \leftarrow FindClosestPointInA(T \cdot b_i)$;
    if $||m_i - T_i|| \leq d_{max}$ **then**
      $w_i \leftarrow 1$;
    else
      $w_i \leftarrow 0$;
    end
  end
  $T \leftarrow \arg\min_T \sum_i w_i ||T \cdot b_i - m_i||^2$;
end

I have used the standard ICP algorithm for calculating the T (new transformation matrix). The initial transformation matrix was T0 = identity(4) i.e. identity matrix of 4x4. Then calculated the closestPoint using the nearest neighbor function. Instead of using the while function, I did only 20 iterations. With tolerance = 0.001. After each iteration the matrix T was updated with the the error taking the min of it and adding to the original transformation matrix.

CIS-PA4 Report

Structure of Code

Modules in ciscode

The program is having the main source code contained in "ciscode" folder. ciscode folder contains the modules

1. **closestPoint.py**
    a. CP → Class
        i. closestPoint_fun → function

closestPoint.py contains the class CP in which the function is closestPoint_fun. This function returns the coordinates of the vertices of triangle of the triangle mesh. Input is V, which is a list containing the vertices coordinates. The return variable is TRI, which is numpy array. each coordinate is 1x3 vector.

1. **icp.py**
    a. best_fit_transform → function
    b. nearest_neighbor → function
    c. icp → function

function name	input	output
best_fit_transform	(A,B) : A and B are two point clouds each of Nx3 numpy array	(T,R,t): T is homogeneous transformation matrix of 4x4 size. R is rotation matrix, extracted from T which is of 3x3 size and t is translation vector which is 3x1 column vector
nearest_neighbor	src: it is the Nx3 array of points and dst: Nx3 array of points. It finds the nearest euclidian distance.	(distance, indices)
icp	(A,B)	T,distance

best_fit_transform:

This function performs the 3D point cloud-3D- point cloud registration. It is the copy of the function ___. This is written just to make the ICP calculation easy.

nearest_neighbor:

The input of this function are two points of size Nx3 and Nx3. In our case the N=75. src is the short abbrivation for source and dst is for distance. It calculates the nearest euclidian neighbor in dst points for each point in src point cloud. Euclidian distance is calculated using the scipy library. It's imported with name cdist for spatial distance. It return the euclidian distance of nearest neighbor by variable distances and the indices represent the dst indices of the nearest neighbor.

icp:

A and B are two sources of 3D points. The other inputs are opitional, I set the max_iteration for icp equal to 20, and inital_pose = None because I have already defined the initial pose earlier in the program(where I am calling the function). the tolerence is set to 0.001. It can be set according to icp convergence. The function returns T which is homogeneous transformation matrix and distance, which is calculated by nearest neighbor.

2. **pa1Functions.py**
   This module is taken from the PA1, it is used for the point cloud-point cloud registration.
   a. **points_registration → function**

   input - A and B

   A is Nx3 numpy array also B is Nx3 numpy array.

   Output - T,R t

   T is homogeneous transformation matrix, 4x4

   R is rotation matrix 3x3

   t is translation vector. 3x1

3. **pointTriangleDistance2.py**
   a. closestPoint → class
      i. centroid → function

ii. pointTriangleDistance → function

PointTriangleDistance is defined in PA3. It calculates the nearest point on the triangle mesh.

4. **readers.py**
   a. **Vertices → class**

   This class is used to read the vertices from the triangle mesh data

   b. **Indices → class**

   It reads the indices of triangle mesh

   c. **RigidBody → class**

   Parses the rigid body A and body B LED and tip coordinate in body coordinate: data.

   d. **sampleReading → class**

   Parses the sample reading data

   Basically, this module is used to read the data from the input data files.

5. **triangleMesh.py**
   a. **findTriangleVertices → class**
      i. **getTriVertice → function**

      This class will find the triangle vertices from give indices and vertex

6. **writers.py**
   a. Writer → class
   b. PA4 → class

   This module is used for writing the output files. The input for this is numpy array containing the data.

pa4_icp_v2.py

This is the main function which calculates the required answer.

1. **main → function**

First step is to import the surface mesh data into the seperate arrays of vertices and indices.

For this I used the **reader** function.

Then I import the RigidbodyA and RigidBodyB data files using the **reader.RigidBody function,** using the reader.py module

Then I have used the two point clouds, and initialized them with empty list - 'point_cloud_sk' and 'point_cloud_ck'.

Then initialize a for loop for reading all the 75 frames in one sample reading file. Calculated the F_bk, F_ak and pointer tip as defined in the PA3.

Then defined a function "FindClosestPointMesh" for calculation the closest point on the triangle. c_k are the closest point on the triangle mesh which are s_k to. c_k is $\vec{c_k}$ and s_k is $\vec{s_k}$. Hence, "point_cloud_sk" which is point cloud variable is formed by collecting all the 75 points s_k from all the 75 frames. And similar procedure is applied for "point_cloud_ck". Later point cloud of s_k is denoted by pt1 and point cloud of c_k by pt2 (both the variables are similar).

ICP Calculation

pt1 and pt2 were passed into icp function and in the output is T which is variable name for Freg. Then I calculated the new sk_new and ck_new using the transformtion. $sk_{new} = T \bullet d_k$ and $ck_{new} = T \bullet d_k$.

The distance $||\vec{s_k} - \vec{c_l}||$ is calculated by np.linalg.norm(ski-cki) for each point in sk and ck after transformation.

Finally I passed the sk,ck and dist to the output file.

Result for Unknown Data

given in next page, output of the unknown data.

Discussion for the results

After the ICP registration, the first three elements of the output are sx,sy,sz and the next three elements are cx,cy,cz and the last element is magnitude of difference $||s_k - c_k||$.

It appears that the value of s_k i.e. (sx,sy,sz) is similar to the value c_k which is (cx,cy,cz). This happened because at the last step we did the transformation of the $s_k = F_{reg} \bullet d_k$ and $c_k = F_{reg} \bullet d_k$ since the F_reg is same in both the case. So basically the two vector elements should be the same. The distance between the sk and ck is zero that means the registation is perfect. If we are having the different coordinates of sk and ck then the registration is not perfect and may be some error is present or the points are not exactly matching. i.e. the Freg is not perfect.

Libraries used

1. scipy
2. numpy
3. math
4. click
5. logging

PA4-G-Unknown-Output

75, PA4-G-Unknown-Output.txt	0
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49.636 20.889 -34.332 49.636 20.889 -34.332 0.000	
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28.658 -10.815 -46.062 28.658 -10.815 -46.062 0.000	
4.122 27.480 -11.859 4.122 27.480 -11.859 0.000	
52.953 3.768 -13.236 52.953 3.768 -13.236 0.000	
58.114 -12.024 -33.565 58.114 -12.024 -33.565 0.000	
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-13.689 -22.988 -53.351 -13.689 -22.988 -53.351 0.000	
23.173 15.519 -28.102 23.173 15.519 -28.102 0.000	
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41.539 18.510 -44.654 41.539 18.510 -44.654 0.000	
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31.387	-17.249	-23.867	31.387	-17.249	-23.867	0.000
8.446	28.710	-13.094	8.446	28.710	-13.094	0.000
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37.618	-5.552	-10.864	37.618	-5.552	-10.864	0.000
52.842	7.887	-15.238	52.842	7.887	-15.238	0.000
-10.325	8.938	-59.586	-10.325	8.938	-59.586	0.000
-18.867	27.231	-55.403	-18.867	27.231	-55.403	0.000
9.382	30.162	-25.427	9.382	30.162	-25.427	0.000
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-23.025	-11.930	-33.570	-23.025	-11.930	-33.570	0.000
40.173	13.610	-13.568	40.173	13.610	-13.568	0.000
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26.758	-0.133	-13.776	26.758	-0.133	-13.776	0.000
43.807	-22.451	-27.360	43.807	-22.451	-27.360	0.000
-8.462	29.150	-53.392	-8.462	29.150	-53.392	0.000
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62.050	1.398	-22.132	62.050	1.398	-22.132	0.000
13.672	28.750	-51.713	13.672	28.750	-51.713	0.000
37.580	-4.714	-53.463	37.580	-4.714	-53.463	0.000
5.192	21.838	-17.751	5.192	21.838	-17.751	0.000
2.289	34.221	-17.533	2.289	34.221	-17.533	0.000
43.449	22.135	-35.295	43.449	22.135	-35.295	0.000
-0.493	30.133	-14.550	-0.493	30.133	-14.550	0.000
-4.384	7.672	-24.670	-4.384	7.672	-24.670	0.000
-28.060	-36.259	-73.033	-28.060	-36.259	-73.033	0.000
-25.456	7.465	-60.233	-25.456	7.465	-60.233	0.000
7.370	28.041	-12.698	7.370	28.041	-12.698	0.000
-18.759	1.552	-24.953	-18.759	1.552	-24.953	0.000
3.155	40.261	-26.592	3.155	40.261	-26.592	0.000
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PA4-H-Unknown-Output

75, PA4-H-Unknown-Output.txt	
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26.533	-13.303	-31.989	26.533	-13.303	-31.989	0.000
-33.189	-32.266	-78.063	-33.189	-32.266	-78.063	0.000
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41.407	9.191	-49.791	41.407	9.191	-49.791	0.000
36.672	-13.566	-41.233	36.672	-13.566	-41.233	0.000
16.377	18.906	-26.754	16.377	18.906	-26.754	0.000
43.394	-3.973	-11.082	43.394	-3.973	-11.082	0.000
29.655	2.874	-7.520	29.655	2.874	-7.520	0.000
47.772	19.505	-18.350	47.772	19.505	-18.350	0.000
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4.716	-0.657	-27.844	4.716	-0.657	-27.844	0.000
-2.544	10.745	-56.132	-2.544	10.745	-56.132	0.000
-48.986	-21.567	-71.760	-48.986	-21.567	-71.760	0.000
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43.152	-15.318	-27.862	43.152	-15.318	-27.862	0.000
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-5.313	41.569	-42.926	-5.313	41.569	-42.926	0.000
49.265	-1.324	-43.804	49.265	-1.324	-43.804	0.000
34.747	12.372	-8.160	34.747	12.372	-8.160	0.000
-37.188	-40.164	-56.227	-37.188	-40.164	-56.227	0.000
-15.852	-25.495	-46.820	-15.852	-25.495	-46.820	0.000
46.778	-1.379	-46.247	46.778	-1.379	-46.247	0.000

-16.437	-13.914	-28.548	-16.437	-13.914	-28.548	0.000
40.166	3.424	-8.023	40.166	3.424	-8.023	0.000
15.004	14.008	-20.870	15.004	14.008	-20.870	0.000
-24.518	6.923	-22.130	-24.518	6.923	-22.130	0.000
-43.928	-14.742	-68.385	-43.928	-14.742	-68.385	0.000
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75, PA4-J-Unknown—Output.txt	0
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38.388 21.881 -48.025 38.388 21.881 -48.025 0.000	
31.436 15.055 -51.078 31.436 15.055 -51.078 0.000	
23.869 22.991 -44.860 23.869 22.991 -44.860 0.000	
19.946 23.769 -41.808 19.946 23.769 -41.808 0.000	
37.451 8.859 -6.211 37.451 8.859 -6.211 0.000	
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17.659	8.447	-44.862	17.659	8.447	-44.862	0.000
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38.487	-7.516	-24.623	38.487	-7.516	-24.623	0.000
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54.462	10.380	-30.727	54.462	10.380	-30.727	0.000
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32.770	-12.525	-47.511	32.770	-12.525	-47.511	0.000	
13.837	39.129	-20.707	13.837	39.129	-20.707	0.000	
20.589	21.163	-44.245	20.589	21.163	-44.245	0.000	