S13

March 6, 2023

1 Point Cloud Alignment

1.1 Task 1 Opend 3D visualization

[ ]:
```
!pip3 install mrob
```

```
Defaulting to user installation because normal site-packages is not writeable
Collecting mrob
  Using cached mrob-0.0.8-py3-none-macosx_10_9_x86_64.whl (1.1 MB)
Installing collected packages: mrob
Successfully installed mrob-0.0.8
WARNING: You are using pip version 21.2.4; however, version 23.0.1 is
available.
You should consider upgrading via the
'/Library/Developer/CommandLineTools/usr/bin/python3 -m pip install --upgrade
pip' command.
```

[ ]:
```
!pip3 install numpy
```

```
Defaulting to user installation because normal site-packages is not writeable
Collecting numpy
  Downloading numpy-1.24.2-cp39-cp39-macosx_10_9_x86_64.whl (19.8 MB)
     |                | 19.8 MB 1.7 MB/s eta 0:00:01
Installing collected packages: numpy
  WARNING: The scripts f2py, f2py3 and f2py3.9 are installed in
'/Users/vladimirberman/Library/Python/3.9/bin' which is not on PATH.
  Consider adding this directory to PATH or, if you prefer to suppress this
warning, use --no-warn-script-location.
Successfully installed numpy-1.24.2
```

```
WARNING: You are using pip version 21.2.4; however, version 23.0.1 is
available.
You should consider upgrading via the
'/Library/Developer/CommandLineTools/usr/bin/python3 -m pip install --upgrade
pip' command.
```

[ ]:
```
!pip3 install open3d
```

```
Defaulting to user installation because normal site-packages is not writeable
Collecting open3d
  Downloading open3d-0.16.1-cp39-cp39-macosx_10_15_x86_64.whl (74.4 MB)
     |                  | 74.4 MB 2.9 MB/s eta 0:00:011
Collecting configargparse
  Downloading ConfigArgParse-1.5.3-py3-none-any.whl (20 kB)
Collecting pillow>=8.2.0
  Downloading Pillow-9.4.0-2-cp39-cp39-macosx_10_10_x86_64.whl (3.3 MB)
     |                  | 3.3 MB 13.4 MB/s eta 0:00:01
Collecting addict
  Using cached addict-2.4.0-py3-none-any.whl (3.8 kB)
Collecting scikit-learn>=0.21
  Using cached scikit_learn-1.2.1-cp39-cp39-macosx_10_9_x86_64.whl (9.1 MB)
Collecting dash>=2.6.0
  Downloading dash-2.8.1-py3-none-any.whl (9.9 MB)
     |                  | 9.9 MB 21.7 MB/s eta 0:00:01
Requirement already satisfied: numpy>1.15 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from open3d)
(1.24.2)
Collecting tqdm
  Downloading tqdm-4.65.0-py3-none-any.whl (77 kB)
     |                  | 77 kB 11.1 MB/s eta 0:00:01
Collecting pyquaternion
  Downloading pyquaternion-0.9.9-py3-none-any.whl (14 kB)
Collecting pyyaml>=5.4.1
  Downloading PyYAML-6.0-cp39-cp39-macosx_10_9_x86_64.whl (197 kB)
     |                  | 197 kB 20.2 MB/s eta 0:00:01
Collecting nbformat==5.5.0
  Downloading nbformat-5.5.0-py3-none-any.whl (75 kB)
     |                  | 75 kB 5.8 MB/s  eta 0:00:01
Collecting pandas>=1.0
  Downloading pandas-1.5.3-cp39-cp39-macosx_10_9_x86_64.whl (12.0 MB)
     |                  | 12.0 MB 13.3 MB/s eta 0:00:01
Collecting matplotlib>=3
  Downloading matplotlib-3.7.1-cp39-cp39-macosx_10_12_x86_64.whl (7.4 MB)
     |                  | 7.4 MB 18.2 MB/s eta 0:00:01
Requirement already satisfied: jupyter_core in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
```

```
nbformat==5.5.0->open3d) (5.1.3)
Requirement already satisfied: traitlets>=5.1 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
nbformat==5.5.0->open3d) (5.8.1)
Collecting jsonschema>=2.6
  Downloading jsonschema-4.17.3-py3-none-any.whl (90 kB)
     |                  | 90 kB 12.4 MB/s eta 0:00:01
Collecting fastjsonschema
  Downloading fastjsonschema-2.16.3-py3-none-any.whl (23 kB)
Collecting dash-table==5.0.0
  Downloading dash_table-5.0.0-py3-none-any.whl (3.9 kB)
Collecting Flask>=1.0.4
  Downloading Flask-2.2.3-py3-none-any.whl (101 kB)
     |                  | 101 kB 16.6 MB/s ta 0:00:01
Collecting plotly>=5.0.0
  Downloading plotly-5.13.1-py2.py3-none-any.whl (15.2 MB)
     |                  | 15.2 MB 20.6 MB/s eta 0:00:01
Collecting dash-html-components==2.0.0
  Downloading dash_html_components-2.0.0-py3-none-any.whl (4.1 kB)
Collecting dash-core-components==2.0.0
  Downloading dash_core_components-2.0.0-py3-none-any.whl (3.8 kB)
Collecting Jinja2>=3.0
  Using cached Jinja2-3.1.2-py3-none-any.whl (133 kB)
Collecting importlib-metadata>=3.6.0
  Downloading importlib_metadata-6.0.0-py3-none-any.whl (21 kB)
Collecting itsdangerous>=2.0
  Downloading itsdangerous-2.1.2-py3-none-any.whl (15 kB)
Collecting click>=8.0
  Using cached click-8.1.3-py3-none-any.whl (96 kB)
Collecting Werkzeug>=2.2.2
  Downloading Werkzeug-2.2.3-py3-none-any.whl (233 kB)
     |                  | 233 kB 34.6 MB/s eta 0:00:01
Collecting zipp>=0.5
  Downloading zipp-3.15.0-py3-none-any.whl (6.8 kB)
Collecting MarkupSafe>=2.0
  Downloading MarkupSafe-2.1.2-cp39-cp39-macosx_10_9_x86_64.whl (13 kB)
Collecting pyrsistent!=0.17.0,!=0.17.1,!=0.17.2,>=0.14.0
  Downloading pyrsistent-0.19.3-cp39-cp39-macosx_10_9_universal2.whl (82 kB)
     |                  | 82 kB 3.0 MB/s  eta 0:00:01
Collecting attrs>=17.4.0
  Downloading attrs-22.2.0-py3-none-any.whl (60 kB)
     |                  | 60 kB 11.2 MB/s eta 0:00:01
Collecting fonttools>=4.22.0
  Using cached fonttools-4.38.0-py3-none-any.whl (965 kB)
Collecting cycler>=0.10
  Using cached cycler-0.11.0-py3-none-any.whl (6.4 kB)
Collecting contourpy>=1.0.1
  Downloading contourpy-1.0.7-cp39-cp39-macosx_10_9_x86_64.whl (244 kB)
```

```
     |                | 244 kB 25.7 MB/s eta 0:00:01
Collecting pyparsing>=2.3.1
  Using cached pyparsing-3.0.9-py3-none-any.whl (98 kB)
Collecting importlib-resources>=3.2.0
  Downloading importlib_resources-5.12.0-py3-none-any.whl (36 kB)
Collecting kiwisolver>=1.0.1
  Downloading kiwisolver-1.4.4-cp39-cp39-macosx_10_9_x86_64.whl (65 kB)
     |                | 65 kB 10.1 MB/s eta 0:00:01
Requirement already satisfied: python-dateutil>=2.7 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib>=3->open3d) (2.8.2)
Requirement already satisfied: packaging>=20.0 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib>=3->open3d) (23.0)
Collecting pytz>=2020.1
  Using cached pytz-2022.7.1-py2.py3-none-any.whl (499 kB)
Collecting tenacity>=6.2.0
  Downloading tenacity-8.2.2-py3-none-any.whl (24 kB)
Requirement already satisfied: six>=1.5 in /Library/Developer/CommandLineTools/L
ibrary/Frameworks/Python3.framework/Versions/3.9/lib/python3.9/site-packages
(from python-dateutil>=2.7->matplotlib>=3->open3d) (1.15.0)
Collecting threadpoolctl>=2.0.0
  Using cached threadpoolctl-3.1.0-py3-none-any.whl (14 kB)
Collecting joblib>=1.1.1
  Using cached joblib-1.2.0-py3-none-any.whl (297 kB)
Collecting scipy>=1.3.2
  Downloading scipy-1.10.1-cp39-cp39-macosx_10_9_x86_64.whl (35.2 MB)
     |                | 35.2 MB 1.3 MB/s eta 0:00:011
Requirement already satisfied: platformdirs>=2.5 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
jupyter_core->nbformat==5.5.0->open3d) (2.6.2)
Installing collected packages: zipp, MarkupSafe, Werkzeug, tenacity, pyrsistent,
Jinja2, itsdangerous, importlib-metadata, click, attrs, threadpoolctl, scipy,
pytz, pyparsing, plotly, pillow, kiwisolver, jsonschema, joblib, importlib-
resources, fonttools, Flask, fastjsonschema, dash-table, dash-html-components,
dash-core-components, cycler, contourpy, tqdm, scikit-learn, pyyaml,
pyquaternion, pandas, nbformat, matplotlib, dash, configargparse, addict, open3d
  WARNING: The script jsonschema is installed in
'/Users/vladimirberman/Library/Python/3.9/bin' which is not on PATH.
  Consider adding this directory to PATH or, if you prefer to suppress this
warning, use --no-warn-script-location.
```

```
  WARNING: The scripts fonttools, pyftmerge, pyftsubset and ttx are
installed in '/Users/vladimirberman/Library/Python/3.9/bin' which is not on
PATH.
  Consider adding this directory to PATH or, if you prefer to suppress this
warning, use --no-warn-script-location.
  WARNING: The script flask is installed in
'/Users/vladimirberman/Library/Python/3.9/bin' which is not on PATH.
  Consider adding this directory to PATH or, if you prefer to suppress this
warning, use --no-warn-script-location.
  WARNING: The script tqdm is installed in
'/Users/vladimirberman/Library/Python/3.9/bin' which is not on PATH.
  Consider adding this directory to PATH or, if you prefer to suppress this
warning, use --no-warn-script-location.
  WARNING: The script jupyter-trust is installed in
'/Users/vladimirberman/Library/Python/3.9/bin' which is not on PATH.
  Consider adding this directory to PATH or, if you prefer to suppress this
warning, use --no-warn-script-location.
  WARNING: The scripts dash-generate-components, dash-update-components and
renderer are installed in '/Users/vladimirberman/Library/Python/3.9/bin' which
is not on PATH.
  Consider adding this directory to PATH or, if you prefer to suppress this
warning, use --no-warn-script-location.
  WARNING: The script open3d is installed in
'/Users/vladimirberman/Library/Python/3.9/bin' which is not on PATH.
  Consider adding this directory to PATH or, if you prefer to suppress this
warning, use --no-warn-script-location.
Successfully installed Flask-2.2.3 Jinja2-3.1.2 MarkupSafe-2.1.2 Werkzeug-2.2.3
addict-2.4.0 attrs-22.2.0 click-8.1.3 configargparse-1.5.3 contourpy-1.0.7
cycler-0.11.0 dash-2.8.1 dash-core-components-2.0.0 dash-html-components-2.0.0
dash-table-5.0.0 fastjsonschema-2.16.3 fonttools-4.38.0 importlib-metadata-6.0.0
importlib-resources-5.12.0 itsdangerous-2.1.2 joblib-1.2.0 jsonschema-4.17.3
kiwisolver-1.4.4 matplotlib-3.7.1 nbformat-5.5.0 open3d-0.16.1 pandas-1.5.3
pillow-9.4.0 plotly-5.13.1 pyparsing-3.0.9 pyquaternion-0.9.9 pyrsistent-0.19.3
pytz-2022.7.1 pyyaml-6.0 scikit-learn-1.2.1 scipy-1.10.1 tenacity-8.2.2
threadpoolctl-3.1.0 tqdm-4.65.0 zipp-3.15.0
```

```
WARNING: You are using pip version 21.2.4; however, version 23.0.1 is
available.
You should consider upgrading via the
'/Library/Developer/CommandLineTools/usr/bin/python3 -m pip install --upgrade
pip' command.
```

[ ]:
```
!pip3 install matplotlib
```

```
Defaulting to user installation because normal site-packages is not writeable
Requirement already satisfied: matplotlib in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (3.7.1)
Requirement already satisfied: kiwisolver>=1.0.1 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib) (1.4.4)
Requirement already satisfied: packaging>=20.0 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib) (23.0)
Requirement already satisfied: pyparsing>=2.3.1 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib) (3.0.9)
Requirement already satisfied: numpy>=1.20 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib) (1.24.2)
Requirement already satisfied: python-dateutil>=2.7 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib) (2.8.2)
Requirement already satisfied: importlib-resources>=3.2.0 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib) (5.12.0)
Requirement already satisfied: cycler>=0.10 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib) (0.11.0)
Requirement already satisfied: contourpy>=1.0.1 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib) (1.0.7)
Requirement already satisfied: pillow>=6.2.0 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib) (9.4.0)
Requirement already satisfied: fonttools>=4.22.0 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
matplotlib) (4.38.0)
Requirement already satisfied: zipp>=3.1.0 in
/Users/vladimirberman/Library/Python/3.9/lib/python/site-packages (from
importlib-resources>=3.2.0->matplotlib) (3.15.0)
Requirement already satisfied: six>=1.5 in /Library/Developer/CommandLineTools/L
ibrary/Frameworks/Python3.framework/Versions/3.9/lib/python3.9/site-packages
```

```
(from python-dateutil>=2.7->matplotlib) (1.15.0)
WARNING: You are using pip version 21.2.4; however, version 23.0.1 is
available.
You should consider upgrading via the
'/Library/Developer/CommandLineTools/usr/bin/python3 -m pip install --upgrade
pip' command.
```

[ ]:
```
import sys
import mrob
import numpy as np
import open3d
import random
import matplotlib.pyplot as plt
from matplotlib import animation, rc
from math import sin, cos, atan2, pi
from IPython.display import display, Math, Latex, Markdown, HTML
```

[ ]:
```
# generate random data
N = 500
X =  np.random.rand(N,3)
T = mrob.geometry.SE3(np.random.rand(6))
Y = T.transform_array(X)+np.random.normal(loc = 0, scale = 0.05, size = (500,3))
```

Creat a function Vis(X, color) that plots a points X with the color using Open3d

[ ]:
```
def vis (X, color = np.array([0,0,1], dtype='float64')):
    pcd = open3d.geometry.PointCloud()
    pcd.points = open3d.utility.Vector3dVector(X)
    pcd.paint_uniform_color(color)
    open3d.visualization.draw_plotly([pcd])
```

[ ]:
```
vis(X, np.array([0,0,1], dtype='float64'))
```

[ ]:
```
print('X = \n', X,'\n T = \n', T.T(),'\n Y =\n', Y)
```

```
X =
 [[8.24960550e-01 4.36882471e-01 2.26935314e-01]
 [8.88800959e-01 4.62475405e-01 9.63816573e-01]
 [9.90778804e-01 7.77245117e-01 8.67758495e-01]
 …
 [1.96120530e-01 6.34608482e-01 2.30975049e-02]
 [8.25175223e-02 4.45473452e-01 9.81461412e-04]
 [6.23701251e-01 7.38548124e-01 7.49214437e-01]]
 T =
 [[ 0.70207326 -0.45785822  0.545398    0.78878796]
 [ 0.71209502  0.45540073 -0.53435088  0.34420741]
```

```
[-0.0037177   0.76352867  0.64576323  0.31455896]
[ 0.          0.          0.          1.        ]]
Y =
[[1.27606587 0.96931945 0.69439038]
[1.73908649 0.61787425 1.3001064 ]
[1.58813009 0.93679356 1.36253565]
…
[0.64310946 0.73280258 0.73545855]
[0.65074786 0.59866467 0.67689477]
[1.28714865 0.71631795 1.32969249]]
```

1.2 Task 2 point cloud Alignment using Arun's Method.

[ ]:
```python
def pcd_1(X, color, T = np.identity(4)):
    pcd = open3d.geometry.PointCloud()
    pcd.points = open3d.utility.Vector3dVector(X)
    pcd.transform(T)
    pcd.paint_uniform_color(color)
    return pcd
```

[ ]:
```python
def vis_her(X, Y, T = np.identity(4)):
    blue = np.array([0,0,1], dtype='float64')
    red = np.array([1,0,0], dtype='float64')
    open3d.visualization.draw_plotly([pcd_1(X,red), pcd_1(Y,blue, T)])
```

[ ]:
```python
def apply_t (X, T):
    pcd = open3d.geometry.PointCloud()
    pcd.points = open3d.utility.Vector3dVector(X)
    pcd.transform(T)
    new_X = np.array(pcd.points)
    return new_X
```

1.2.1 TODO:

-use the function mrob.registration.arun() on the two point clouds.

-Plot the two point clouds befor and after the solution.

[ ]:
```python
# solve the problem
# TODO:
#* use the function mrob.registration.arun() on the two point clouds.
#* Plot the two point clouds befor and after the solution.

vis_her(X, Y)
T_arun = mrob.registration.arun(X, Y)
print('Arun solution =\n', T_arun.T())
vis_her(Y, X, np.asarray(T_arun.T()))
```

```
Arun solution =
 [[ 0.77702078 -0.60526241  0.17290495  0.23837799]
 [ 0.62470412  0.77522451 -0.09365741  0.72276812]
 [-0.07735285  0.18078819  0.98047548  0.5104911 ]
 [ 0.          0.          0.          1.        ]]
```

1.2.2 TODO:

- Calculate the Rotation Distance and Translation Distance of arun't method output and ground truth.

[ ]:
```
# Claculate the error:
# err = np.std(X - Y)
# TODO:
#* Calculate the Rotation Distance and Translation Distance of arun't method output and ground truth.

print('Rotation Distance: ', T_arun.distance_rotation(mrob.geometry.SE3(T)))
print('Translation Distance: ', T_arun.distance_trans(mrob.geometry.SE3(T)))
```

```
Rotation Distance:  0.0025942272449513784
Translation Distance:  0.0030609144401729208
```

2 ICP:

[ ]:
```
# Genrate data:
angle = pi / 8
R_true = np.array([[cos(angle), -sin(angle), 0],
                   [sin(angle),  cos(angle), 0],
                   [0, 0, 1]])
t_true = np.array([[-2], [5], [0]])
num_points = 30
true_data = np.zeros((3, num_points))
true_data[0, :] = range(0, num_points)
true_data[1, :] = 0.2 * true_data[0, :] * np.sin(0.5 * true_data[0, :])
transformed_data = R_true.dot(true_data) + t_true

Q = true_data.T
P = transformed_data.T
vis_her(Q, P)
```

2.1 Task 1:

2.1.1 Calculate correspondence

[ ]:
```
def get_correspondence_indices(P, Q):
    """TODO
    #*For each point in P find closest one in Q."""
    correspondences = np.zeros([2, len(P)])
    correspondences[0, :] = np.arange(len(P))
    for i in range(len(P)):
            correspondences[1, i] = np.argmin((np.asarray(P[i, 0]) - np.
 ↪asarray(Q[:, 0])) ** 2 +
                                              (np.asarray(P[i, 1]) - np.
 ↪asarray(Q[:, 1])) ** 2 +
                                              (np.asarray(P[i, 2]) - np.
 ↪asarray(Q[:, 2])) ** 2)

    return correspondences.T
```

[ ]:
```
result = get_correspondence_indices(P, Q)
print(result)
```

```
[[ 0.  0.]
 [ 1.  0.]
 [ 2.  0.]
 [ 3.  2.]
 [ 4.  3.]
 [ 5.  3.]
 [ 6.  4.]
 [ 7.  4.]
 [ 8.  5.]
 [ 9.  5.]
 [10.  5.]
 [11. 14.]
 [12. 15.]
 [13. 15.]
 [14. 15.]
 [15. 15.]
 [16. 15.]
 [17. 16.]
 [18. 16.]
 [19. 16.]
 [20. 16.]
 [21. 16.]
 [22. 17.]
 [23. 17.]
 [24. 28.]
 [25. 28.]
```

```
[26. 28.]
[27. 28.]
[28. 28.]
[29. 28.]]
```

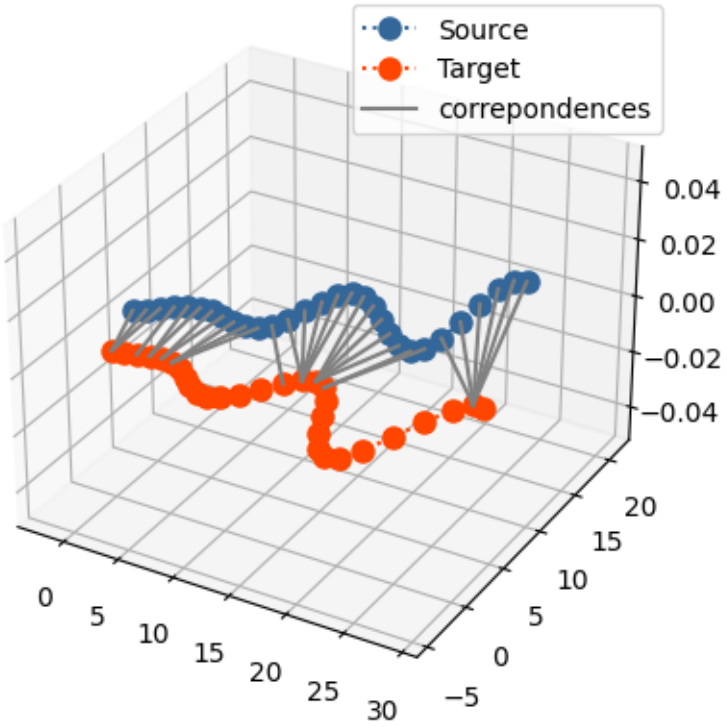
[ ]:
```python
correspondences = list(map(tuple, result.astype('int')))
correspondences
```

[ ]:
```
[(0, 0),
 (1, 0),
 (2, 0),
 (3, 2),
 (4, 3),
 (5, 3),
 (6, 4),
 (7, 4),
 (8, 5),
 (9, 5),
 (10, 5),
 (11, 14),
 (12, 15),
 (13, 15),
 (14, 15),
 (15, 15),
 (16, 15),
 (17, 16),
 (18, 16),
 (19, 16),
 (20, 16),
 (21, 16),
 (22, 17),
 (23, 17),
 (24, 28),
 (25, 28),
 (26, 28),
 (27, 28),
 (28, 28),
 (29, 28)]
```

[ ]:
```python
def draw_correspondeces(P, Q, correspondences, ax):
    label_added = False
    for i, j in correspondences:
        x = [P[i, 0], Q[j, 0]]
        y = [P[i, 1], Q[j, 1]]
        z = [P[i, 2], Q[j, 2]]
        if not label_added:
            ax.plot(x, y,z, color='grey', label='correpondences')
```

```
            label_added = True
        else:
            ax.plot(x, y, z,color='grey')
    ax.legend()
```

[ ]:
```
fig = plt.figure()
ax = plt.axes(projection='3d')
ax.plot(P[:,0], P[:,1], P[:,2],color='#336699', markersize=8, marker='o',␣
 ↪linestyle=":", label = 'Source')
ax.plot(Q[:,0], Q[:,1], Q[:,2],color='orangered', markersize=8, marker='o',␣
 ↪linestyle=":", label = 'Target')
draw_correspondeces(P, Q, correspondences, ax)
plt.show()
```



2.1.2 Use the Arun's method to calculat first correction of ICP:

[ ]:
```
X = Q
Y = np.zeros_like(X)
for i, j in correspondences:
    Y[i] = Q[j]

T_arun = mrob.registration.arun(Y, X)
```

```
print(T_arun.T())
vis_her(Q,P, np.asarray(T_arun.T()))
```

```
[[ 0.99424538  0.10712671  0.          0.90844785]
 [-0.10712671  0.99424538  0.         -0.80778366]
 [ 0.          0.          1.          0.        ]
 [ 0.          0.          0.          1.        ]]
```

2.2 Let's Make it iterative:

[ ]:
```
P = apply_t(P, T_arun.T())
correspondences = list(map(tuple, get_correspondence_indices(P, Q).
  ↪astype('int')))
X = Q
Y = np.zeros_like(X)
for i, j in correspondences:
    Y[i] = Q[j]

T_arun = mrob.registration.arun(Y, X)
print(T_arun.T())
vis_her(Q,P, np.asarray(T_arun.T()))
```

```
[[ 0.99437369  0.10592902  0.         -1.90483931]
 [-0.10592902  0.99437369  0.          0.13180864]
 [ 0.          0.          1.          0.        ]
 [ 0.          0.          0.          1.        ]]
```