alexge / **3d-point-cloud-analytics**

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README.md

Introduction

Python implementation of basic point cloud manipulation.

Homework Solution

1. Build Dataset for Assignment 01

Download ModelNet40 Dataset

The script is available at **/workspace/data/get-modelnet40.sh**

```
# change directory to data folder:
cd /workspace/data
# download:
./get-modelnet40.sh
# extract:
unzip ModelNet40.zip
```

Select One Point Cloud from Each Category

The following Python script can be used for sample set creation

```
# change directory to data folder:
cd /workspace/data
# downsample:
./sample-modelnet40.py
```

2. Perform PCA for the 40 Objects and Visualize

Below is the code for PCA

```
def PCA(data, correlation=False, sort=True):
    """ Calculate PCA for given point cloud

    Parameters:
        data：点云，NX3的矩阵
        correlation：区分np的cov和corrcoef，不输入时默认为False
        sort: 特征值排序，排序是为了其他功能方便使用，不输入时默认为True

    Returns:
        eigenvalues：特征值
        eigenvectors：特征向量
    """

    # TODO 01: PCA
    # format as numpy array:
    N = data.shape[0]
    X = data.to_numpy()

    # normalize by center:
    mu = np.mean(X, axis=0)
    X_normalized = X - mu

    # get function:
    func = np.cov if not correlation else np.corrcoef
    H = func(X_normalized, rowvar=False, bias=True)

    # get eigen pairs:
    eigenvalues, eigenvectors = np.linalg.eig(H)

    if sort:
        sort = eigenvalues.argsort()[::-1]
        eigenvalues = eigenvalues[sort]
        eigenvectors = eigenvectors[:, sort]

    return eigenvalues, eigenvectors
```

And its visualization using Open3D LineSet

```python
def get_pca_o3d(w, v, points):
    """ Build open3D geometry for PCA

    Parameters:
        w: eigenvalues in descending order
        v: eigenvectors in descending order

    Returns:
        pca_set: o3d line set for pca visualization
    """
    # calculate centroid & variation along main axis:
    centroid = points.mean()
    projs = np.dot(points.to_numpy(), v[:,0])
    scale = projs.max() - projs.min()

    points = centroid.to_numpy() + np.vstack(
        (
            np.asarray([0.0, 0.0, 0.0]),
            scale * v.T
        )
    ).tolist()
    lines = [
        [0, 1],
        [0, 2],
        [0, 3]
    ]
    # from the largest to the smallest: RGB
    colors = np.identity(3).tolist()

    # build pca line set:
    pca_o3d = o3d.geometry.LineSet(
        points=o3d.utility.Vector3dVector(points),
        lines=o3d.utility.Vector2iVector(lines),
    )
    pca_o3d.colors = o3d.utility.Vector3dVector(colors)

    return pca_o3d
```

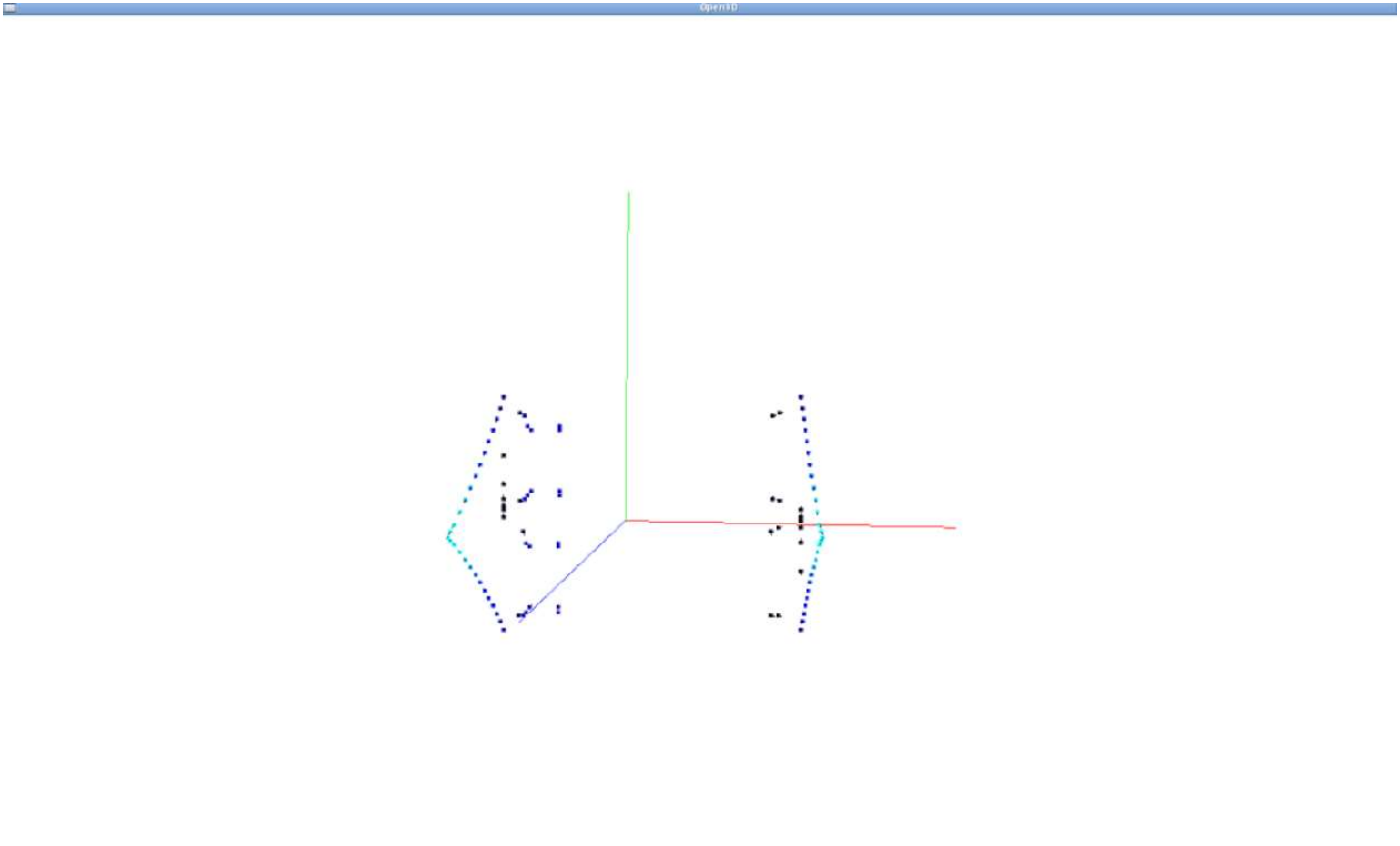
3. Perform Surface Normal Estimation for Each Point of Each Object and Visualize

Below is the code for surface normal estimation

```
def get_surface_normals(pcd, points, knn=5):
    # create search tree:
    pcd_tree = o3d.geometry.KDTreeFlann(pcd)

    # init:
    N = len(pcd.points)
    normals = []

    for i in range(N):
        # find knn:
        [k, idx, _] = pcd_tree.search_knn_vector_3d(pcd.points[i], knn)
        # get normal:
        w, v = PCA(points.iloc[idx])
        normals.append(v[:, 0])

    return np.array(normals, dtype=np.float64)
```

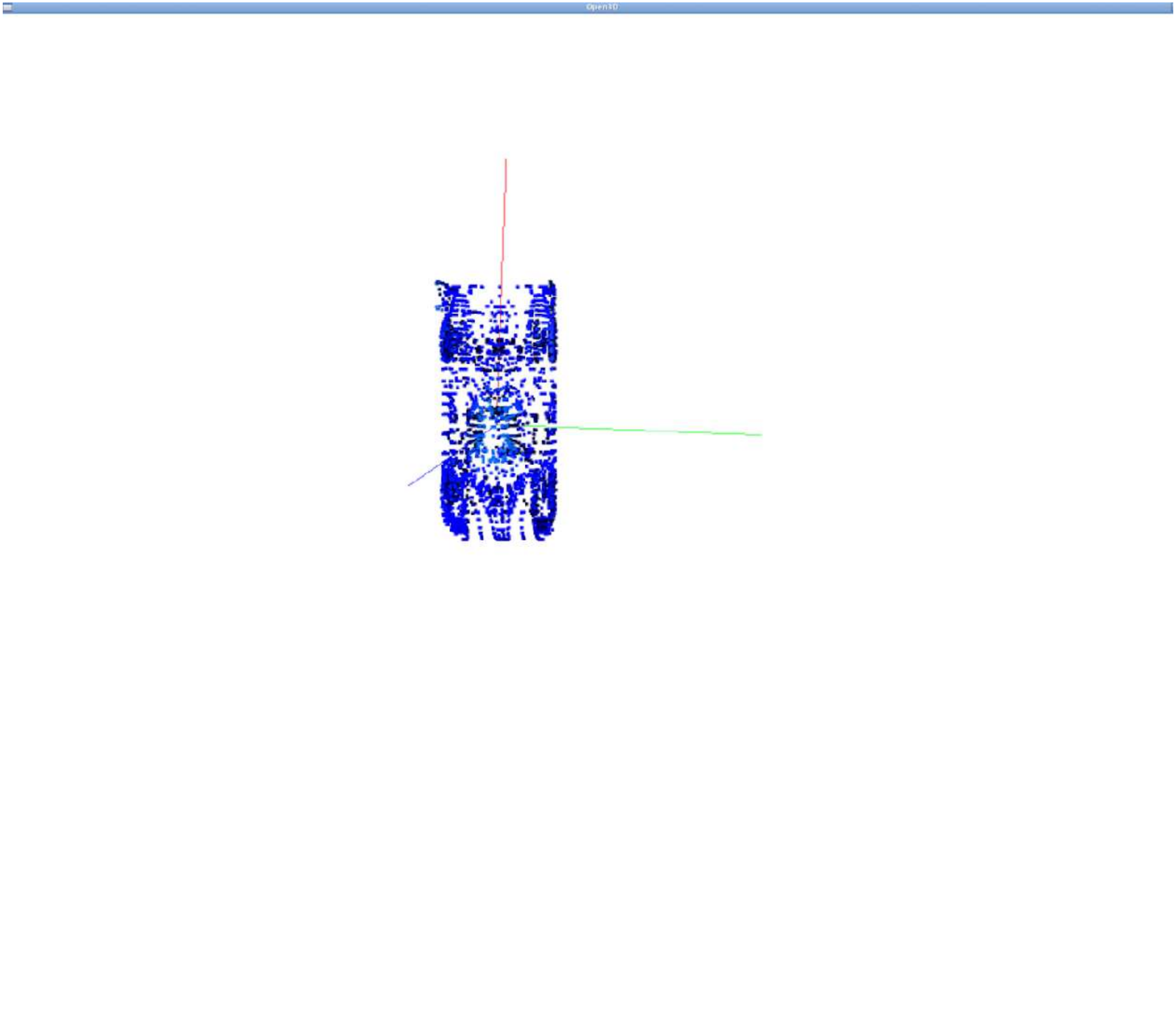
And its visualization using Open3D LineSet

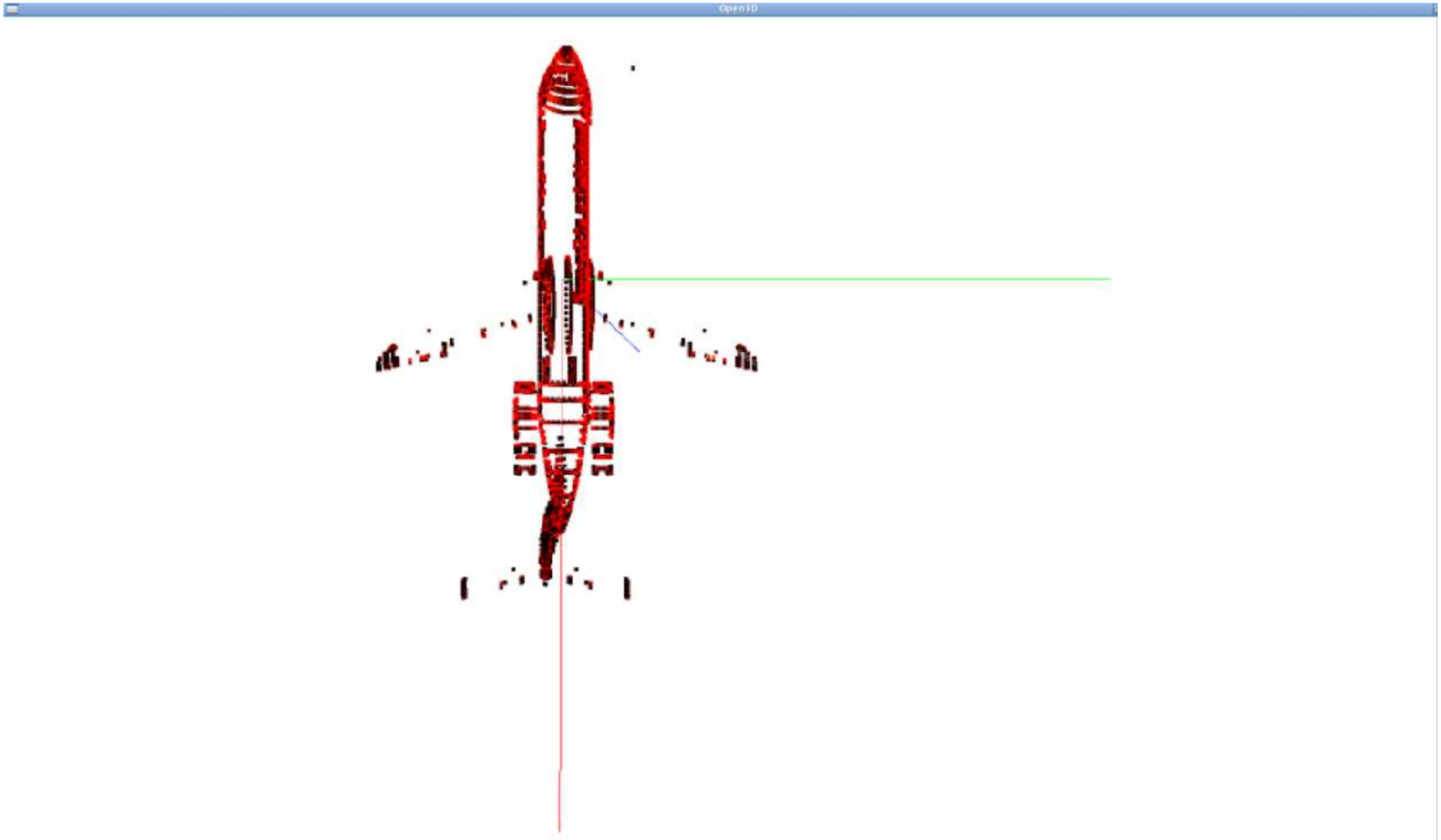
Below is one sample visualization for tents. The eigenvectors with corresponding eigenvalues in descending order are colored in R,G,B respectively.



```
def get_surface_normals_o3d(normals, points, scale=2):
    """ Build open3D geometry for surface normals

    Parameters:
        normals(numpy.ndarray): surface normals for each point
        points(pandas.DataFrame): points in the point cloud
        scale(float): the length of each surface normal vector

    Returns:
        surface_normals_o3d: o3d line set for surface normal visualization
    """
    # total number of points:
    N = points.shape[0]

    points = np.vstack(
        (points.to_numpy(), points.to_numpy() + scale * normals)
    )
    lines = [[i, i+N] for i in range(N)]
    colors = np.zeros((N, 3)).tolist()

    # build pca line set:
    surface_normals_o3d = o3d.geometry.LineSet(
        points=o3d.utility.Vector3dVector(points),
        lines=o3d.utility.Vector2iVector(lines),
    )
    surface_normals_o3d.colors = o3d.utility.Vector3dVector(colors)

    return surface_normals_o3d
```

Below are two sample visualization for airplane and car. Surface normal for the given point is drawn in black on each point.


Open3D

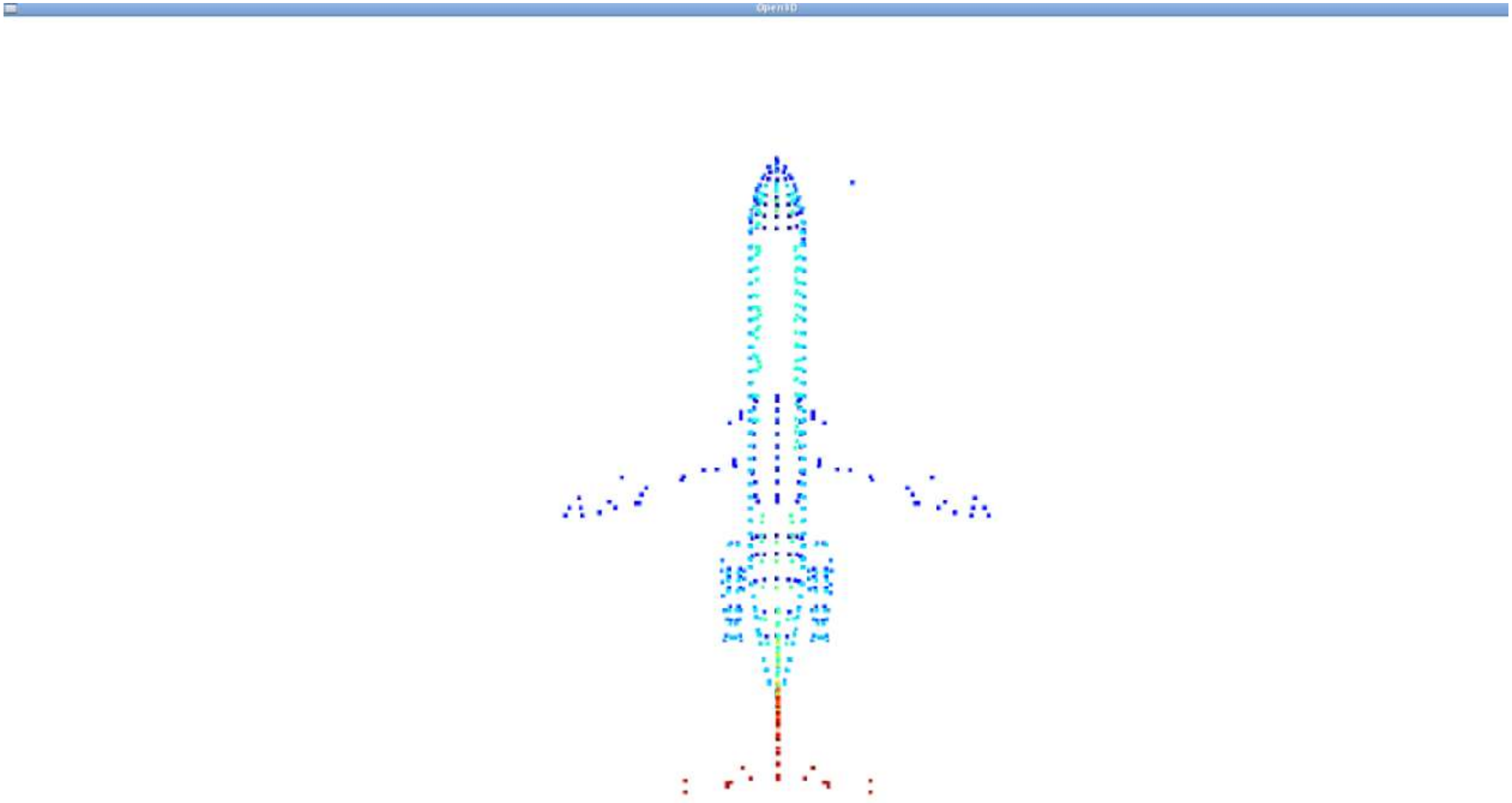


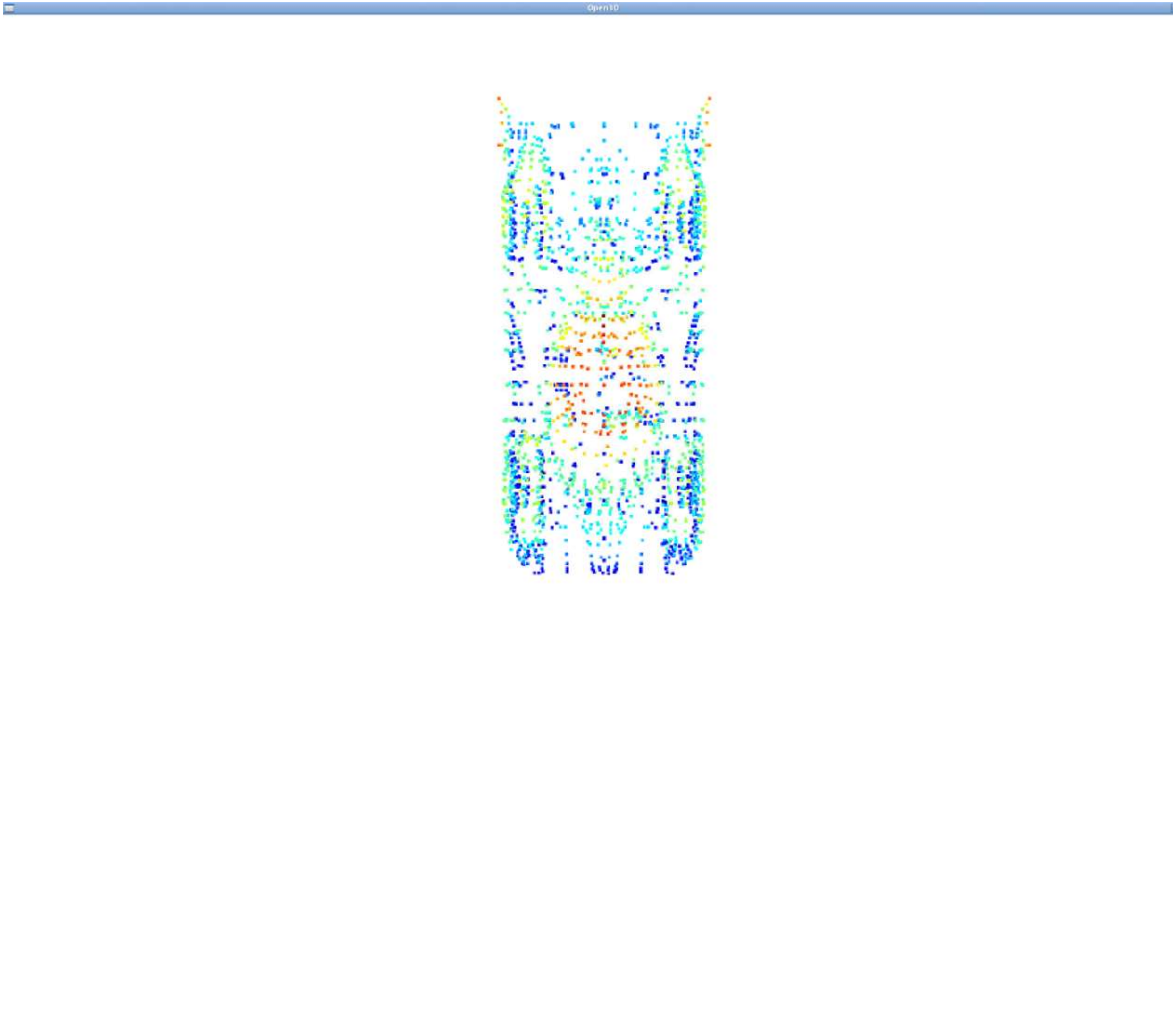
4. Dowmsample Each Object using Voxel Grid Downsampling(Exact, Centroid and Random) and Visualize

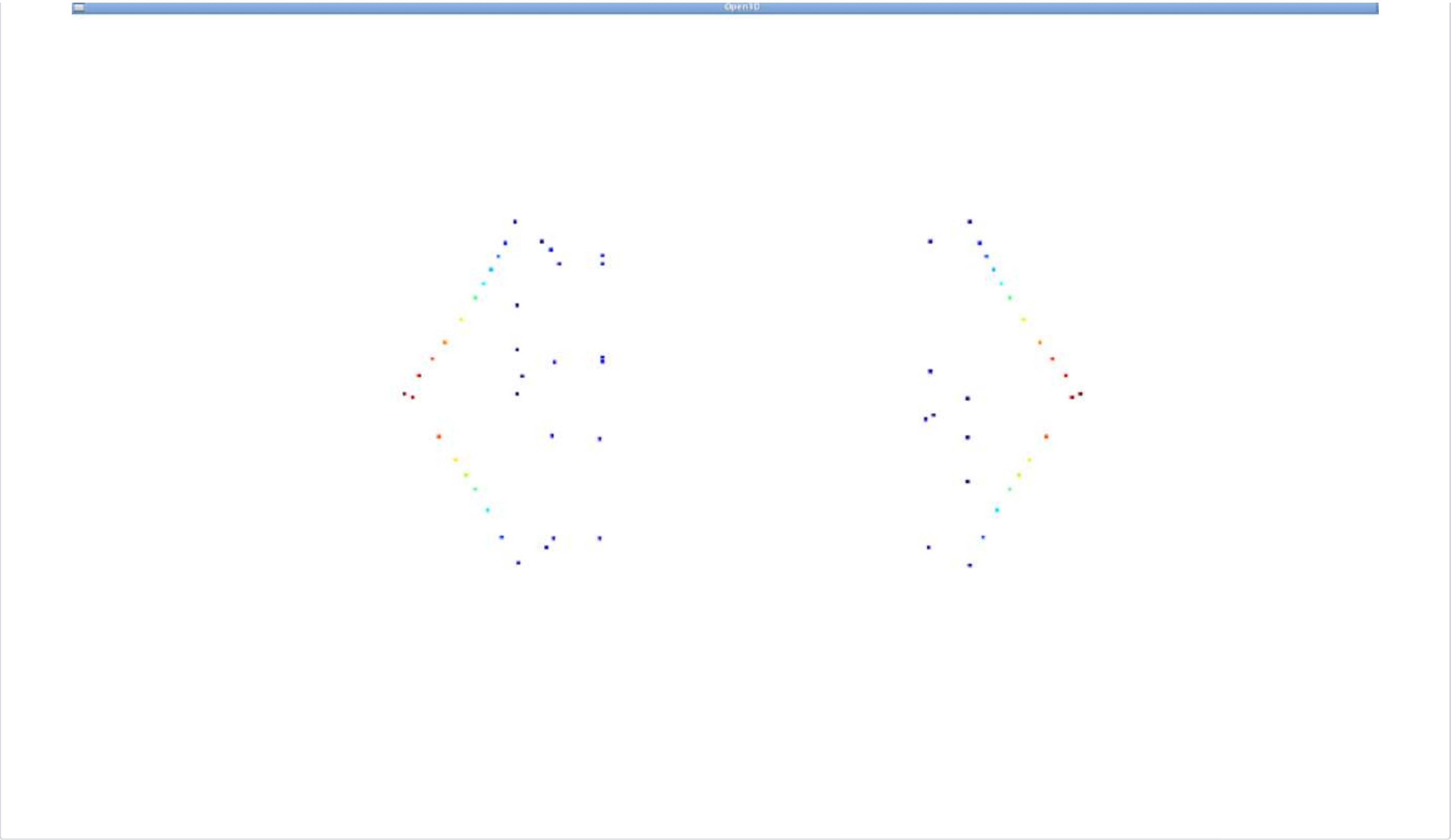
Voxel grid filtering can be implemented efficiently using point cloud in Pandas format

```
def get_voxel_grid_classifier(points, leaf_size):
    """ Get a function for 3D point -- voxel grid assignment

    Parameters:
        points(pandas.DataFrame): points in the point cloud
    """
    # get bounding box:
    (p_min, p_max) = (points.min(), points.max())
    (D_x, D_y, D_z) = (
        np.ceil((p_max['x'] - p_min['x']) / leaf_size).astype(np.int),
        np.ceil((p_max['y'] - p_min['y']) / leaf_size).astype(np.int),
        np.ceil((p_max['z'] - p_min['z']) / leaf_size).astype(np.int),
    )

    def classifier(x, y, z):
        """ assign given 3D point to voxel grid

        Parameters:
            x(float): X
            y(float): Y
            z(float): Z

        Return:
            idx(int): voxel grid index
        """
        (i_x, i_y, i_z) = (
            np.floor((x - p_min['x']) / leaf_size).astype(np.int),
            np.floor((y - p_min['y']) / leaf_size).astype(np.int),
            np.floor((z - p_min['z']) / leaf_size).astype(np.int),
        )

        idx = i_x + D_x * i_y + D_x * D_y * i_z

        return idx

    return classifier

def voxel_filter(points, leaf_size, method='centroid'):
    """ Downsample point cloud using voxel grid

    Parameters:
        points(pandas.DataFrame): points in the point cloud
        leaf_size(float): voxel grid resolution
        method(str): downsample method. 'centroid' or 'random'. defaults to 'centroid'
    Returns:
        filtered_points(numpy.ndarray): downsampled point cloud
    """
    filtered_points = None

    # TODO 03: voxel grid filtering
    working_points = points.copy(deep = True)

    # get voxel grid classifier:
    classifier = get_voxel_grid_classifier(working_points, leaf_size)
    # assign to voxel grid:
    working_points['voxel_grid_id'] = working_points.apply(
        lambda row: classifier(row['x'], row['y'], row['z']), axis = 1
    )

    # centroid:
    if method == 'centroid':
        filtered_points = working_points.groupby(['voxel_grid_id']).mean().to_numpy()
    elif method == 'random':
        filtered_points = working_points.groupby(['voxel_grid_id']).apply(
            lambda x: x[['x', 'y', 'z']].sample(1)
        ).to_numpy()

    return filtered_points
```

Below are the filtered point clouds for airplane, car and tent.


Open3D


Open3D


Open3D