Homework of Chapter 1

How to run this code?

This code is based on ROS noetic on ubuntu 20.04. The homework completed by C++ and is tested by a node named "chapter_1" in package "small_projects".

1. Down load the whole workspace "3D_PointCloud_Processing".
2. Check or modify the source file /src/small_projects/src/chapter_1.cpp
3. Compile the package as follows.

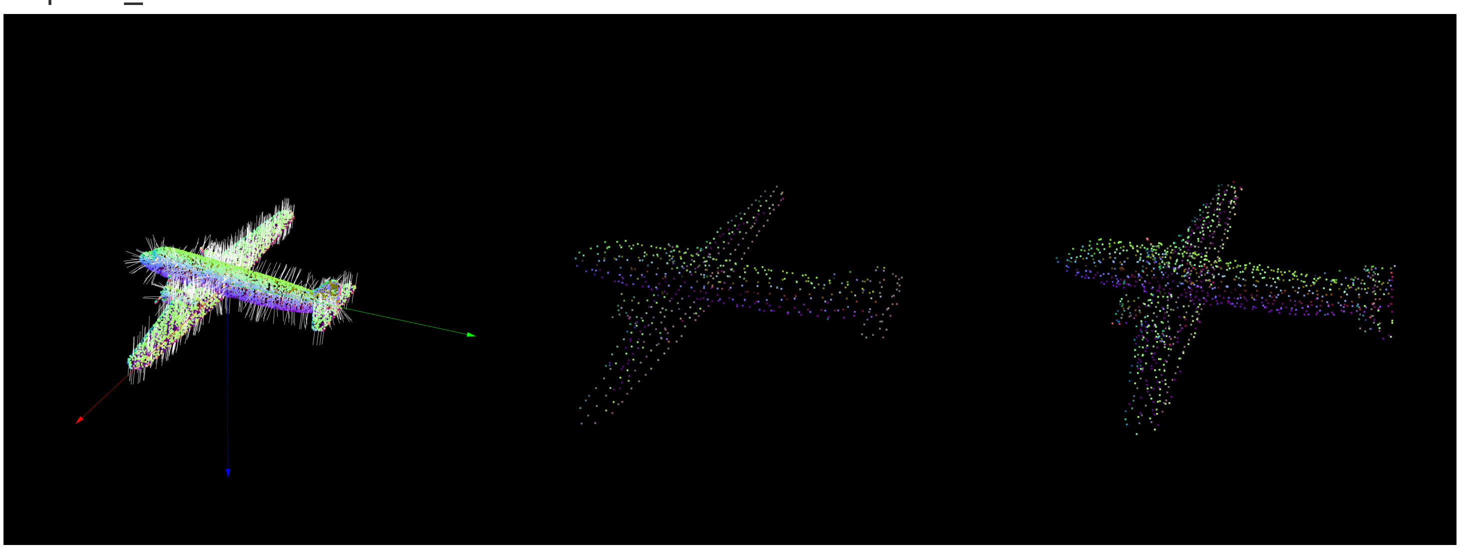
```
cd 3D_PointClud_Processing
catkin_make
```

4. Run the chapter_1 node as follows, remember to replace the file path with your own ModelNet40 file path.

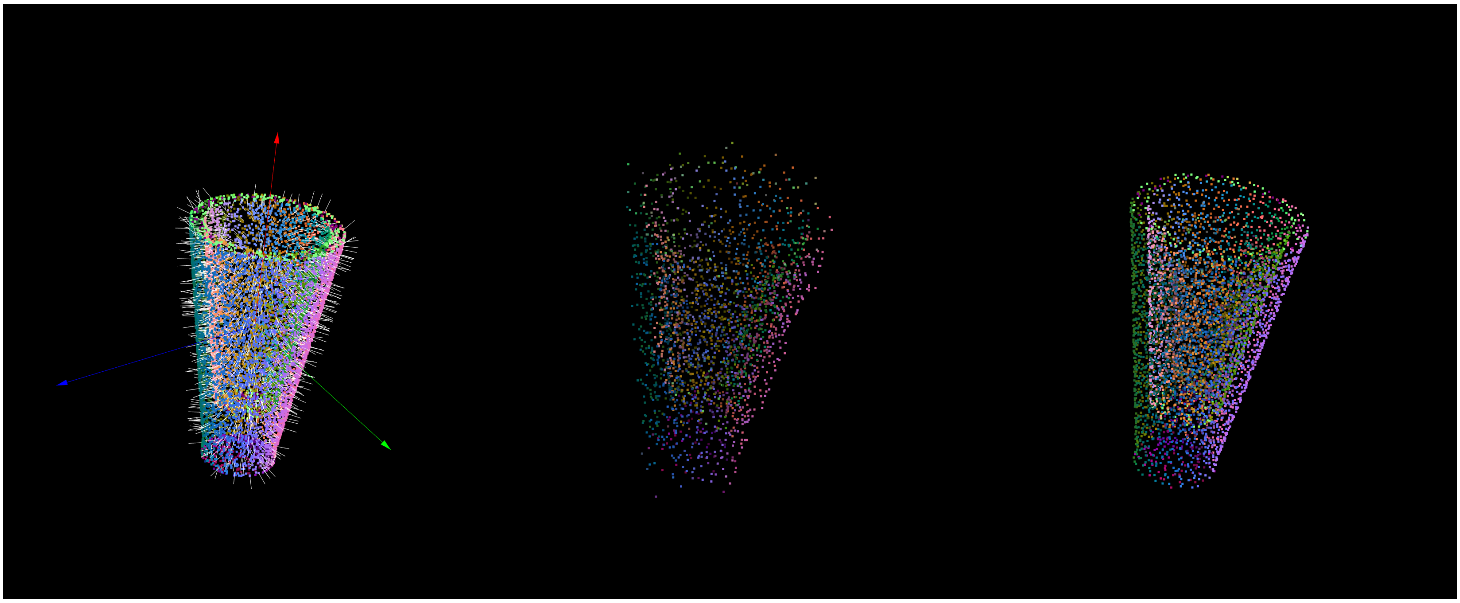
```
source ./devel/setup.bash
roscore
# run below command in another terminal
rosrun small_projects chapter_1 data/modelnet40_normal_resampled/airplane/airplane_0
```

Result

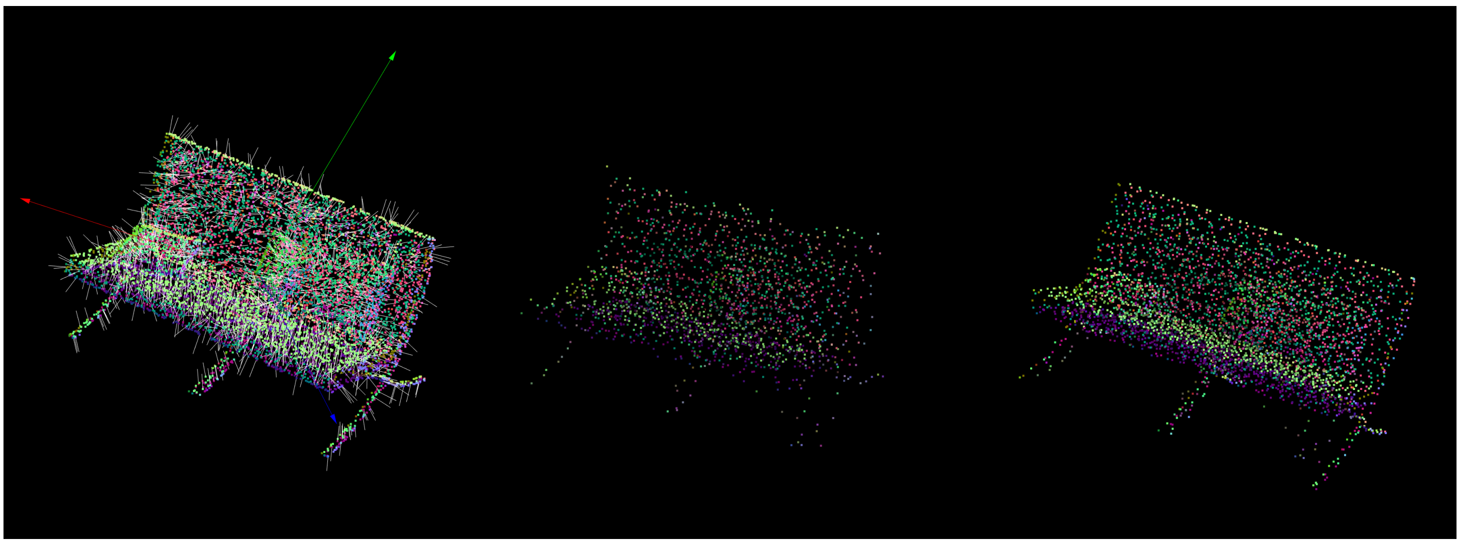
aieplane_0004.txt



cup_0004.txt



sofa_0004.txt



Key Code

API

All the algorithm is completed in a class named BasicAlgorithm defined in small_projects/include/chapter_1/basic_algorithm.h. The API of BasicAlgorithm refer to small_projects/src/chapter_1.cpp as follows.

```cpp
// small_projects/src/chapter_1.cpp

// PCA
BasicAlgorithm basic_algorithm;
Eigen::Matrix3f matrix_u; // used to store the U matrix based on SVD of input x
basic_algorithm.setInputPointCloud(cloud);
basic_algorithm.execPCA();
basic_algorithm.getMatrixU(matrix_u);

// Estimate normals
pcl::PointCloud<pcl::Normal>::Ptr normals (new pcl::PointCloud<pcl::Normal>); // used tc
float neighbourhood_radius = 0.1;
basic_algorithm.setOutputNormals(normals);
basic_algorithm.estimateNormal(neighbourhood_radius);
basic_algorithm.getNormals(normals);

// Voxel grid downsample
pcl::PointCloud<pcl::PointXYZRGBA>::Ptr downsampled_cloud(new pcl::PointCloud<pcl::Point
float voxel_size = 0.05;
// basic_algorithm.voxelGridDownSample(0.05, "random"); // voxel grid downsampling basec
basic_algorithm.voxelGridDownSample(voxel_size, "centroid"); // voxel grid downsampling
basic_algorithm.getDownSampledCloud(downsampled_cloud);
```

PCA

Steps of PCA:

1. Normalized by center.
2. Compute SVD.
3. Take the vectors of matrix U as the pinciple vectors.

```
// small_projects/include/chapter_1/basic_algorithm.h

void execPCA()
{
   // normalization
   normalize();
   // svd based on Eigen
   Eigen::JacobiSVD<Eigen::MatrixXf> svd(normalized_x_, Eigen::ComputeThinU | Eigen::Com
   // get the matrix u as the priciple components
   matrix_u_ = svd.matrixU();
}
// normalize the input cloud
void normalize()
{
   // calcualate the center
   centroid_ = Eigen::Vector3f::Zero();
   for (auto point : cloud_->points)
   {
      centroid_(0) += point.x;
      centroid_(1) += point.y;
      centroid_(2) += point.z;
   }
   centroid_(0) /= cloud_->points.size();
   centroid_(1) /= cloud_->points.size();
   centroid_(2) /= cloud_->points.size();
   // calculate the normalized x matrix
   normalized_x_.resize(3, cloud_->points.size());

   for (int point_index = 0; point_index < cloud_->points.size(); ++point_index)
   {
      normalized_x_(0, point_index) = cloud_->points.at(point_index).x - centroid_(0);
      normalized_x_(1, point_index) = cloud_->points.at(point_index).y - centroid_(1);
      normalized_x_(2, point_index) = cloud_->points.at(point_index).z - centroid_(2);
   }
}
```

Estimate Normals

Steps of estimate normals

1. For each point, find the neighbours.
2. PCA on neighbours.
3. Select the last principle vector as the normal vector.

```cpp
// small_projects/include/chapter_1/basic_algorithm.h

void estimateNormal(float radius)
{
   std::vector<int> neighbours; // vector container, used to store the indexes of neighb
   Eigen::MatrixXf normalized_x; // 3*X matrix, used to store the normalized neighbours
   for (int point_index = 0; point_index < cloud_->points.size(); ++point_index)
   {
      findNeighbours(point_index, radius, neighbours); // find the neighbours of point_i
      normalize(neighbours, normalized_x); // calculate the normalized neighbours

      // svd & calculate the normal vector
      Eigen::JacobiSVD<Eigen::MatrixXf> svd(normalized_x, Eigen::ComputeThinU | Eigen::C
      Eigen::Matrix3f matrix_u = svd.matrixU();
      Eigen::Vector3f normal_vector = matrix_u.col(2); // select the 3rd vector of matri
      normals_->points.at(point_index).normal_x = normal_vector(0);
      normals_->points.at(point_index).normal_y = normal_vector(1);
      normals_->points.at(point_index).normal_z = normal_vector(2);
   }
}

// find the neighbours of a center point, based on teh radius
void findNeighbours(int center_point_index, float radius, std::vector<int>& neighbours)
{
   neighbours.clear();
   float dist_squre; // the squre of Euclid Distance
   for (int point_index = 0; point_index < cloud_->points.size(); ++point_index)
   {
      dist_squre = std::pow((cloud_->points.at(point_index).x - cloud_->points.at(center
                         std::pow((cloud_->points.at(point_index).y - cloud_->points.at(
                         std::pow((cloud_->points.at(point_index).z - cloud_->points.at(
      if (dist_squre <= radius*radius) // if Euclid Distance of a neighbour less than th
      {
         neighbours.push_back(point_index); // add the neighbour in the neighbours vecto
      }
   }
}

// a overload of normalize function, used to normalized the points based on neighbours i
void normalize(const std::vector<int>& neighbours, Eigen::MatrixXf& normalized_x)
{
   // calcualate the centroid
   Eigen::Vector3f centroid = Eigen::Vector3f::Zero();
   for (int neighbour_index = 0; neighbour_index < neighbours.size(); ++neighbour_index)
   {
      centroid(0) += cloud_->points.at(neighbours.at(neighbour_index)).x;
      centroid(1) += cloud_->points.at(neighbours.at(neighbour_index)).y;
      centroid(2) += cloud_->points.at(neighbours.at(neighbour_index)).z;
   }
   centroid(0) /= neighbours.size();
```

```
    centroid(1) /= neighbours.size();
    centroid(2) /= neighbours.size();

    // calculate the normalized x matrix
    normalized_x.resize(3, neighbours.size());
    for (int neighbour_index = 0; neighbour_index < neighbours.size(); ++neighbour_index)
    {
      normalized_x(0, neighbour_index) = cloud_->points.at(neighbours.at(neighbour_index
      normalized_x(1, neighbour_index) = cloud_->points.at(neighbours.at(neighbour_index
      normalized_x(2, neighbour_index) = cloud_->points.at(neighbours.at(neighbour_index
    }
  }
```

Voxel Grid DownSample

Steps of voxel grid downsample

1. Compute the min and max of the point cloud.
2. Compute the dimensions of the voxel grid.
3. Compute the voxel index of each point.
4. Sort the points based on the voxel index.
5. Generate one point (centroid or random) from a batch (points with same voxel index).

```
// small_projects/include/chapter_1/basic_algorithm.h

void voxelGridDownSample(float voxel_size, std::string method)
{
   // compute the max and min of the points
   Eigen::Vector3f min, max;
   getMinMax(min, max);
   // calculate the dimensions of each voxel
   int dx = ceil((max(0) - min(0))/voxel_size);
   int dy = ceil((max(1) - min(1))/voxel_size);
   // compute the voxel index for each point
   std::vector<index_st> index_vector(cloud_->size()); // each element stores the index
   for (int point_index = 0; point_index < cloud_->size(); ++point_index)
   {
      index_vector.at(point_index).voxel_index = getVoxelIndex(cloud_->points.at(point_i
      index_vector.at(point_index).point_index = point_index; // update the point cloud
   }
   // sort the vector based on the voxel index
   td::sort(index_vector.begin(), index_vector.end(), less_based_on_voxel_index);
   // select a point from points with same voxel index
   int begin_position = 0; // the first position of a batch (points with same index)
   int end_position; // the last position of a batch (points with same index)
   index_st dumy_index;
   dumy_index.point_index = -1;
   dumy_index.voxel_index = -1;
   index_vector.push_back(dumy_index); // add a dumy_index at the end of vector, in orde
   for (int vector_index = 0; vector_index < index_vector.size() - 1; ++vector_index)
   {
      if (index_vector.at(vector_index).voxel_index != index_vector.at(vector_index + 1)
      {
         end_position = vector_index;
         pcl::PointXYZRGBA downsampled_point;
         // generate a point from a batch (points with same voxel index) based on the ir
         getPointFromBatch(downsampled_point, method, index_vector, begin_position, end_
         downsampled_cloud_->push_back(downsampled_point);
         begin_position = vector_index + 1;
      }
   }
}

// struct index_st is used to store the index of both voxel and point info
struct index_st
{
    int voxel_index;
    int point_index;
};

// function less_based_on_voxel_index is used as the input of std::sort
bool less_based_on_voxel_index(index_st a, index_st b)
{
```

```
    return a.voxel_index < b.voxel_index;
}

// calculate the min and max points for the cloud_
void getMinMax(Eigen::Vector3f& min, Eigen::Vector3f& max)
{
   min(0) = max(0) = cloud_->points.at(0).x;
   min(1) = max(1) = cloud_->points.at(0).y;
   min(2) = max(2) = cloud_->points.at(0).z;
   for (auto point : cloud_->points)
   {
      min(0) = std::min(min(0), point.x);
      min(1) = std::min(min(1), point.y);
      min(2) = std::min(min(2), point.z);
      max(0) = std::max(max(0), point.x);
      max(1) = std::max(max(1), point.y);
      max(2) = std::max(max(2), point.z);
   }
}

// calculate the voxel index of each point
int getVoxelIndex(const pcl::PointXYZRGBA& point, const Eigen::Vector3f& min, const floa
{
   int hx = floor((point.x - min(0))/voxel_size);
   int hy = floor((point.y - min(1))/voxel_size);
   int hz = floor((point.z - min(2))/voxel_size);
   int h = hx + hy * dx + hz * dx * dy;
   return h;
}

// generate a point from a batch (points with same voxel index), based on the input meth
void getPointFromBatch(pcl::PointXYZRGBA& downsampled_point, std::string& method, std::v
{
   if (method == "centroid")
   {
      float x = 0;
      float y = 0;
      float z = 0;
      uint16_t r = 0;
      uint16_t g = 0;
      uint16_t b = 0;
      for (int position = begin_position; position < end_position; ++position)
      {
         x += cloud_->points.at(index_vector.at(position).point_index).x;
         y += cloud_->points.at(index_vector.at(position).point_index).y;
         z += cloud_->points.at(index_vector.at(position).point_index).z;
         r += cloud_->points.at(index_vector.at(position).point_index).r;
         g += cloud_->points.at(index_vector.at(position).point_index).g;
         b += cloud_->points.at(index_vector.at(position).point_index).b;
      }
      // the centroid of batch (points with same voxel index)
```

```
        x /= (end_position - begin_position + 1);
        y /= (end_position - begin_position + 1);
        z /= (end_position - begin_position + 1);
        // calculate the average of color as the new color of centroid point
        r = static_cast<uint8_t>(r/(end_position - begin_position + 1));
        g = static_cast<uint8_t>(g/(end_position - begin_position + 1));
        b = static_cast<uint8_t>(b/(end_position - begin_position + 1));
        downsampled_point.x = x;
        downsampled_point.y = y;
        downsampled_point.z = z;
        downsampled_point.r = r;
        downsampled_point.g = g;
        downsampled_point.b = b;
    }
    else if (method == "random")
    {
        int rand_index = (std::rand() % (end_position - begin_position +1 ))+ begin_positi
        downsampled_point = cloud_->points.at(index_vector.at(rand_index).point_index);
    }
    else
    {
        std::cerr << "The voxel grid downsample method is invalid" << std::endl;
    }
}
```