Introduction to PCL: The Point Cloud Library

1 - basic topics

DIPARTIMENTO DI INGEGNERIA INFORMATICA
AUTOMATICA E GESTIONALE ANTONIO RUBERTI

SAPIENZA
UNIVERSITÀ DI ROMA

Alberto Pretto

Thanks to Radu Bogdan Rusu, Bastian Steder and Jeff Delmerico for some of the slides!

Contact

Alberto Pretto, PhD

Assistant Professor

Location: DIAG A209

pretto@dis.uniroma1.it

Point clouds: a definition

A point cloud is a data structure used to represent a collection of **multi-dimensional points** and is commonly used to represent three-dimensional data.

The points usually represent the X, Y, and Z geometric coordinates of a sampled surface.

Each point can hold additional information: RGB colors, intensity values, etc...

Where do they come from?

2/3D Laser scans

Laser triangulation

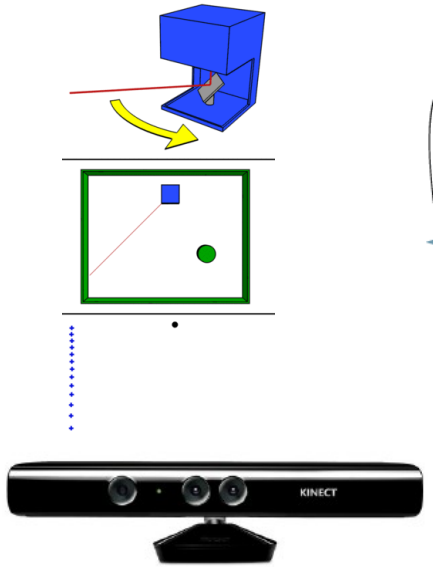
Stereo cameras

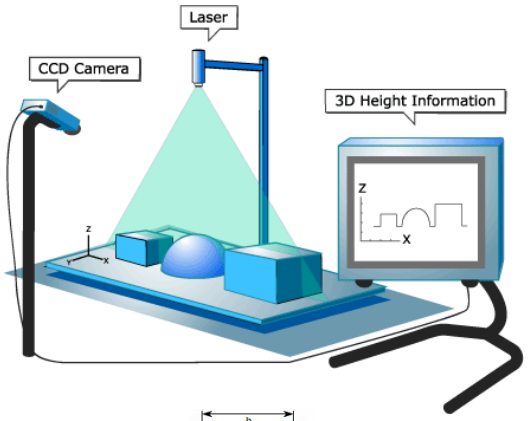
RGB-D cameras

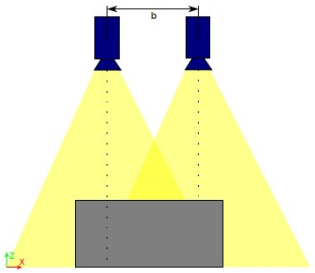
Time of flight cameras

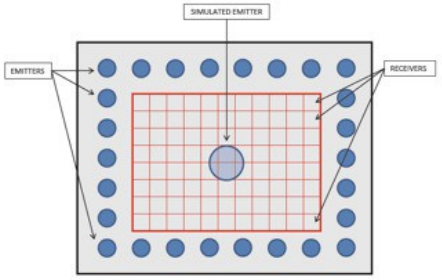
Simulation

...







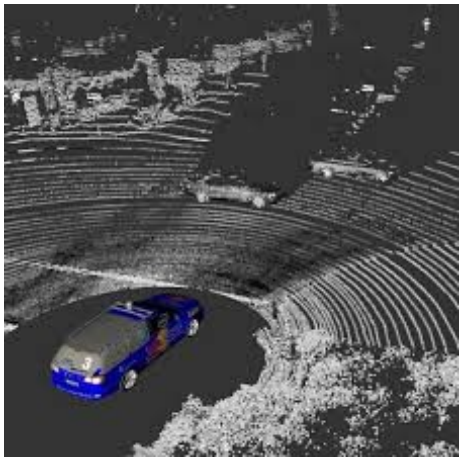


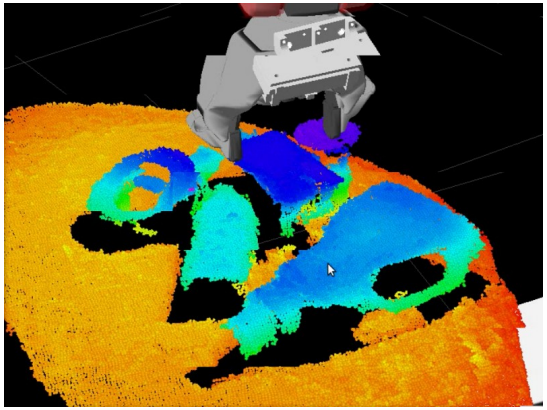
Point clouds in robotics

Navigation / Obstacle avoidance

Object recognition and registration

Grasping and manipulation





Point Cloud Library

→ pointclouds.org

The Point Cloud Library (PCL) is a standalone, large scale, open source (C++) library for 2D/3D image and point cloud processing.

PCL is released under the terms of the BSD license, and thus free for commercial and research use.

PCL provides the 3D processing pipeline for ROS, so you can

also get the perception pcl stack and still use PCL standalone.

Among others, PCL depends on Boost, Eigen, OpenMP,...

PCL Basic Structures: PointCloud

A PointCloud is a templated C++ class which basically contains the following data fields:

- **width (int)** - specifies the width of the point cloud dataset in the number of points.
  → the total number of points in the cloud (equal with the number of elements in points) for unorganized datasets
  → the width (total number of points in a row) of an organized point cloud dataset
- **height (int)** - Specifies the height of the point cloud dataset in the number of points
  → set to 1 for unorganized point clouds
  → the height (total number of rows) of an organized point cloud dataset
- **points (std::vector <PointT>)** - Contains the data array where all the points of type PointT are stored.
-

PointCloud vs. PointCloud2

We distinguish between two data formats

for the point clouds:

- **PointCloud<PointType>** with a specific data type (for actual usage in the code)
- **PointCloud2** as a general representation containing a header defining the point cloud structure (e.g., for loading, saving or sending as a ROS message)

Conversion between the two frameworks is easy:

- **pcl::fromROSMsg** and **pcl::toROSMsg**

Important: clouds are often handled using smart pointers, e.g.:

- PointCloud<PointType> :: Ptr cloud_ptr;

Point Types

PointXYZ - float x, y, z

PointXYZI - float x, y, z, intensity

PointXYZRGB - float x, y, z, rgb

PointXYZRGBA - float x, y, z, uint32 t rgba

Normal - float normal[3], curvature

PointNormal - float x, y, z, normal[3], curvature

→ See pcl/include/pcl/point_types.h for more examples.

Building PCL Stand-alone Projects

```
# CMakeLists.txt
project( pcl_test )
cmake_minimum_required (VERSION 2.8)
cmake_policy(SET CMP0015 NEW)

find_package(PCL 1.7 REQUIRED )
add_definitions(${PCL_DEFINITIONS})

include_directories(... ${PCL_INCLUDE_DIRS})
link_directories(... ${PCL_LIBRARY_DIRS})

add_executable(pcl_test pcl_test.cpp ...)
target_link_libraries( pcl_test${PCL_LIBRARIES})
```

PCL structure

PCL is a collection of smaller, modular C++ libraries:

- **libpcl_features**: many 3D features (e.g., normals and curvatures, boundary points, moment invariants, principal curvatures, Point Feature Histograms (PFH), Fast PFH, ...)
- **libpcl_surface**: surface reconstruction techniques (e.g., meshing, convex hulls, Moving Least Squares, ...)
- **libpcl_filters**: point cloud data filters (e.g., downsampling, outlier removal, indices extraction, projections, ...)
- **libpcl_io**: I/O operations (e.g., writing to/reading from PCD (Point Cloud Data) and BAG files)
- **libpcl_segmentation**: segmentation operations (e.g.,cluster extraction, Sample Consensus model fitting, polygonal prism extraction, ...)
- **libpcl_registration**: point cloud registration methods (e.g., Iterative Closest Point (ICP), non linear optimizations, ...)
- **libpcl_range_image**: range image class with specialized methods

It provides unit tests, examples, tutorials, ...

Point Cloud file format

Point clouds can be stored to disk as files, into the **PCD (Point Cloud Data) format**:

- # Point Cloud Data (PCD) file format v .5
  FIELDS x y z rgba
  SIZE 4 4 4 4
  TYPE F F F U
  WIDTH 307200
  HEIGHT 1
  POINTS 307200
  DATA binary
  ...<data>...

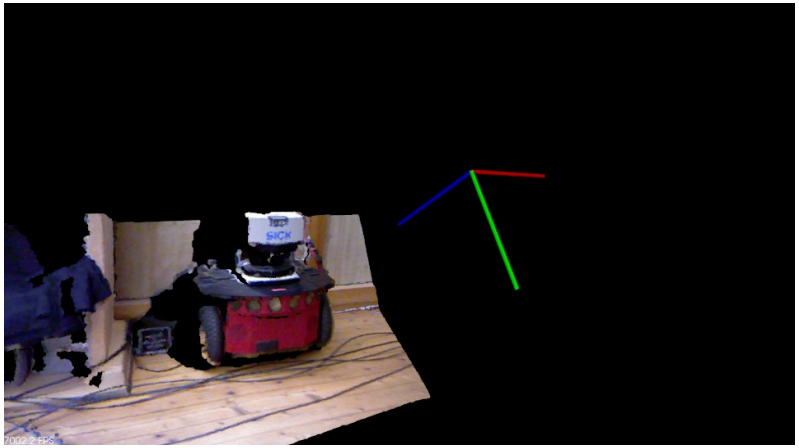
Funtions: **pcl::io::loadPCDFile** and **pcl::io::savePCDFile**

Example: create and save a PC

```
#include<pcl/io/pcd_io.h>
#include<pcl/point_types.h>
 //....
 pcl::PointCloud<pcl::PointXYZ>:: Ptr cloud_ptr (new pcl::PointCloud<pcl::PointXYZ>);
 cloud->width=50;
 cloud->height=1;
 cloud->isdense=false;
 cloud->points.resize(cloud.width*cloud.height);
 for(size_t i=0; i<cloud.points.size(); i++){
  cloud->points[i].x=1024*rand()/(RANDMAX+1.0f);
  cloud->points[i].y=1024*rand()/(RANDMAX+1.0f);
  cloud->points[i].z=1024*rand()/(RANDMAX+1.0f);
 }
 pcl::io::savePCDFileASCII("testpcd.pcd",*cloud);
```

Visualize a cloud

```
viewer->setBackgroundColor (0, 0, 0);
viewer->addPointCloud<pcl::PointXYZ> ( in_cloud, cloud_color,
                                                  "Input cloud" );
viewer->setPointCloudRenderingProperties
    (pcl::visualization::PCL_VISUALIZER_POINT_SIZE, 1, "Input cloud");
viewer->initCameraParameters ();
viewer->addCoordinateSystem (1.0);
while (!viewer->wasStopped ())   viewer->spinOnce ( 1 );
```



Basic Module Interface

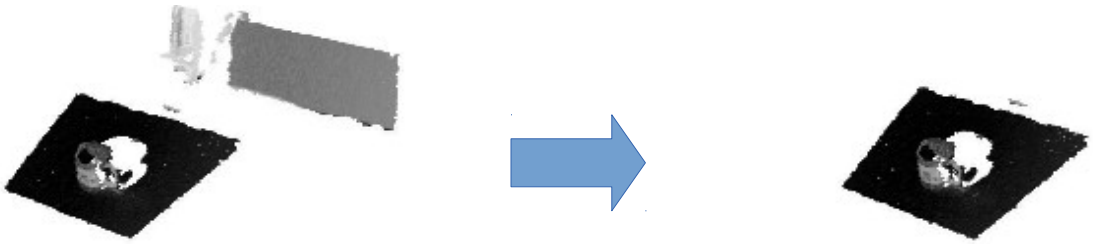
Filters, Features, Segmentation all use the same basic usage interface:

- use **setInputCloud()** to give the input
- set some parameters
- call **compute()** or **filter()** or **align()** or **...** to get the output

PassThrough Filter

Filter out points outside a specified range in one dimension.

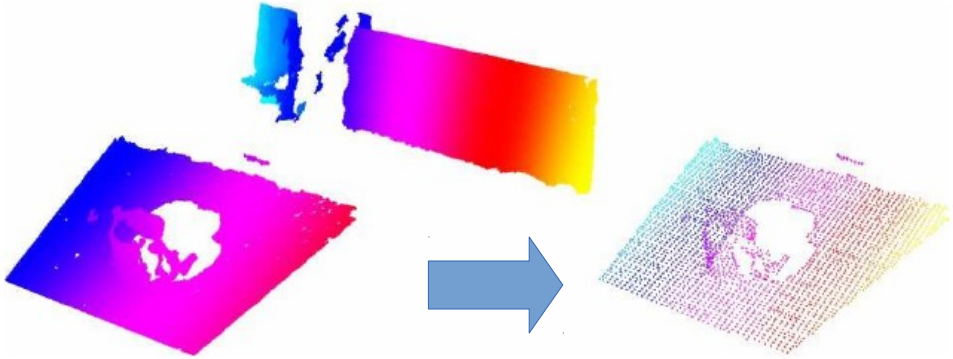
- pcl::PassThrough<T> pass_through;
  pass_through.setInputCloud (in_cloud);
  pass_through.setFilterLimits (0.0, 0.5);
  pass_through.setFilterFieldName ("z");
  pass_through.filter(*cutted_cloud);



Downsampling

Voxelize the cloud to a 3D grid. Each occupied voxel is approximated by the centroid of the points inside it.

- pcl::VoxelGrid<T> voxel_grid;
  voxel_grid.setInputCloud (input_cloud);
  voxel_grid.setLeafSize (0.01, 0.01, 0.01);
  voxel_grid.filter (*subsamp_cloud) ;



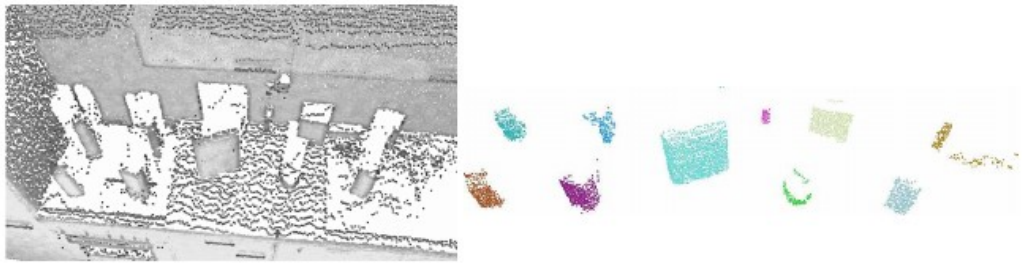
Features example: normals

```
pcl::NormalEstimation<T, pcl::Normal> ne;
ne.setInputCloud (in_cloud);
pcl::search::KdTree<pcl::PointXYZ>::Ptr tree (new
                        pcl::search::KdTree<pcl::PointXYZ> ());
ne.setSearchMethod (tree);
ne.setRadiusSearch (0.03);
ne.compute ( *cloud_normals );
```

Segmentation example

A clustering method divides an unorganized point cloud int into smaller, correlated, parts. **EuclideanClusterExtraction** uses a distance threshold to the nearest neighbors of each point to decide if the two points belong to the same cluster.

- pcl::EuclideanClusterExtraction<T> ec;
  ec.setInputCloud (in_cloud);
  ec.setMinClusterSize (100);
  ec.setClusterTolerance (0.05); // distance threshold
  ec.extract (cluster_indices);



Iterative Closest Point - 1

ICP iteratively revises the transformation (translation,rotation) needed to minimize the distance between the points of two raw scans.

- **Inputs**: points from two raw scans, initial estimation of the transformation, criteria for stopping the iteration.
- **Output**: refined transformation.

Iterative Closest Point - 2

The algorithm steps are :

- 1. Associate points of the two cloud using the nearest neighbor criteria.
- 2. Estimate transformation parameters using a mean square cost function.
- 3. Transform the points using the estimated parameters.
- 4. Iterate (re-associate the points and so on).

Iterative Closest Point - 3

```
IterativeClosestPoint<PointXYZ, PointXYZ> icp;
// Set the input source and target
icp.setInputCloud (cloud_source);
icp.setInputTarget (cloud_target);
// Set the max correspondence distance to 5cm
icp.setMaxCorrespondenceDistance (0.05);
// Set the maximum number of iterations (criterion 1)
icp.setMaximumIterations (50);
// Set the transformation epsilon (criterion 2)
icp.setTransformationEpsilon (1e-8);
// Set the euclidean distance difference epsilon (criterion 3)
icp.setEuclideanFitnessEpsilon (1);
// Perform the alignment
icp.align (cloud_source_registered);
// Obtain the transformation that aligned cloud_source to cloud_source_registered
Eigen::Matrix4f transformation = icp.getFinalTransformation ();
```