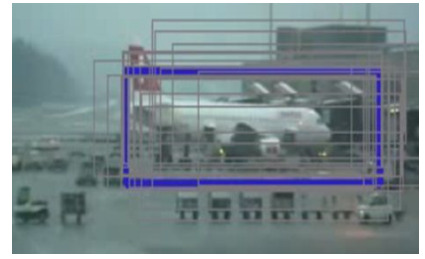
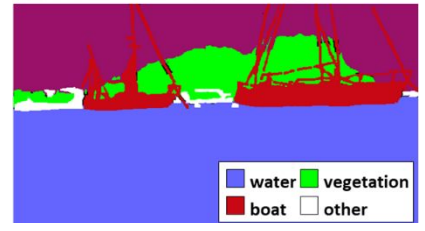


UNIVERSITÀ DEGLI STUDI
DELLA BASILICATA

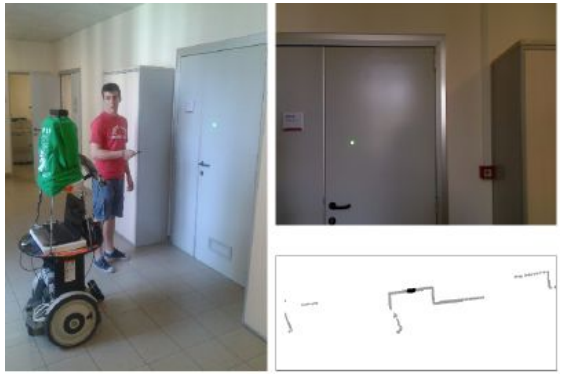
Corso di Visione e Percezione

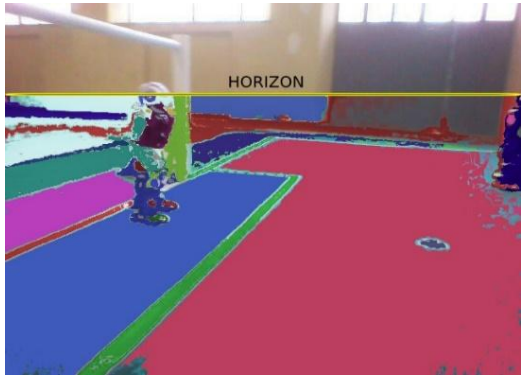
Docente
Domenico D. Bloisi

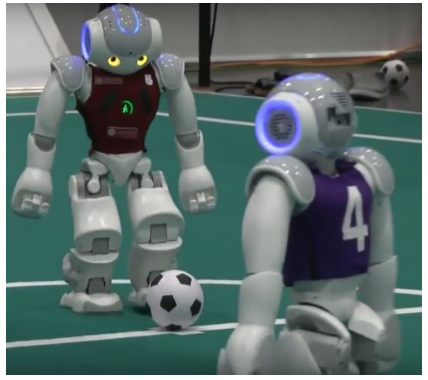





Visualizzazione dati 3D





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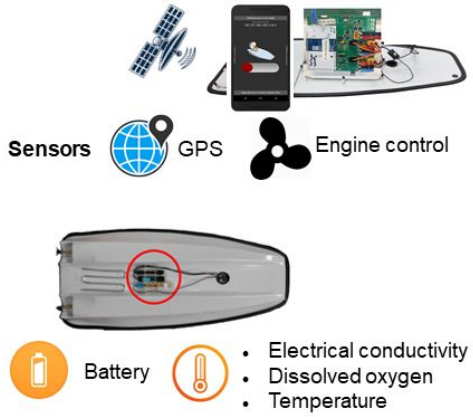
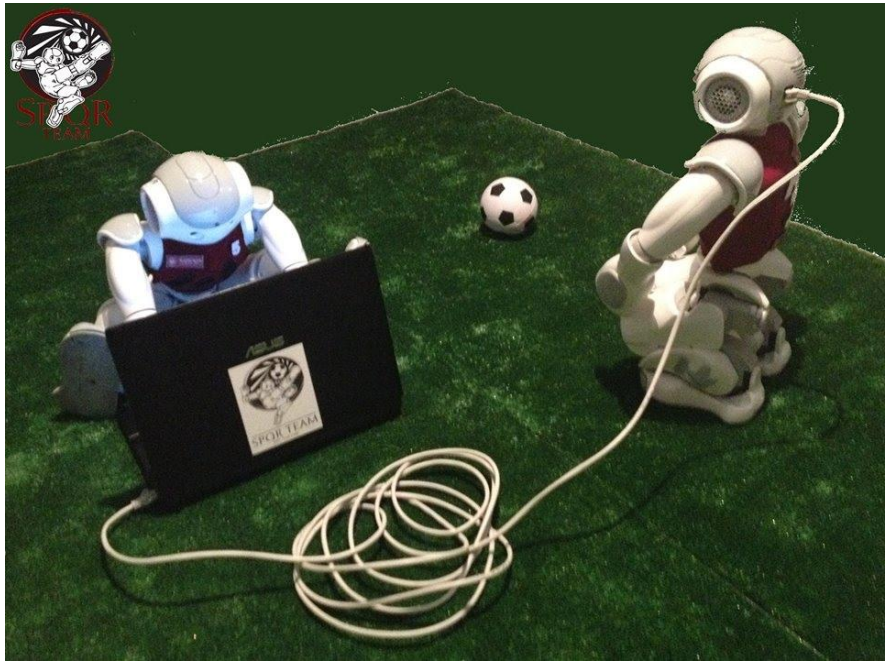




Informazioni sul corso

- Home page del corso
  http://web.unibas.it/bloisi/corsi/visione-e-percezione.html
- Docente: Domenico Daniele Bloisi
- Periodo: II semestre marzo 2021 – giugno 2021

  Martedì 17:00-19:00 (Aula COPERNICO)
  Mercoledì 8:30-10:30 (Aula COPERNICO)

Codice corso Google Classroom:
https://classroom.google.com/c/NjI2MjA4MzgzNDFa?cjc=xgolays

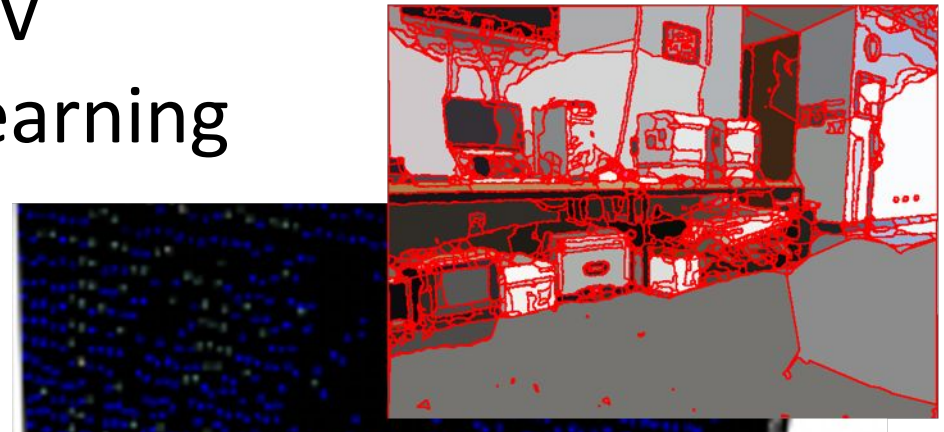
Ricevimento

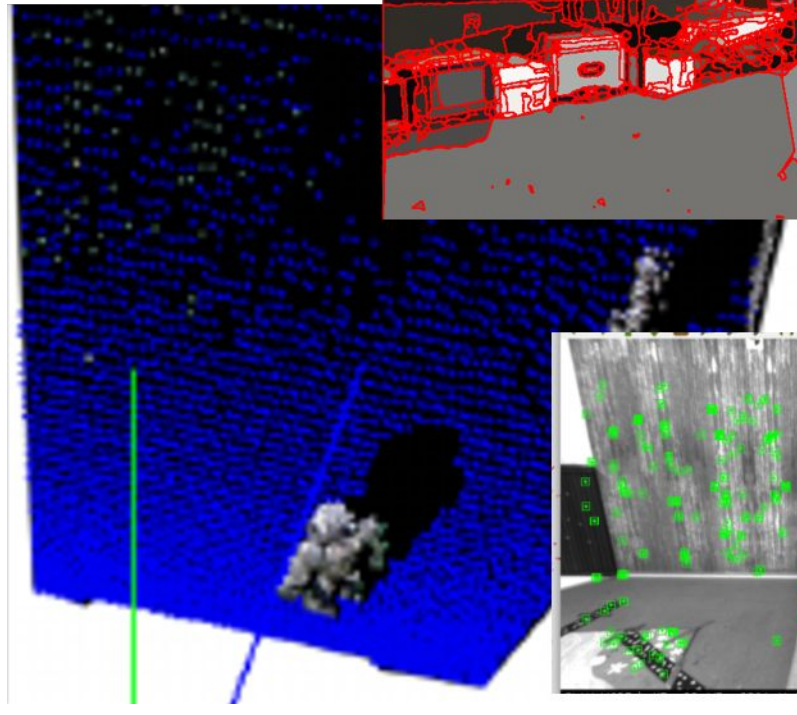
- Su appuntamento tramite Google Meet

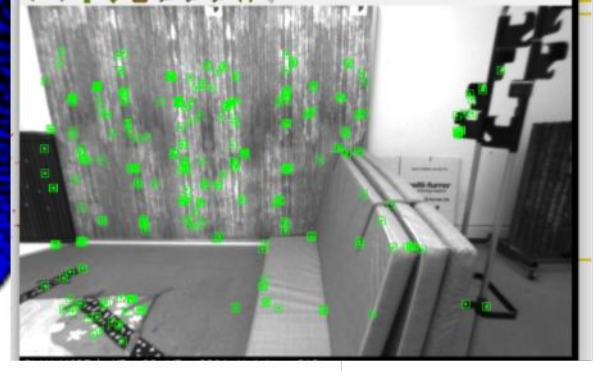
Per prenotare un appuntamento inviare una email a domenico.bloisi@unibas.it

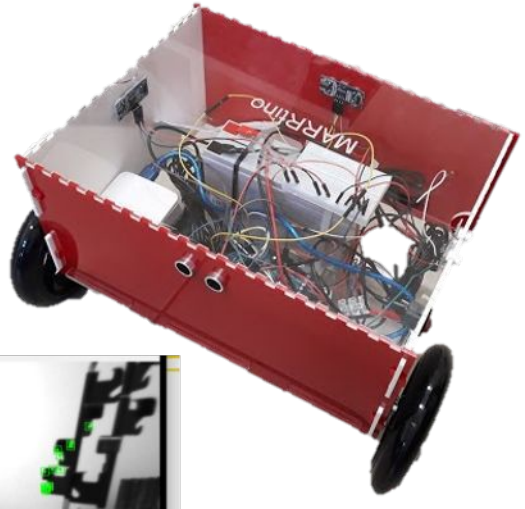
Programma – Visione e Percezione

- Introduzione al linguaggio Python
- Elaborazione delle immagini con Python
- Percezione 2D – OpenCV
- Introduzione al Deep Learning
- ROS
- Il paradigma publisher and subscriber
- Simulatori
- Percezione 3D - PCL









References and Credits

Queste slide sono adattate da:

Alberto Pretto – Sapienza Università di Roma
Introduction to PCL: The Point Cloud Library
Basic topics

http://www.dis.uniroma1.it/~pretto/download/pcl_intro.pdf

Gestione dati 2D

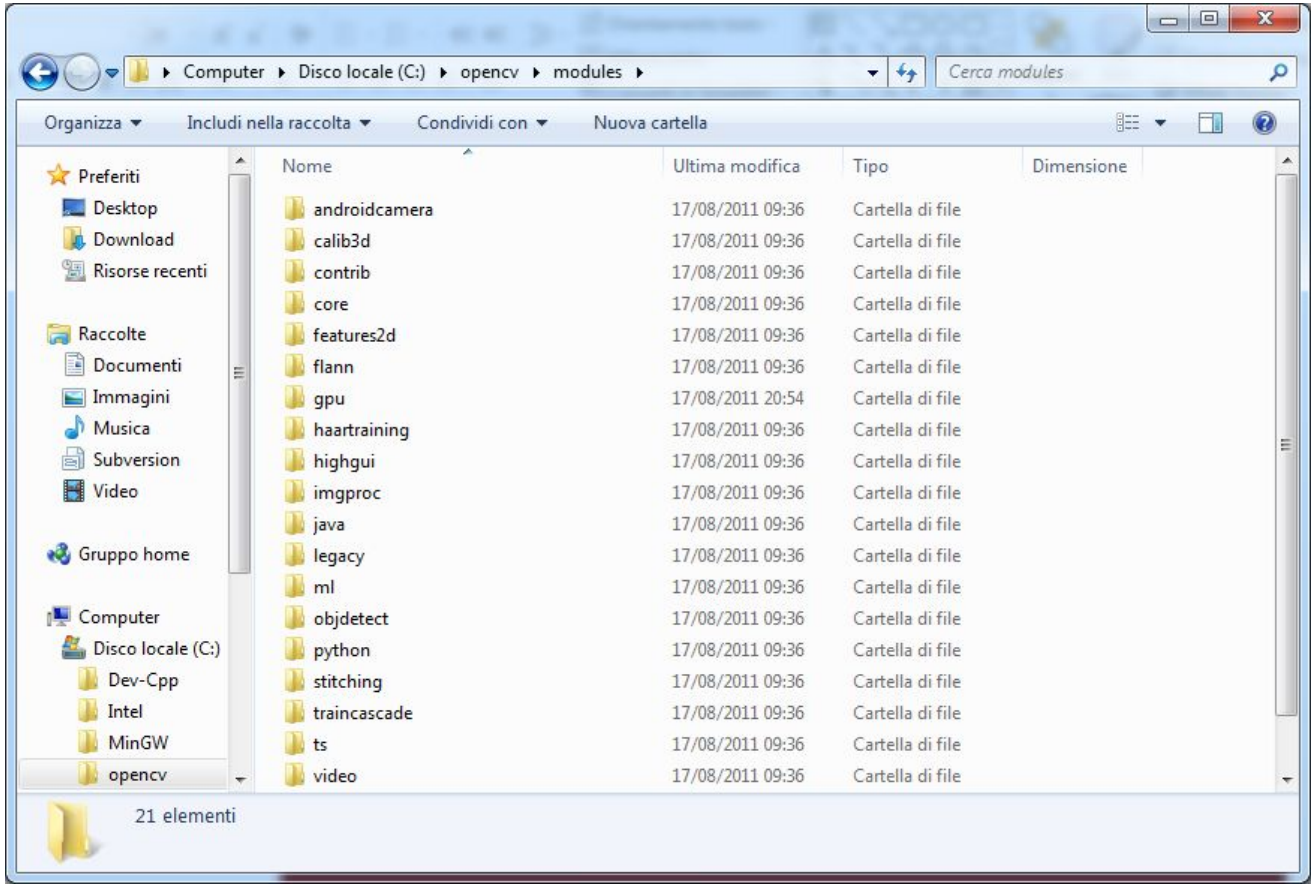
OpenCV (Open Source Computer Vision) is a library of programming functions for real-time computer vision

- BSD Licensed - free for commercial use
- C++, C, Python and Java (Android) interfaces
- Supports Windows, Linux, Android, iOS and Mac OS
- More than 2500 optimized algorithms

Moduli OpenCV

OpenCV has a modular structure

- core
- imgproc
- video
- calib3d
- features2d
- objdetect
- highgui
- gpu
- ...



Processamento delle immagini

core - a compact module defining basic data structures, including the dense multi-dimensional array Mat and basic functions used by all other modules.

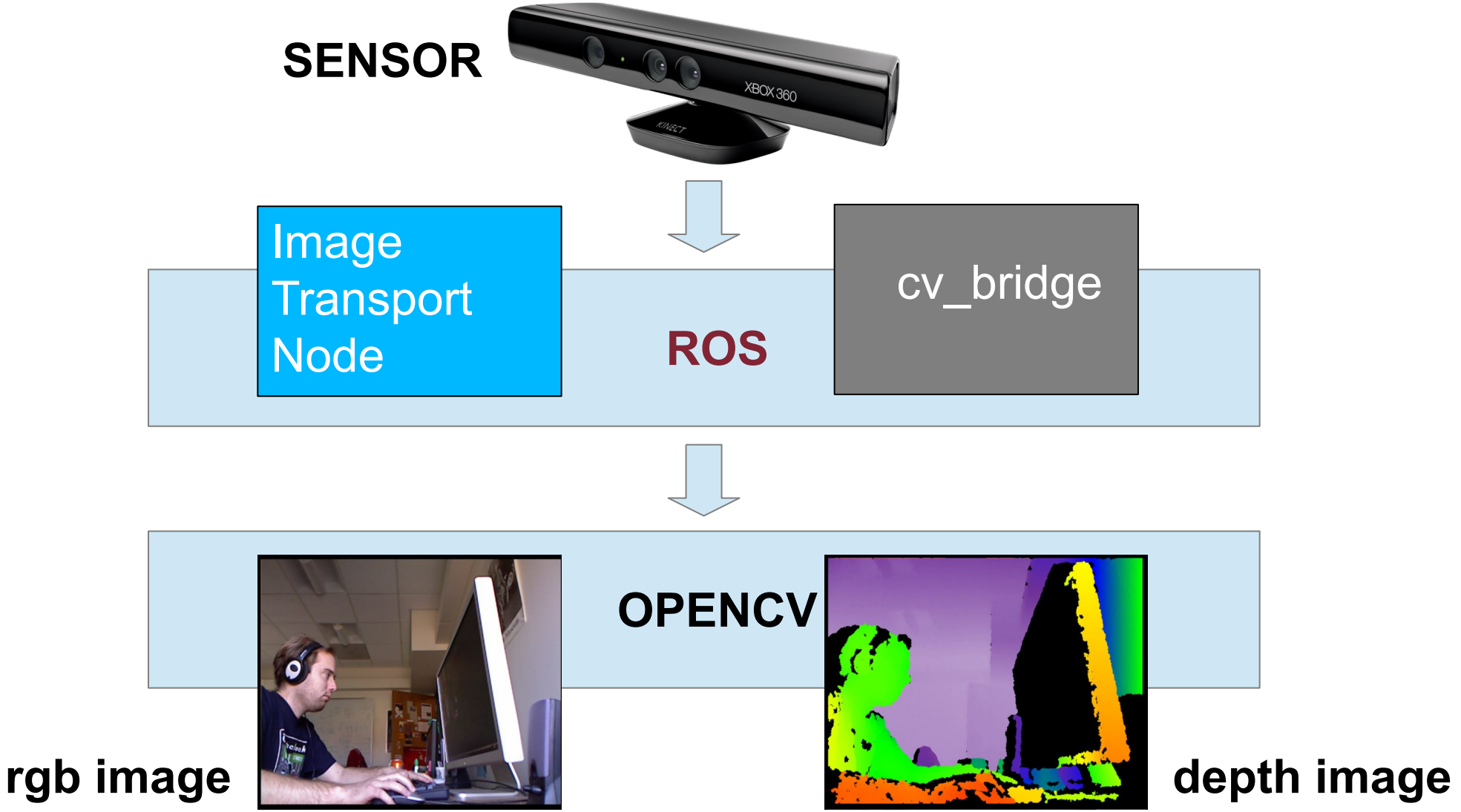
imgproc - an image processing module that includes linear and non-linear image filtering, geometrical image transformations (resize, affine and perspective warping, generic table-based remapping), color space conversion, histograms, and so on.

features2d - salient feature detectors, descriptors, and descriptor matchers.

highgui - an easy-to-use interface to video capturing, image and video codecs, as well as simple UI capabilities.

objdetect - detection of objects and instances of the predefined classes (for example, faces, eyes, mugs, people, cars, and so on).

OpenCV e ROS

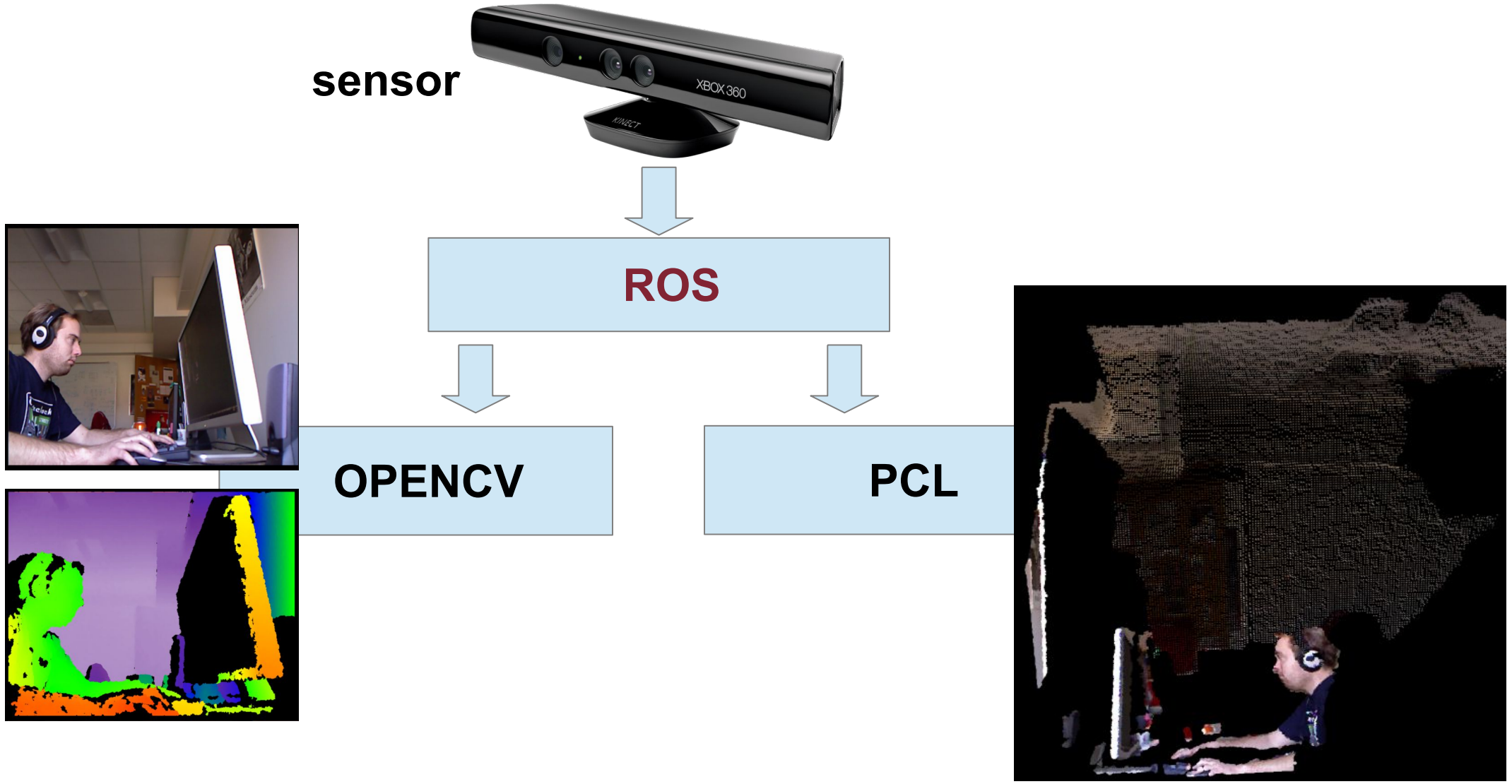

SENSOR
XBOX 360
KINECT
Image Transport Node
ROS
cv_bridge
OPENCV
rgb image
depth image

Gestione dati 3D

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

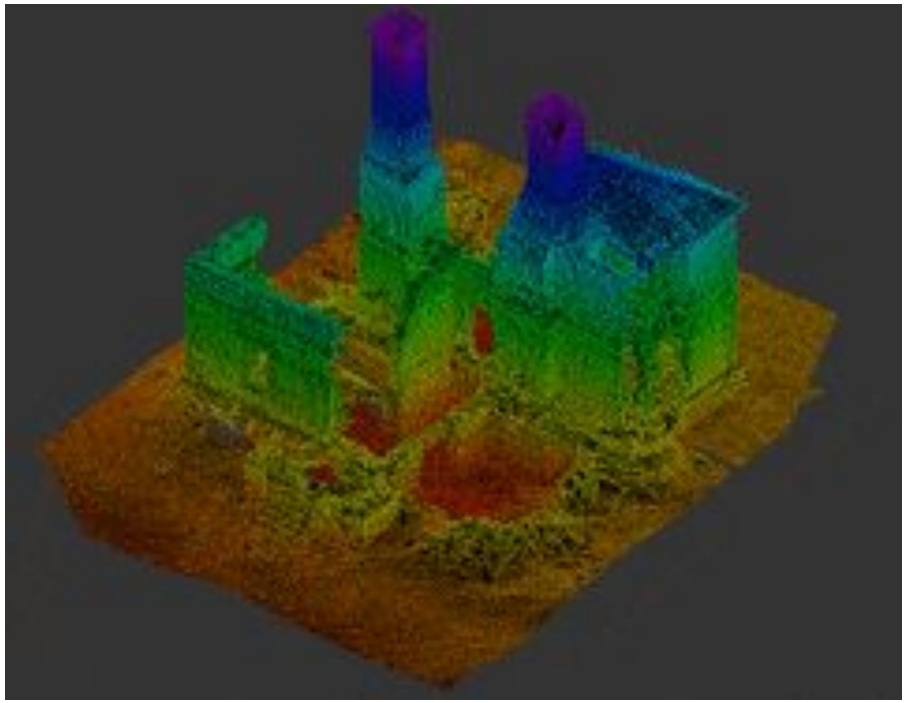
- Collection of Libraries focused on Point Cloud processing
- More than 450 developers/contributors
- Over 60 Tutorials and many examples
- BSD Licensed - free for commercial use

PCL e ROS



Point cloud: a definition

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

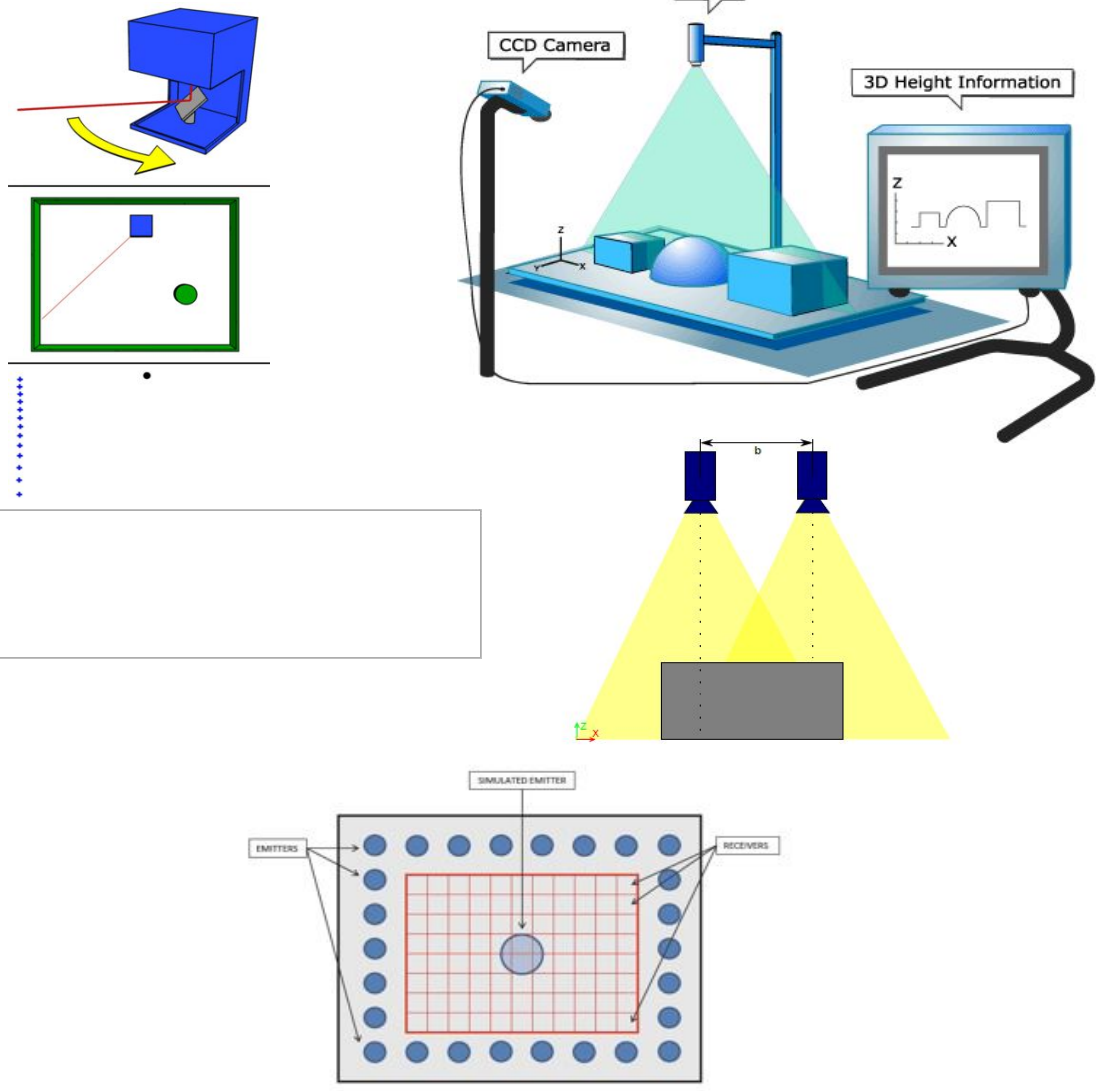


Point cloud: a definition

- The points in the point cloud usually represent the X, Y, and Z geometric coordinates of a sampled surface
- Each point can hold additional information: RGB colors, intensity values, etc...

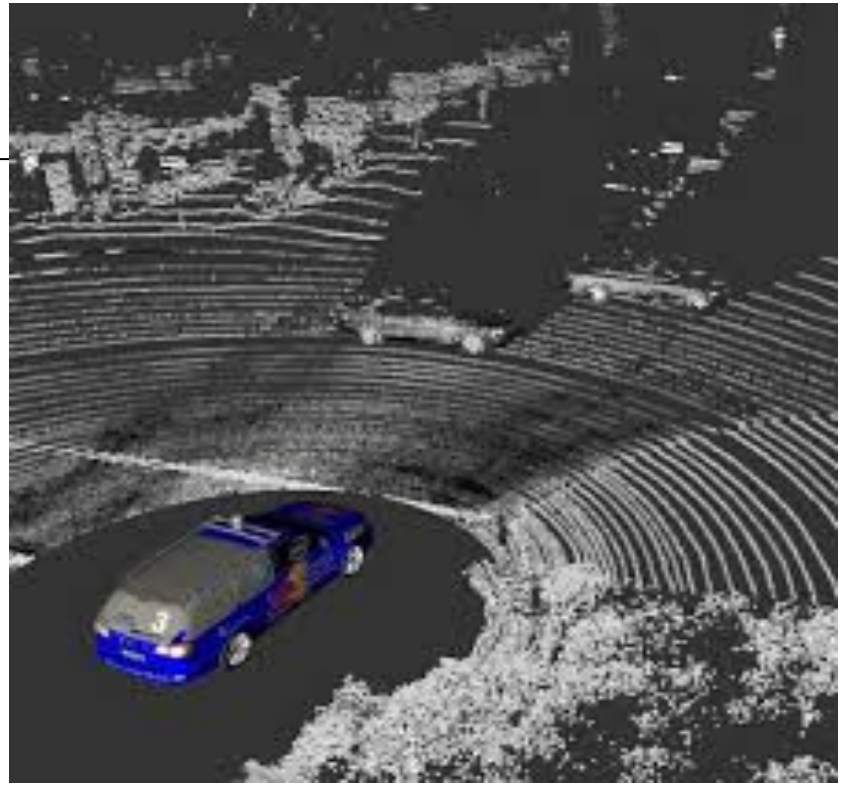
Where do they come from?

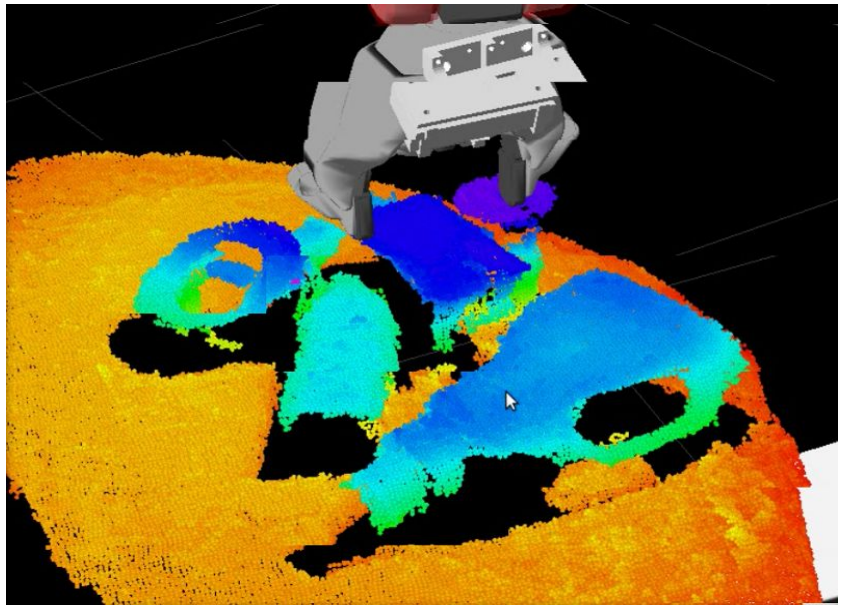
- 2/3D Laser scans
- Laser triangulation
- Stereo cameras
- RGB-D cameras
- Structured light cameras
- Time of flight cameras

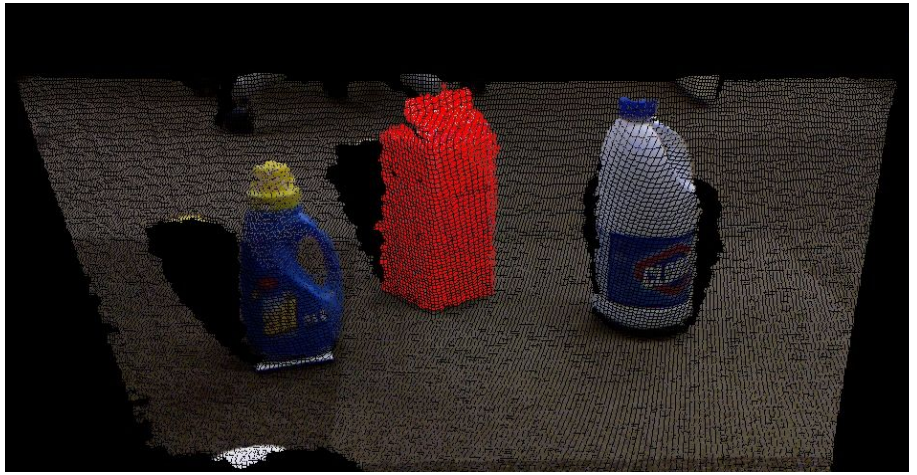


Point clouds in robotics

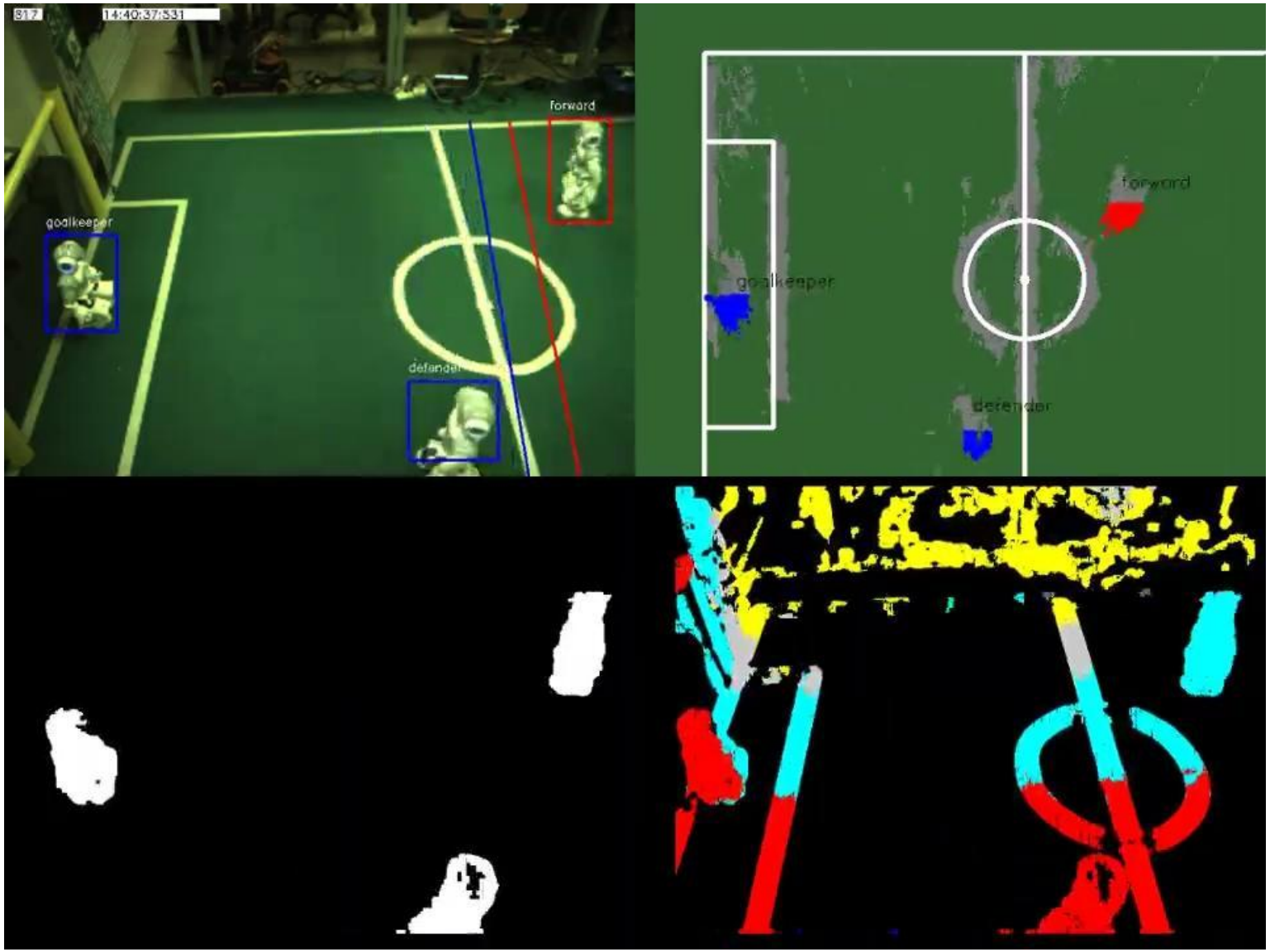
- Navigation/Obstacle avoidance
- Object recognition and registration
- Grasping and manipulation







Offside detection



Grasping

https://youtu.be/HIMIEOdsttU

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 + ROS

- 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 that 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

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

Point Cloud file format

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

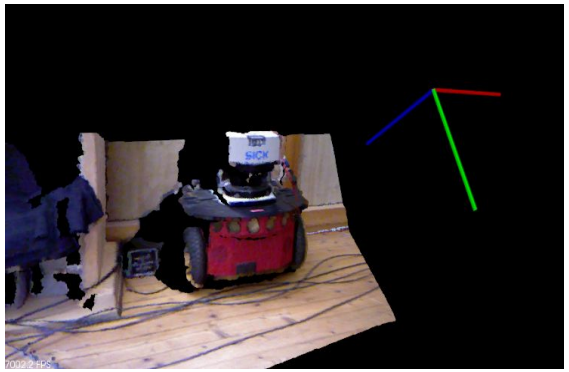
```
# Point Cloud Data (PCD) file format v.5
FIELDS x y z rgba
SIZE 4 4 4 4
TYPE F F F U
WIDTH 307200
HEIGHT 1
POINTS 307200
DATA binary
...<data>...
```

Funtions: `pcl::io::loadPCDFile` and `pcl::io::savePCDFile`

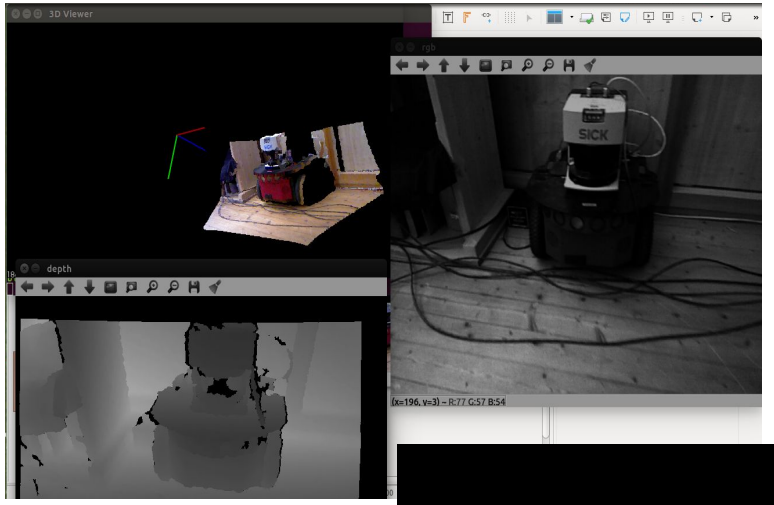
Create and save a PC

```
#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);

  //....
```

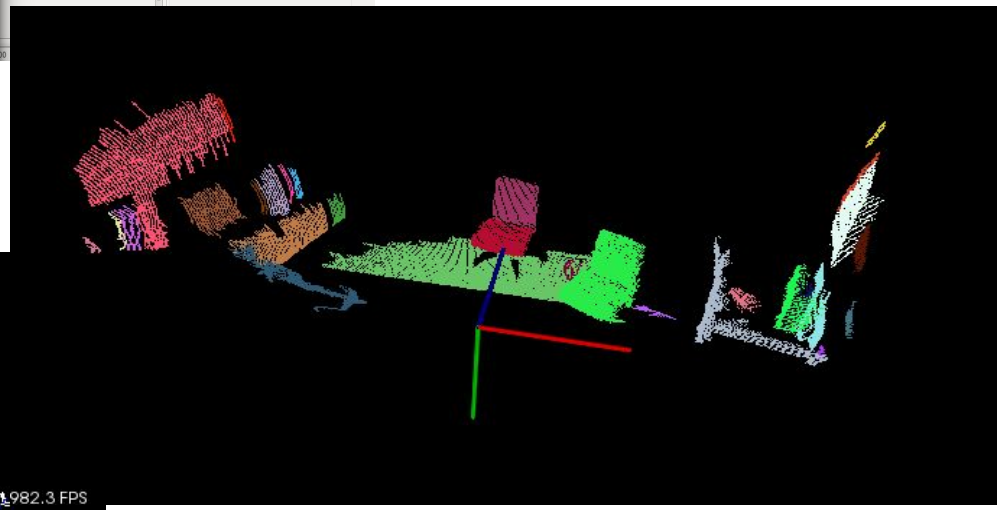
pcl_examples



Viewer

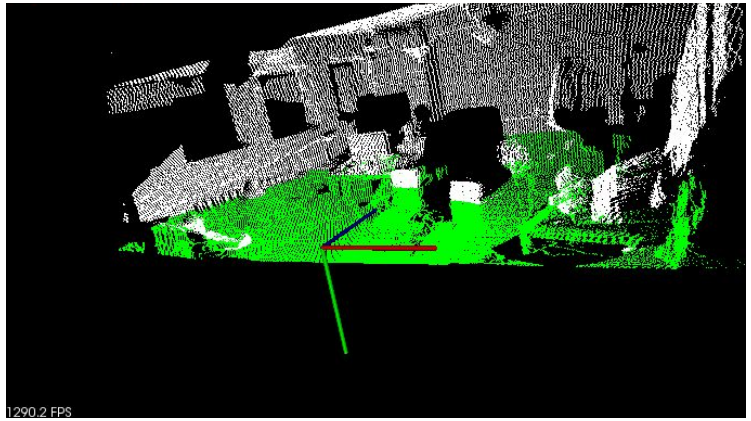


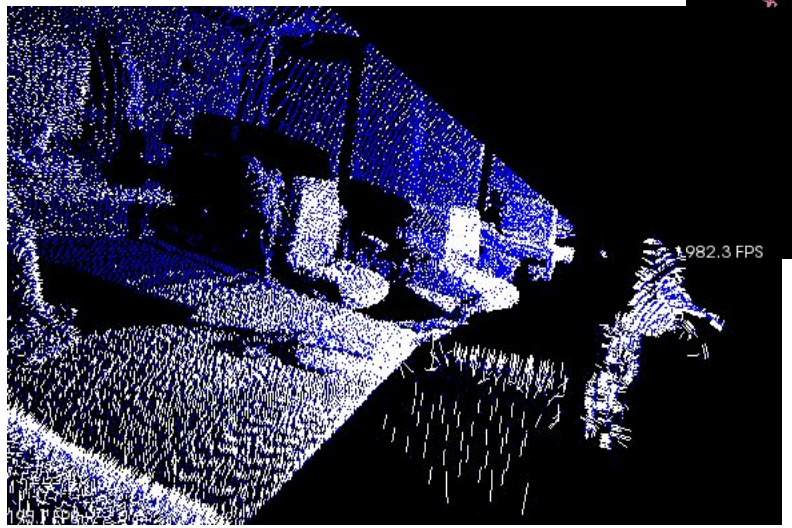
Depth2cloud



Clustering

Cloud_filters

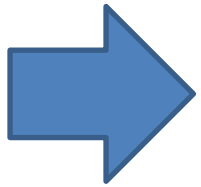




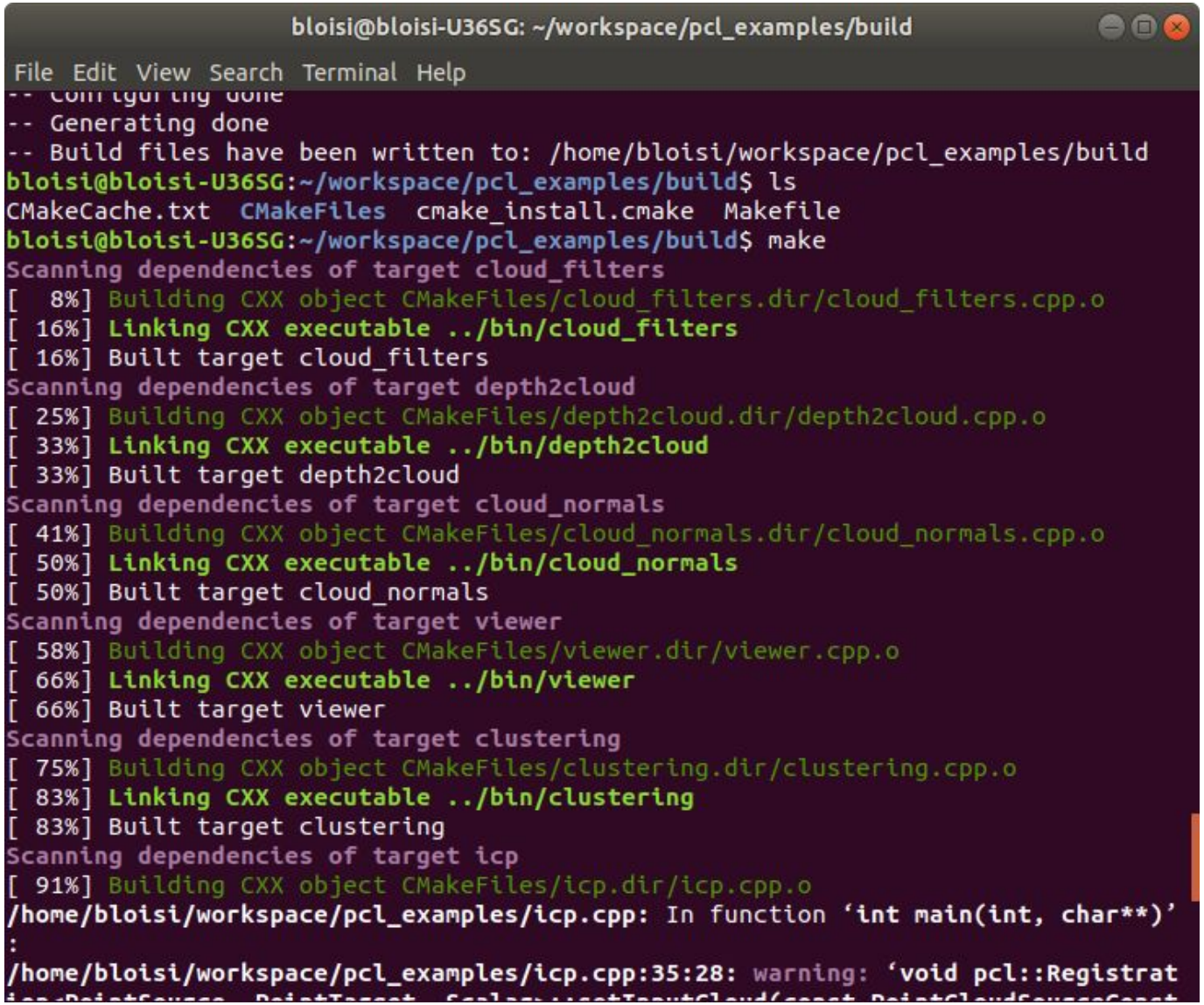
Cloud_normals

Compilare pcl_examples

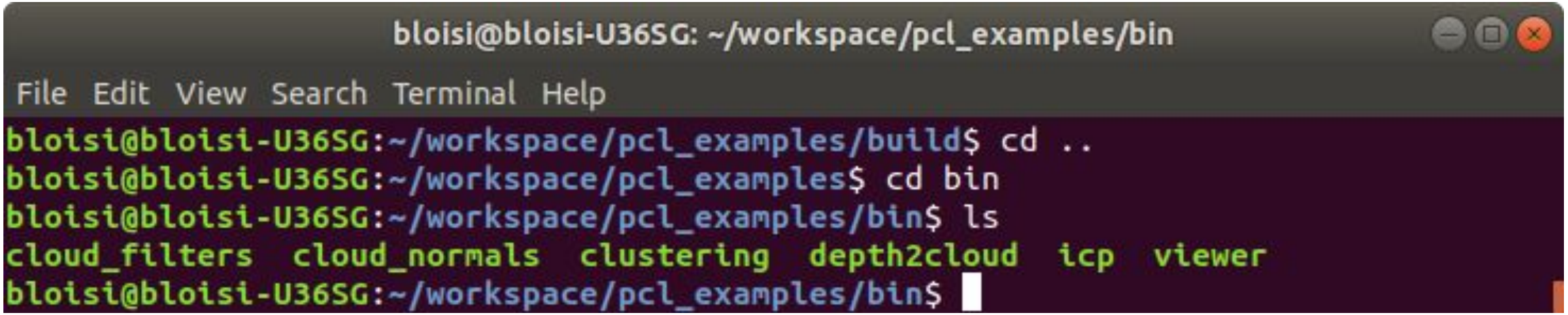
```
bloisi@bloisi-U36SG: ~/workspace/pcl_examples/build
File  Edit  View  Search  Terminal  Help
bloisi@bloisi-U36SG:~$ cd workspace/pcl_examples/
bloisi@bloisi-U36SG:~/workspace/pcl_examples$ mkdir build
bloisi@bloisi-U36SG:~/workspace/pcl_examples$ cd build/
bloisi@bloisi-U36SG:~/workspace/pcl_examples/build$ cmake ..
-- The C compiler identification is GNU 7.5.0
-- The CXX compiler identification is GNU 7.5.0
-- Check for working C compiler: /usr/bin/cc
-- Check for working C compiler: /usr/bin/cc -- works
-- Detecting C compiler ABI info
-- Detecting C compiler ABI info - done
-- Detecting C compile features
-- Detecting C compile features - done
-- Check for working CXX compiler: /usr/bin/c++
-- Check for working CXX compiler: /usr/bin/c++ -- works
-- Detecting CXX compiler ABI info
-- Detecting CXX compiler ABI info - done
-- Detecting CXX compile features
-- Detecting CXX compile features - done
-- Checking for module 'eigen3'
--   Found eigen3, version 3.3.4
-- Found eigen: /usr/include/eigen3
-- Looking for pthread.h
-- Looking for pthread.h - found
-- Performing Test CMAKE_HAVE_LIBC_PTHREAD
```



Compilare pcl_examples

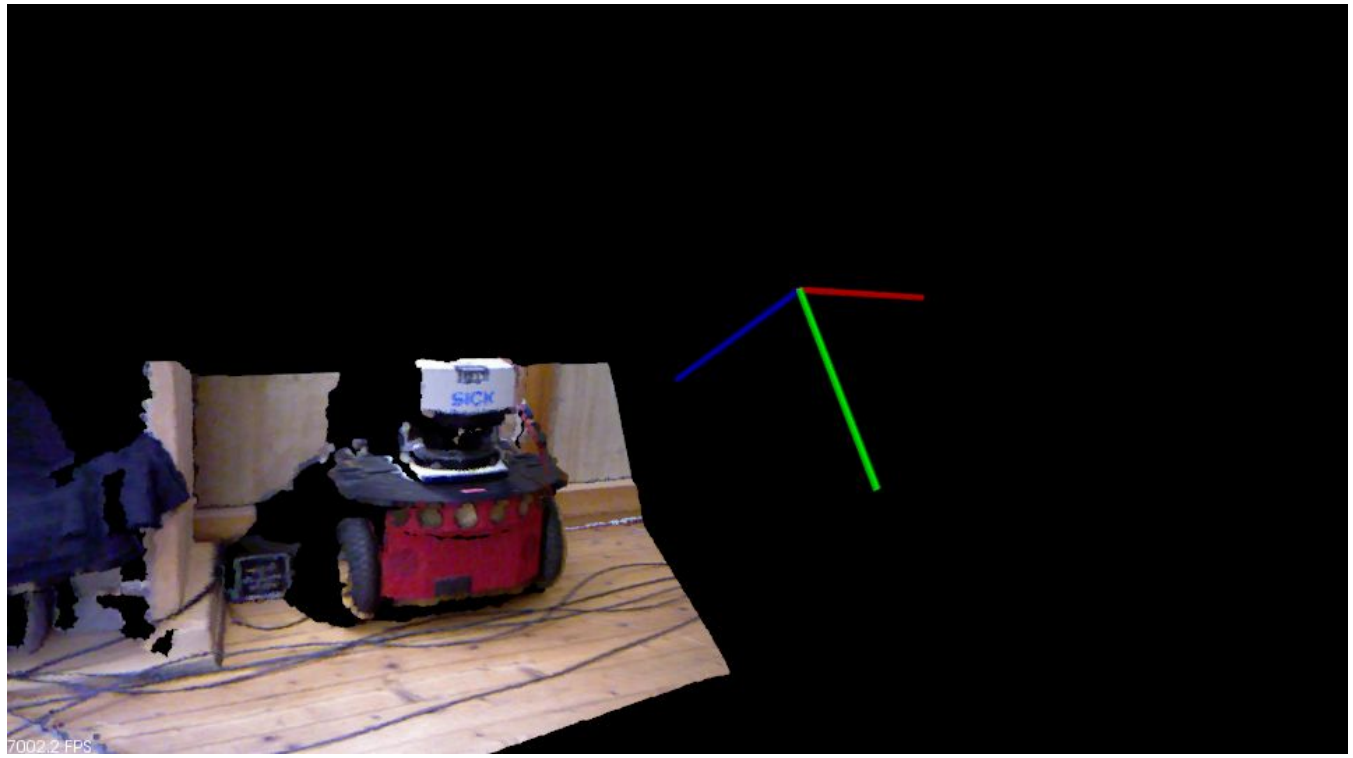


Compilare pcl_examples

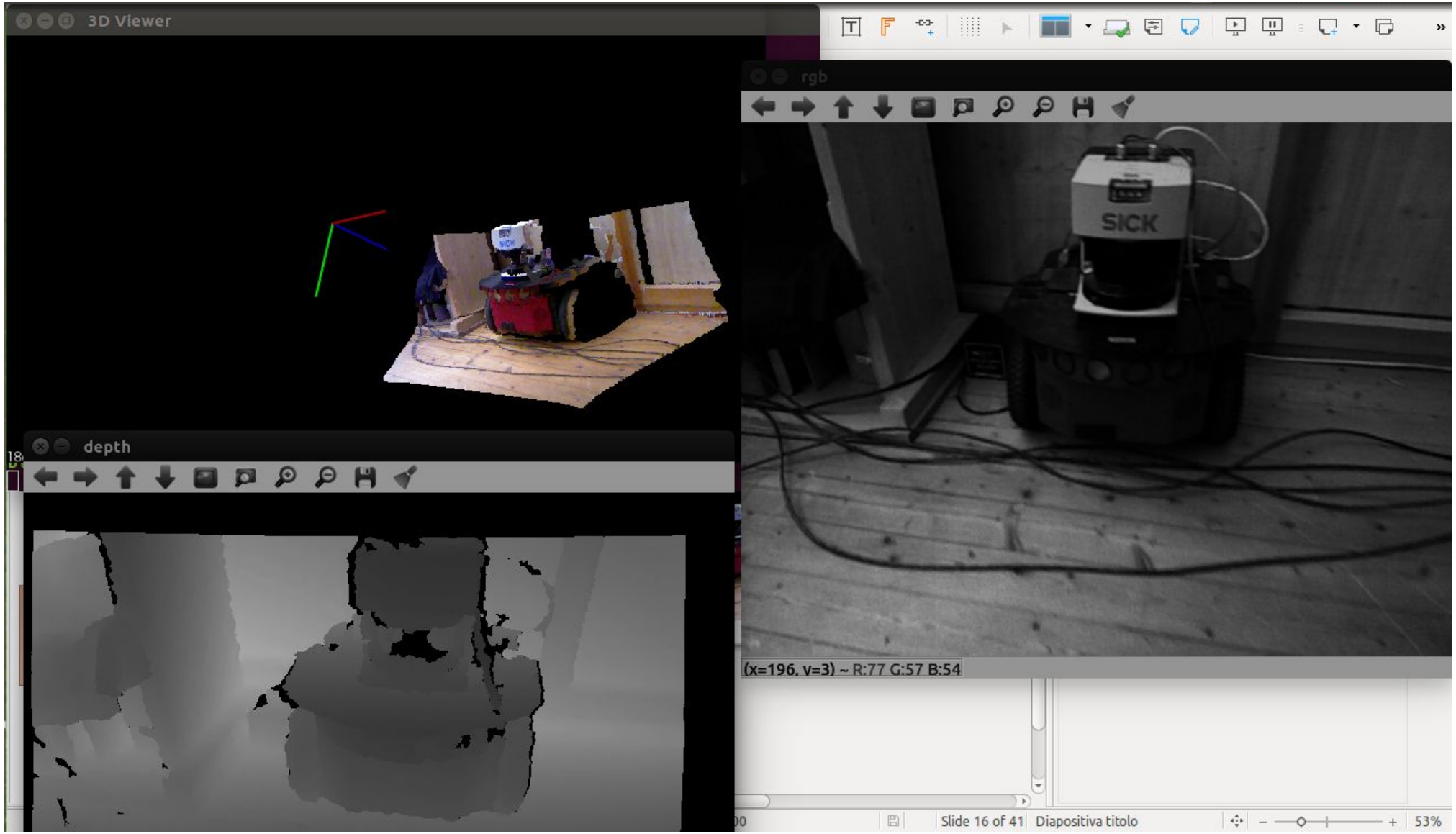


Visualize a cloud

```
boost::shared_ptr<pcl::visualization::PCLVisualizer> viewer(new
                    pcl::visualization::PCLVisualizer("3D Viewer"));
viewer->setBackgroundColor(0, 0, 0);
viewer->addPointCloud<pcl::PointXYZ>(in_cloud, cloud_color, "Input cloud");
viewer->initCameraParameters();
viewer->addCoordinateSystem(1.0);
while(!viewer->wasStopped()) {
   viewer->spinOnce(1);
}
```



depth2cloud.cpp



Basic Module Interface

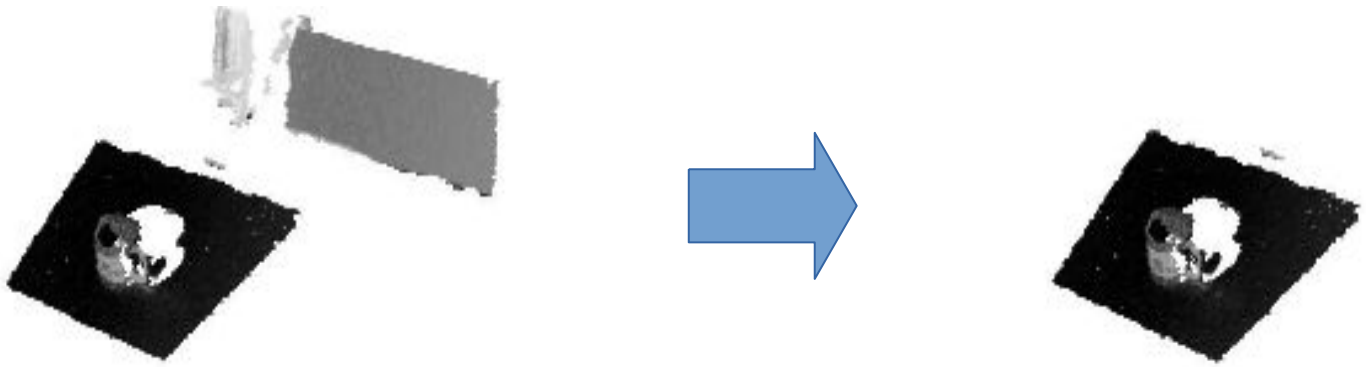
Filters, Features, Segmentation all use the same basic usage interface:

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

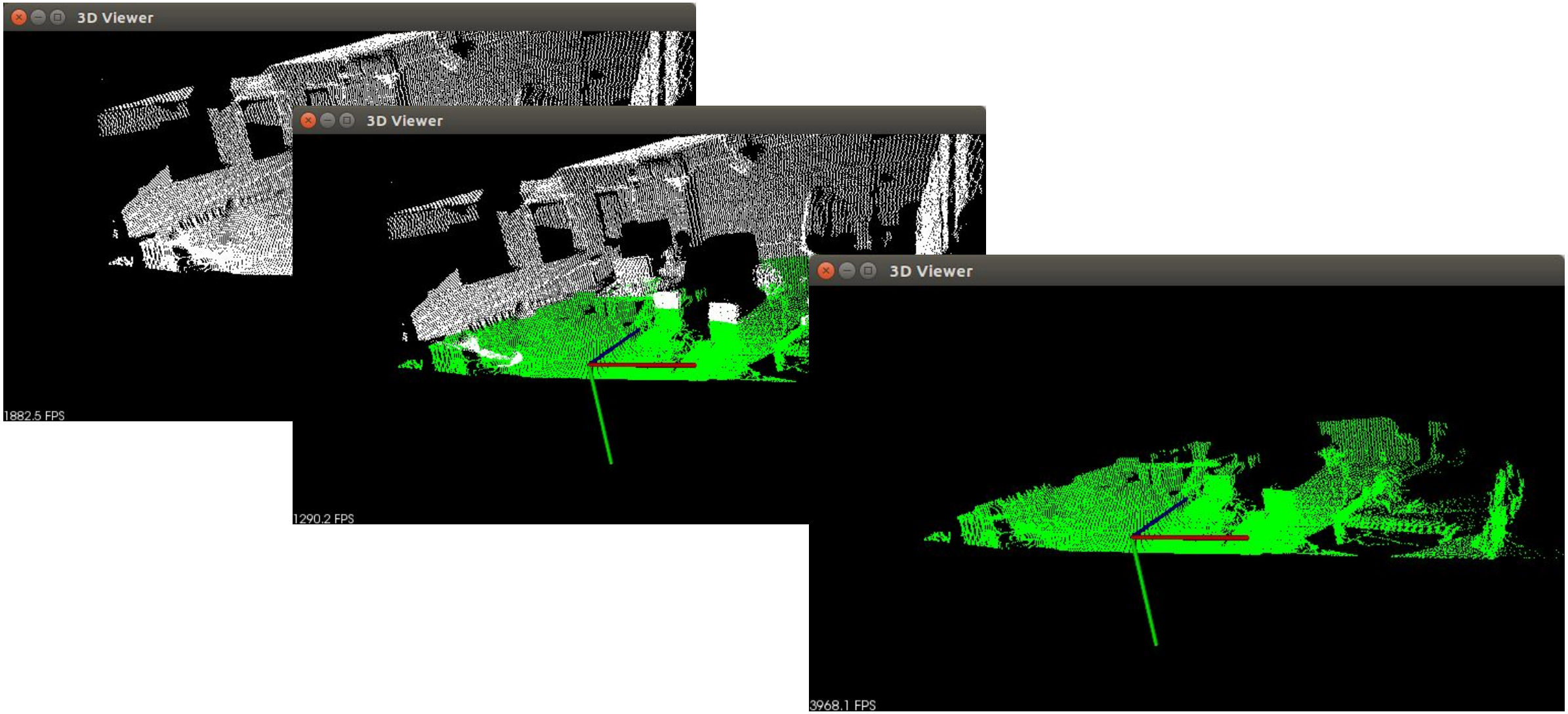
PassThrough Filter

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);
```



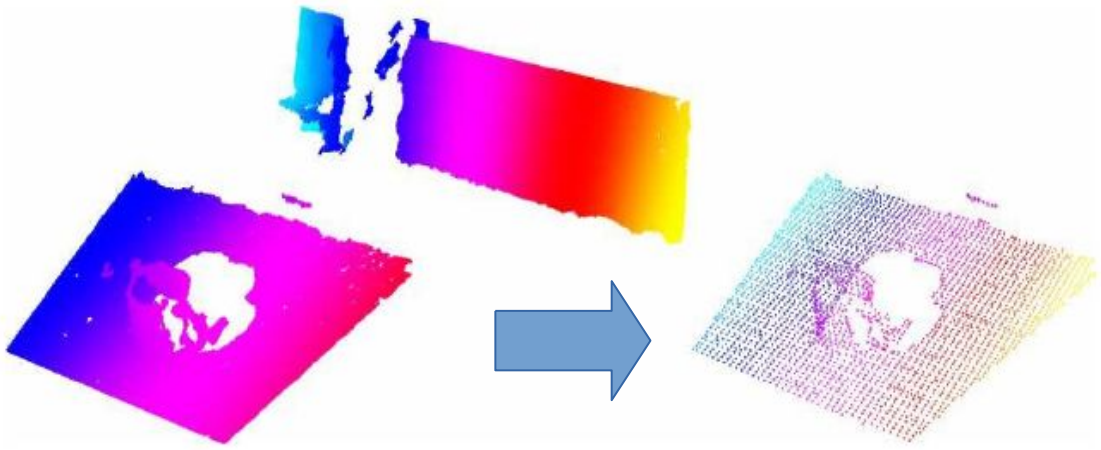
cloud_filters.cpp



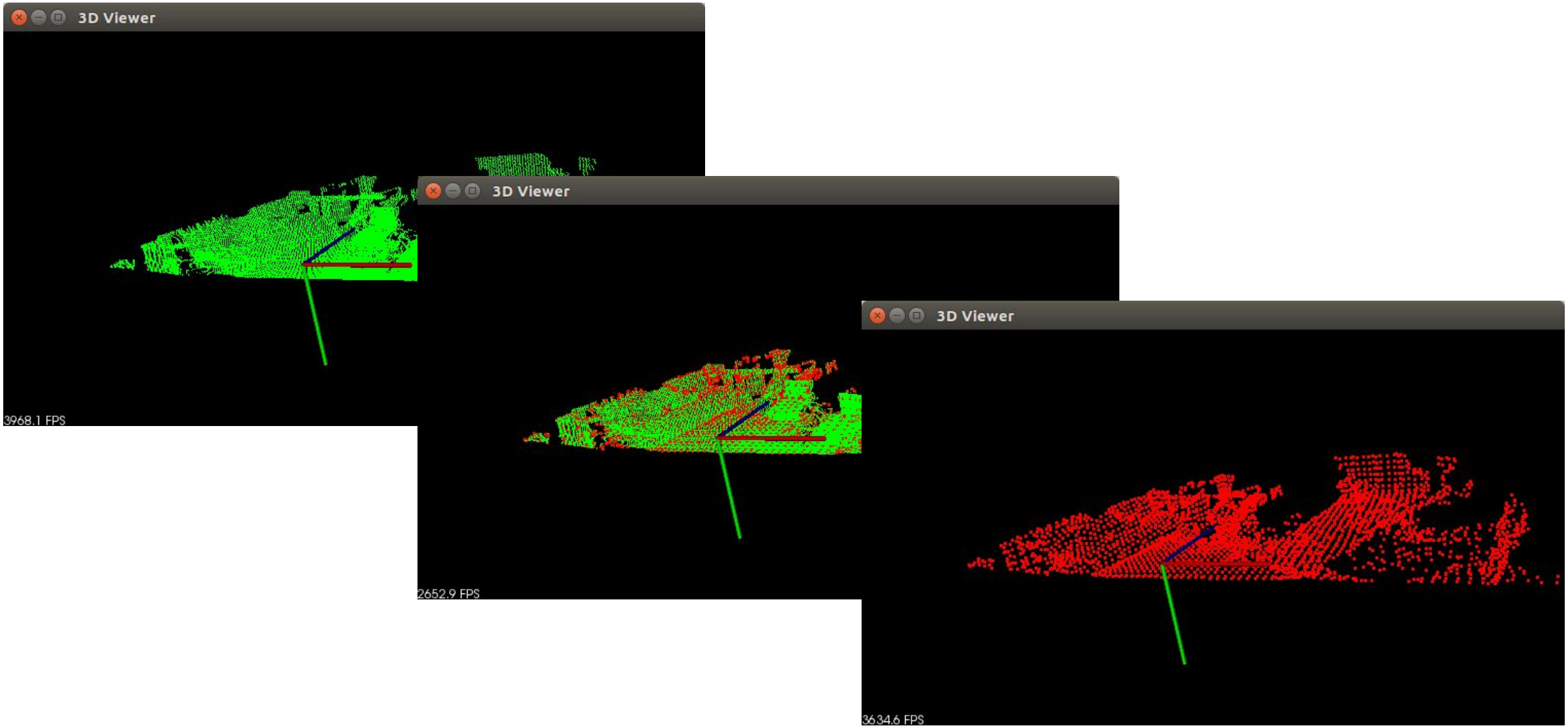
Downsampling

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);
```



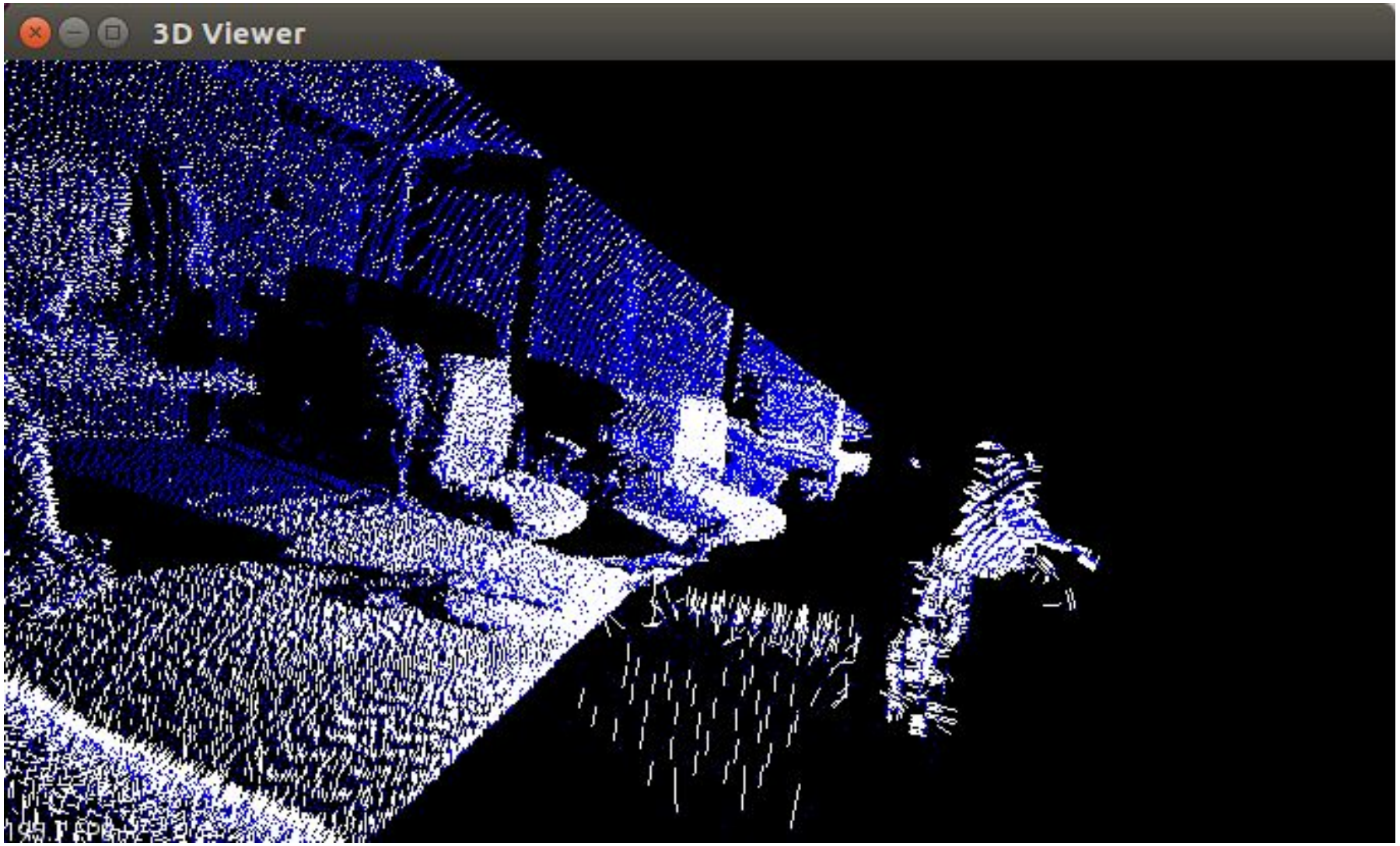
cloud_filters.cpp



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)
```

cloud_normals.cpp



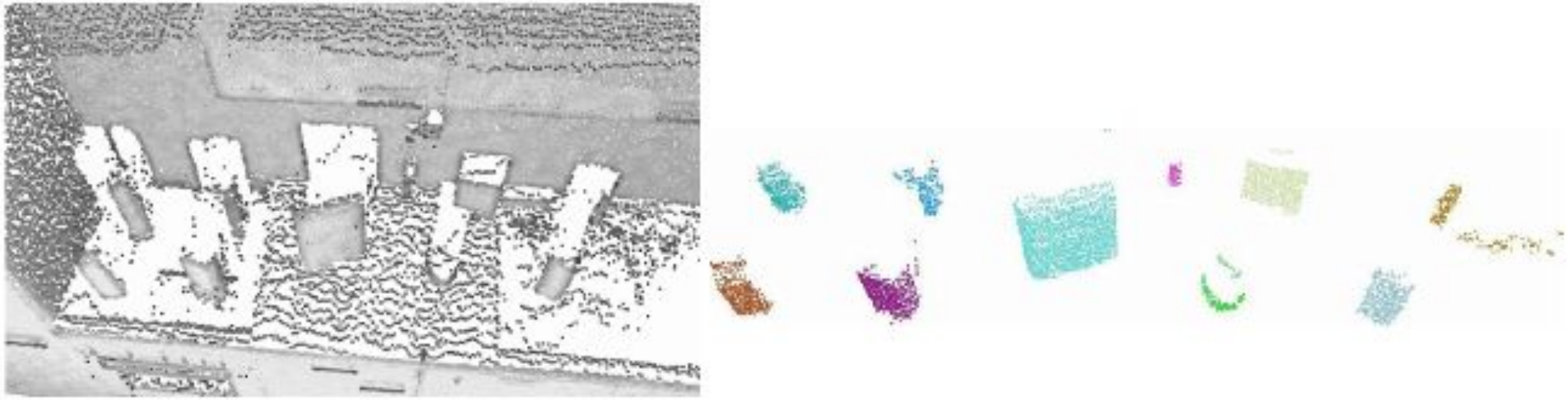
Segmentation

A clustering method divides an unorganized point cloud into smaller, correlated, parts

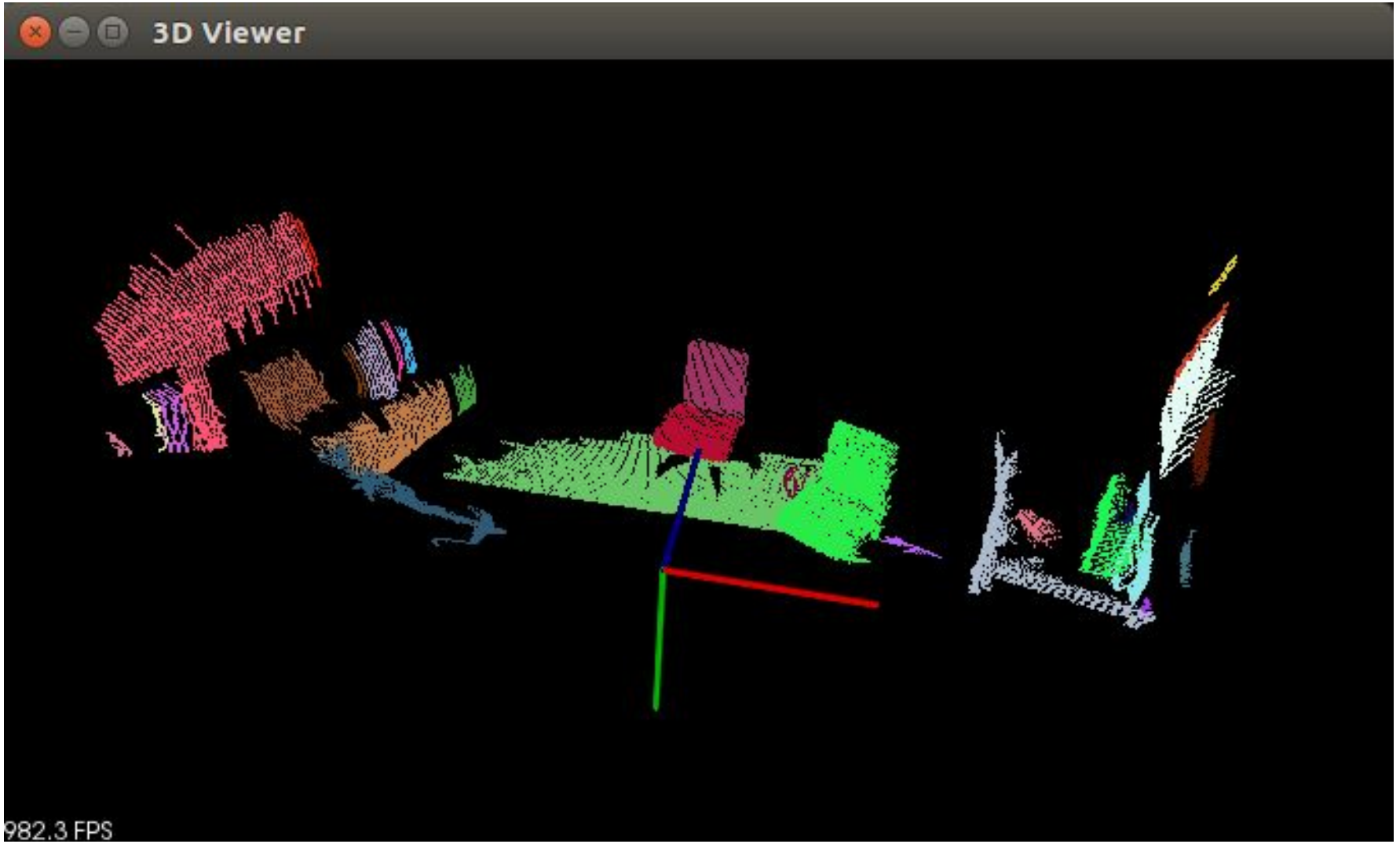
`EuclideanClusterExtraction` uses a distance threshold to the nearest neighbors of each point to decide if the two points belong to the same cluster.

Segmentation example

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

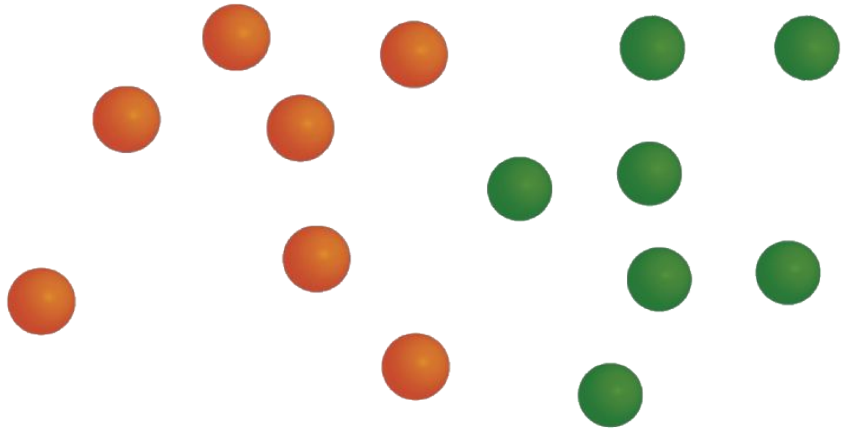


clustering.cpp



Point Cloud Registration

We want to find the translation and the rotation that maximize the overlap between two point clouds



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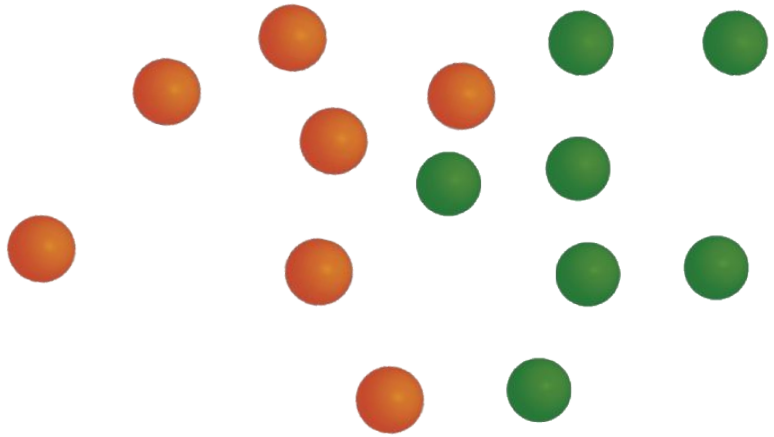

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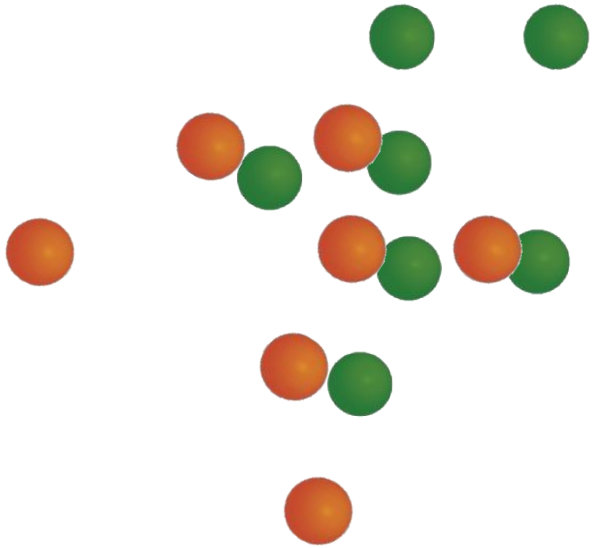

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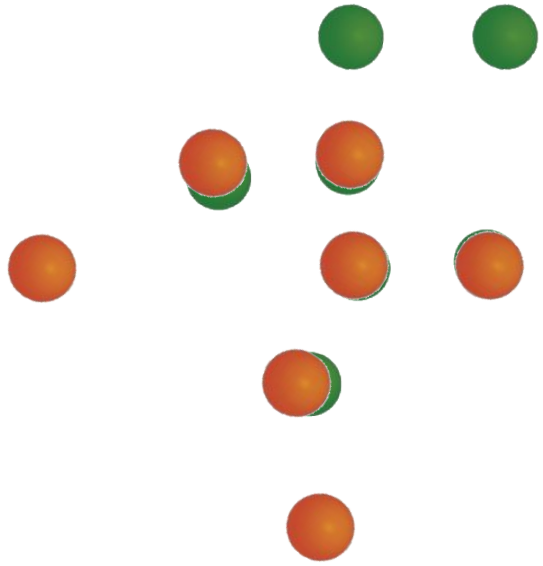

Point Cloud Registration

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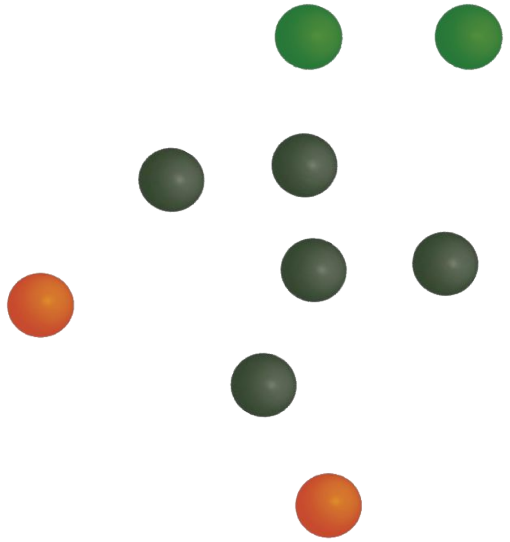


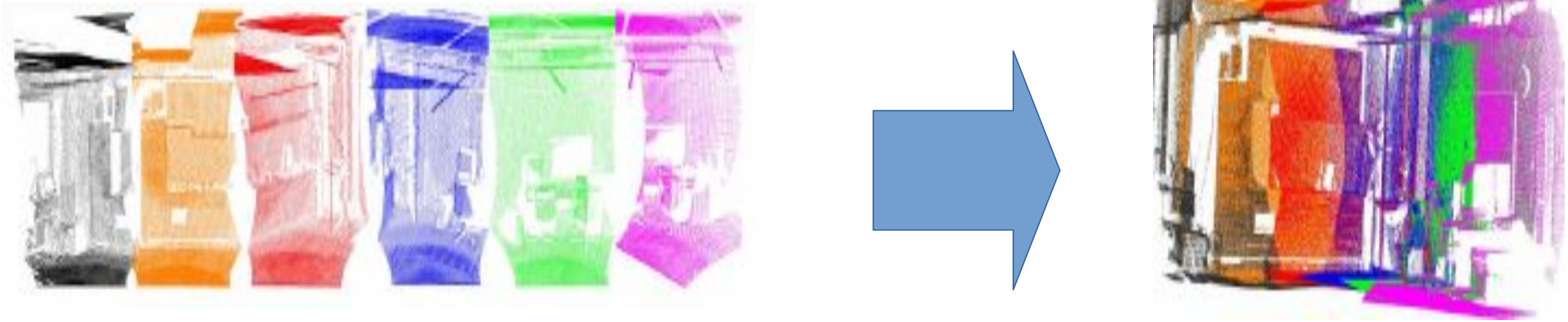
Iterative Closest Point

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

Input: points from two raw scans, initial estimation of the transformation, criteria for stopping the iteration

Output: refined transformation

Iterative Closest Point: Example



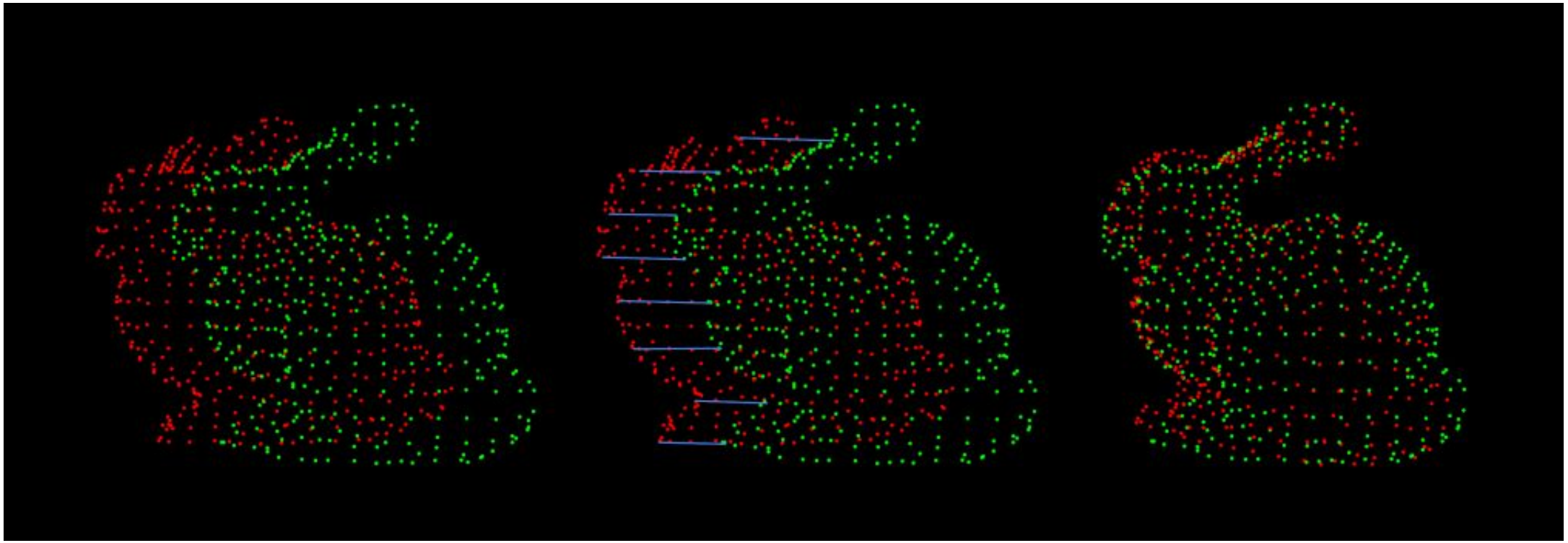
Iterative Closest Point: Algorithm

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)

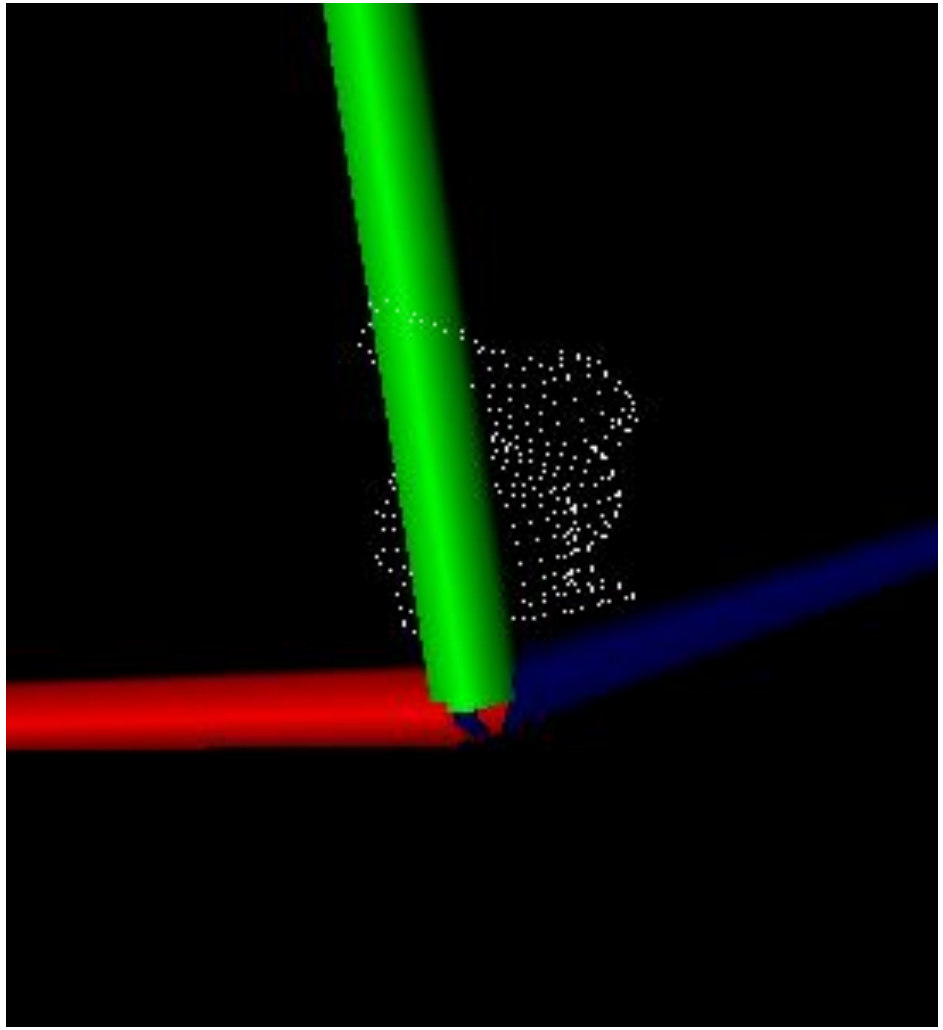
Iterative Closest Point: Code

```
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);
// Align cloud_source to cloud_source_registered
Eigen::Matrix4f transformation = icp.getFinalTransformation();
```

Iterative Closest Point: Example



icp.cpp

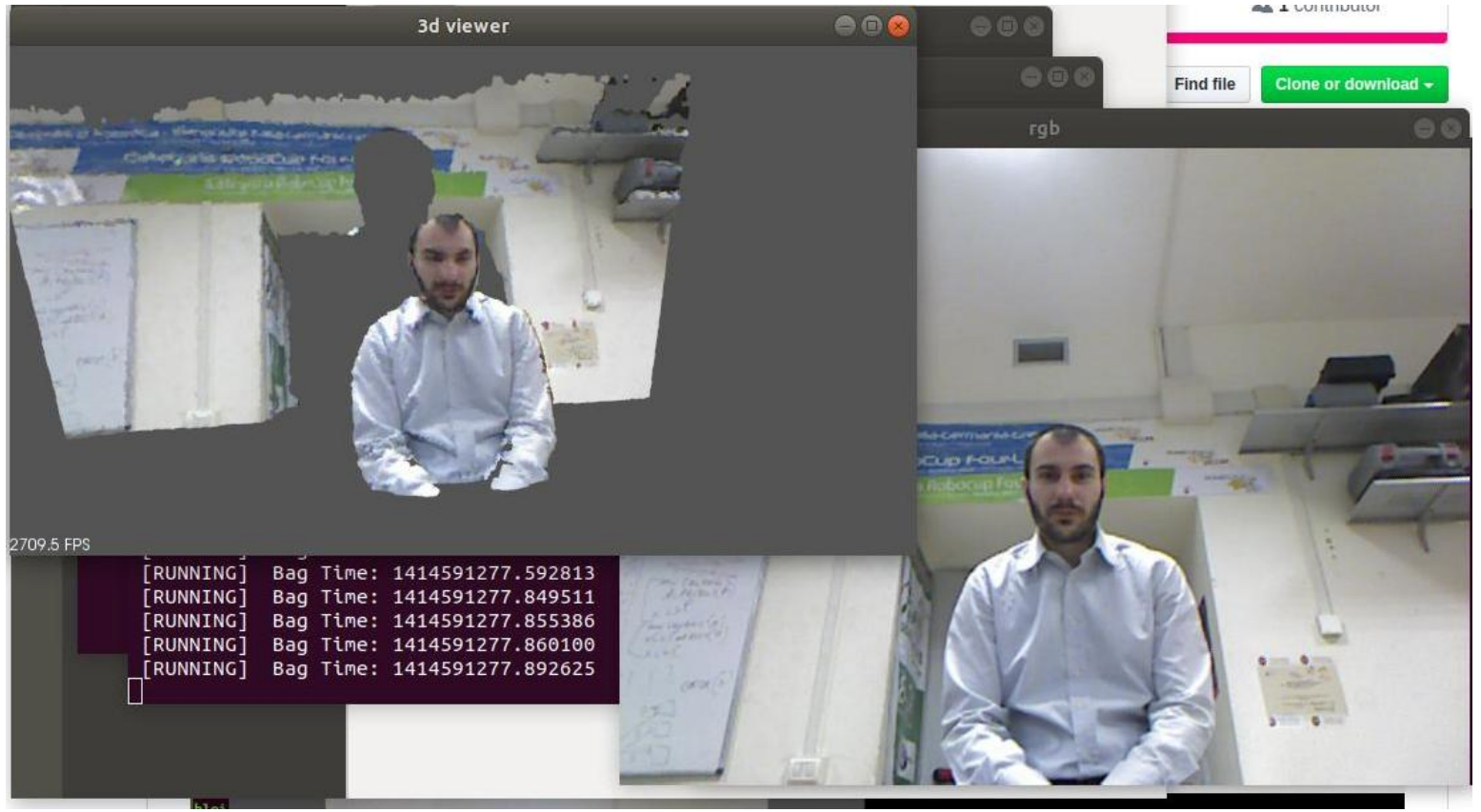


basic 3D visualizer

A simple 3D visualizer for RGBD data

basic_3d_visualizer uses

- ROS (tested with melodic)
- OpenCV (tested with version 4.2)
- PCL (tested with version 1.8)

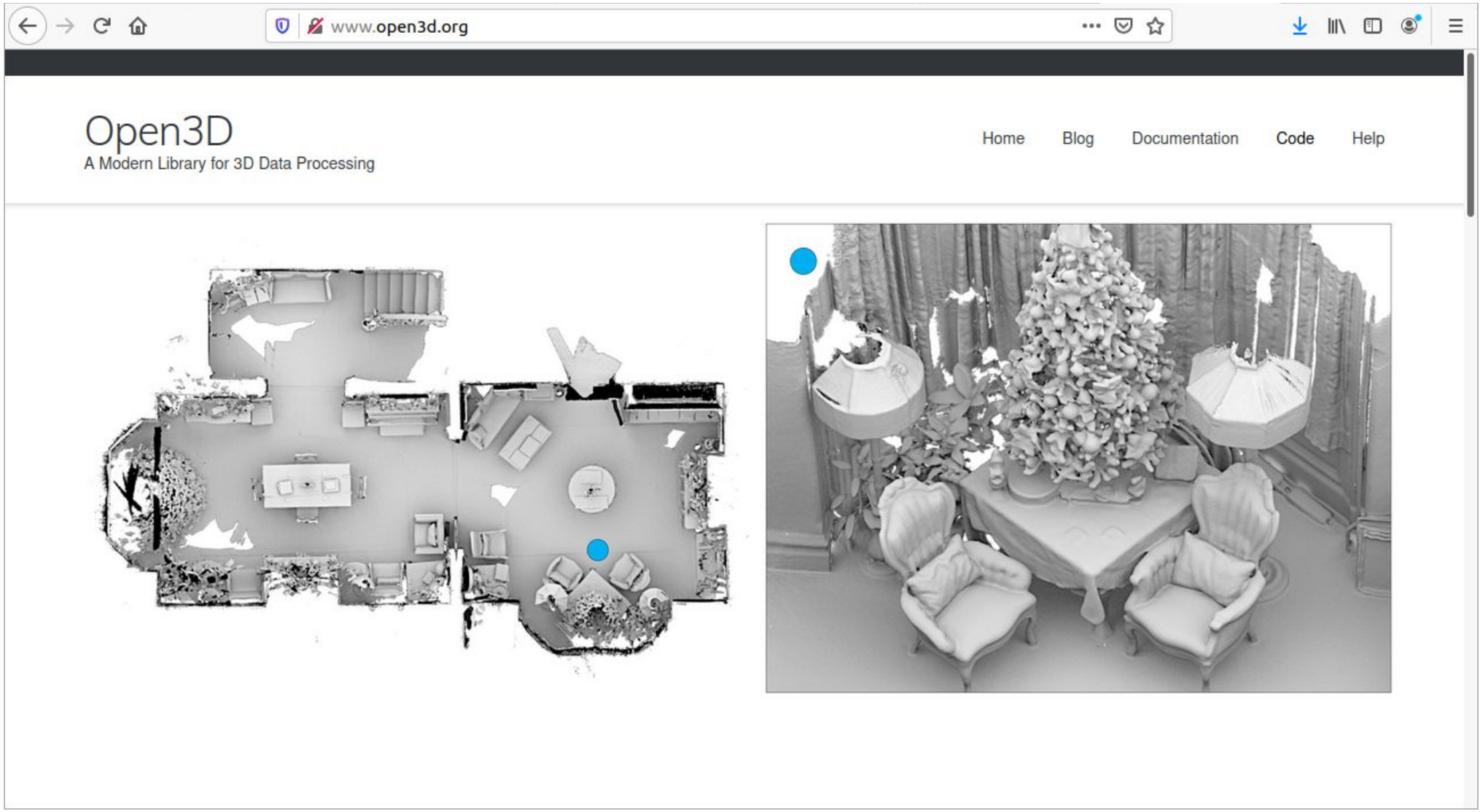


https://github.com/dbloisi/basic_3d_visualizer

basic 3D visualizer

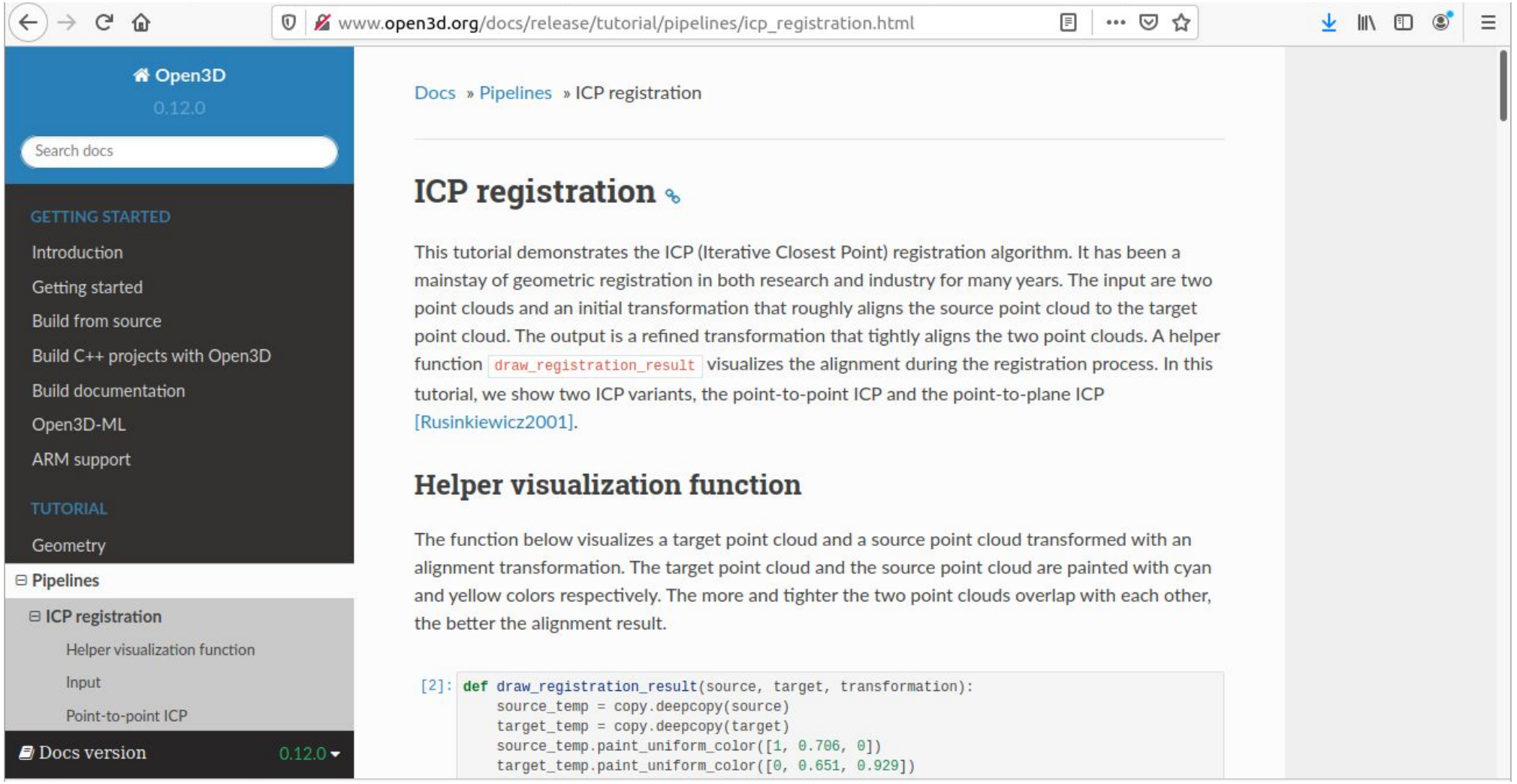
https://youtu.be/HTCxk7520Sc

Open3D



http://www.open3d.org/

Open3D - registration



http://www.open3d.org/docs/release/tutorial/pipelines/icp_registration.html



UNIVERSITÀ DEGLI STUDI
DELLA BASILICATA

Corso di Visione e Percezione

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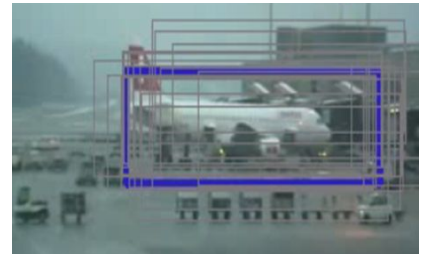

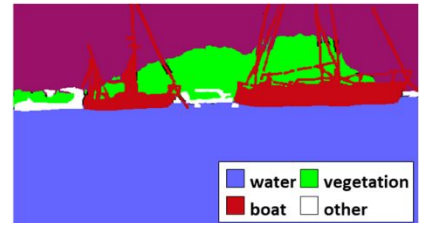

Visualizzazione dati 3D