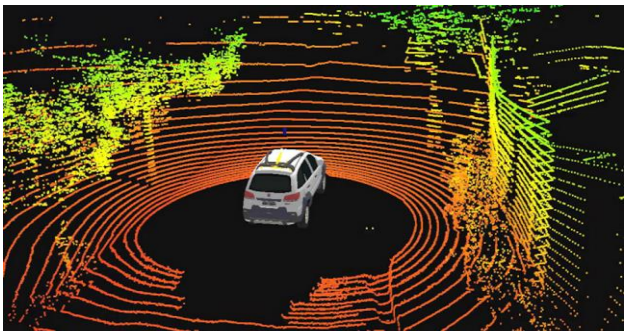
## Prerequisites and preparation

In this work, the goal is to develop a C/C++ program to solve an engineering problem related to Artificial Sensor-based Perception: which finds applications in autonomous driving and mobile robotics navigation. In particular, a ground/road detection system will be developed having as input data from a 3D LiDAR sensor. The figure below shows, on the left, a point-cloud from a LiDAR (the Velodyne HDL-32 mounted on the roof of a car); on the right, the most usual Velodyne LiDAR models are depicted.



**Point Cloud – the LiDAR is mounted on the car roof**


**LiDAR sensors from Velodyne**

This practical assignment is divided in two parts. The first part involves POSIX routines, implemented in C, and the objective is to guarantee that the **threads** do not run at the same time. Therefore, it is necessary to explore and understand the concept of Synchronization services, namely **mutex** (it can be understood as a kind of binary semaphore).
The second part requires the ROS (Robot Operating System) framework, and programming languages will be C/C++.

## Practical Implementation (part I)

In this assignment we will write a program (in C), following POSIX routines [Ref1], to perform **detection of ground/road points from 3D Point-clouds**. This work comprises the following tasks:

**1)** write a code in C to open the file (*point_cloud1.txt*), read the values from the file and pass the values to arrays/matrix inside a *struct* variable (created by you). The values, organized in columns in the file, represent the 3D Cartesian (***x,y,z***) points of a Point-Cloud from a LiDAR with 16 channels/layers (ie, from the Velodyne VLP-16 sensor). Considering the LiDAR points-values in the *struct* variable, the program has to calculate and *print*: the number of points; the minimum, the maximum and the average values of each coordinate-axis (x,y,z); and also the stand-deviation. It is recommended to create a function that receives (as one of its arguments) the file name and returns (the output) a pointer to the *struct* variable. Using the same program, repeat the process for the files: *point_cloud2.txt* and *point_cloud3.txt*.

**2)** create another function that takes as input a pointer to the *struct* variable from the program developed previously (item 1). This function has to perform a "pre-processing" stage, namely:
2.1) remove all the points that are located in the "back/behind" part of the car with respect to the sensor (ie, negative values of ***x***). Consider the X axis is the longitudinal axis and it is pointing ahead the car.
2.2) detect and remove two groups (clusters) of points that are located very close to the car - in the car forepart - using any technique that you think may be necessary (suggestion: a

visualization/display interface would facilitate this problem-solving: use Matlab or any software of your choice).
2.3) discard those points that clearly do not correspond to the ground/road (ie, the *Outliers*). The output of this function/routine, ie a processed point-cloud, should be write to the same *struct* variable that has been used throughout the exercise.

**3)** using, as input, the *struct* variable from before, developed a new function/routine to detect the points that belong to the drivable area with respect to the car, ie LIDAR points that belong to the ground/road.

**4)** Calculate (using *clock_gettime* based solution) and *print* the computation time associated to each of the three functions developed before. It should be guaranteed that the total computation time, considering all the *functions*, is less than 95 ms.

**5)** Write a program to run, in separate *threads*, each of the functions developed in the previous exercises: items 1, 2 and 3. It is mandatory to avoid all the three threads access the "*point-cloud variable*" at the same time (ie, to avoid they read-write data concurrently in the same memory location associated with the so called *struct* variable). Therefore, it is necessary to use synchronization primitives (eg, *mutex*). In other words, only one *thread* can access or write in the *struct* variable while the other threads should wait their turn to work on the *struct* variable.

Notes:
The *threads* will be activated in a sequential manner: thread#2 will process the data after thread#1 concludes its operation, and so on. The activation frequency is 10Hz (ie, a new Point-Cloud is available every 100ms) and it is the same for all *threads*.

## Practical Implementation (part II)

This part of the exercise requires the ROS (Robot Operating System) framework, and programming languages will be C/C++. First, install ROS Kinetic on your Laptop. Alternatively, you can use the Desktop machines available in the Lab. It is recommended to install ROS under a LTS Ubuntu release (16.04): http://wiki.ros.org/kinetic/Installation/Ubuntu

It is only necessary the "Desktop Install" version: *sudo apt-get install ros-kinetic-desktop*
Note: for more details, see the [Ref2] **'Supp_material1_ROS.pdf'**

**6)** Adapt the program(s)/code(s), for the first *thread*, in order to perform the conversion of the message type *sensor_msgs::PointCloud2* (LIDAR sensor message format) to the message format *sensor_msgs::PointCloud*. Moreover, the output of the third *thread* should be published, as *geometry_msgs::PointCloud*, to a topic named "output_results": this will allow offline visualization using Rviz.

Notes:

- An example of ROS implementation is provided in [Ref2]
- See http://docs.ros.org/api/sensor_msgs/html/namespacesensor__msgs.html (convertPointCloud2ToPointCloud)
- The PointCloud (global) from the Rosbag file has to be passed to the (local) *struct* variable.

## References

[Ref1] The IEEE and The Open Group. [POSIX Specification] The Open Group Base Specifications Issue 7; IEEE Std 1003.1TM-2008, 2008. [Online]. Available: http://www.opengroup.org/onlinepubs/9699919799/ .

[Ref2] L. Garrote, C. Premebida; "Robot Operating System (ROS)". Supplemental material; File: 'Supp_material1_ROS.pdf'.

[Ref3] Rui Araújo; "Sistemas de Tempo Real: Apontamentos Teóricos (Parte I)"; File: 'actstr17.pdf'.

[Ref4] Rui Araújo. "Sistemas de Tempo Real - 2014/2015". [Online]. Available: http://home.isr.uc.pt/~rui/str/str1415.html .

[Ref5] Mark Mitchell, Jeffrey Oldham, Alex Samuel. "Advanced Linux Programming." Available at: http://www.cse.hcmut.edu.vn/~hungnq/courses/nap/alp.pdf