Part III. Autoware Programming (2 hours)

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Outline

- pcap play
- Lidar sensors
- nodelet lidar driver

pcap Play

Step 1: Setup, Build, Install nodelet_lidar_driver

- $ cd # change to home directory
- $ cp –r ~/shared_dir/pcap_demo/nodelet_lidar_driver Autoware/src/autoware/core_perception
- $ cd Autoware
- $ colcon build --packages-select nodelet_lidar_driver
  # setup, build and install nodelet_lidar_driver
- $ source install/setup.bash
  # to register nodelet_lidar_driver package into ROS pkg path
- $ gnome-terminal # prepare another terminal to run rviz
- $ vi install/nodelet_lidar_driver/share/nodelet_lidar_driver/cfg/nodelet_frontend_default.yaml

 # lidar_num 값 설정: 1 or 3

 # pcap file 경로 설정: "/home/autoware/shared_dir/pcap_demo/20190821_kcity_ouster_degree0.pcap"

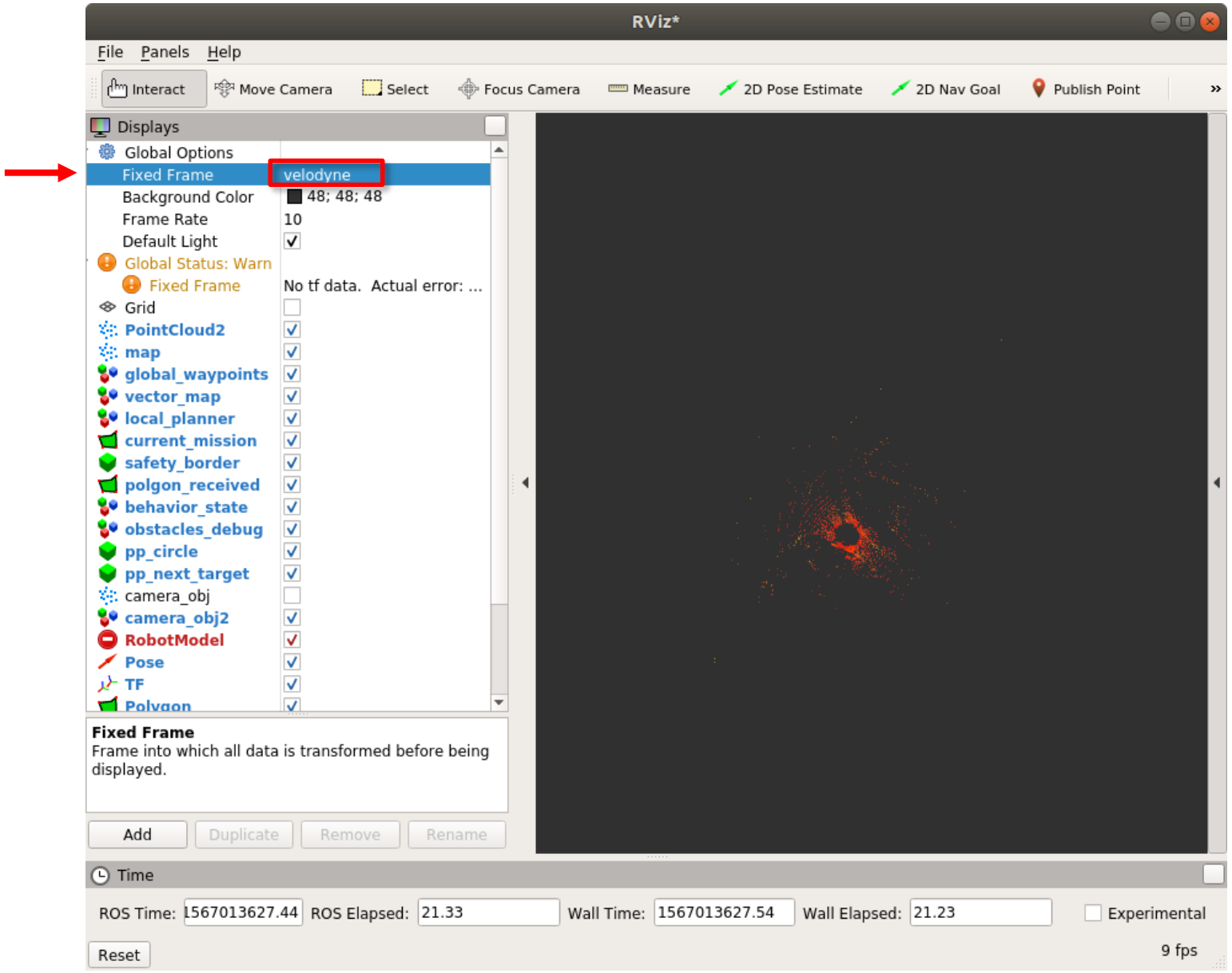
- $ roslaunch nodelet_lidar_driver nodelet_lidar_driver.launch
- [terminal] $ rviz

Note: Ouster OS-1-64 라이더를 구동하고 **socket**를 통해 **lidar msg**를 수신하는 경우에는 **nodelet_lidar_driver** 실행 전에 다음 명령어를 먼저 입력해야 함

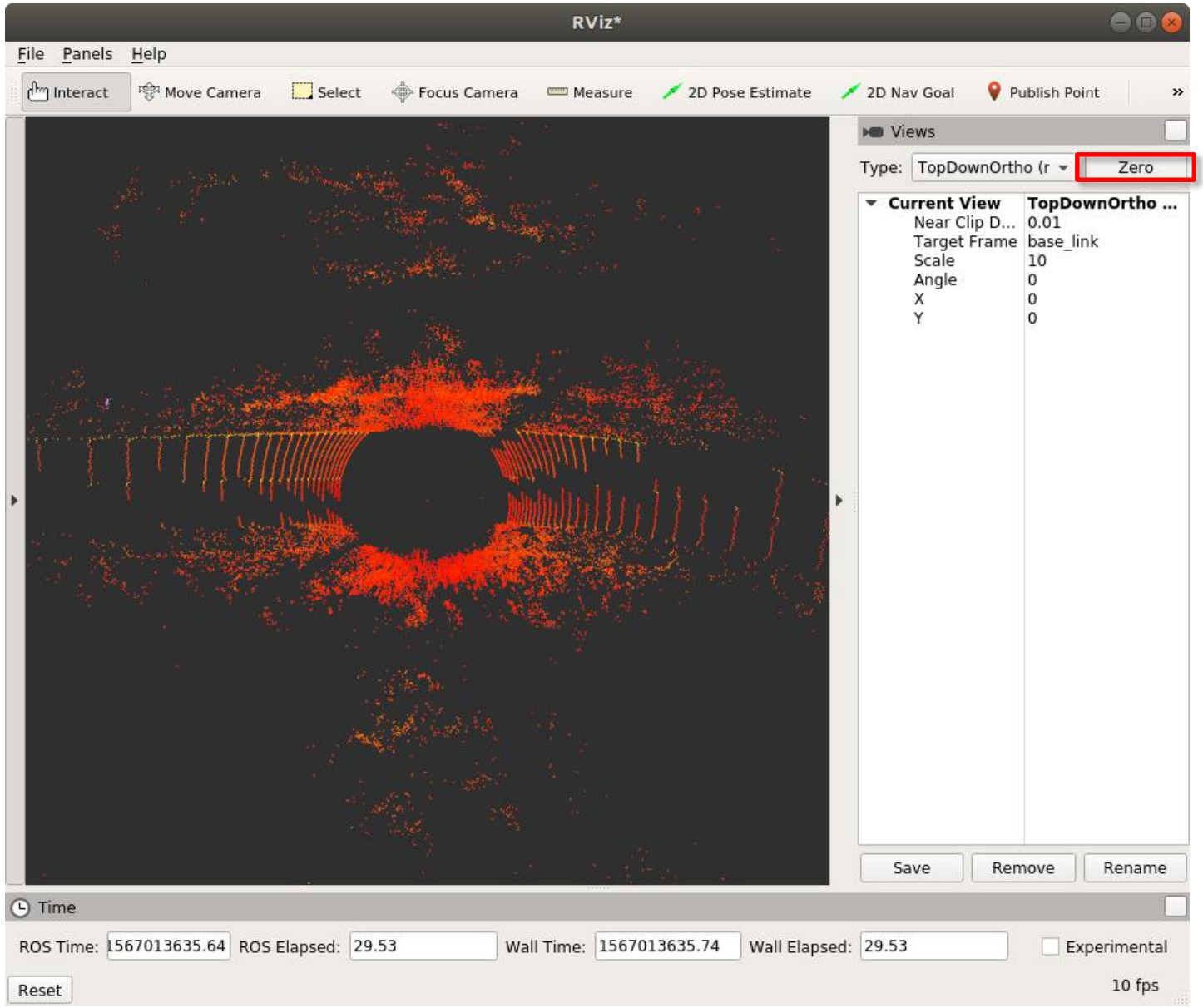
$ nc 192.168.1.2 7501 set_udp_ip 192.168.1.77

 # 192.168.1.2 ouster ip, 192.168.1.77 host ip

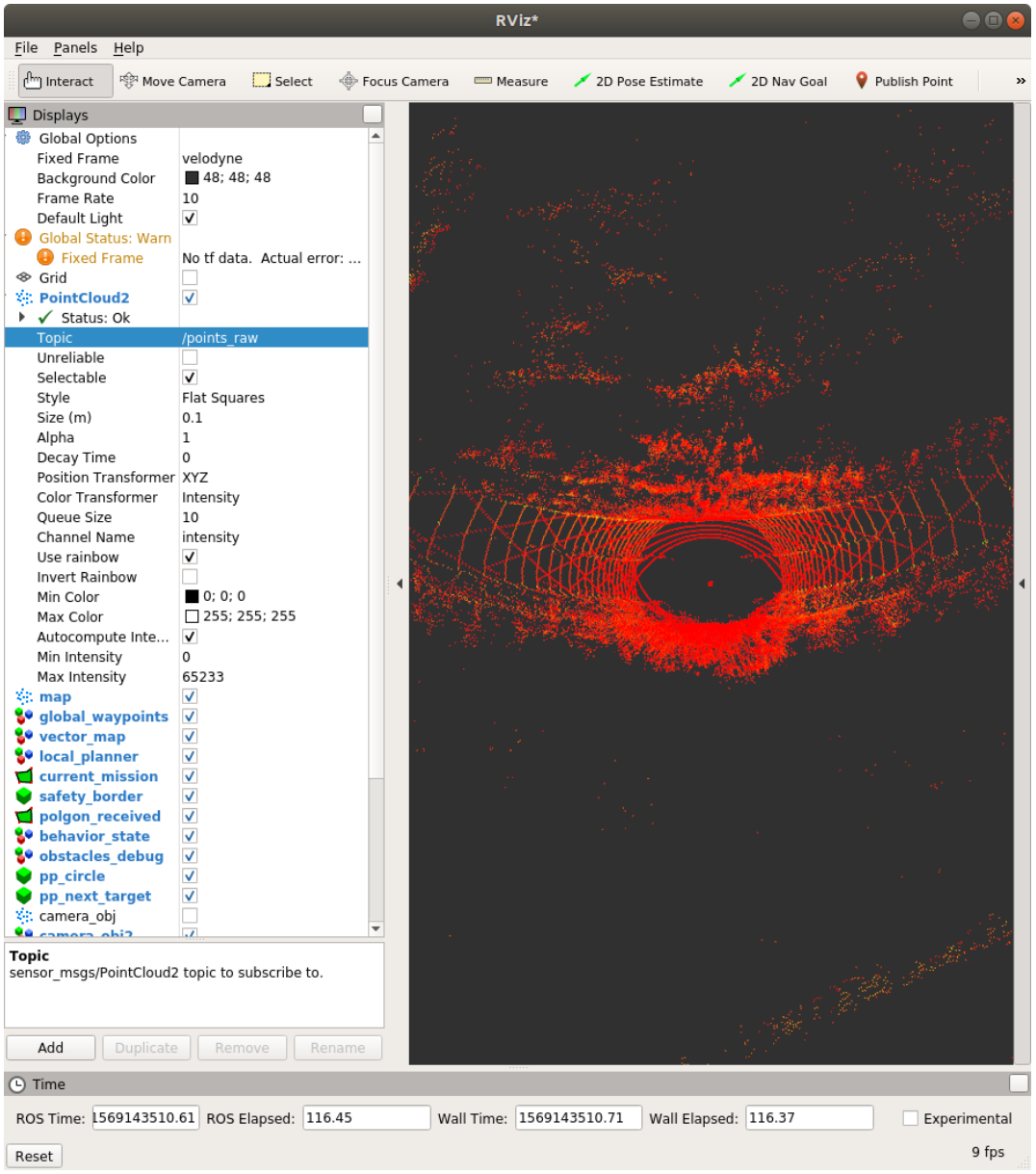
Step 2: Run ‘rviz’



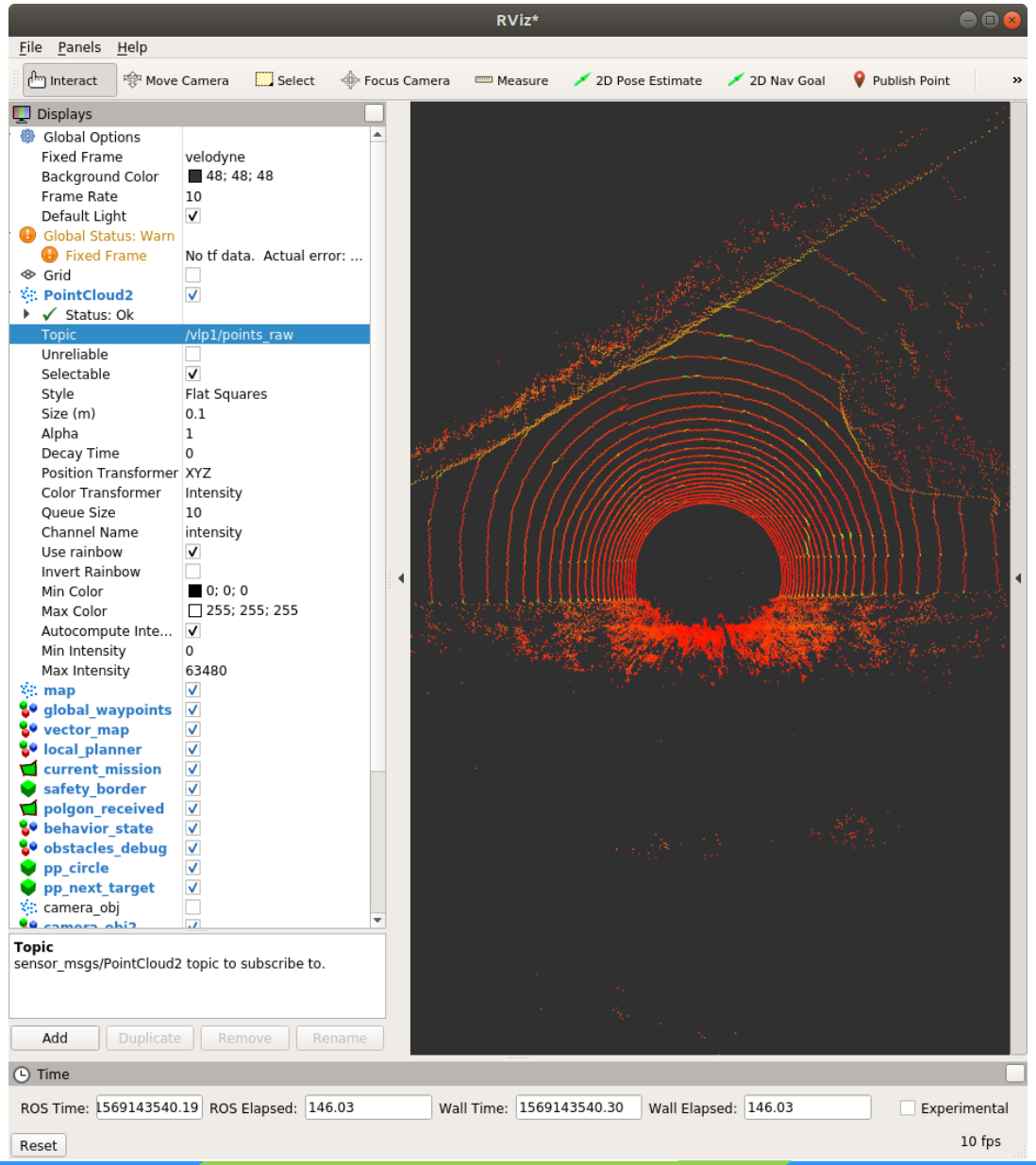
Step 2: Run ‘rviz’ : /points_raw (lidar_num == 1)



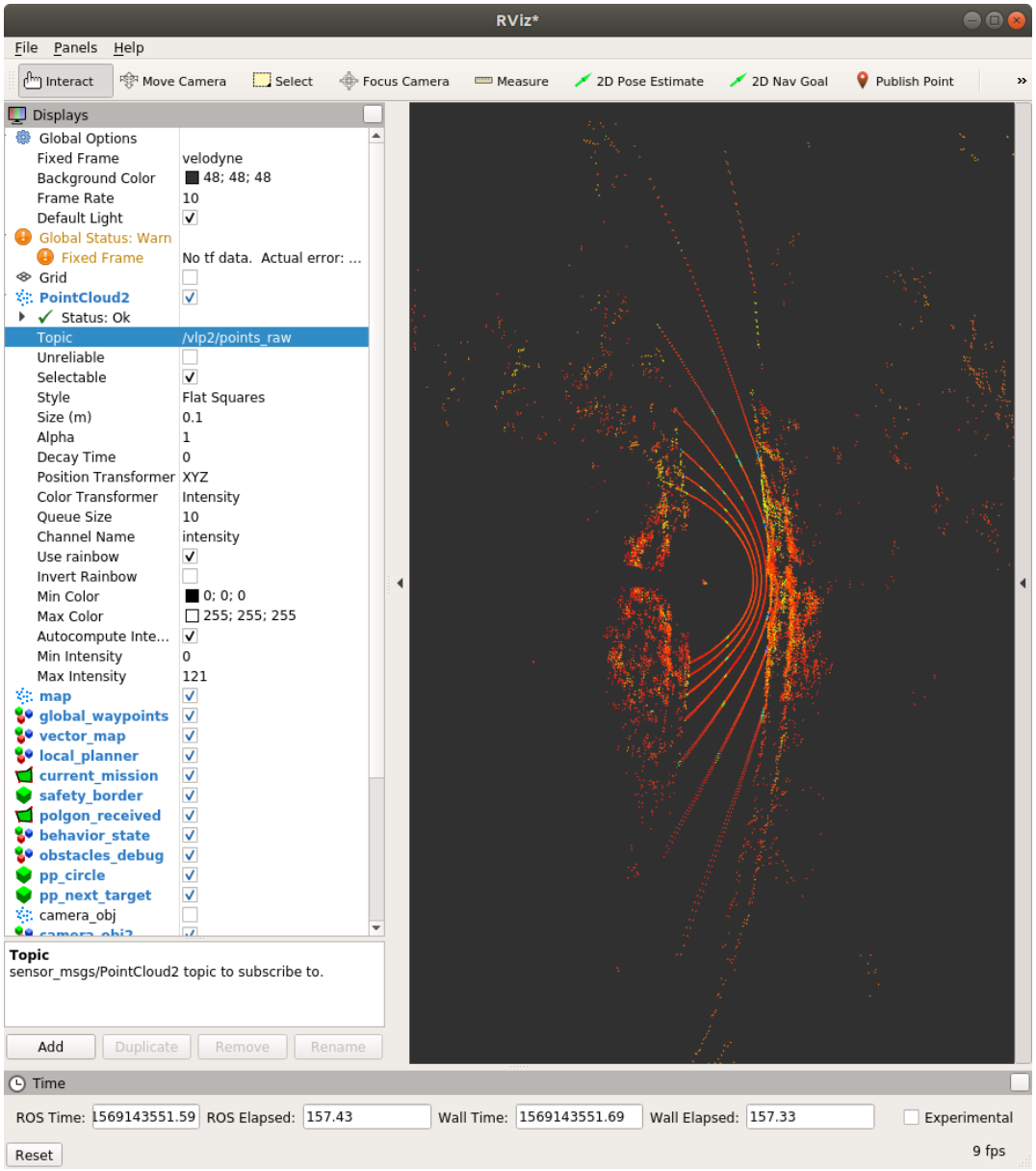
Step 2: Run ‘rviz’ : /points_raw (lidar_num == 3)



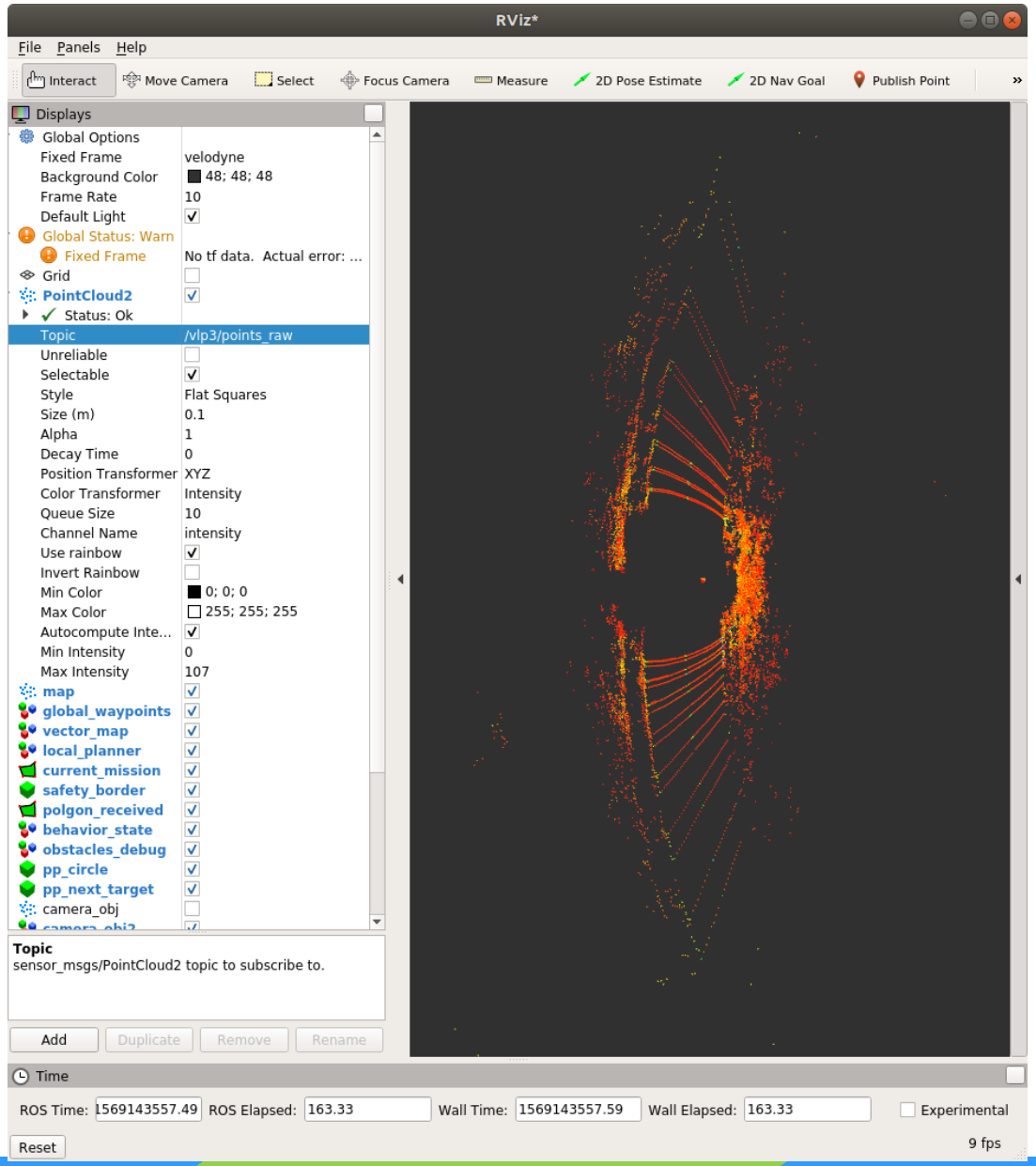
Step 2: Run ‘rviz’ : /vlp1/points_raw



Step 2: Run ‘rviz’ : /vlp2/points_raw



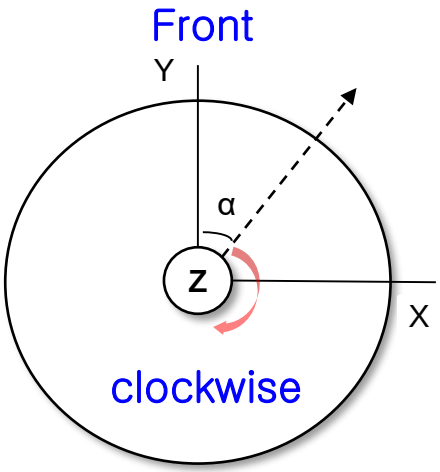
Step 2: Run ‘rviz’ : /vlp3/points_raw

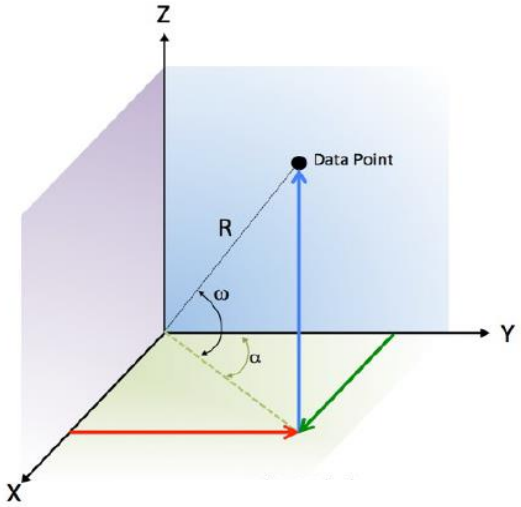


LiDAR Sensors

Lidar : Geometry

Velodyne VLP16

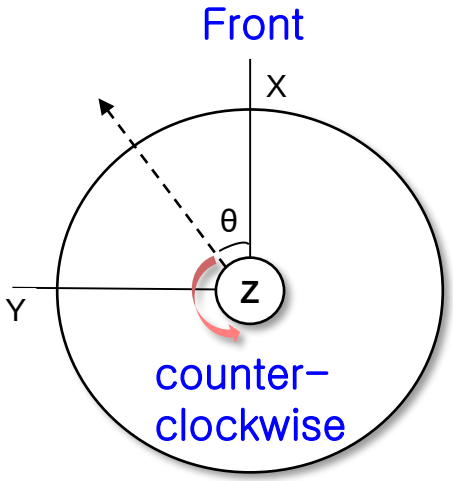


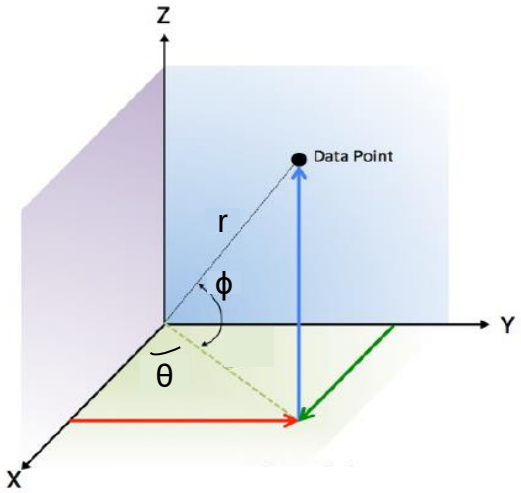


수식

$$x = R * \cos\omega * \sin\alpha$$
$$y = R * \cos\omega * \cos\alpha$$
$$z = R * \sin\omega$$

Ouster OS-1-64





수식

$$x = r\cos\theta\cos\varphi$$
$$y = -r\sin\theta\cos\varphi$$
$$z = r\sin\varphi$$

Lidar : Message Structure (VLP16)

Velodyne VLP16 (Single Return Mode)

Azimuth N+23
(Firing sequence 23)

size	Data Block 0	Data Block 1	…	Data Block 11
2 bytes	Flag x FFEE	Flag x FFEE	…	Flag x FFEE
2 bytes	Azimuth N	Azimuth N+2	…	Azimuth N+22
3 bytes	Channel 0 Data	Channel 0 Data	…	Channel 0 Data
…	…	Channel 1~14 Data	…	Channel 1~14 Data
3 bytes	Channel 15 Data	Channel 15 Data	…	Channel 15 Data
3 bytes	Channel 0 Data	Channel 0 Data	…	Channel 0 Data
…	…	Channel 1~14 Data	…	Channel 1~14 Data
3 bytes	Channel 15 Data	Channel 15 Data	…	Channel 15 Data
				TimeStamp (4 bytes)`
				Factory (2 bytes)

Azimuth N 을 의미
(Firing sequence 0)

Azimuth N+1 필드가 없지만,
Azimuth N+1 을 의미함
(Firing sequence 1)

총 1206 bytes

Lidar : Message Structure (VLP16)

- Firing sequence
  - 하나의 azimuth 에 대해서 모든 채널들의 레이저가 발사됨을 의미
  - 레이저 재충전 시간이 포함되어 있음
- Laser channel
  - 하나의 channel 은 단일 903 nm 레이저 emitter 및 detector 쌍임
  - 각 channel 은 센서의 수평면을 기준으로 특정 높이 각으로 고정됨
  - 각 channel 은 고유한 laser ID 번호가 부여됨
- Data point
  - data point 는 하나의 channel 로부터 발사된 laser 파동의 반사 신호에 대한 측정값
  - data point 는 3 byte (distance 2 bytes, calibrated reflectivity 1 byte) 로 구성됨
    - distance 는 부호 없는 정수
    - calibrated reflectivity 는 NIST 기준으로 하고, 0~255의 크기

Lidar : Message Structure (VLP16)

- Azimuth
  - laser firing 들의 사이 각으로서 2 bytes 크기임
  - azimuth 값은 부호 없는 정수로 1/100 의 각도를 표현함
    - 예: 27742 → 277.42˚
- Data block
  - 16개 laser channel 로 구성된 2개의 firing sequence 를 표현함
  - 각 패킷에는 12개의 data block , 24개의 firing sequence 가 포함됨
- Time stamp
  - 4 bytes 크기의 부호 없는 정수로서 단위는 μs 임
  - 첫번째 data block 의 첫번째 firing sequence 에서 첫번째 data point 의 측정 순간을 의미함
- Factory bytes
  - 2 bytes 크기로서 모든 data 패킷에 포함됨
  - 패킷에서 azimuths 와 data point 가 구성되는 방식을 표현함

Lidar : Message Structure (OS-1-64)

Ouster OS-1-64

word	Azimuth Block 0	Azimuth Block 1	…	Azimuth Block 15
word 0,1	Timestamp	Timestamp	…	Timestamp
word 2[0:15]	Measurement ID	Measurement ID	…	Measurement ID
word 2[16:31]	Frame ID	Frame ID	…	Frame ID
word 3	Encoder Count	Encoder Count	…	Encoder Count
word 4,5,6	Channel 0 Data Block	Channel 0 Data Block	…	Channel 0 Data Block
word 7,8,9	Channel 1 Data Block	Channel 1 Data Block	…	Channel 1 Data Block
…	…	…	…	…
word 193,194,195	Channel 63 Data Block	Channel 63 Data Block	…	Channel 63 Data Block
word 196	Packet Status	Packet Status	…	Packet Status

*word = 32 bits

Lidar : Message Structure (OS-1-64)

- Time stamp
  - ns 단위의 측정 time stamp
- Measurement ID
  - 0부터 시작하여 순차적으로 증가하는 azimuth ID
  - 512 mode 에서는 0 부터 511 까지, 1024 mode 에서는 0 부터 1023 까지, 2048 mode 에서는 0 부터 2047 까지 값을 가짐
- Frame ID
  - Lidar 의 rotation count 를 의미함
- Encoder count
  - azimuth angle 를 의미하는 encoder tick 개수
  - 0 부터 최대 90111 의 값을 가짐
  - azimuth angle 마다 2048 mode 에서는 44 ticks 가 증가하고, 1024 mode 에서는 88 ticks 가 증가하고, 512 mode 에서는 176 ticks 가 증가함

Lidar : Message Structure (OS-1-64)

- Data block (사실상 data point를 의미함)
  - 64 pixel 각각에 대한 3개의 data words 로 구성됨
    - 20 bits 의 range : 12 mm 단위의 거리 측정값
    - 16 bits 의 reflectivity : laser 반사 신호의 세기
    - 16 bits 의 signal photons : laser 반사 신호의 photons
    - 16 bits 의 ambient noise photons : 주변 noise 의 photons
- Packet status
  - Good = 0xFFFFFFFF or Bad = 0x0

Lidar : Message Structure

Velodyne VLP16

Ouster OS-1-64

Distance – 2 bytes,
Calibrated reflectivity (intensity) – 1 byte

Terms

Velodyne VLP16		Ouster OS-1-64
Firing sequence		
Laser channel		
Data block		
Factory bytes		
Data point		**Data block**
Timestamp	µs ns	**Timestamp**
Azimuth		Measurement ID
		Frame ID
		Encoder count
		Packet status

Range (distance) – 20 bits
Reflectivity(intensity) – 16 bits

* 같은 의미

Lidar : Timing

Velodyne VLP16

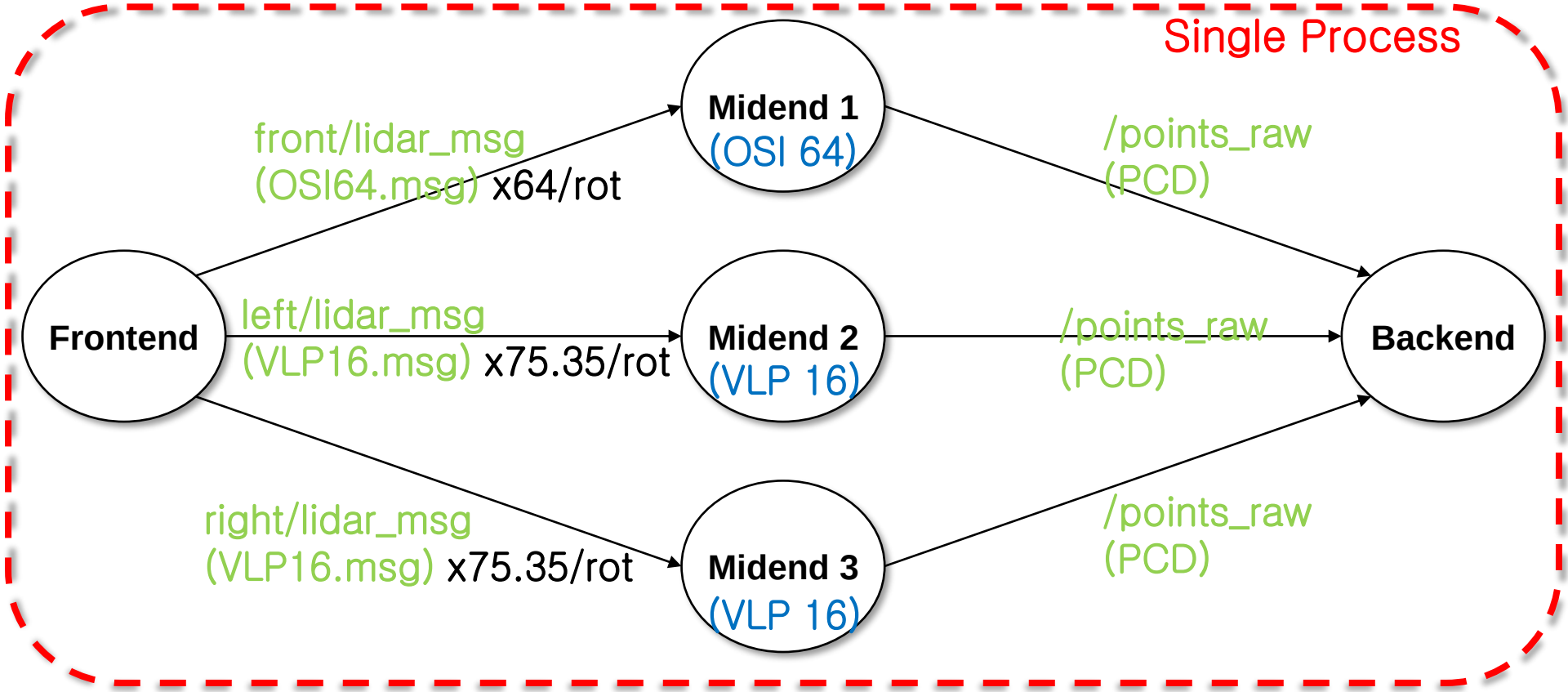
- Firing sequence timing = 55.296 μs (cannot be changed)
- Assuming lidar rotation rate = 10 hz
  - Azimuth = 0.2˚
  - 18084 firings / sec
  - 753.5 messages / sec = 18084 firings / sec × 1 message / 24 firings
  - 75.35 messages / rotation
  - 1206 bytes / message → 1 packet

Ouster OS-1-64

- Assuming 1024 mode × lidar rotation rate = 10 hz
- Firing sequence timing = 97.656 μs (programmable by selecting mode)
  - Azimuth = 0.35˚
  - 10240 firings / sec
  - 640 messages / sec = 10240 firings / sec × 1 message / 16 firings
  - 64 messages / rotation
  - 12608 bytes / message → 9 packets { 1472, 1480, ..., 1480, 776 }

nodelet_lidar_driver

nodelet_lidar_driver : Node Graph



*VLP16.msg
time ts
unit8[1206] buf
unit32 size

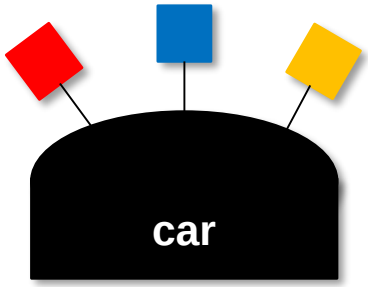
*OSI64.msg
time ts
unit8[12608] buf
unit32 size

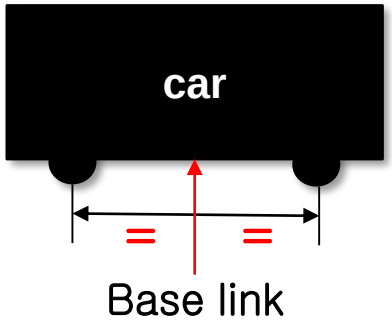
*토픽명
(형식)
*PCD = point cloud

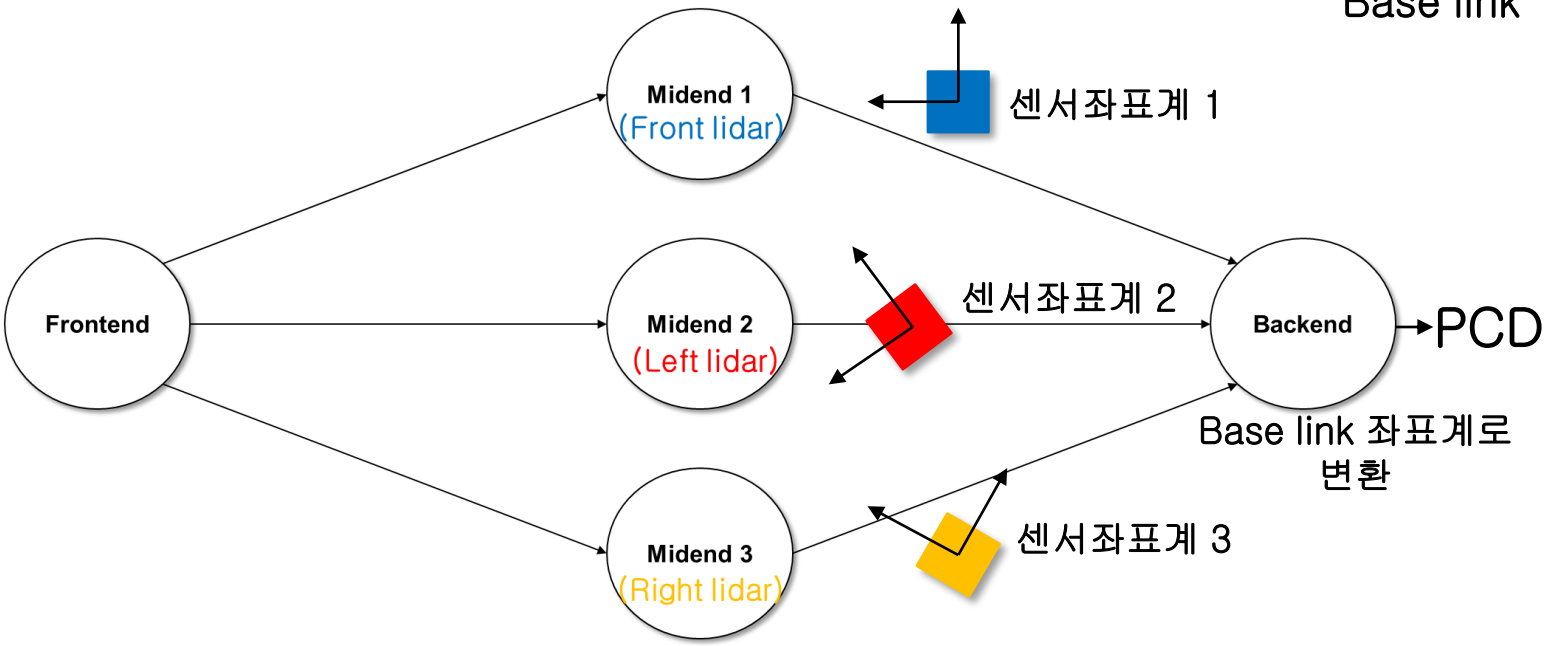
nodelet_frontend_default.yaml

```
###
### number of lidars used
###
lidar_num : 1

###
### pcap file used to replay
###
pcap_file : "/home/autoware/shared_dir/pcap_demo/20190821_kcity_ouster_degree0.pcap"

###
### lidar model selection:
### 0 means VLP16 (Velodyne Puck 16 model)
### 1 means OSI64 (Ouster-1-64 model)
###
mode_front : 1
mode_left  : 0
mode_right : 0

###
### ip address of each lidar
###
ip_add_front : "192.168.1.2"
ip_add_left  : "192.168.1.202"
ip_add_right : "192.168.1.203"
```

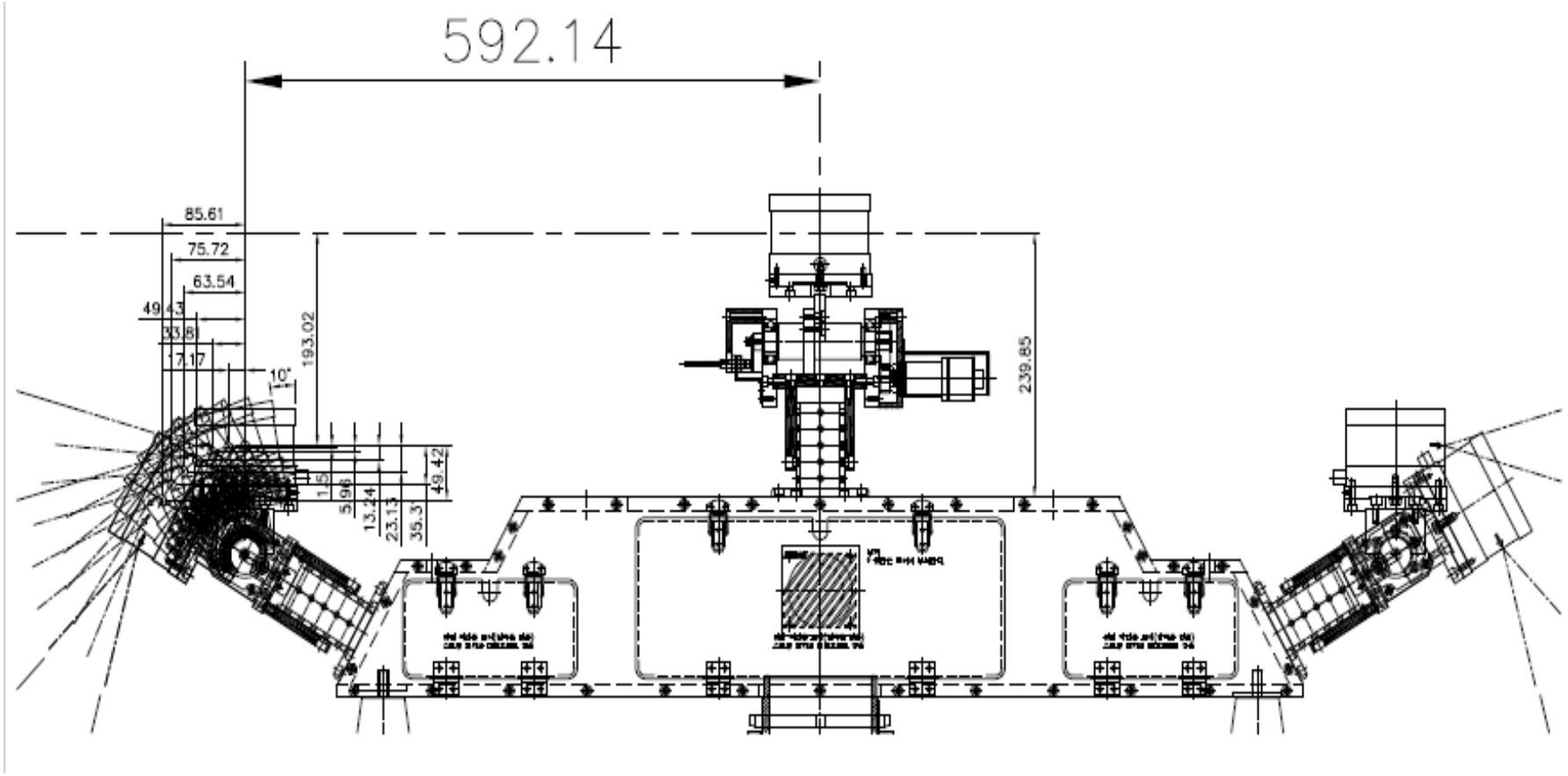
nodelet_lidar_driver : Transform



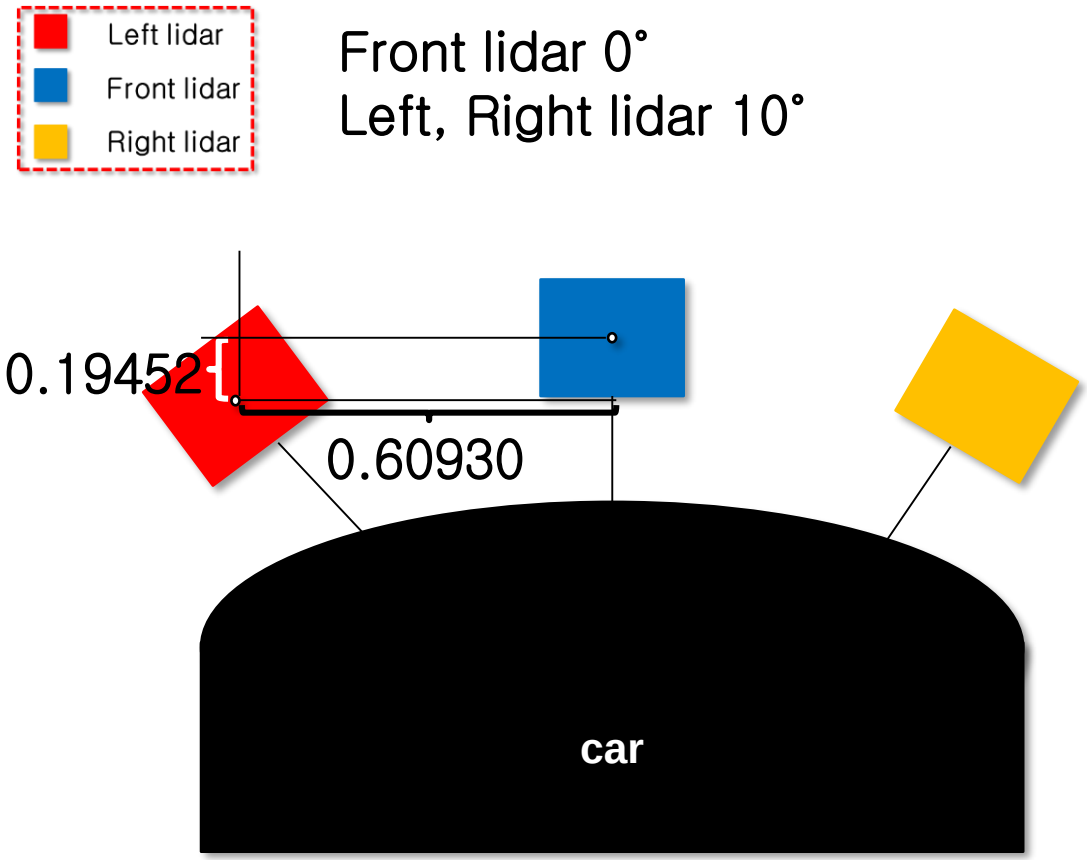




nodelet_lidar_driver : Transform



nodelet_lidar_driver : Transform



*m 단위

```
CloudIn1: # Front
  topic_name: /vlp1/points_raw
  pose_yaw: 0
  pose_pitch: 0
  pose_roll: 0
  pose_x: 0
  pose_y: 0
  pose_z: 0.0045
CloudIn2: # Left
  topic_name: /vlp2/points_raw
  pose_yaw: 90
  pose_pitch: 10
  pose_roll: 0
  pose_x: 0
  pose_y: 0.60930
  pose_z: -0.19902
CloudIn3: # Right
  topic_name: /vlp3/points_raw
  pose_yaw: -90
  pose_pitch: 10
  pose_roll: 0
  pose_x: 0
  pose_y: -0.60930
  pose_z: -0.19902
```

nodelet_lidar_driver : Transform

- lidar 기울어진 각도에 따른 yaml 파일
  - pose_yaw, pitch, roll 정보와 x, y, z 좌표 정보를 가지고 있음)
  - Autoware/src/core_perception/nodelet_lidar_driver/cfg_backend

Front lidar 각도	**Left, Right** 각도	**.yaml** 파일
0˚	0˚	Clouds_0_0_height_45.yaml
	5˚	Clouds_0_5_height_45.yaml
	10˚	Clouds_0_10_height_45.yaml
	15˚	Clouds_0_15_height_45.yaml
	20˚	Clouds_0_20_height_45.yaml
5˚	0˚	Clouds_5_0_height_45.yaml
	5˚	Clouds_5_5_height_45.yaml
	10˚	Clouds_5_10_height_45.yaml
	15˚	Clouds_5_15_height_45.yaml
	20˚	Clouds_5_20_height_45.yaml
10˚	0˚	Clouds_10_0_height_45.yaml
	5˚	Clouds_10_5_height_45.yaml
	10˚	Clouds_10_10_height_45.yaml
	15˚	Clouds_10_15_height_45.yaml
	20˚	Clouds_10_20_height_45.yaml

nodelet_lidar_driver : Source Tree

- nodelet_lidar_driver/
  - cfg/ : .yaml files
  - cfg_backend/ : .yaml files for tf transform
  - include/ : header files
  - launch/ : launch file
  - msg/ : .msg files
  - src/ : source files

nodelet_lidar_driver : package.xml

```xml
<?xml version="1.0"?>
<package format="2">
  <name>nodelet_lidar_driver</name>
  <version>0.9.0</version>
  <description>The nodelet_lidar_driver package</description>
  <maintainer email="kim.kanghee@gmail.com">Kanghee Kim</maintainer>
  <license>Apache 2</license>

  <buildtool_depend>autoware_build_flags</buildtool_depend>
  <buildtool_depend>catkin</buildtool_depend>

  <build_depend>message_generation</build_depend>

  <depend>roscpp</depend>
  <depend>sensor_msgs</depend>
  <depend>std_msgs</depend>
  <depend>pcl_ros</depend>
  <depend>pcl_conversions</depend>
  <depend>nodelet</depend>

  <exec_depend>message_runtime</exec_depend>

  <export>
    <nodelet plugin="${prefix}/nodelet_lidar_driver.xml"/>
  </export>
</package>
```

build tool dependency

build dependency

build & execution dependency

execution dependency

nodelet plugin xml

nodelet_lidar_driver : nodelet_lidar_driver.xml

```
<library path="lib/libnodelet_lidar_driver">
  <class name="nodelet_lidar_driver/LidarNodeletFront" type="LidarNodeletFront::LidarNodeletFront"
  base_class_type="nodelet::Nodelet">
    <description>
      LidarNodeletFront.
    </description>
  </class>
  <class name="nodelet_lidar_driver/LidarNodeletMid" type="LidarNodeletMid::LidarNodeletMid"
  base_class_type="nodelet::Nodelet">
    <description>
      LidarNodeletMid.
    </description>
  </class>
  <class name="nodelet_lidar_driver/LidarNodeletBack" type="LidarNodeletBack::LidarNodeletBack"
  base_class_type="nodelet::Nodelet">
    <description>
      LidarNodeletBack.
    </description>
  </class>
</library>
```

nodelet_lidar_driver : CMakeLists.txt

```
cmake_minimum_required(VERSION 2.8.3)
project(nodelet_lidar_driver)

#find_package(PCL REQUIRED)
find_package(autoware_build_flags REQUIRED)
find_package(catkin REQUIRED COMPONENTS
    roscpp
    sensor_msgs
    std_msgs
    pcl_ros
    pcl_conversions
    nodelet
    message_generation
    )

add_message_files(FILES
    OSI64.msg
    VLP16.msg
    )

generate_messages(DEPENDENCIES
    std_msgs
    )

catkin_package(
    CATKIN_DEPENDS
    roscpp
    sensor_msgs
    std_msgs
    pcl_ros
    pcl_conversions
    nodelet
    message_runtime
    #DEPENDS PCL
    )
```

```
# Resolve system dependency on yaml-cpp, which apparently does not
# provide a CMake find_package() module.
find_package(PkgConfig REQUIRED)
pkg_check_modules(YAML_CPP REQUIRED yaml-cpp)
find_path(YAML_CPP_INCLUDE_DIR NAMES yaml_cpp.h PATHS ${YAML_CPP_I
find_library(YAML_CPP_LIBRARY NAMES YAML_CPP PATHS ${YAML_CPP_LIBR
link_directories(${YAML_CPP_LIBRARY_DIRS})
if(NOT ${YAML_CPP_VERSION} VERSION_LESS "0.5")
  add_definitions(-DHAVE_NEW_YAMLCPP)
endif(NOT ${YAML_CPP_VERSION} VERSION_LESS "0.5")
```

nodelet_lidar_driver : CMakeLists.txt (cont'd)

```
48  ############################
49  ### build configuration ###
50  ############################
51
52  include_directories(
53      ${catkin_INCLUDE_DIRS}
54      ${Boost_INCLUDE_DIR}
55      ${PCL_INCLUDE_DIRS}
56      include
57      )
58
59  add_library(nodelet_lidar_driver
60      src/nodelet_midend.cpp
61      src/calibration.cpp
62      src/lidar.cpp
63      src/packet.cpp
64      src/nodelet_frontend.cpp
65      src/nodelet_backend.cpp
66      src/util.cpp
67      )
68
69  set(libpcap_LIBRARIES "-lpcap")
70
71  target_link_libraries(nodelet_lidar_driver
72      ${catkin_LIBRARIES}
73      ${libpcap_LIBRARIES}
74      ${YAML_CPP_LIBRARIES}
75      )
76
77  install(TARGETS nodelet_lidar_driver
78          ARCHIVE DESTINATION ${CATKIN_PACKAGE_LIB_DESTINATION}
79          LIBRARY DESTINATION ${CATKIN_PACKAGE_LIB_DESTINATION}
80          RUNTIME DESTINATION ${CATKIN_PACKAGE_BIN_DESTINATION}
81      )
82
83  install(FILES nodelet_lidar_driver.xml
84          DESTINATION ${CATKIN_PACKAGE_SHARE_DESTINATION}
85      )
86
87  install(DIRECTORY launch/
88          DESTINATION ${CATKIN_PACKAGE_SHARE_DESTINATION}/launch
89      )
90
91  install(DIRECTORY cfg/
92          DESTINATION ${CATKIN_PACKAGE_SHARE_DESTINATION}/cfg
93      )
```