GAZEBO

AI ROBOT

Exported on 12/04/2021

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1 GAZEBO

1.1 Why GAZEBO

Simulation

Gazebo offers the ability to accurately and efficiently simulate populations of robots in complex indoor and outdoor environments. At your fingertips is a robust physics engine, high-quality graphics, and convenient programmatic and graphical interfaces.

- URDF에서 rviz로 로봇을 관찰하는 것은 즐거운 일이지만, 물성(중력, 관성, 충돌)을 보여주지는 않는다
- 이런 경우 물리엔진이 탑재가 된 프로그램이 필요한데
- ROS 유저는 GAZEBO를 많이 사용함

1.2 Gazebo에서 필요한 수치

- Inertia: 물체의 관성
- Gazebo Physical Properties: 색상, 마찰 등
- Collisions: 충돌 (바닥위에 놓여있는 속성 등에 필요)
- Gazebo Sensors: 카메라, 컨트롤러, 센서 등

1.3 일단 간단하게 mira_simple.urdf 복사본 하나 생성

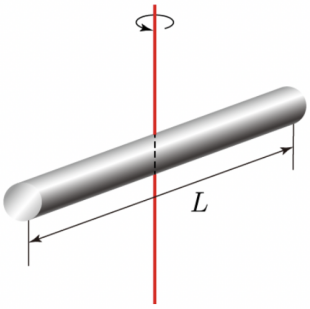
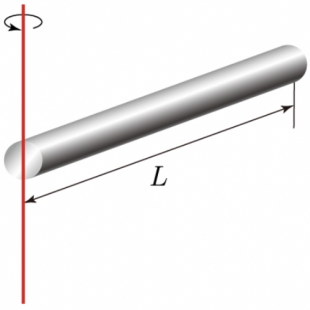
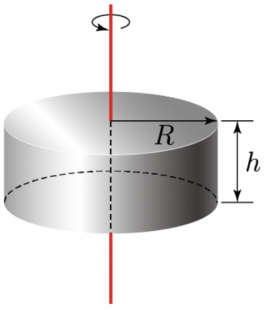
```
pw@melodic:~/ws/src/urdf_exam/urdf$
pw@melodic:~/ws/src/urdf_exam/urdf$
pw@melodic:~/ws/src/urdf_exam/urdf$
pw@melodic:~/ws/src/urdf_exam/urdf$
pw@melodic:~/ws/src/urdf_exam/urdf$ cp mira_simple.urdf mira_gazebo.urdf
pw@melodic:~/ws/src/urdf_exam/urdf$
pw@melodic:~/ws/src/urdf_exam/urdf$
pw@melodic:~/ws/src/urdf_exam/urdf$
```

1.4 base_link에 inertial 항목 추가

```
    <link name="base_link">

        <inertial>
            <origin xyz="0 0 0" rpy="0 0 0"/>
            <mass value="0.18" />
            <inertia ixx="0.0002835" ixy="0.0" ixz="0.0" iyy="0.0002835" iyz="0.0" izz="
            0.000324"/>
        </inertial>

        <visual>
            <origin rpy="0.0 0 0" xyz="0 0 0"/>
            <geometry>
                <mesh filename="package://urdf_exam/meshes/mira_body_v3.dae"/>
            </geometry>
        </visual>
    </link>
```

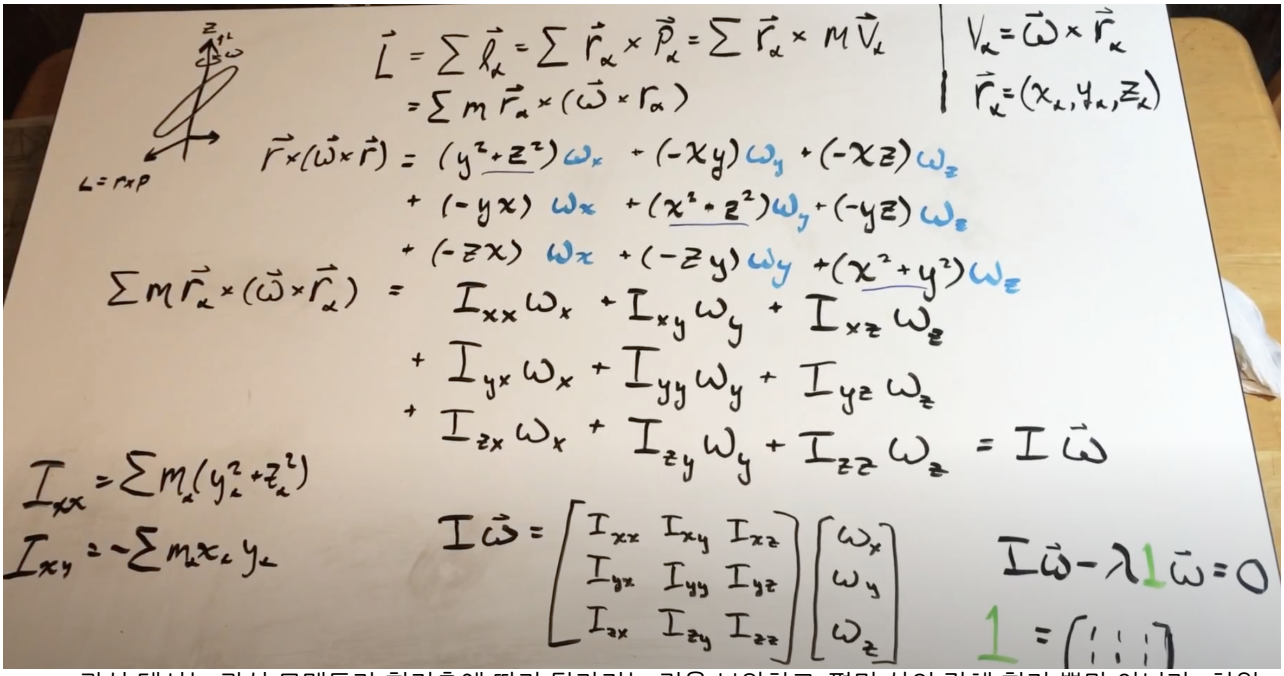
- **origin**: 해당 요소의 위치와 자세를 지정
- **mass**: 요소의 질량
- **inertia**: 관성행렬 inertia matrix

1.5 inertia란?

회전축이 중심에 있는 길이 L인 얇은 막대	회전축이 막대 끝에 있는 길이 L인 얇은 막대	반지름과 높이가 각각 R, h인 원판
		
$\frac{1}{12}ML^2$	$\frac{1}{3}ML^2$	$\frac{1}{2}MR^2$

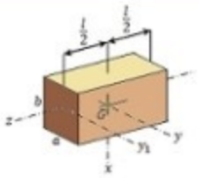
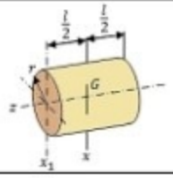
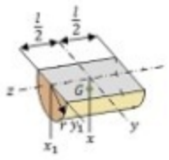
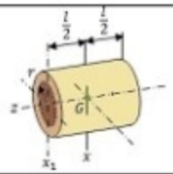
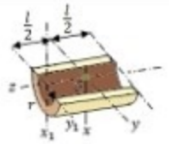
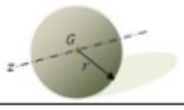
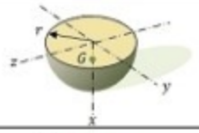
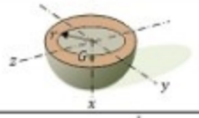
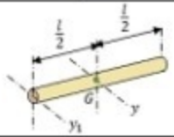
- 물체가 자신의 회전을 유지하는 정도를 나타내는 회전량
- 그래서 x, y, z 축 중심 회전 성분과 x에서 바라본 x축 회전, 등의 요소들이 있음
- 간단한 예) https://pinkwink.kr/37
- 간단한 예) https://pinkwink.kr/352
- 실제 작업에서 inertia는 기계 설계 파트에서 제공해 줄 때가 많다
- 그러나 로봇엔지니어가 직접 계산할 수도 있어야한다 (대충이라도)

1.6 Tensor of inertia



- 관성 텐서는 관성 모멘트가 회전축에 따라 달라지는 것을 보완하고, 평면 상의 강체 회전 뿐만 아니라 3차원 상의 회전을 기술하기 위한 물리량이다.

1.7 inertial의 계산

Body	Figure	Mass Center	Moments of Inertia
Rectangular Parallelepiped		–	$I_{xx}=\frac{1}{12}m(a^2+l^2)$ $I_{yy}=\frac{1}{12}m(b^2+l^2)$ $I_{zz}=\frac{1}{12}m(a^2+b^2)$ $I_{y_1y_1}=\frac{1}{12}mb^2+\frac{1}{3}ml^2$
Circular Cylinder		–	$I_{xx}=\frac{1}{4}mr^2+\frac{1}{12}ml^2$ $I_{x_1x_1}=\frac{1}{4}mr^2+\frac{1}{3}ml^2$ $I_{zz}=\frac{1}{2}mr^2$
Semicylinder		$\bar{x}=\frac{4r}{3\pi}$	$I_{xx}=I_{yy}=\frac{1}{4}mr^2+\frac{1}{12}ml^2$ $I_{x_1x_1}=I_{y_1y_1}=\frac{1}{4}mr^2+\frac{1}{3}ml^2$ $I_{zz}=\frac{1}{2}mr^2$
Circular Cylindrical Shell		–	$I_{xx}=\frac{1}{2}mr^2+\frac{1}{12}ml^2$ $I_{x_1x_1}=\frac{1}{2}mr^2+\frac{1}{3}ml^2$ $I_{zz}=mr^2$
Half Cylindrical Shell		$\bar{x}=\frac{2r}{\pi}$	$I_{xx}=I_{yy}=\frac{1}{2}mr^2+\frac{1}{12}ml^2$ $I_{x_1x_1}=I_{y_1y_1}=\frac{1}{2}mr^2+\frac{1}{3}ml^2$ $I_{zz}=mr^2$
Sphere		–	$I_{zz}=\frac{2}{5}mr^2$
Spherical Shell		–	$I_{zz}=\frac{2}{3}mr^2$
Hemisphere		$\bar{x}=\frac{3r}{8}$	$I_{xx}=I_{yy}=I_{zz}=\frac{2}{5}mr^2$
Hemispherical Shell		$\bar{x}=\frac{r}{2}$	$I_{xx}=I_{yy}=I_{zz}=\frac{2}{3}mr^2$
Uniform Slender Rod		–	$I_{yy}=\frac{1}{12}ml^2$ $I_{y_1y_1}=\frac{1}{3}ml^2$

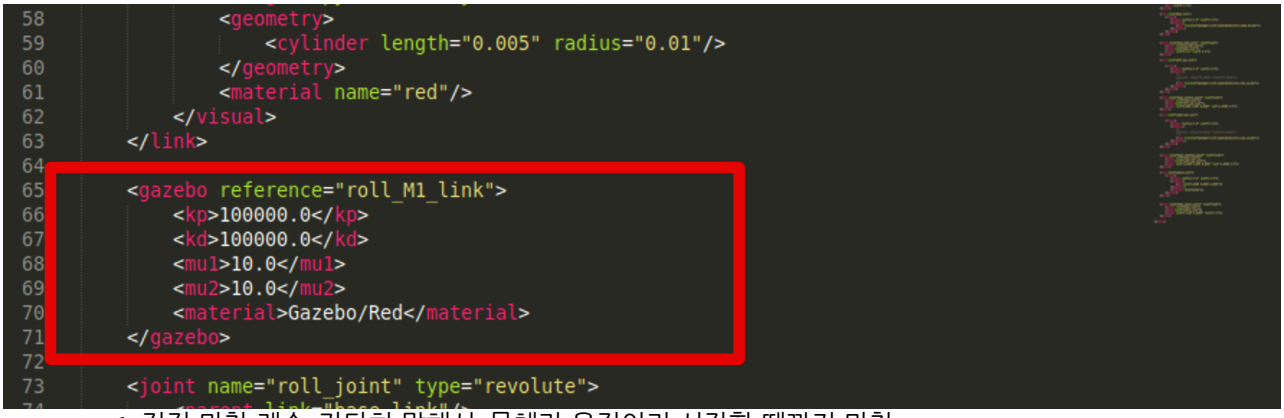
1.8 base_link의 collision 설정

```
23
24      <link name="base_link">
25
26          <inertial>
27              <origin xyz="0 0 0" rpy="0 0 0"/>
28              <mass value="0.18" />
29              <inertia ixx="0.0002835" ixy="0.0" ixz="0.0" iyy="0.0002835" iyz="0.0" izz="
                0.000324"/>
30          </inertial>
31
32          <collision>
33              <origin xyz="0 0 0" rpy="0 0 0"/>
34              <geometry>
35                  <cylinder radius="0.06" length="0.09"/>
36              </geometry>
37          </collision>
38
39          <visual>
40              <origin rpy="0.0 0 0" xyz="0 0 0"/>
41              <geometry>
42                  <mesh filename="package://urdf_exam/meshes/mira_body_v3.dae"/>
43              </geometry>
44          </visual>
45      </link>
```

1.9 roll_M1_link의 inertial 설정

```
48      <link name="roll_M1_link">
49
50          <inertial>
51              <origin xyz="0 0 0" rpy="0 0 0"/>
52              <mass value="0.001" />
53              <inertia ixx="2.70833333333e-08" ixy="0.0" ixz="0.0" iyy="2.70833333333e-08" iyz=
                "0.0" izz="5e-08"/>
54          </inertial>
55
56          <visual>
57              <origin rpy="0 0 0" xyz="0 0 0"/>
58              <geometry>
59                  <cylinder length="0.005" radius="0.01"/>
60              </geometry>
61              <material name="red"/>
62          </visual>
63      </link>
```

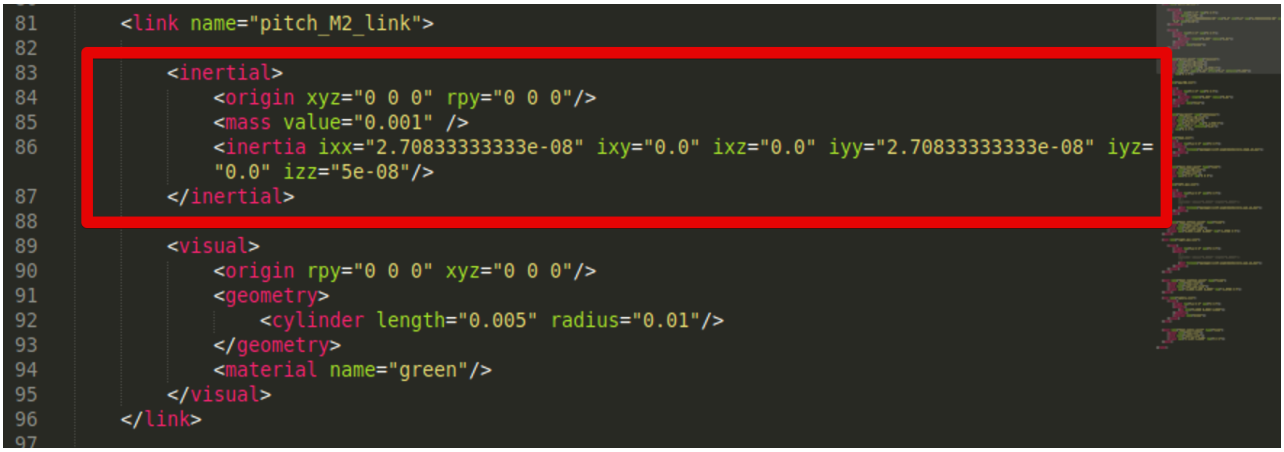
1.10 물리엔진 시뮬레이션을 위한 gazebo 파라미터 설정



```
58              <geometry>
59                  <cylinder length="0.005" radius="0.01"/>
60              </geometry>
61              <material name="red"/>
62          </visual>
63      </link>
64
65      <gazebo reference="roll_M1_link">
66          <kp>100000.0</kp>
67          <kd>100000.0</kd>
68          <mu1>10.0</mu1>
69          <mu2>10.0</mu2>
70          <material>Gazebo/Red</material>
71      </gazebo>
72
73      <joint name="roll_joint" type="revolute">
```

- mu1: 정적 마찰 계수. 간단히 말해서, 물체가 움직이기 시작할 때까지 마찰
- mu2: 동적 마찰 계수. 간단히 말해서, 물체가 움직일 때 마찰
- kp: 정적 접촉 강성. 예를들어 링크 재질이 대리석에 가까운 지 (매우 강하고 큰 값) 고무 (부드러운 재질, 낮은 값)에 더 가까운지를 결정
- kd: 동적 접촉 강성.

1.11 pitch_M2_link에 inertia 추가



```
81      <link name="pitch_M2_link">
82
83          <inertial>
84              <origin xyz="0 0 0" rpy="0 0 0"/>
85              <mass value="0.001" />
86              <inertia ixx="2.70833333333e-08" ixy="0.0" ixz="0.0" iyy="2.70833333333e-08" iyz=
                "0.0" izz="5e-08"/>
87          </inertial>
88
89          <visual>
90              <origin rpy="0 0 0" xyz="0 0 0"/>
91              <geometry>
92                  <cylinder length="0.005" radius="0.01"/>
93              </geometry>
94              <material name="green"/>
95          </visual>
96      </link>
```

1.12 pitch_M2_link에 gazebo 물리수치 입력

```
            </geometry>
            <material name="green"/>
        </visual>
    </link>

    <gazebo reference="pitch_M2_link">
        <kp>100000.0</kp>
        <kd>100000.0</kd>
        <mu1>10.0</mu1>
        <mu2>10.0</mu2>
        <material>Gazebo/Green</material>
    </gazebo>


    <joint name="pitch_joint" type="revolute">
        <parent link="roll_M1_link"/>
        <child link="pitch_M2_link"/>
```

1.13 yaw_M3_link에 inertial 추가

```
    <link name="yaw_M3_link">

        <inertial>
            <origin xyz="0 0 0" rpy="0 0 0"/>
            <mass value="0.001" />
            <inertia ixx="2.70833333333e-08" ixy="0.0" ixz="0.0" iyy="2.70833333333e-08" iyz=
            "0.0" izz="5e-08"/>
        </inertial>

        <visual>
            <origin rpy="0 0 0" xyz="0 0 0"/>
            <geometry>
                <cylinder length="0.005" radius="0.01"/>
            </geometry>
            <material name="blue"/>
        </visual>
    </link>

    <joint name="yaw_joint" type="continuous">
        <parent link="pitch_M2_link"/>
```

1.14 yaw_M3_link의 gazebo 물리 수치 입력

```
127             </geometry>
128             <material name="blue"/>
129         </visual>
130     </link>
131
132     <gazebo reference="yaw_M3_link">
133         <kp>100000.0</kp>
134         <kd>100000.0</kd>
135         <mu1>10.0</mu1>
136         <mu2>10.0</mu2>
137         <material>Gazebo/Blue</material>
138     </gazebo>
139
140
141     <joint name="yaw_joint" type="continuous">
142         <parent link="pitch_M2_link"/>
143         <child link="yaw_M3_link"/>
144         <origin xyz="0.01 0 0" rpy="0 1.5708 0"/>
```

1.15 head_link에 inertial 추가

```
144         <origin xyz="0.01 0 0" rpy="0 1.5708 0"/>
145         <limit effort="0.1" velocity="0.01"/>
146         <axis xyz="0 0 1"/>
147     </joint>
148
149     <link name="head_link">
150
151         <inertial>
152             <origin xyz="0 0 0" rpy="0 0 0"/>
153             <mass value="0.02" />
154             <inertia ixx="2.61666666667e-05" ixy="0.0" ixz="0.0" iyy="2.61666666667e-05" iyz=
                "0.0" izz="3.6e-05"/>
155         </inertial>
156
157         <visual>
158             <origin rpy="0.0 0 0" xyz="0 0 0"/>
159             <geometry>
160                 <mesh filename="package://urdf_exam/meshes/mira_head_v5.dae"/>
161             </geometry>
162         </visual>
163     </link>
164
165
166     <joint name="base_head_joint" type="fixed">
```

1.16 head_link에 collision 추가

```
149     <link name="head_link">
150
151         <inertial>
152             <origin xyz="0 0 0" rpy="0 0 0"/>
153             <mass value="0.02" />
154             <inertia ixx="2.61666666667e-05" ixy="0.0" ixz="0.0" iyy="2.61666666667e-05" iyz=
                "0.0" izz="3.6e-05"/>
155         </inertial>
156
157         <collision>
158             <origin xyz="0 0 0.015" rpy="0 0 0"/>
159             <geometry>
160                 <sphere radius="0.06"/>
161             </geometry>
162         </collision>
163
164         <visual>
165             <origin rpy="0.0 0 0" xyz="0 0 0"/>
166             <geometry>
167                 <mesh filename="package://urdf_exam/meshes/mira_head_v5.dae"/>
168             </geometry>
169         </visual>
170     </link>
```

1.17 head_link 물성치 추가

```
167         </visual>
168     </link>
169
170     <gazebo reference="head_link">
171         <kp>100000.0</kp>
172         <kd>100000.0</kd>
173         <mu1>10.0</mu1>
174         <mu2>10.0</mu2>
175         <material>Gazebo/White</material>
176     </gazebo>
177
178
179     <joint name="base_head_joint" type="fixed">
180         <parent link="yaw_M3_link"/>
181         <child link="head_link"/>
```

1.18 left_eye_link에 inertial 추가

```
176         <origin xyz="0 0 0" rpy="0 0 0"/>
177     </joint>
178
179     <link name="left_eye_link">
180
181         <inertial>
182             <origin xyz="0 0 0" rpy="0 0 0"/>
183             <mass value="0.001" />
184             <inertia ixx="9.1875e-09" ixy="0.0" ixz="0.0" iyy="9.1875e-09" iyz="0.0" izz="
                1.378125e-08"/>
185         </inertial>
186
187         <visual>
188             <origin rpy="0.0 0 0" xyz="0 0 0"/>
189             <geometry>
190                 <!--
191                 <cylinder radius="0.00525" length="0.00525"/>
192                 -->
193                 <mesh filename="package://urdf_exam/meshes/mira_eye_v4.dae"/>
194             </geometry>
195         </visual>
196     </link>
```

1.19 left_eye 물성치

```
99                  <mesh filename="package://urdf_exam/meshes/mira_eye_v4.dae"/>
00              </geometry>
01          </visual>
02      </link>
03
04      <gazebo reference="left_eye_link">
05          <kp>100000.0</kp>
06          <kd>100000.0</kd>
07          <mu1>10.0</mu1>
08          <mu2>10.0</mu2>
09          <material>Gazebo/White</material>
10      </gazebo>
11
12      <joint name="head_lefteye_joint" type="fixed">
13          <parent link="head_link"/>
14          <child link="left_eye_link"/>
```

1.20 right_eye_link에 inertial 추가

```
            </geometry>
        </visual>
    </link>

    <joint name="head_lefteye_joint" type="fixed">
        <parent link="head_link"/>
        <child link="left_eye_link"/>
        <origin xyz="0.0095 0.057 0.0085" rpy="-1.5708 0 0"/>
    </joint>

    <link name="right_eye_link">

        <inertial>
            <origin xyz="0 0 0" rpy="0 0 0"/>
            <mass value="0.001" />
            <inertia ixx="9.1875e-09" ixy="0.0" ixz="0.0" iyy="9.1875e-09" iyz="0.0" izz="
            1.378125e-08"/>
        </inertial>

        <visual>
            <origin rpy="0.0 0 0" xyz="0 0 0"/>
            <geometry>
                <!--
                <cylinder radius="0.00525" length="0.00525"/>
                -->
                <mesh filename="package://urdf_exam/meshes/mira_eye_v4.dae"/>
            </geometry>
```

1.21 right_eye 물성치

```
                <mesh filename="package://urdf_exam/meshes/mira_eye_v4.dae"/>
            </geometry>
        </visual>
    </link>

    <gazebo reference="right_eye_link">
        <kp>100000.0</kp>
        <kd>100000.0</kd>
        <mu1>10.0</mu1>
        <mu2>10.0</mu2>
        <material>Gazebo/White</material>
    </gazebo>


    <joint name="head_righteye_joint" type="fixed">
        <parent link="head_link"/>
        <child link="right_eye_link"/>
        <origin xyz="-0.0095 0.057 0.0085" rpy="-1.5708 0 0"/>
```

1.22 지금까지의 실습파일

mira_gazebo.urdf

(see page 5)

2 GOD의 영역에 가볼까

2.1 gazebo에 spawn하기 위해 mira_spawn.launch 작성

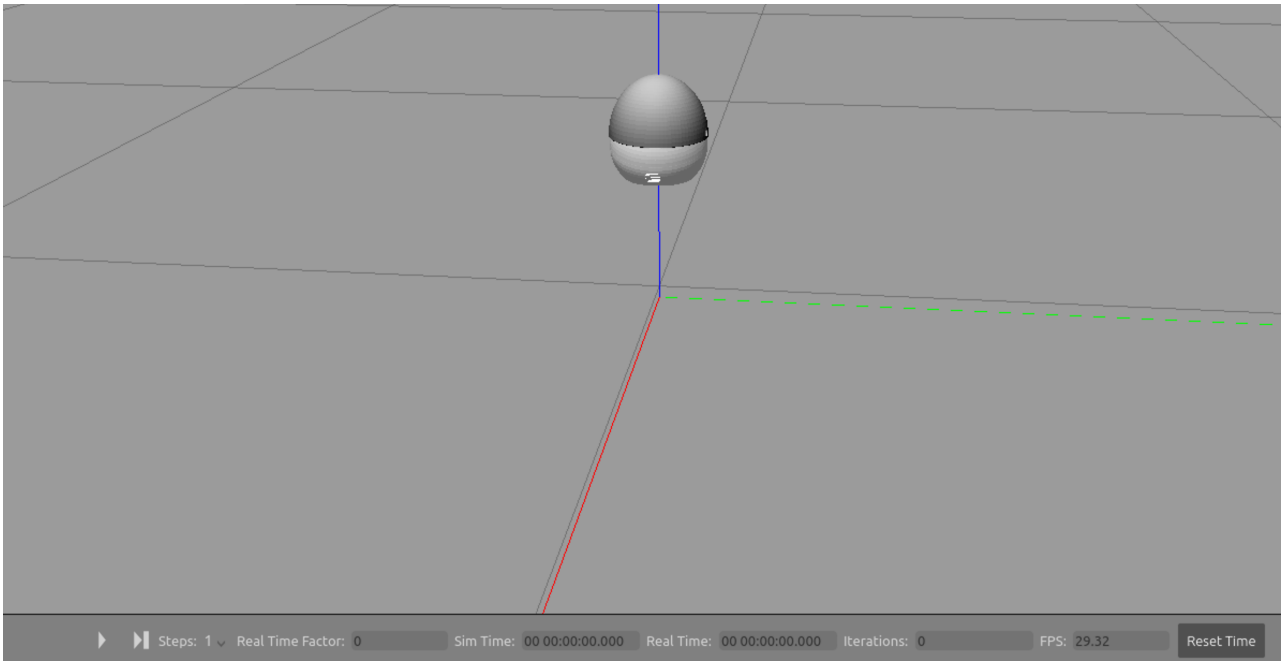
```
<?xml version="1.0" encoding="UTF-8"?>
<launch>
    <param name="robot_description" command="cat '$(find urdf_exam)/urdf/mira_gazebo.urdf'"/>

    <arg name="x" default="0"/>
    <arg name="y" default="0"/>
    <arg name="z" default="0.2"/>

    <include file="$(find gazebo_ros)/launch/empty_world.launch">
      <arg name="paused" value="true"/>
      <arg name="use_sim_time" value="true"/>
      <arg name="gui" value="true"/>
    </include>

    <node name="spawn_urdf" pkg="gazebo_ros" type="spawn_model" output="screen"
          args="-urdf -param robot_description -model mira -x $(arg x) -y $(arg y) -z $(arg z)" />

</launch>
```

2.2 gazebo관련 pkg 설치

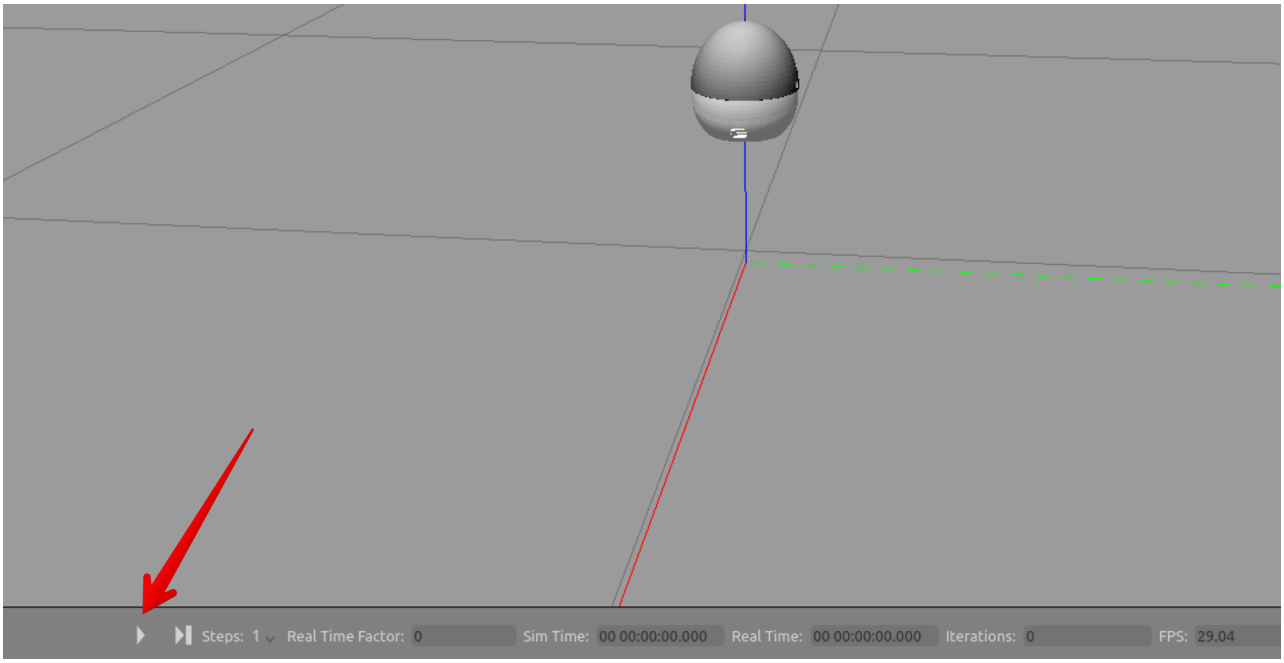
```
pw@melodic:~/ws/src/urdf_exam/urdf$
pw@melodic:~/ws/src/urdf_exam/urdf$ sudo apt install ros-melodic-gazebo-
ros-melodic-gazebo-dev                ros-melodic-gazebo-ros-control
ros-melodic-gazebo-msgs               ros-melodic-gazebo-ros-control-dbgsym
ros-melodic-gazebo-plugins            ros-melodic-gazebo-ros-dbgsym
ros-melodic-gazebo-plugins-dbgsym     ros-melodic-gazebo-ros-pkgs
ros-melodic-gazebo-ros
pw@melodic:~/ws/src/urdf_exam/urdf$ sudo apt install ros-melodic-gazebo-*
[sudo] password for pw:
Reading package lists... Done
Building dependency tree
Reading state information... Done
Note, selecting 'ros-melodic-gazebo-ros-control' for glob 'ros-melodic-gazebo-*'
Note, selecting 'ros-melodic-gazebo-ros-dbgsym' for glob 'ros-melodic-gazebo-*'
Note, selecting 'ros-melodic-gazebo-plugins' for glob 'ros-melodic-gazebo-*'
```

2.3 실행

- roslaunch urdf_exam mira_spawn.launch


Steps: 1
Real Time Factor: 0
Sim Time: 00 00:00:00.000
Real Time: 00 00:00:00.000
Iterations: 0
FPS: 29.32
Reset Time

2.4 play


Steps: 1
Real Time Factor: 0
Sim Time: 00 00:00:00.000
Real Time: 00 00:00:00.000
Iterations: 0
FPS: 29.04

2.5 터미널에 이런 에러가 나타난다면

```
INFO] [1590239231.562443, 0.000000]: Waiting for service /gazebo/spawn_urdf_model
 INFO] [1590239232.089949307]: waitForService: Service [/gazebo/set_physics_properties] is now avai
able.
 INFO] [1590239232.110633801]: Physics dynamic reconfigure ready.
INFO] [1590239232.165839, 0.000000]: Calling service /gazebo/spawn_urdf_model
INFO] [1590239232.293912, 0.000000]: Spawn status: SpawnModel: Successfully spawned entity
spawn_urdf-4] process has finished cleanly
og file: /home/pw/.ros/log/4fc4e860-9cf6-11ea-9a72-001c420be203/spawn_urdf-4*.log
Err] [REST.cc:205] Error in REST request

ibcurl: (51) SSL: no alternative certificate subject name matches target host name 'api.ignitionfue
.org'
```

2.6 ~/.ignition/fuel/config.yaml 을 열어서

```
ROS1 is activated
pw@melodic:~$ subl ~/.ignition/fuel/config.yaml
pw@melodic:~$
```

2.7 표시된 url을

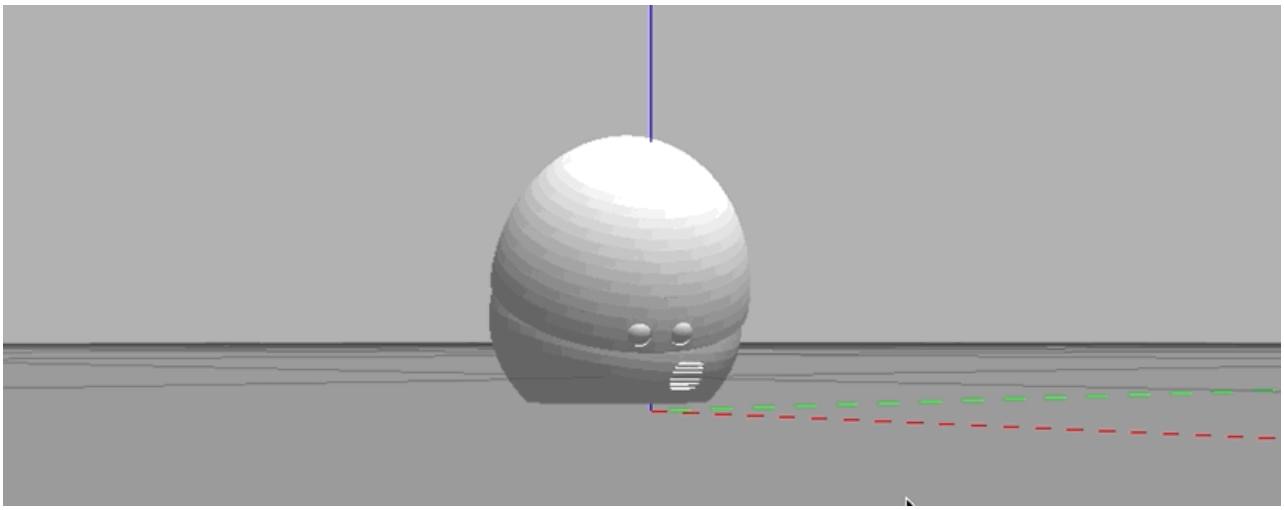
```
1   ---
2   # The list of servers.
3   servers:
4     -
5       name: osrf
6       url: https://api.ignitionfuel.org
7
8     # -
9       # name: another_server
10      # url: https://myserver
11
12  # Where are the assets stored in disk.
13  # cache:
14  #   path: /tmp/ignition/fuel
15
```

2.8 api.ignitionrobotics.org 로 변경

```
1   ---
2   # The list of servers.
3   servers:
4     -
5       name: osrf
6       url: https://api.ignitionrobotics.org
7
8     # -
9       # name: another_server
10      # url: https://myserver
11
12  # Where are the assets stored in disk.
13  # cache:
```

2.9 그리고 다시 실행하면 에러가 사라지고 없다

2.10 아마 물리엔진을 살짝 구경할 수 있을 겁니다.

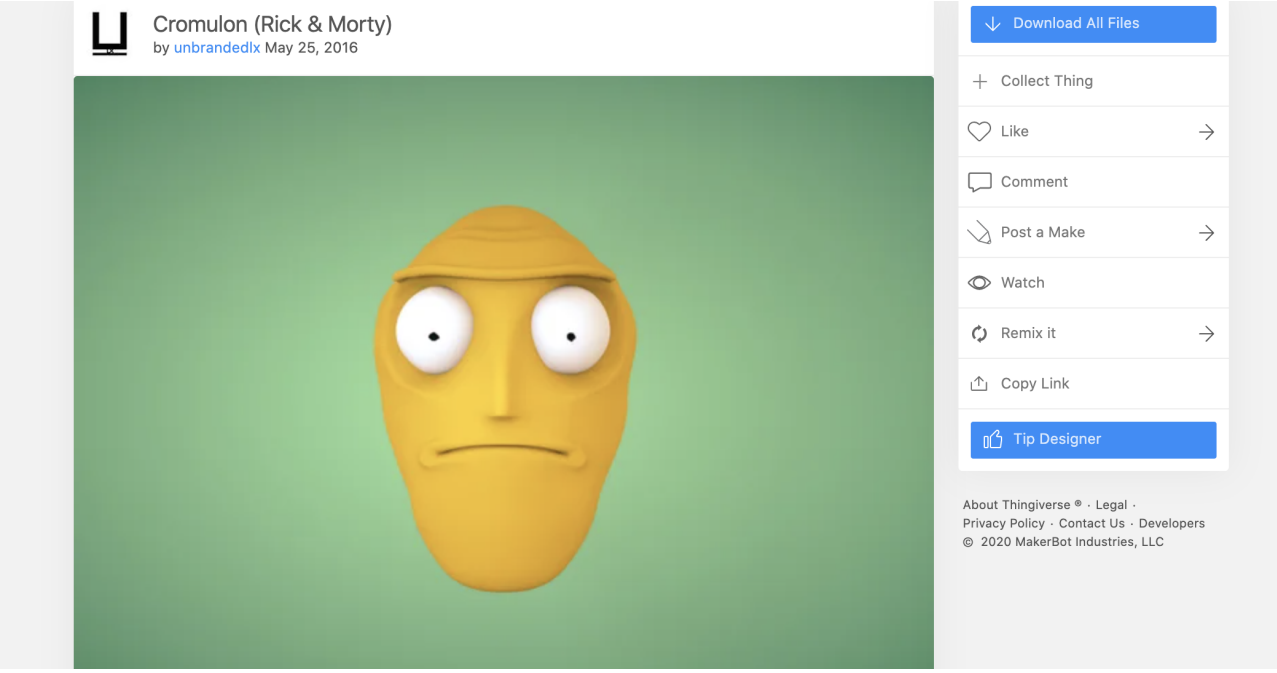


2.11 mira_spawn.launch

```
<?xml version="1.0" encoding="UTF-8"?>
<launch>
    <param name="robot_description" command="cat '$(find urdf_exam)/urdf/mira_gazebo.urdf'"/>

    <arg name="x" default="0"/>
    <arg name="y" default="0"/>
    <arg name="z" default="0.2"/>

    <include file="$(find gazebo_ros)/launch/empty_world.launch">
```

```
      <arg name="paused" value="true"/>
      <arg name="use_sim_time" value="true"/>
      <arg name="gui" value="true"/>
    </include>

    <node name="spawn_urdf" pkg="gazebo_ros" type="spawn_model" output="screen"
          args="-urdf -param robot_description -model mira -x $(arg x) -y $(arg y) -z $(arg z)" />

</launch>
```

2.12 보너스 - 재미를 찾아보자



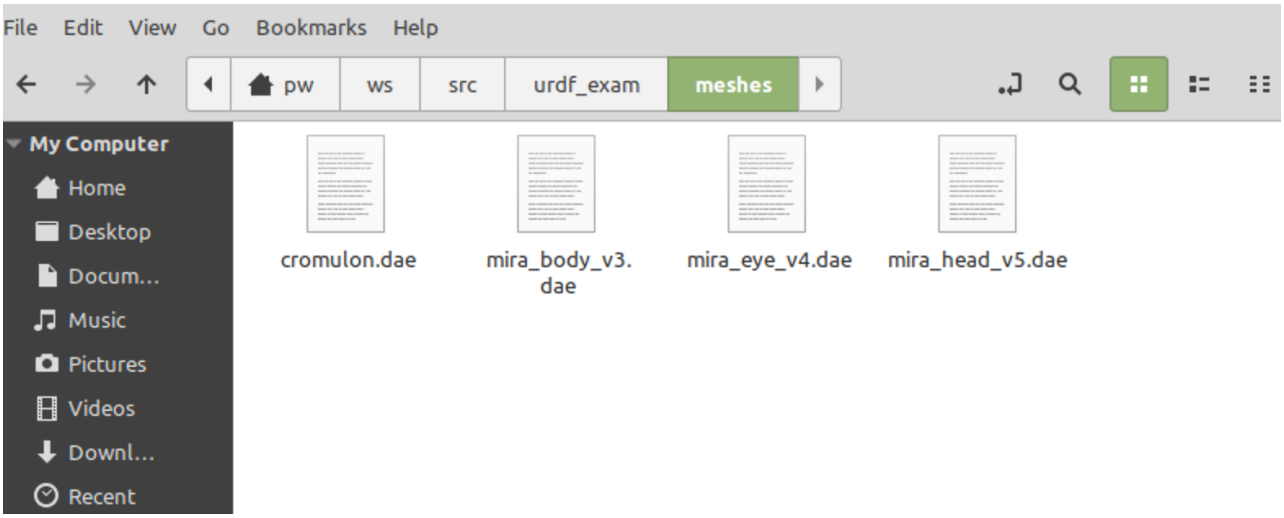
- https://www.thingiverse.com/thing:1587203

2.13 dae 파일

cromulon.dae

(see page 5)

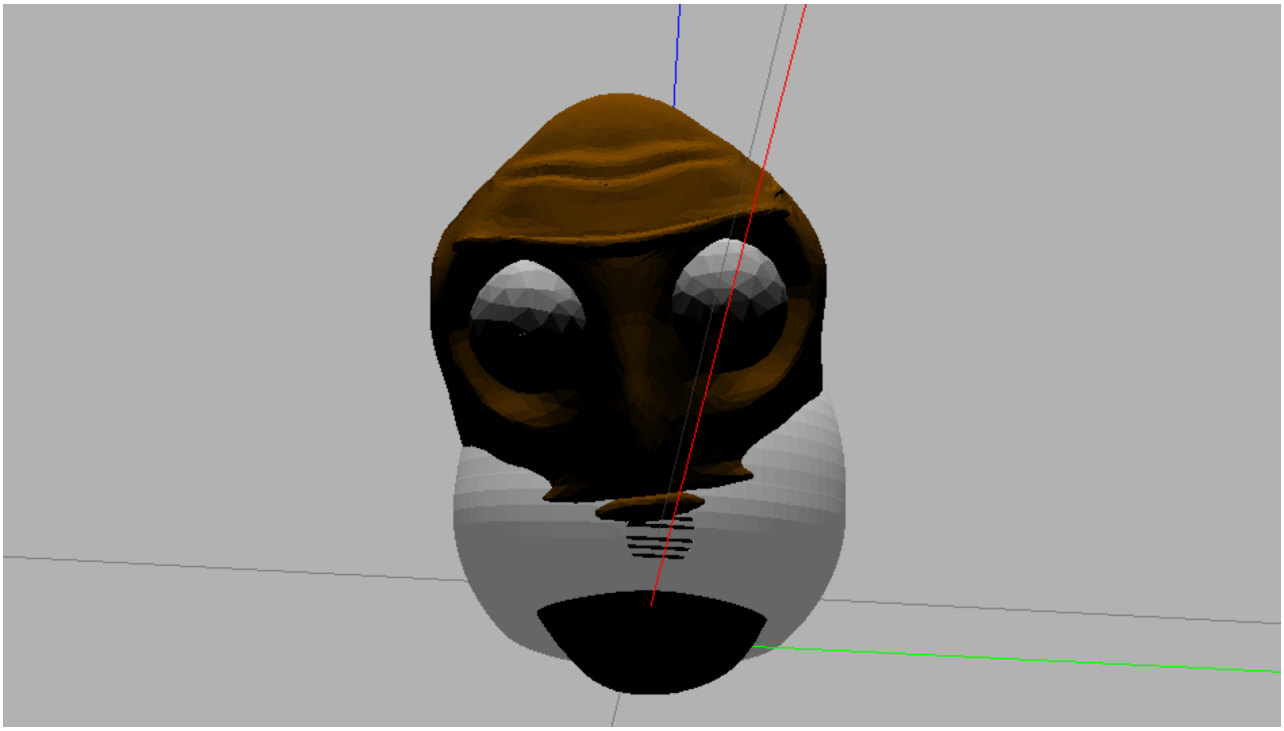
2.14 복사하고



2.15 head_link 부분 수정

```
149     <link name="head_link">
150
151         <inertial>
152             <origin xyz="0 0 0" rpy="0 0 0"/>
153             <mass value="0.02" />
154             <inertia ixx="2.61666666667e-05" ixy="0.0" ixz="0.0" iyy="2.61666666667e-05" iyz
                ="0.0" izz="3.6e-05"/>
155         </inertial>
156
157         <collision>
158             <origin xyz="0 0 0.015" rpy="0 0 0"/>
159             <geometry>
160                 <sphere radius="0.06"/>
161             </geometry>
162         </collision>
163
164         <visual>
165             <origin rpy="0.0 0 0" xyz="0 0 0"/>
166             <geometry>
167                 <!-- <mesh filename="package://urdf_exam/meshes/mira_head_v5.dae"/> -->
168                 <mesh filename="package://urdf_exam/meshes/cromulon.dae"/>
169             </geometry>
170         </visual>
171     </link>
```

2.16 약간 무섭나요?



3 구동축 만들어 주기

3.1 urdf 파일을 복사해서 만들어서 시작하자

```
pw@melodic:~/ws/src/urdf_exam/urdf$
pw@melodic:~/ws/src/urdf_exam/urdf$ cp mira_gazebo.urdf mira_gazebo_controller.urdf
pw@melodic:~/ws/src/urdf_exam/urdf$ ls
mira_gazebo_controller.urdf  mira_gazebo.urdf  mira_simple.urdf
pw@melodic:~/ws/src/urdf_exam/urdf$
pw@melodic:~/ws/src/urdf_exam/urdf$
```

3.2 joint tag

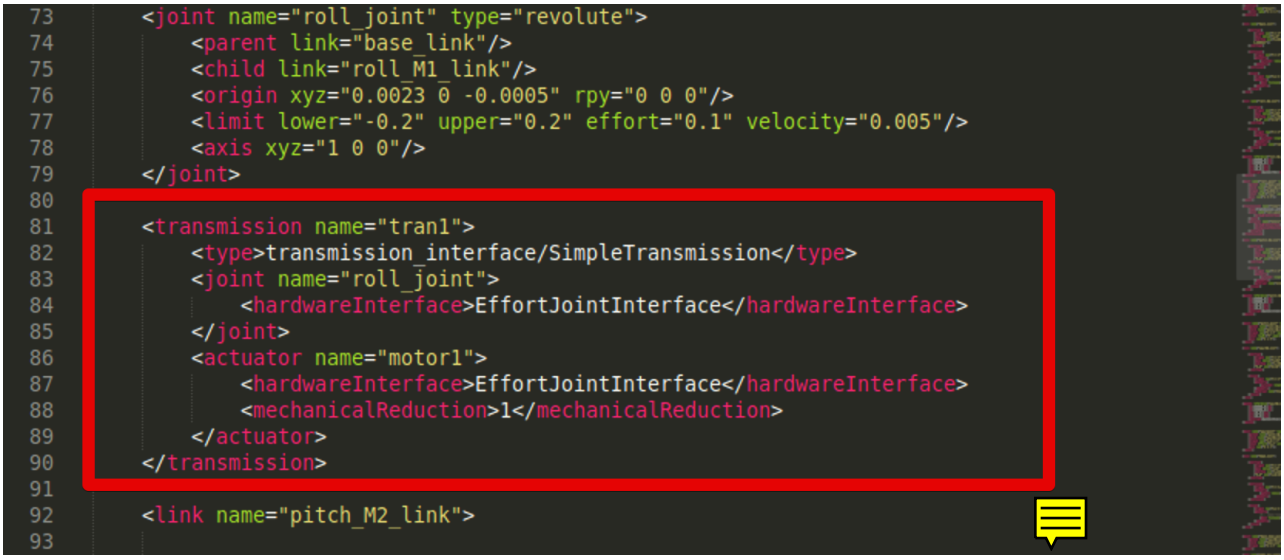
```
73      <joint name="roll_joint" type="revolute">
74          <parent link="base_link"/>
75          <child link="roll_M1_link"/>
76          <origin xyz="0.0023 0 -0.0005" rpy="0 0 0"/>
77          <limit lower="-0.2" upper="0.2" effort="0.1" velocity="0.005"/>
78          <axis xyz="1 0 0"/>
79      </joint>
```

- 조인트의 한계와 속도, 힘과 관련된 부분의 설정
- 그러나 딱 맞아 떨어지지는 않아서 자주 튜닝이 필요하다

3.3 ROS controllers

- **effort_controllers**: Torque / current based controller
  - ***joint_effort_controller***
  - ***joint_position_controller***
  - ***joint_velocity_controller***
- **position_controllers**
  - ***joint_position_controller***
- **velocity_controllers**
  - ***joint_velocity_controller***
- **joint_state_controller**
  - ***joint_state_controller***

3.4 roll_joint에 액츄에이터 추가



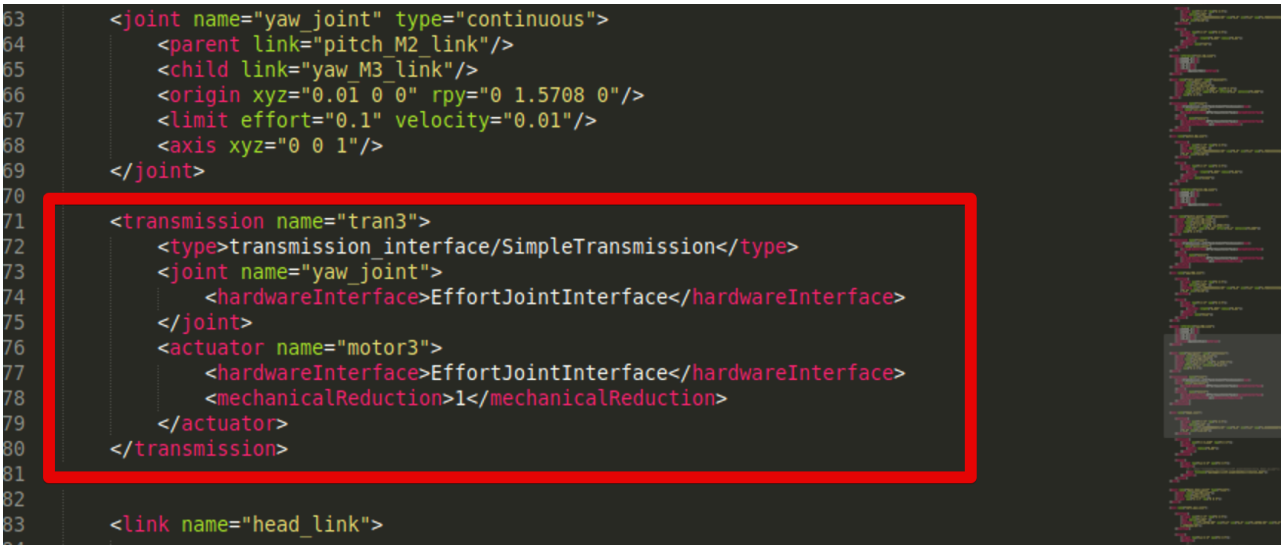
```
    <transmission name="tran1">
        <type>transmission_interface/SimpleTransmission</type>
        <joint name="roll_joint">
            <hardwareInterface>EffortJointInterface</hardwareInterface>
        </joint>
        <actuator name="motor1">
            <hardwareInterface>EffortJointInterface</hardwareInterface>
            <mechanicalReduction>1</mechanicalReduction>
        </actuator>
    </transmission>
```

3.5 pitch_joint에 엑츄에이터 추가

```
118     <joint name="pitch_joint" type="revolute">
119         <parent link="roll_M1_link"/>
120         <child link="pitch_M2_link"/>
121         <origin xyz="0 0 0" rpy="0 -1.5708 0"/>
122         <limit lower="0" upper="0.44" effort="0.1" velocity="0.005"/>
123         <axis xyz="0 1 0"/>
124     </joint>
125 
126     <transmission name="tran2">
127         <type>transmission_interface/SimpleTransmission</type>
128         <joint name="pitch_joint">
129             <hardwareInterface>EffortJointInterface</hardwareInterface>
130         </joint>
131         <actuator name="motor2">
132             <hardwareInterface>EffortJointInterface</hardwareInterface>
133             <mechanicalReduction>1</mechanicalReduction>
134         </actuator>
135     </transmission>
136 
137     <link name="yaw_M3_link">
138 
139         <inertial>
140             <origin xyz="0 0 0" rpy="0 0 0"/>
141             <mass value="0.001" />
142             <inertia ixx="2.70833333333e-08" ixy="0.0" ixz="0.0" iyy="2.70833333333e-08" iyz
```

```
<transmission name="tran2">
    <type>transmission_interface/SimpleTransmission</type>
    <joint name="pitch_joint">
        <hardwareInterface>EffortJointInterface</hardwareInterface>
    </joint>
    <actuator name="motor2">
        <hardwareInterface>EffortJointInterface</hardwareInterface>
        <mechanicalReduction>1</mechanicalReduction>
    </actuator>
</transmission>
```

3.6 yaw_joint에 엑츄에이터 추가



```
    <joint name="yaw_joint" type="continuous">
        <parent link="pitch_M2_link"/>
        <child link="yaw_M3_link"/>
        <origin xyz="0.01 0 0" rpy="0 1.5708 0"/>
        <limit effort="0.1" velocity="0.01"/>
        <axis xyz="0 0 1"/>
    </joint>

    <transmission name="tran3">
        <type>transmission_interface/SimpleTransmission</type>
        <joint name="yaw_joint">
            <hardwareInterface>EffortJointInterface</hardwareInterface>
        </joint>
        <actuator name="motor3">
            <hardwareInterface>EffortJointInterface</hardwareInterface>
            <mechanicalReduction>1</mechanicalReduction>
        </actuator>
    </transmission>


    <link name="head_link">
```

```
<transmission name="tran3">
    <type>transmission_interface/SimpleTransmission</type>
    <joint name="yaw_joint">
        <hardwareInterface>EffortJointInterface</hardwareInterface>
    </joint>
    <actuator name="motor3">
        <hardwareInterface>EffortJointInterface</hardwareInterface>
        <mechanicalReduction>1</mechanicalReduction>
    </actuator>
</transmission>
```

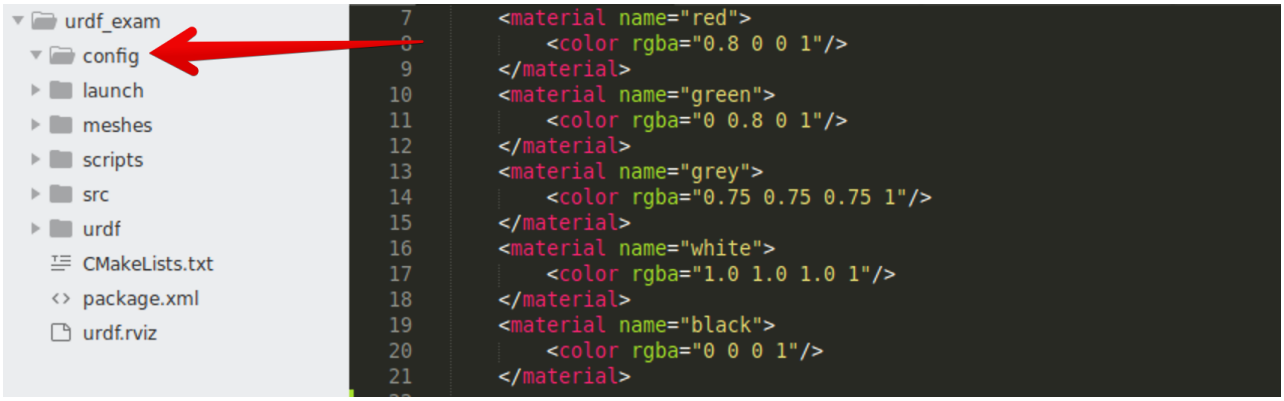
3.7 gazebo 제어기 플러그인 추가

```
    <material name="black">
        <color rgba="0 0 0 1"/>
    </material>

    <gazebo>
        <plugin name="gazebo_ros_control" filename="libgazebo_ros_control.so">
            <robotNamespace>/mira</robotNamespace>
        </plugin>
    </gazebo>


    <link name="base_link">

        <inertial>
            <origin xyz="0 0 0" rpy="0 0 0"/>
```

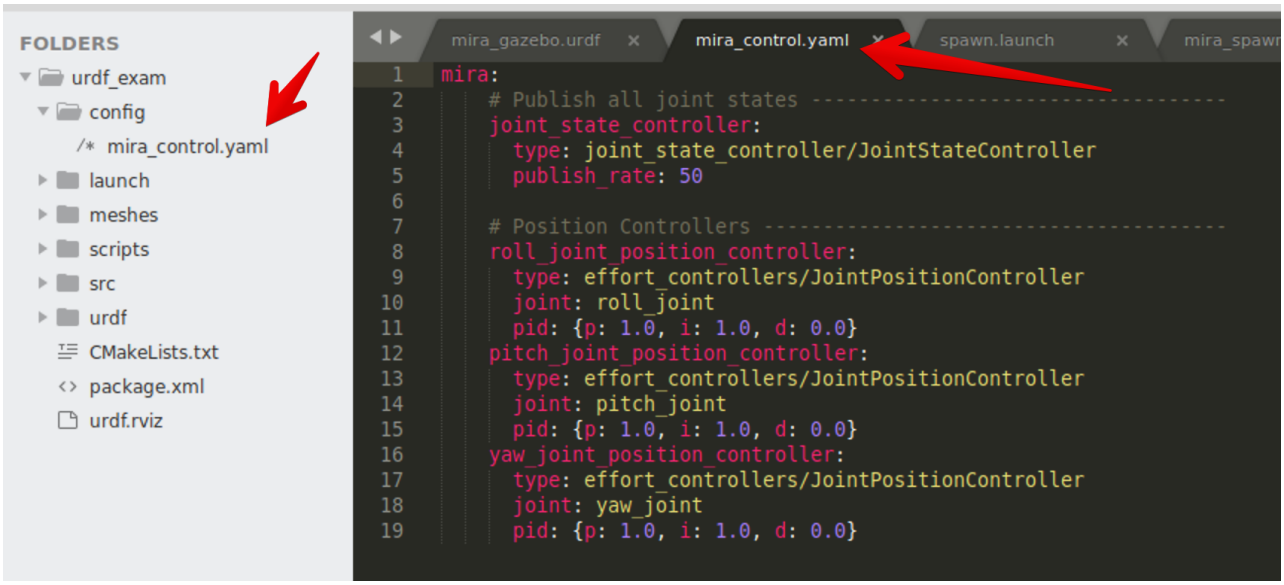
```
<gazebo>
    <plugin name="gazebo_ros_control" filename="libgazebo_ros_control.so">
        <robotNamespace>/mira</robotNamespace>
```

```
        </plugin>
    </gazebo>
```

3.8 config 폴더 하나 추가



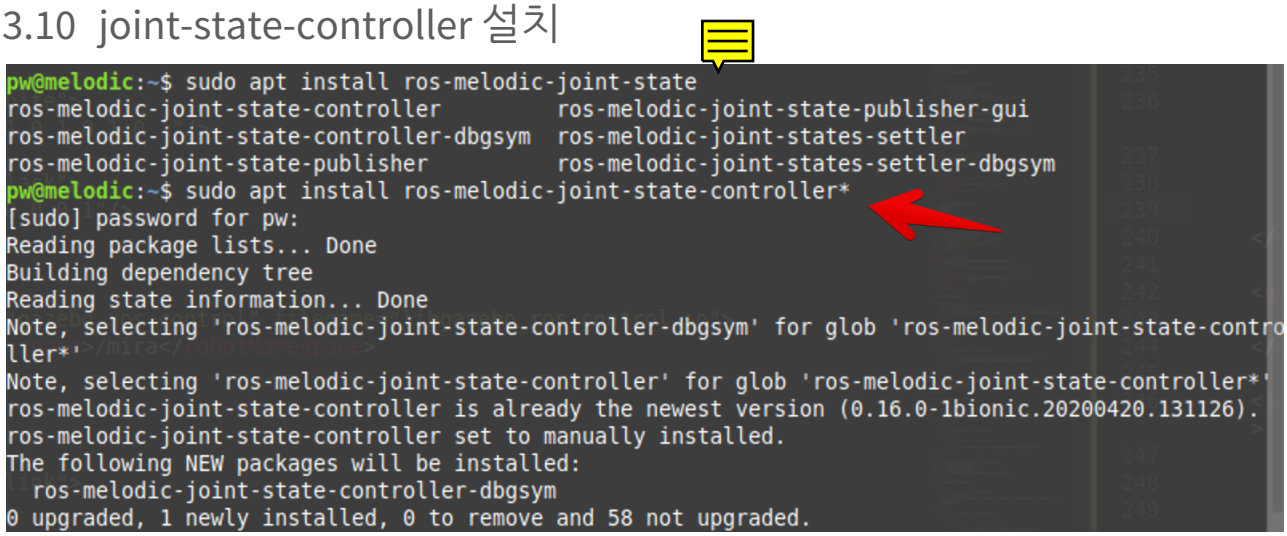
3.9 각 조인트 제어기 설정



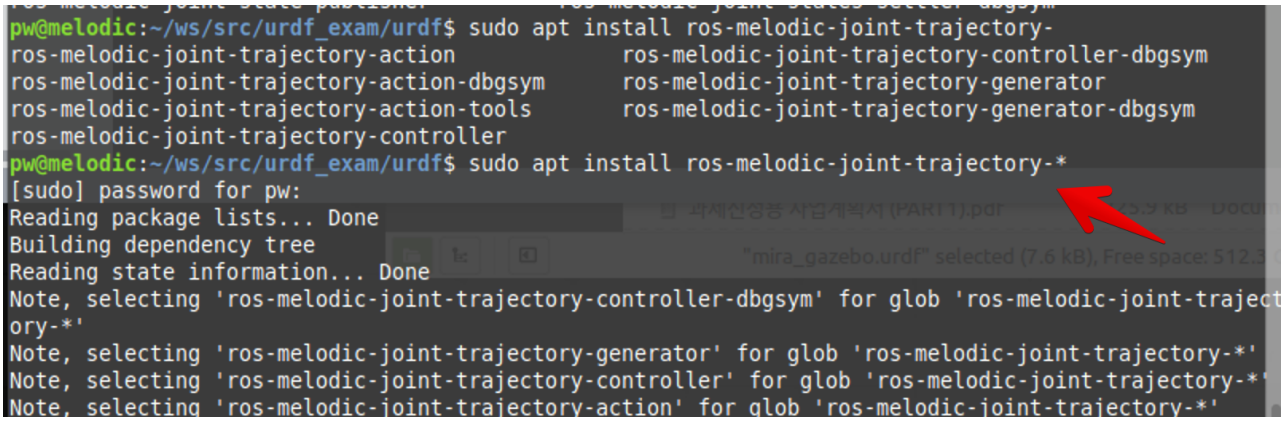

```
mira:
    # Publish all joint states ----------------------------------
    joint_state_controller:
      type: joint_state_controller/JointStateController
      publish_rate: 50

    # Position Controllers ---------------------------------------
    roll_joint_position_controller:
      type: effort_controllers/JointPositionController
      joint: roll_joint
      pid: {p: 1.0, i: 1.0, d: 0.0}
```

```
  pitch_joint_position_controller:
    type: effort_controllers/JointPositionController
    joint: pitch_joint
    pid: {p: 1.0, i: 1.0, d: 0.0}
  yaw_joint_position_controller:
    type: effort_controllers/JointPositionController
    joint: yaw_joint
    pid: {p: 1.0, i: 1.0, d: 0.0}
```

3.10 joint-state-controller 설치



3.11 trajectory-controller 설치



3.12 effort controller 설치

```
pw@melodic:~/ws/src/urdf_exam/urdf$ sudo apt install ros-melodic-effort-controllers
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following NEW packages will be installed:
  ros-melodic-effort-controllers
0 upgraded, 1 newly installed, 0 to remove and 58 not upgraded.
Need to get 80.0 kB of archives.
After this operation, 339 kB of additional disk space will be used.
Get:1 http://packages.ros.org/ros/ubuntu bionic/main amd64 ros-melodic-effort-controllers amd64 0.16
.0-1bionic.20200420.132256 [80.0 kB]
Fetched 80.0 kB in 4s (21.4 kB/s)
Selecting previously unselected package ros-melodic-effort-controllers.
```

3.13 mira_gazebo_controller.urdf를 만들자

```
<?xml version="1.0" encoding="UTF-8"?>
<launch>
    <param name="robot_description" command="cat '$(find urdf_exam)/urdf/mira_gazebo_controller.urdf'"/>

    <arg name="x" default="0"/>
    <arg name="y" default="0"/>
    <arg name="z" default="0.045"/>

    <include file="$(find gazebo_ros)/launch/empty_world.launch">
      <arg name="paused" value="true"/>
      <arg name="use_sim_time" value="true"/>
      <arg name="gui" value="true"/>
    </include>

    <node name="spawn_urdf" pkg="gazebo_ros" type="spawn_model" output="screen"
          args="-urdf -param robot_description -model mira -x $(arg x) -y $(arg y) -z $(arg z)" />

    <rosparam file="$(find urdf_exam)/config/mira_control.yaml" command="load"/>

    <node name="controller_spawner" pkg="controller_manager" type="spawner" respawn="false"
        output="screen" ns="/mira" args="roll_joint_position_controller pitch_joint_position_controller
        yaw_joint_position_controller joint_state_controller"/>

    <node name="robot_state_publisher" pkg="robot_state_publisher" type="robot_state_publisher"
        respawn="false" output="screen">
        <remap from="/joint_states" to="/mira/joint_states" />
    </node>

</launch>
```

(see page 5)

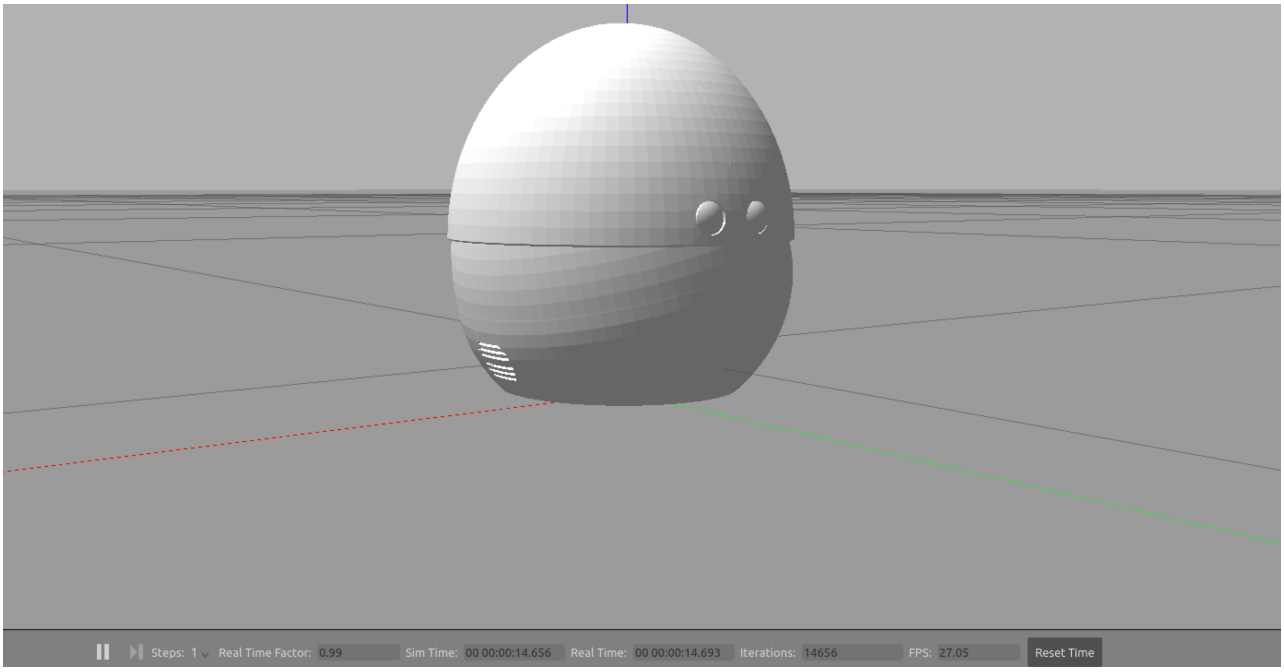
(see page 5)

```
<?xml version="1.0" encoding="UTF-8"?>
<launch>
    <param name="robot_description" command="cat '$(find urdf_exam)/urdf/mira_gazebo_controller.urdf'"/>

    <arg name="x" default="0"/>
    <arg name="y" default="0"/>
    <arg name="z" default="0.045"/>

    <include file="$(find gazebo_ros)/launch/empty_world.launch">
      <arg name="paused" value="true"/>
      <arg name="use_sim_time" value="true"/>
      <arg name="gui" value="true"/>
    </include>

    <node name="spawn_urdf" pkg="gazebo_ros" type="spawn_model" output="screen"
          args="-urdf -param robot_description -model mira -x $(arg x) -y $(arg y) -z $(arg z)" />

    <rosparam file="$(find urdf_exam)/config/mira_control.yaml" command="load"/>

    <node name="controller_spawner" pkg="controller_manager" type="spawner" respawn="false"
        output="screen" ns="/mira" args="roll_joint_position_controller pitch_joint_position_controller
yaw_joint_position_controller joint_state_controller"/>

    <node name="robot_state_publisher" pkg="robot_state_publisher" type="robot_state_publisher"
        respawn="false" output="screen">
        <remap from="/joint_states" to="/mira/joint_states" />
    </node>

</launch>
```

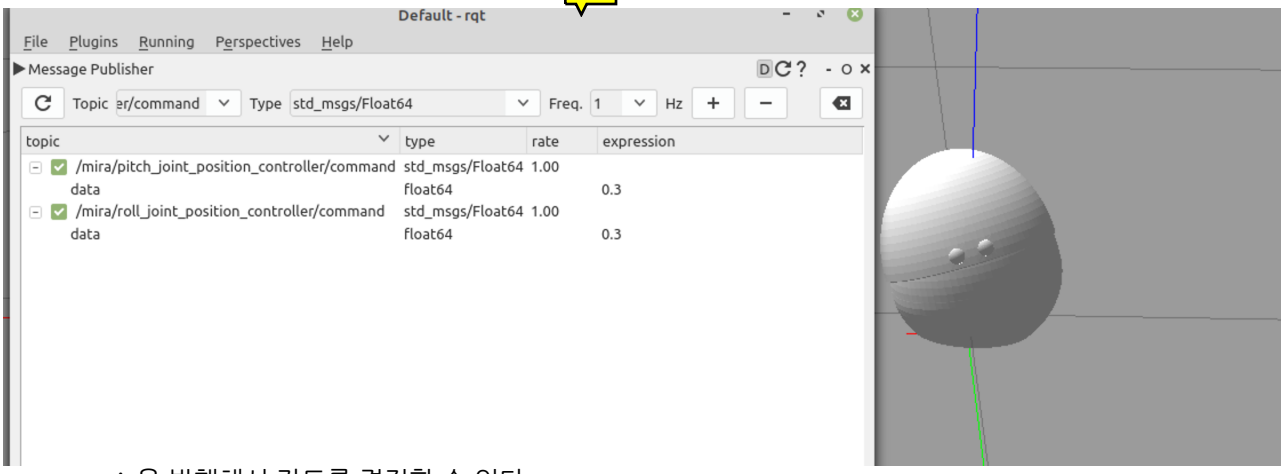
3.14 실행해보자

```
pw@melodic:~/ws/src/urdf_exam/urdf$
pw@melodic:~/ws/src/urdf_exam/urdf$ roslaunch urdf_exam mira_spawn_controller.launch
... logging to /home/pw/.ros/log/d13c3716-9d11-11ea-b41a-001c420be203/roslaunch-melodic-19253.log
Checking log directory for disk usage. This may take a while.
Press Ctrl-C to interrupt
Done checking log file disk usage. Usage is <1GB.

started roslaunch server http://melodic:42445/

SUMMARY
========

PARAMETERS
 * /gazebo/enable_ros_network: True
 * /mira/joint_state_controller/publish_rate: 50
```

3.15 이제 버틴다

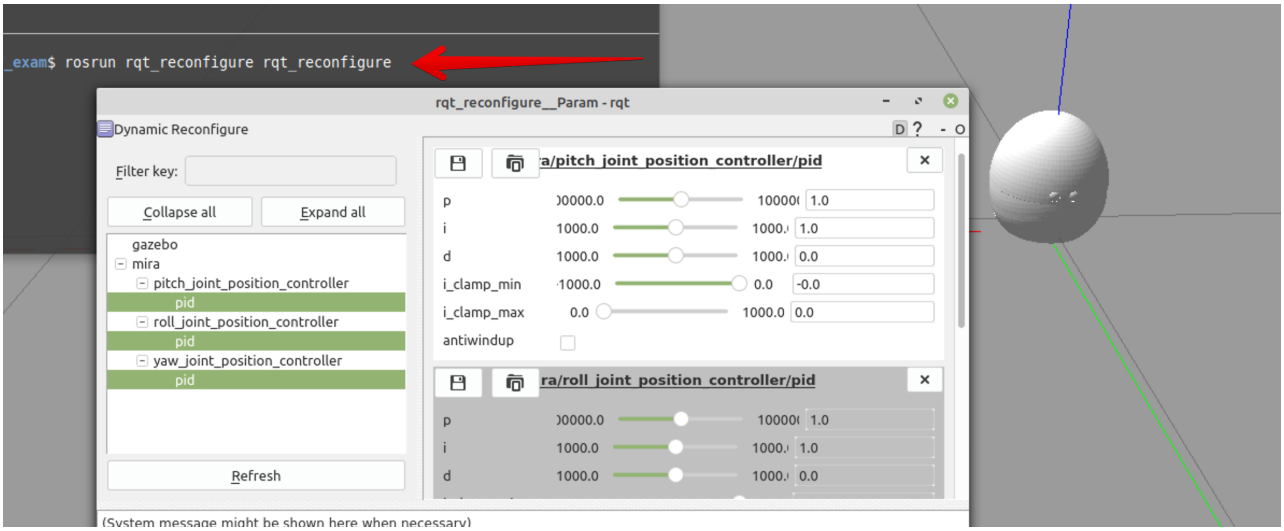


3.16 rosrun rqt_gui rqt_gui



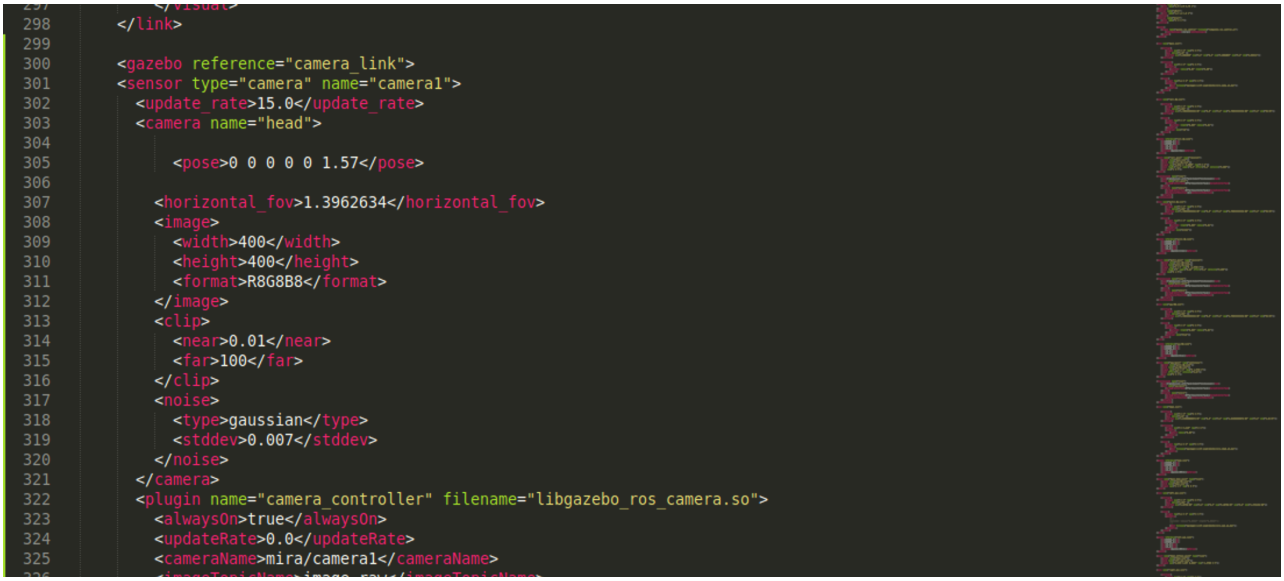
- topic을 발행해서 각도를 결정할 수 있다

3.17 만약 각 관절의 PID값을 실시간으로 변경하고 싶다면



4 GAZEBO에서 센서 사용하기

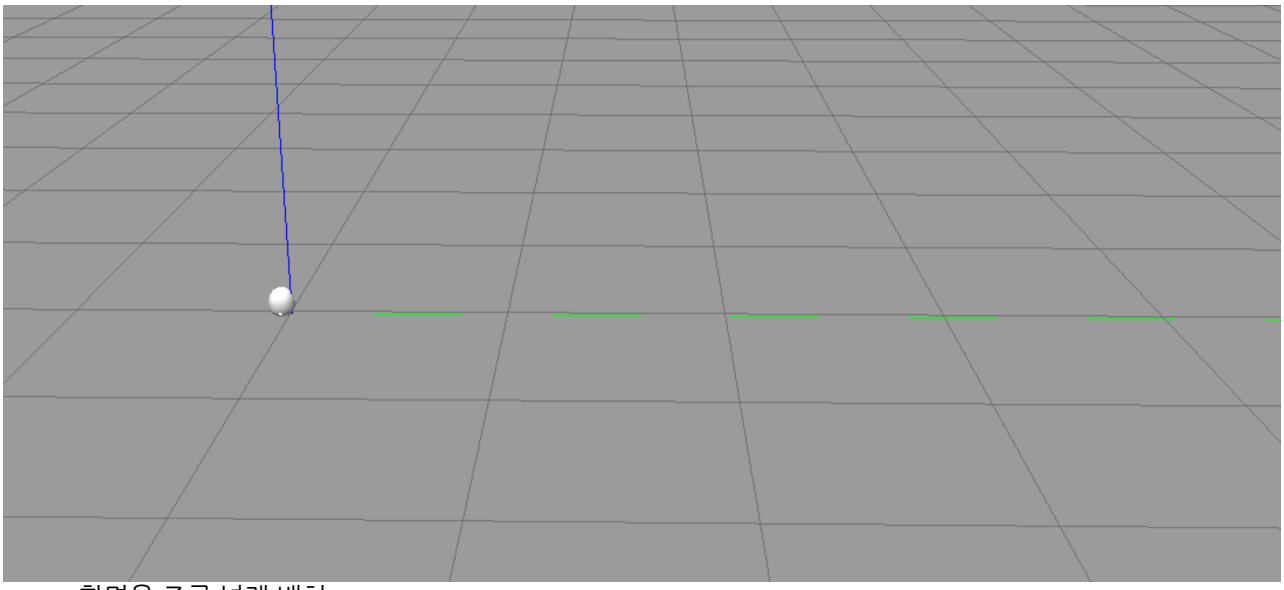
4.1 urdf에 카메라 plugin 추가



```
<gazebo reference="camera_link">
  <sensor type="camera" name="camera1">
    <update_rate>15.0</update_rate>
    <camera name="head">

        <pose>0 0 0 0 0 1.57</pose>

      <horizontal_fov>1.3962634</horizontal_fov>
      <image>
        <width>400</width>
        <height>400</height>
        <format>R8G8B8</format>
      </image>
      <clip>
        <near>0.01</near>
        <far>100</far>
      </clip>
      <noise>
        <type>gaussian</type>
        <stddev>0.007</stddev>
      </noise>
    </camera>
    <plugin name="camera_controller" filename="libgazebo_ros_camera.so">
      <alwaysOn>true</alwaysOn>
      <updateRate>0.0</updateRate>
      <cameraName>mira/camera1</cameraName>
      <imageTopicName>image_raw</imageTopicName>
      <cameraInfoTopicName>camera_info</cameraInfoTopicName>
      <frameName>camera_link</frameName>
```

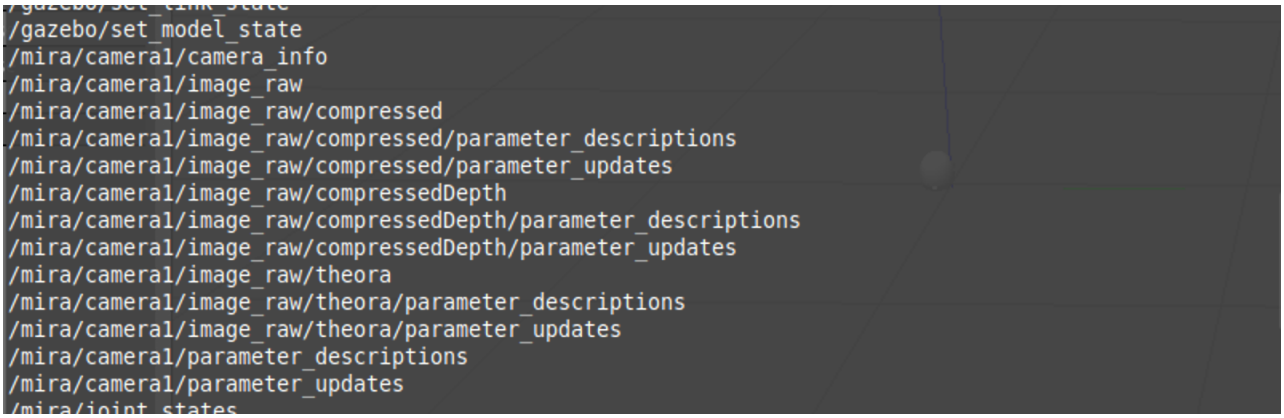
```
        <hackBaseline>0.07</hackBaseline>
        <distortionK1>0.0</distortionK1>
        <distortionK2>0.0</distortionK2>
        <distortionK3>0.0</distortionK3>
        <distortionT1>0.0</distortionT1>
        <distortionT2>0.0</distortionT2>
      </plugin>
    </sensor>
  </gazebo>
```

4.2 다시 roslaunch urdf_exam mira_spawn_controller.launch

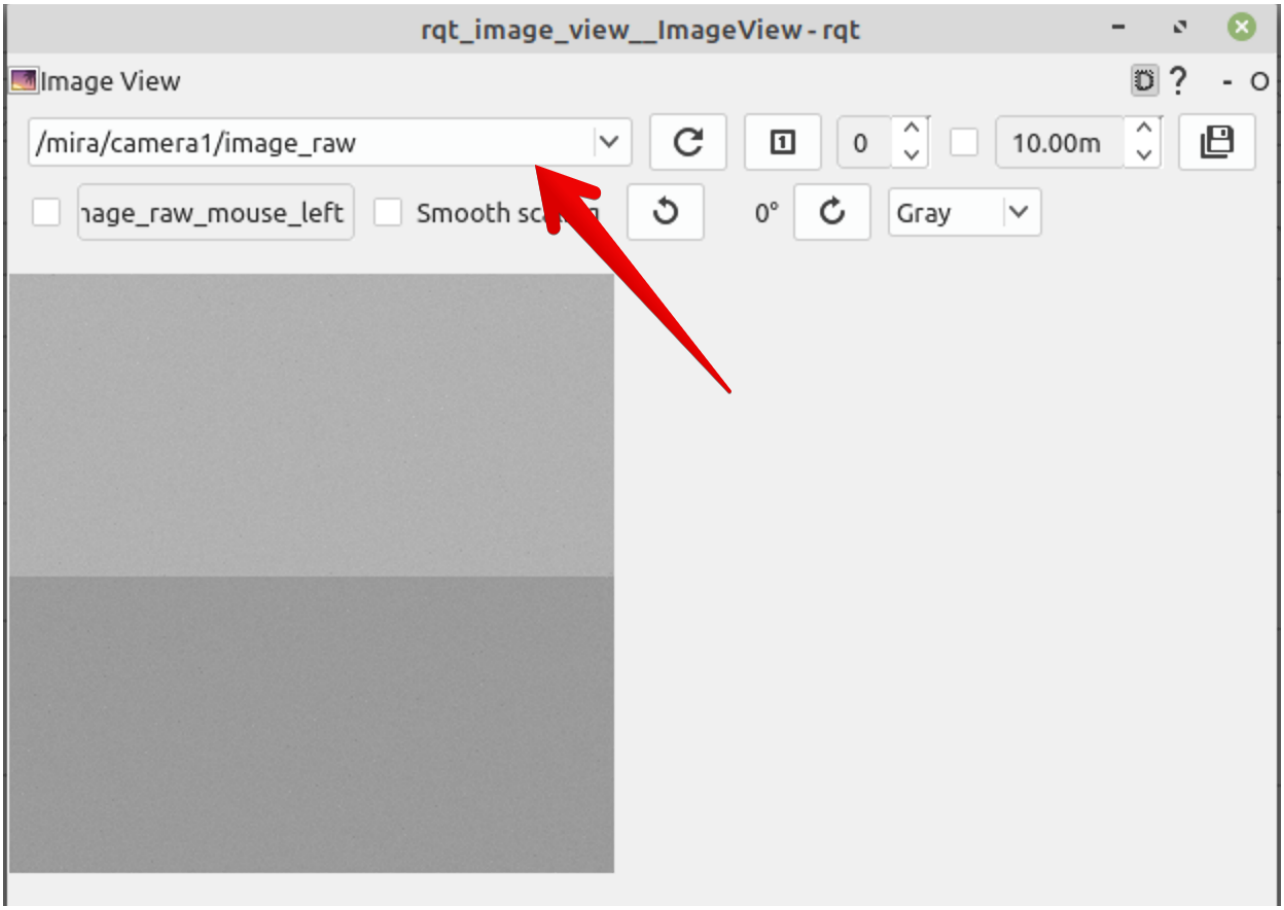


- 화면을 조금 넓게 배치

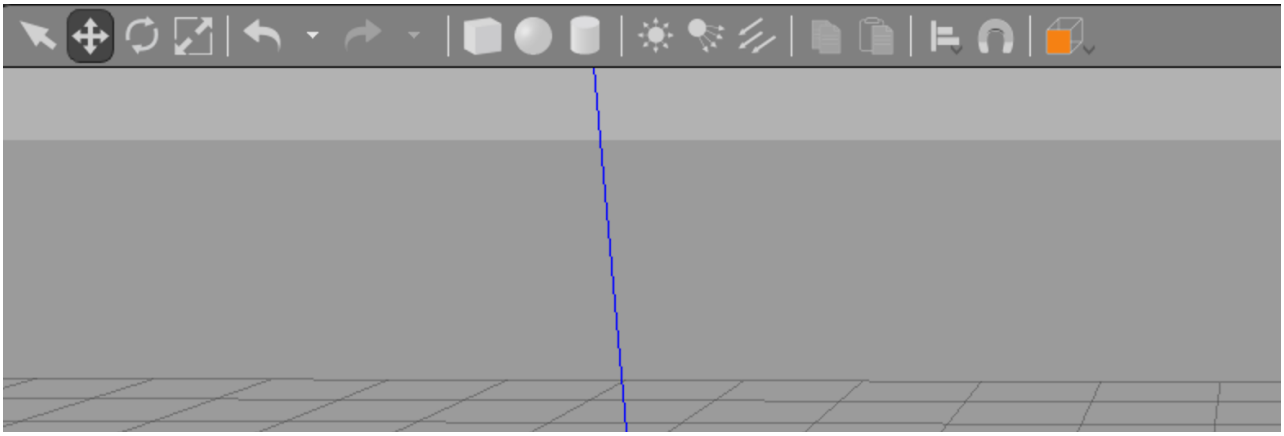
4.3 rostopic list를 보면 카메라 관련 토픽이 나타난 것이 보인다



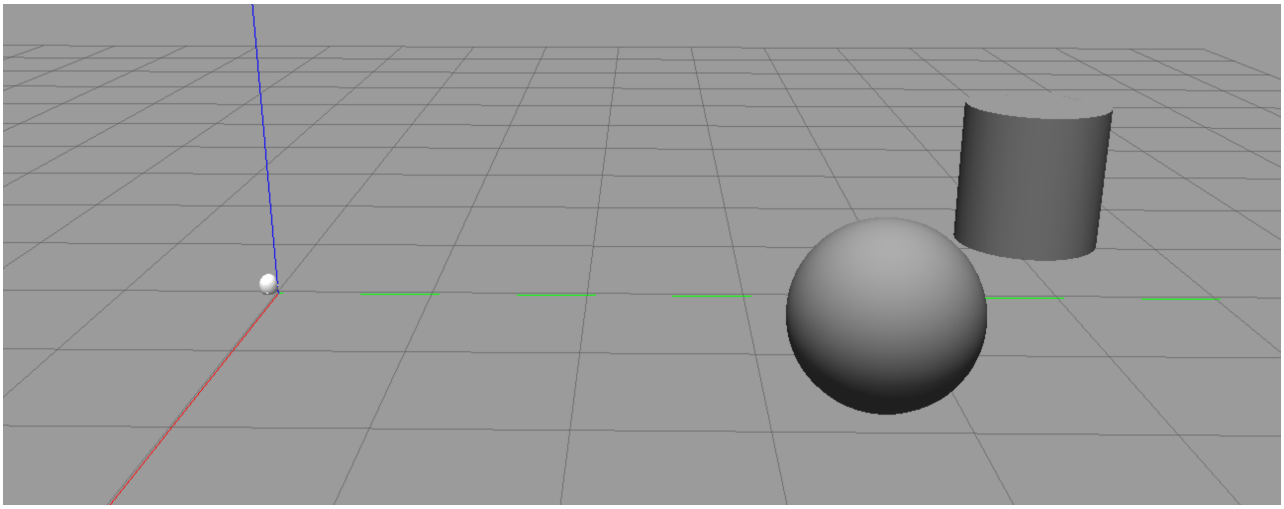
4.4 rosrun rqt_image_view rqt_image_view



4.5 적당히



4.6 배치해보자



4.7 나타난다~^^