ROS理论与实践

—— 第6讲：构建机器人仿真平台

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1. 优化物理仿真模型

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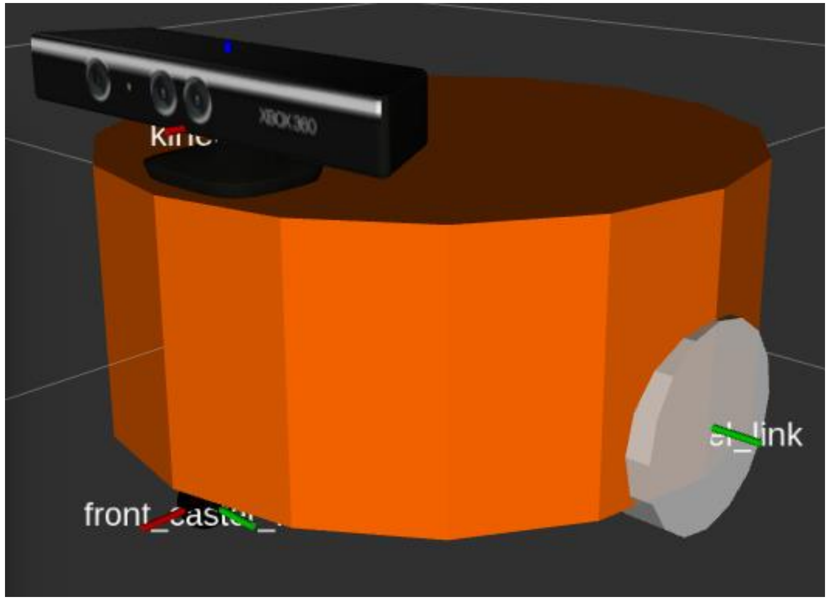
- 在机器人模型中添加控制器插件

1. 优化物理仿真模型



URDF建模存在哪些问题？

- 模型冗长，重复内容过多；
- 参数修改麻烦，不便于二次开发；
- 没有参数计算的功能；
- …

```xml
<?xml version="1.0" ?>
<robot name="mbot">

    <link name="base_link">
        <visual>
            <origin xyz=" 0 0 0" rpy="0 0 0" />
            <geometry>
                <cylinder length="0.16" radius="0.20"/>
            </geometry>
            <material name="yellow">
                <color rgba="1 0.4 0 1"/>
            </material>
        </visual>
    </link>

    <joint name="left_wheel_joint" type="continuous">
        <origin xyz="0 0.19 -0.05" rpy="0 0 0"/>
        <parent link="base_link"/>
        <child link="left_wheel_link"/>
        <axis xyz="0 1 0"/>
    </joint>

    <link name="left_wheel_link">
        <visual>
            <origin xyz="0 0 0" rpy="1.5707 0 0" />
            <geometry>
                <cylinder radius="0.06" length = "0.025"/>
            </geometry>
            <material name="white">
                <color rgba="1 1 1 0.9"/>
            </material>
        </visual>
    </link>

</robot>
```

URDF模型

1. 优化物理仿真模型

URDF模型的进化版本——xacro模型文件

- 精简模型代码
  - 创建宏定义
  - 文件包含
- 提供可编程接口
  - 常量
  - 变量
  - 数学计算
  - 条件语句

```xml
<?xml version="1.0"?>
<robot xmlns:xacro="http://www.ros.org/wiki/xacro">

    <xacro:property name="M_PI" value="3.14159"/>
    <xacro:property name="wheel_radius" value="0.033"/>
    <xacro:property name="wheel_length" value="0.017"/>
    <xacro:property name="base_link_radius" value="0.13"/>
    <xacro:property name="base_link_length" value="0.005"/>
    <xacro:property name="motor_radius" value="0.02"/>
    <xacro:property name="motor_length" value="0.08"/>
    <xacro:property name="motor_x" value="-0.055"/>
    <xacro:property name="motor_y" value="0.075"/>
    <xacro:property name="plate_height" value="0.07"/>
    <xacro:property name="standoff_x" value="0.12"/>
    <xacro:property name="standoff_y" value="0.10"/>

    <!-- 定义MRobot本体的宏 -->
    <xacro:macro name="mrobot_standoff_2in" params="parent number x_loc y_loc z_loc">
        <joint name="standoff_2in_${number}_joint" type="fixed">
            <origin xyz="${x_loc} ${y_loc} ${z_loc}" rpy="0 0 0" />
            <parent link="${parent}"/>
            <child link="standoff_2in_${number}_link" />
        </joint>

        <link name="standoff_2in_${number}_link">
            <inertial>
                <mass value="0.001" />
                <origin xyz="0 0 0" />
                <inertia ixx="0.0001" ixy="0.0" ixz="0.0"
                         iyy="0.0001" iyz="0.0"
                         izz="0.0001" />
            </inertial>

            <visual>
                <origin xyz=" 0 0 0 " rpy="0 0 0" />
                <geometry>
                    <box size="0.01 0.01 0.07" />
                </geometry>
                <material name="black">
                    <color rgba="0.16 0.17 0.15 0.9"/>
                </material>
            </visual>

            <collision>
                <origin xyz="0.0 0.0 0.0" rpy="0 0 0" />
                <geometry>
                    <box size="0.01 0.01 0.07" />
                </geometry>
            </collision>
        </link>
    </xacro:macro>
```

xacro优化后的URDF模型

1. 优化物理仿真模型

常量定义

```
<xacro:property name="M_PI"   value="3.14159"/>
```

常量使用

```
<origin xyz="0 0 0"   rpy="${M_PI/2} 0 0" />
```

```
<!-- PROPERTY LIST -->
<xacro:property name="M_PI" value="3.1415926"/>
<xacro:property name="base_radius" value="0.20"/>
<xacro:property name="base_length" value="0.16"/>

<xacro:property name="wheel_radius" value="0.06"/>
<xacro:property name="wheel_length" value="0.025"/>
<xacro:property name="wheel_joint_y" value="0.19"/>
<xacro:property name="wheel_joint_z" value="0.05"/>

<xacro:property name="caster_radius" value="0.015"/>
<xacro:property name="caster_joint_x" value="0.18"/>
```

常量定义

```
<joint name="base_footprint_joint" type="fixed">
    <origin xyz="0 0 ${base_length/2 + caster_radius*2}" rpy="0 0 0" />
    <parent link="base_footprint"/>
    <child link="base_link" />
</joint>

<link name="base_link">
    <visual>
        <origin xyz=" 0 0 0" rpy="0 0 0" />
        <geometry>
            <cylinder length="${base_length}" radius="${base_radius}"/>
        </geometry>
        <material name="yellow" />
    </visual>
</link>
```

常量使用

1. 优化物理仿真模型

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数学计算

<origin xyz="0 ${(motor_length+wheel_length)/2} 0" rpy="0 0 0"/>

```xml
<joint name="base_footprint_joint" type="fixed">
    <origin xyz="0 0 ${base_length/2 + caster_radius*2}" rpy="0 0 0" />
    <parent link="base_footprint"/>
    <child link="base_link" />
</joint>
```

数学计算

注意：所有数学运算都会转换成浮点数进行，以保证运算精度

1. 优化物理仿真模型

宏定义

```
<xacro:macro name="name"  params="A B C">
    ......
</xacro:macro>
```

宏调用

```
<name A= "A_value" B= "B_value" C= "C_value" />
```

```
<!-- Macro for robot wheel -->
<xacro:macro name="wheel" params="prefix reflect">
    <joint name="${prefix}_wheel_joint" type="continuous">
        <origin xyz="0 ${reflect*wheel_joint_y} ${-wheel_joint_z}" rpy="0 0 0"/>
        <parent link="base_link"/>
        <child link="${prefix}_wheel_link"/>
        <axis xyz="0 1 0"/>
    </joint>

    <link name="${prefix}_wheel_link">
        <visual>
            <origin xyz="0 0 0" rpy="${M_PI/2} 0 0" />
            <geometry>
                <cylinder radius="${wheel_radius}" length = "${wheel_length}"/>
            </geometry>
            <material name="gray" />
        </visual>
    </link>
</xacro:macro>
```

宏定义

```
<wheel prefix="left" reflect="-1"/>
<wheel prefix="right" reflect="1"/>
```

宏调用

1. 优化物理仿真模型

古月居 GYH.AI

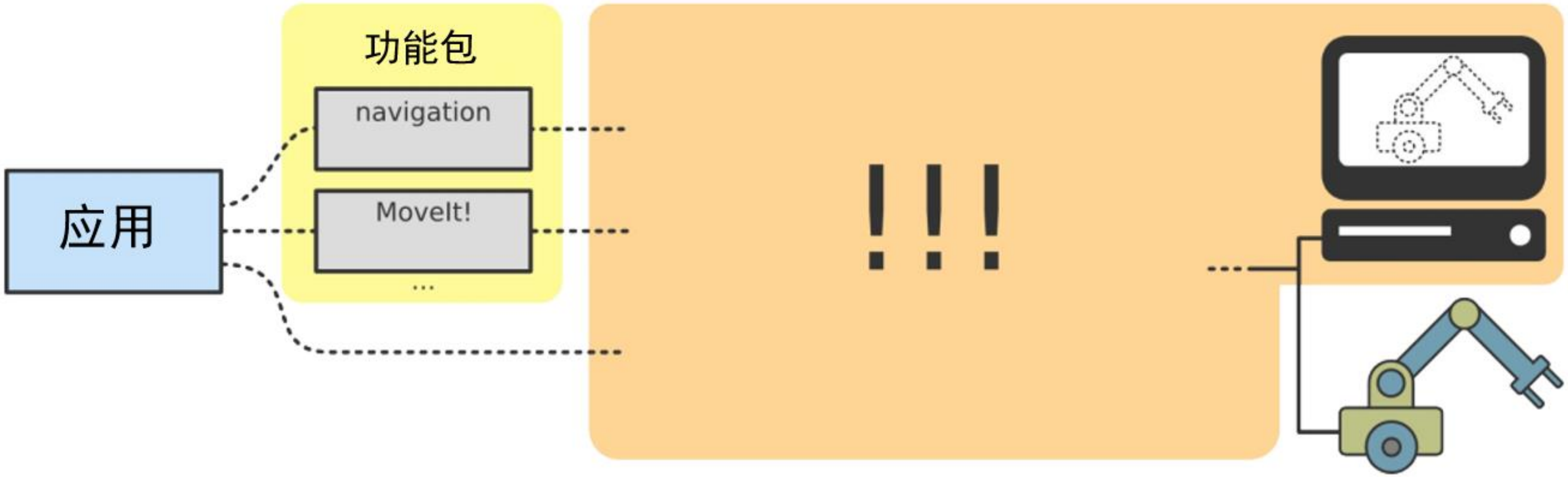
文件包含

<xacro:include filename="$(find mbot_description)/urdf/mbot_base_gazebo.xacro" />

```
<xacro:include filename="$(find mbot_description)/urdf/mbot_base_gazebo.xacro" />
<xacro:include filename="$(find mbot_description)/urdf/sensors/camera_gazebo.xacro" />
```

文件包含

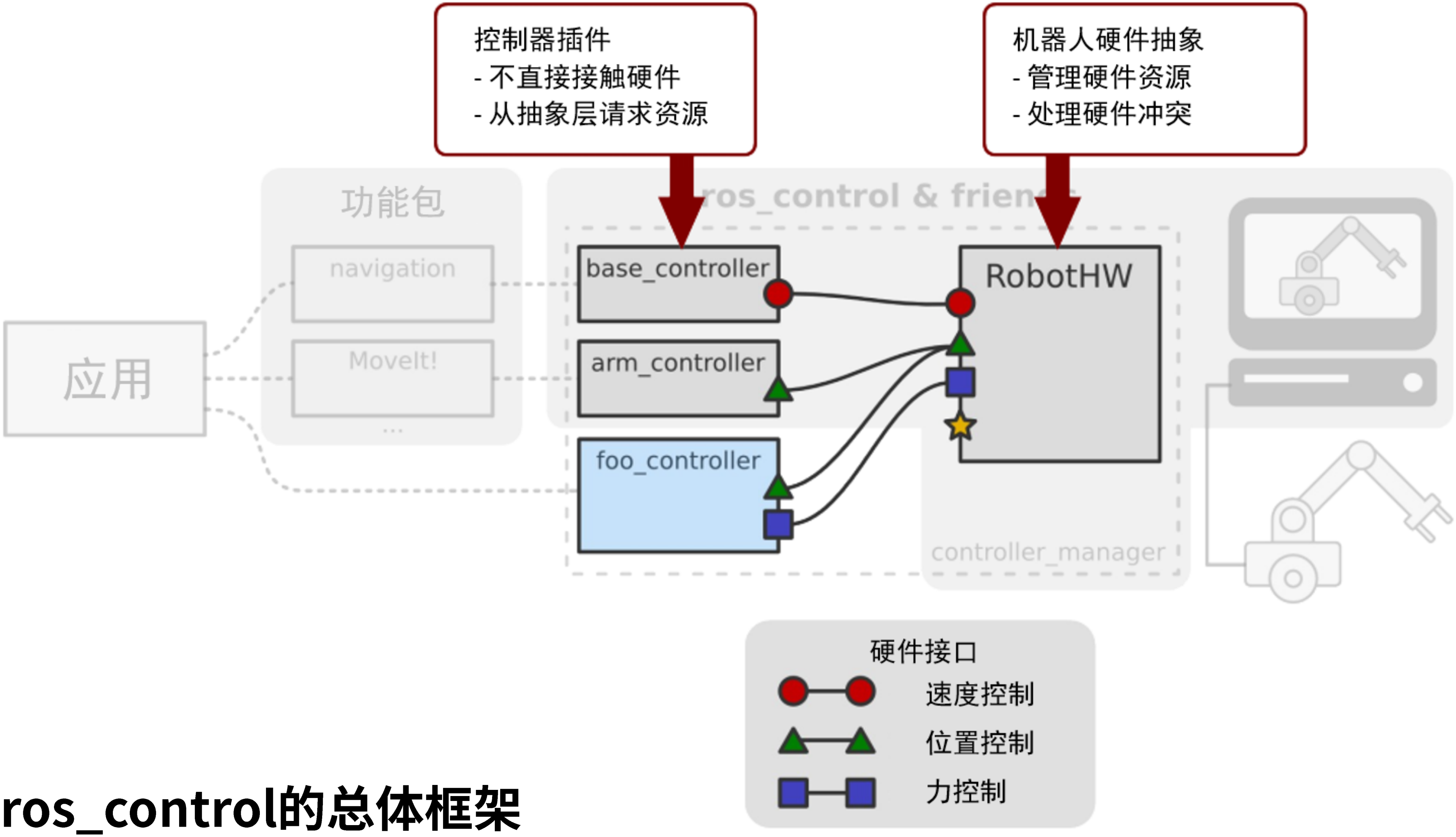
1. 优化物理仿真模型



ros_control是什么?

- ROS为开发者提供的机器人控制中间件
- 包含一系列控制器接口、传动装置接口、硬件接口、控制器工具箱等等
- 可以帮助机器人应用功能包快速落地，提高开发效率

1. 优化物理仿真模型



ros_control的总体框架

1. 优化物理仿真模型

➢ 控制器管理器

提供一种通用的接口来管理不同的控制器。

➢ 控制器

读取硬件状态，发布控制命令，完成每个joint的控制。

➢ 硬件资源

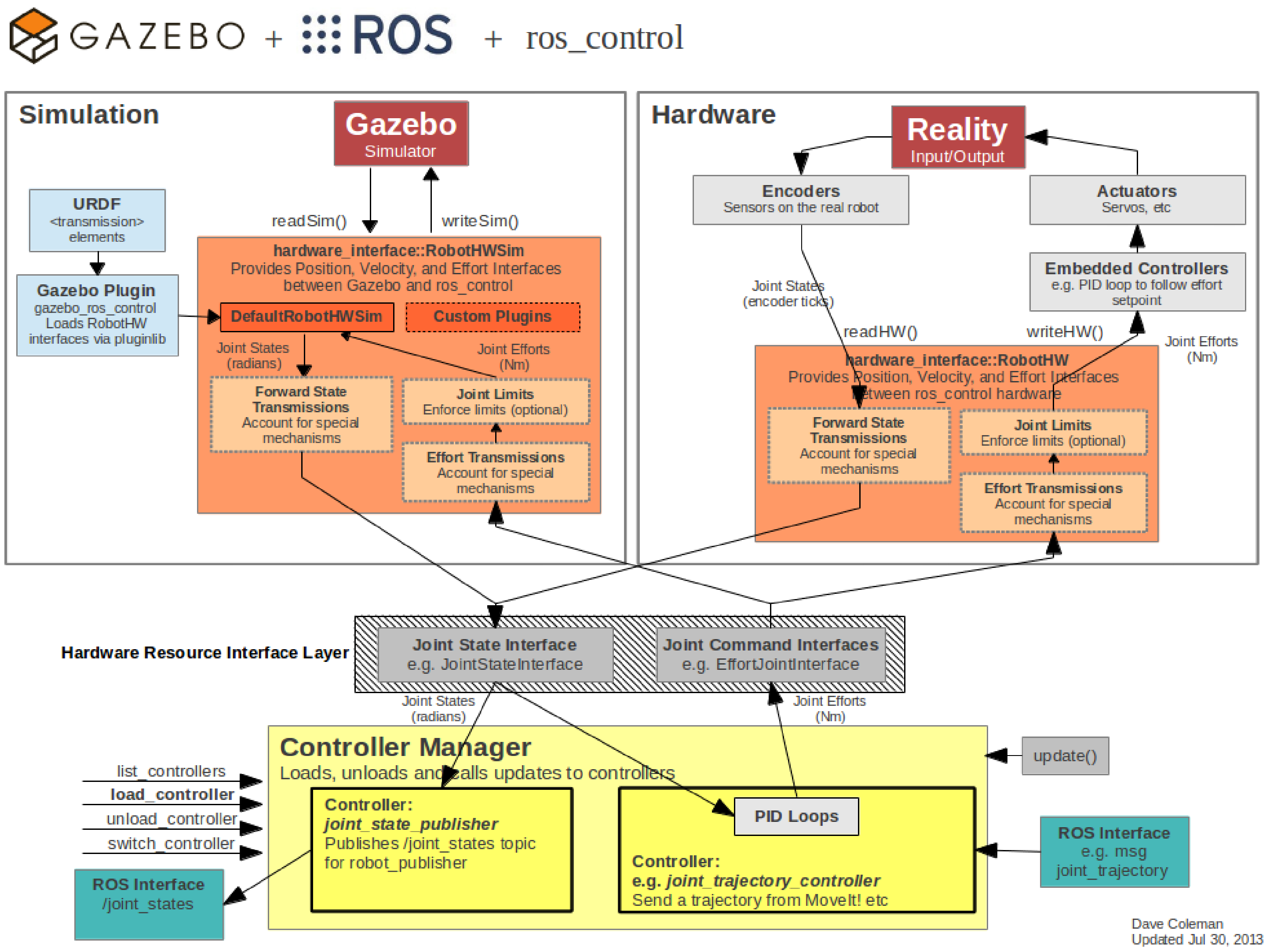
为上下两层提供硬件资源的接口。

➢ 机器人硬件抽象

机器人硬件抽象和硬件资源直接打交道，通过write和read方法完成硬件操作。

➢ 真实机器人

执行接收到的命令。



1. 优化物理仿真模型

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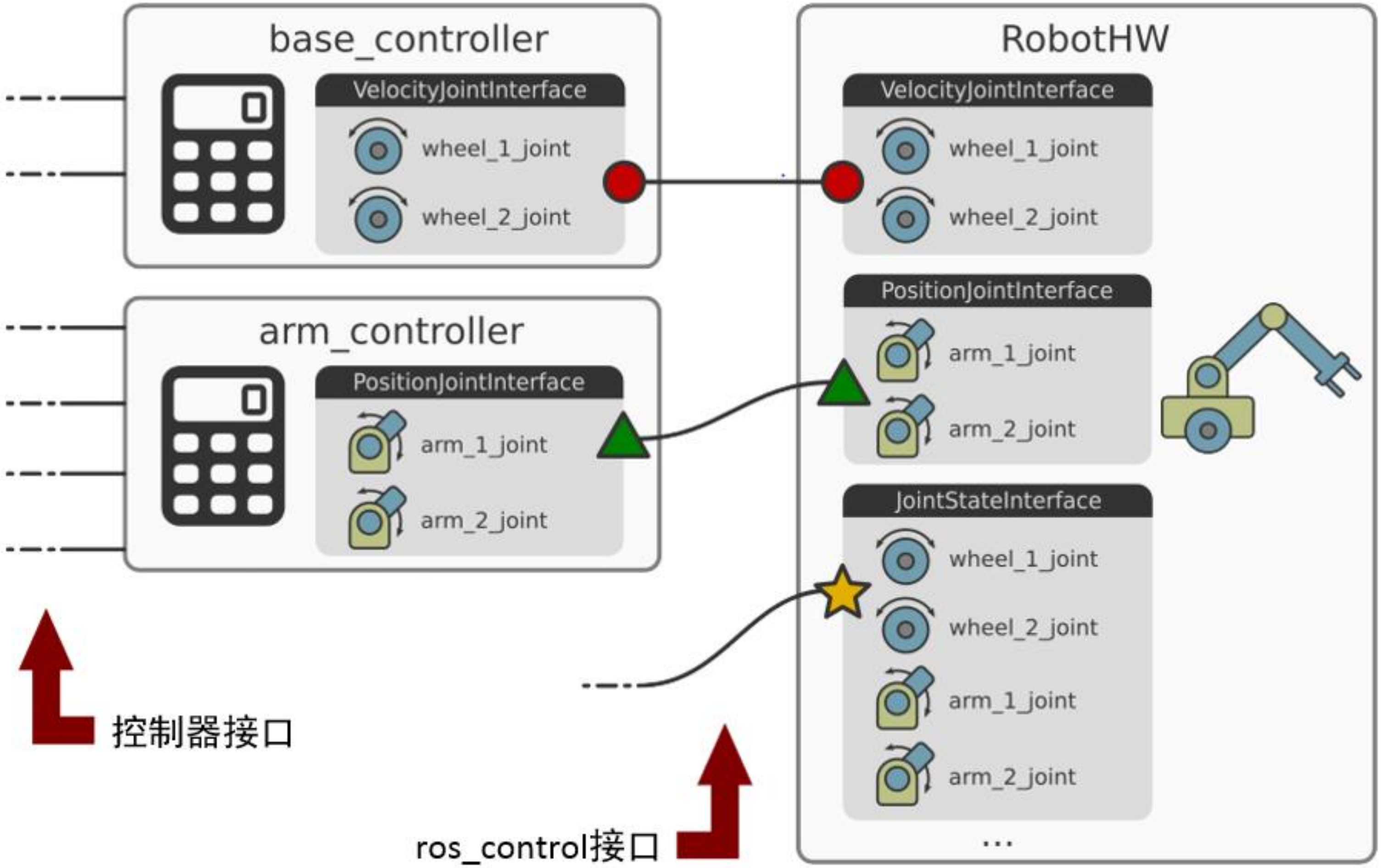
控制器（Controllers）

- ➢ joint_state_controller
- ➢ joint_effort_controller
- ➢ joint_position_controller
- ➢ joint_velocity_controller



可参考：https://github.com/ros-controls/ros_control/wiki/controller_interface

1. 优化物理仿真模型

第一步：为link添加惯性参数和碰撞属性

```xml
<xacro:macro name="cylinder_inertial_matrix" params="m r h">
    <inertial>
        <mass value="${m}" />
        <inertia ixx="${m*(3*r*r+h*h)/12}" ixy = "0" ixz = "0"
            iyy="${m*(3*r*r+h*h)/12}" iyz = "0"
            izz="${m*r*r/2}" />
    </inertial>
</xacro:macro>

<link name="base_link">
    <visual>
        <origin xyz=" 0 0 0" rpy="0 0 0" />
        <geometry>
            <cylinder length="${base_length}" radius="${base_radius}"/>
        </geometry>
        <material name="yellow" />
    </visual>
    <collision>
        <origin xyz=" 0 0 0" rpy="0 0 0" />
        <geometry>
            <cylinder length="${base_length}" radius="${base_radius}"/>
        </geometry>
    </collision>
    <cylinder_inertial_matrix  m="${base_mass}" r="${base_radius}" h="${base_length}" />
</link>
```

古月居 GYH.AI

第二步：为link添加gazebo标签

```xml
<gazebo reference="base_link">
    <material>Gazebo/Blue</material>
</gazebo>
```

```xml
<gazebo reference="${prefix}_wheel_link">
    <material>Gazebo/Gray</material>
</gazebo>
```

```xml
<gazebo reference="base_footprint">
    <turnGravityOff>false</turnGravityOff>
</gazebo>
```

```xml
<gazebo reference="${prefix}_caster_link">
    <material>Gazebo/Black</material>
</gazebo>
```

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第三步：为joint添加传动装置

```xml
<!-- Transmission is important to link the joints and the controller -->
<transmission name="${prefix}_wheel_joint_trans">
    <type>transmission_interface/SimpleTransmission</type>
    <joint name="${prefix}_wheel_joint" >
        <hardwareInterface>hardware_interface/VelocityJointInterface</hardwareInterface>
    </joint>
    <actuator name="${prefix}_wheel_joint_motor">
        <hardwareInterface>hardware_interface/VelocityJointInterface</hardwareInterface>
        <mechanicalReduction>1</mechanicalReduction>
    </actuator>
</transmission>
```

1. 优化物理仿真模型

第四步：添加gazebo控制器插件

- **<robotNamespace>**：机器人的命名空间。
- **<leftJoint>和<rightJoint>**：左右轮转动的关节joint。
- **<wheelSeparation>和<wheelDiameter>**：机器人模型的相关尺寸，在计算差速参数时需要用到。
- **<commandTopic>**：控制器订阅的速度控制指令，生成全局命名时需要结合<robotNamespace>中设置的命名空间。
- **<odometryFrame>**：里程计数据的参考坐标系，ROS中一般都命名为odom。

```xml
<!-- controller -->
<gazebo>
    <plugin name="differential_drive_controller"
            filename="libgazebo_ros_diff_drive.so">
        <rosDebugLevel>Debug</rosDebugLevel>
        <publishWheelTF>true</publishWheelTF>
        <robotNamespace>/</robotNamespace>
        <publishTf>1</publishTf>
        <publishWheelJointState>true</publishWheelJointState>
        <alwaysOn>true</alwaysOn>
        <updateRate>100.0</updateRate>
        <legacyMode>true</legacyMode>
        <leftJoint>left_wheel_joint</leftJoint>
        <rightJoint>right_wheel_joint</rightJoint>
        <wheelSeparation>${wheel_joint_y*2}</wheelSeparation>
        <wheelDiameter>${2*wheel_radius}</wheelDiameter>
        <broadcastTF>1</broadcastTF>
        <wheelTorque>30</wheelTorque>
        <wheelAcceleration>1.8</wheelAcceleration>
        <commandTopic>cmd_vel</commandTopic>
        <odometryFrame>odom</odometryFrame>
        <odometryTopic>odom</odometryTopic>
        <robotBaseFrame>base_footprint</robotBaseFrame>
    </plugin>
</gazebo>
```

1. 优化物理仿真模型

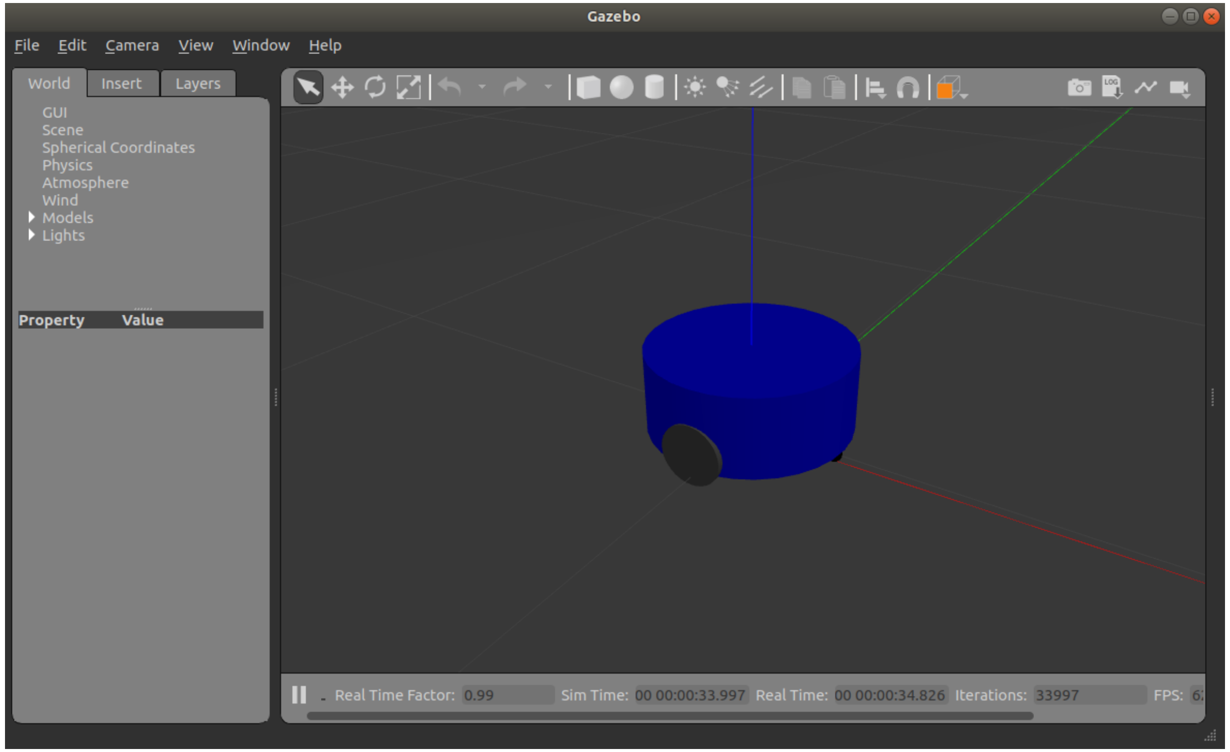
```
<launch>

    <!-- 设置launch文件的参数 -->
    <arg name="paused" default="false"/>
    <arg name="use_sim_time" default="true"/>
    <arg name="gui" default="true"/>
    <arg name="headless" default="false"/>
    <arg name="debug" default="false"/>

    <!-- 运行gazebo仿真环境 -->
    <include file="$(find gazebo_ros)/launch/empty_world.launch">
        <arg name="debug" value="$(arg debug)" />
        <arg name="gui" value="$(arg gui)" />
        <arg name="paused" value="$(arg paused)"/>
        <arg name="use_sim_time" value="$(arg use_sim_time)"/>
        <arg name="headless" value="$(arg headless)"/>
    </include>

    <!-- 加载机器人模型描述参数 -->
    <param name="robot_description" command="$(find xacro)/xacro --inorder '$(find
    mbot_description)/urdf/mbot_gazebo.xacro'" />

    <!-- 运行joint_state_publisher节点，发布机器人的关节状态  -->
    <node name="joint_state_publisher" pkg="joint_state_publisher" type="joint_state_publisher" ></node>

    <!-- 运行robot_state_publisher节点，发布tf  -->
    <node name="robot_state_publisher" pkg="robot_state_publisher" type="robot_state_publisher"  output="screen" >
        <param name="publish_frequency" type="double" value="50.0" />
    </node>

    <!-- 在gazebo中加载机器人模型-->
    <node name="urdf_spawner" pkg="gazebo_ros" type="spawn_model" respawn="false" output="screen"
          args="-urdf -model mrobot -param robot_description"/>

</launch>
```

在gazebo中加载机器人模型

view_mbot_gazebo_empty_world.launch

1. 优化物理仿真模型

空环境中的机器人



$ roslaunch mbot_gazebo view_mbot_gazebo_empty_world.launch

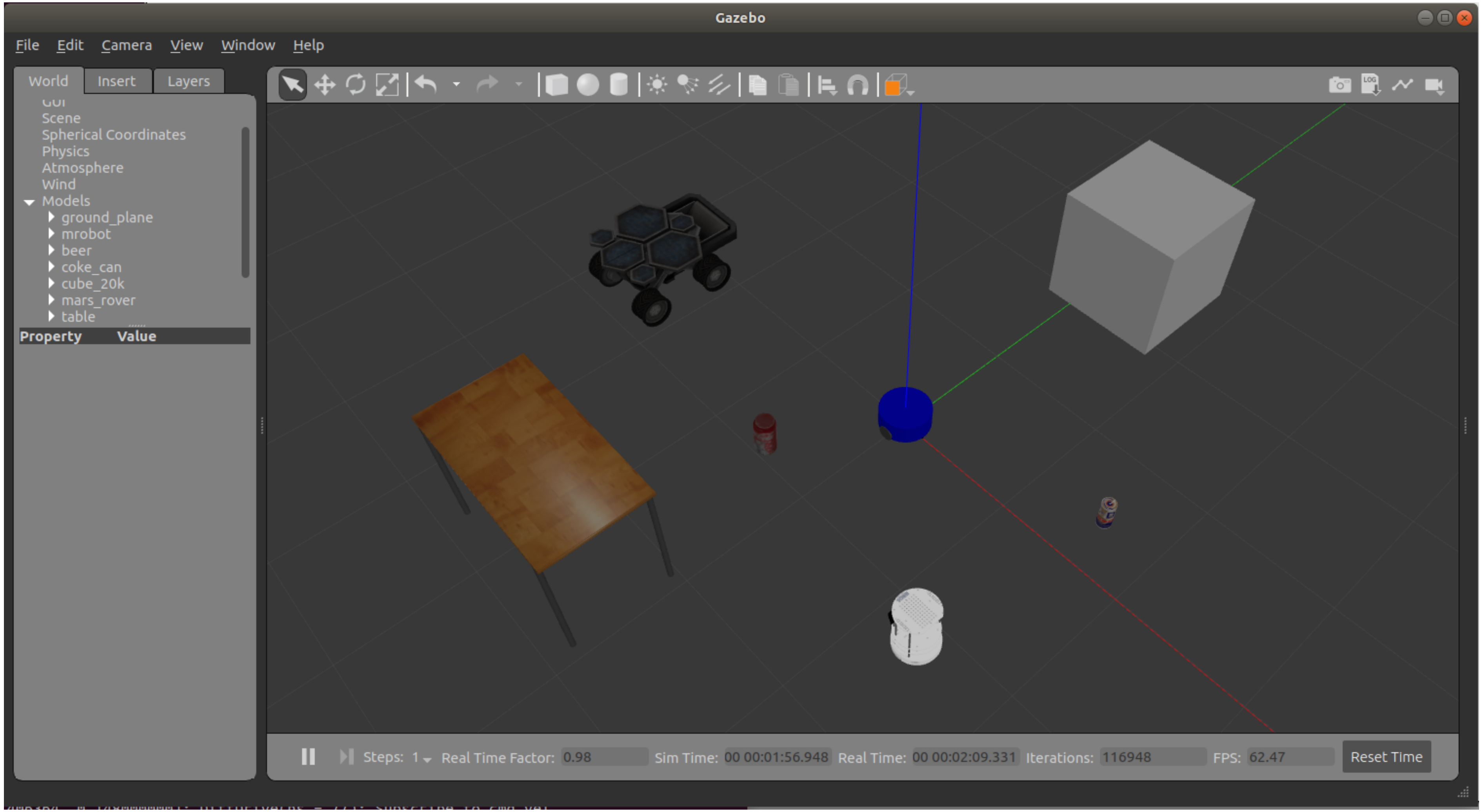
建议：为保证模型顺利加载，请将离线模型文件库下载并放置到~/.gazebo/models下

https://bitbucket.org/osrf/gazebo_models/downloads/

2. 创建物理仿真环境

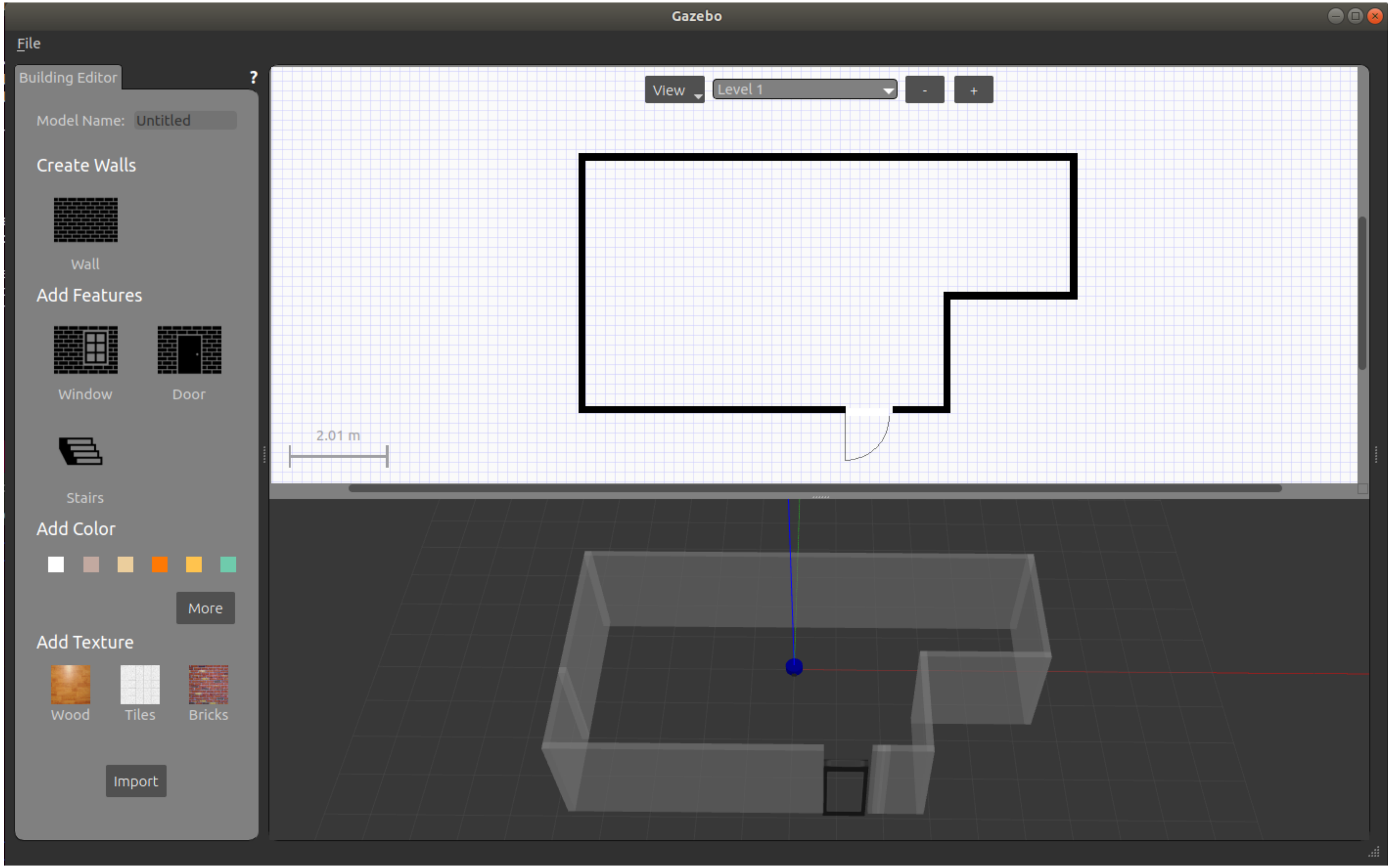
2. 创建物理仿真环境

第一种方法：直接添加环境模型

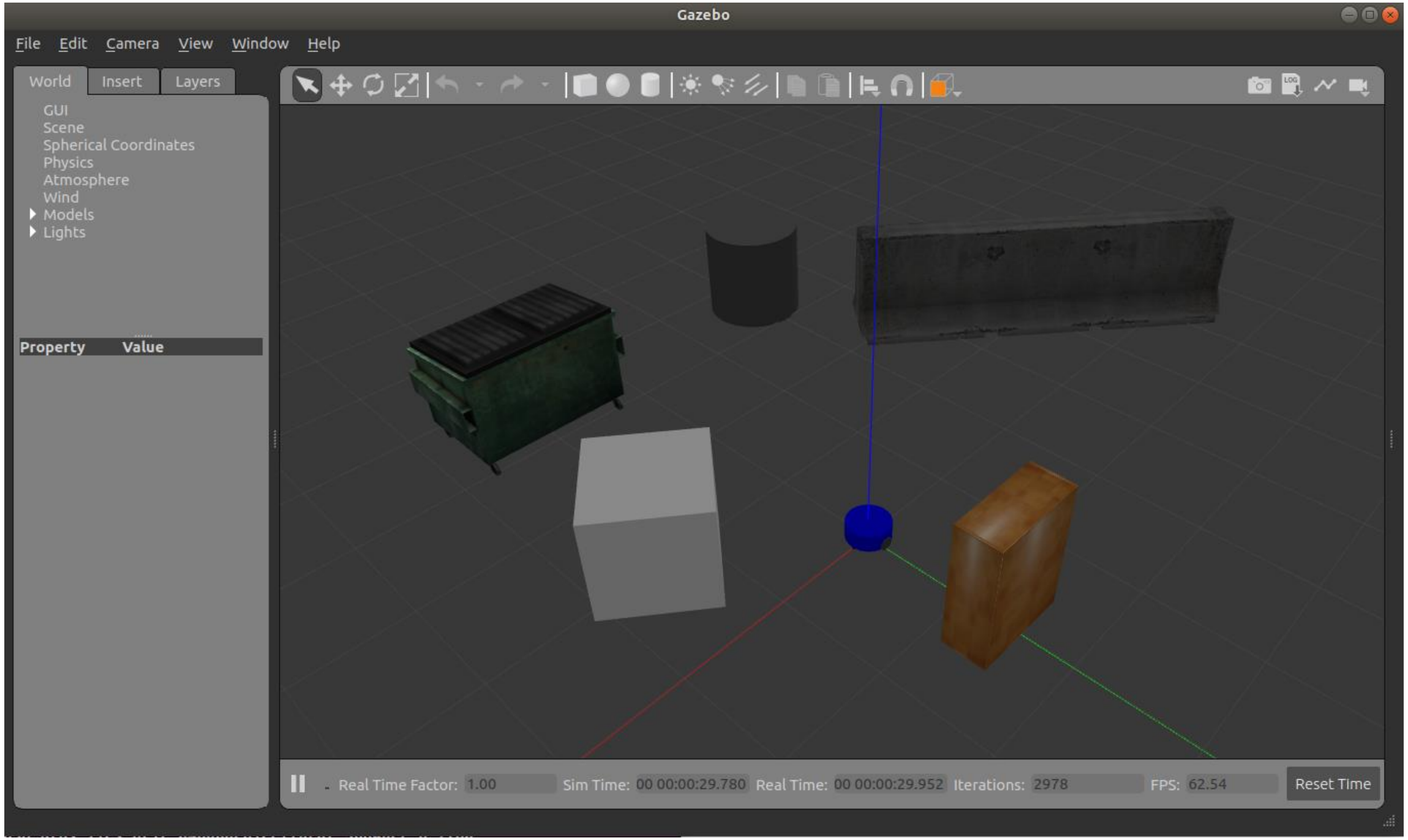


2. 创建物理仿真环境

第二种方法：使用Building Editor



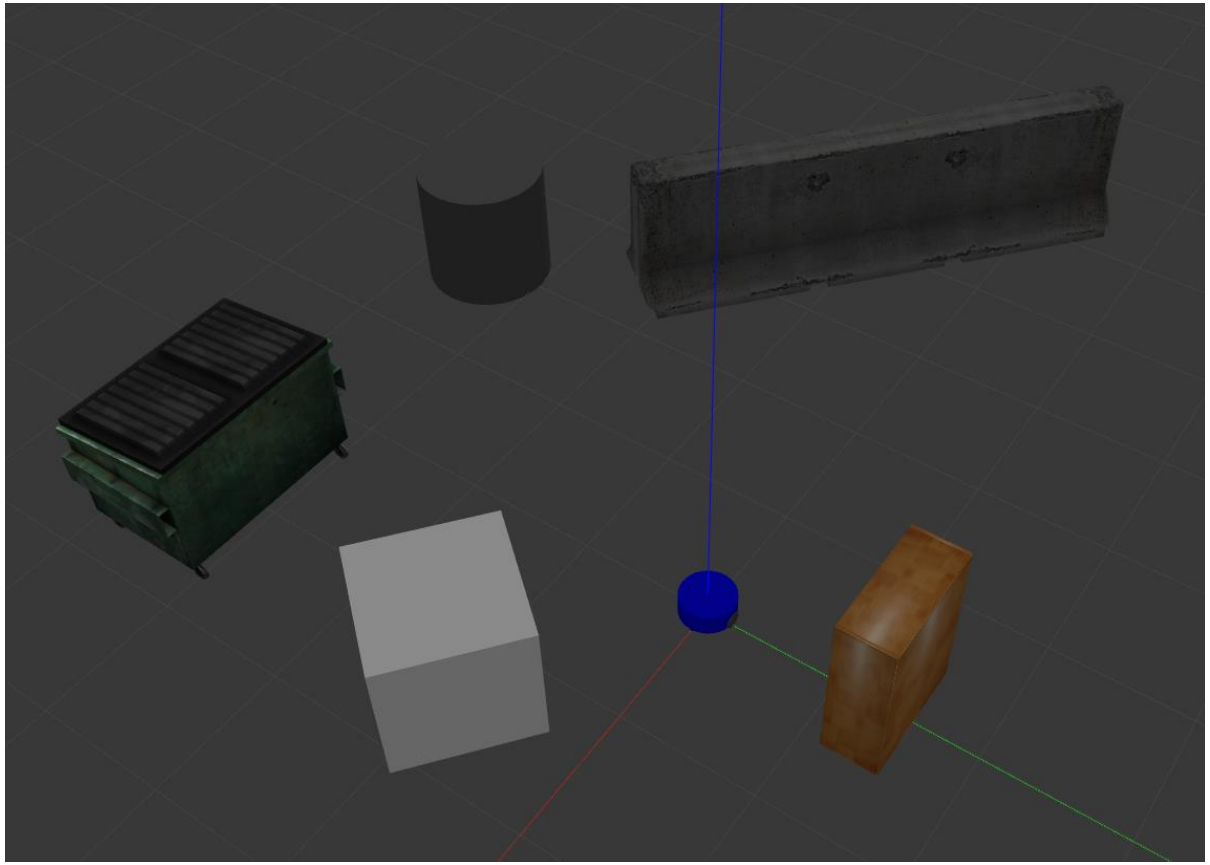
2. 创建物理仿真环境



启动仿真环境 roslaunch mbot_gazebo view_mbot_gazebo_play_ground.launch

2. 创建物理仿真环境

```
hcx@hcx-pc:~$ rostopic list
/clock
/cmd_vel
/gazebo/link_states
/gazebo/model_states
/gazebo/parameter_descriptions
/gazebo/parameter_updates
/gazebo/set_link_state
/gazebo/set_model_state
/joint_states
/odom
/rosout
/rosout_agg
/tf
/tf_static
```



启动键盘控制　roslaunch mbot_teleop mbot_teleop.launch

3. 传感器仿真及应用

3. 传感器仿真及应用

摄像头仿真

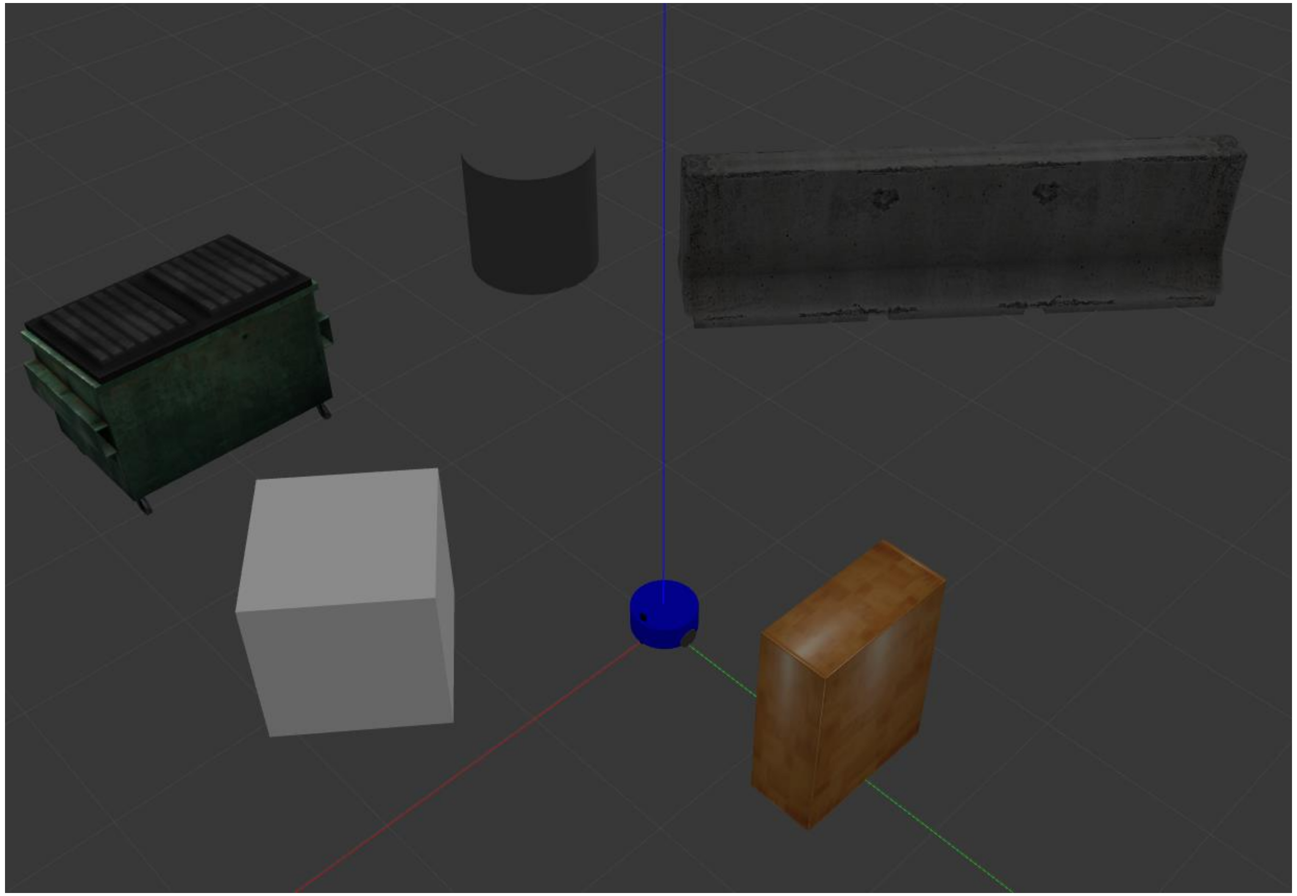
- **<sensor>标签：描述传感器**
  - type：传感器类型，camera
  - name：摄像头命名，自由设置
- **<camera>标签：描述摄像头参数**
  - 分辨率，编码格式，图像范围，噪音参数等
- **<plugin>标签：加载摄像头仿真插件**

  libgazebo_ros_camera.so
  - 设置插件的命名空间、发布图像的话题、参考坐标系等

```xml
<gazebo reference="${prefix}_link">
    <sensor type="camera" name="camera_node">
        <update_rate>30.0</update_rate>
        <camera name="head">
            <horizontal_fov>1.3962634</horizontal_fov>
            <image>
                <width>1280</width>
                <height>720</height>
                <format>R8G8B8</format>
            </image>
            <clip>
                <near>0.02</near>
                <far>300</far>
            </clip>
            <noise>
                <type>gaussian</type>
                <mean>0.0</mean>
                <stddev>0.007</stddev>
            </noise>
        </camera>
        <plugin name="gazebo_camera" filename="libgazebo_ros_camera.so">
            <alwaysOn>true</alwaysOn>
            <updateRate>0.0</updateRate>
            <cameraName>/camera</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>
```

camera_gazebo.xacro

3. 传感器仿真及应用



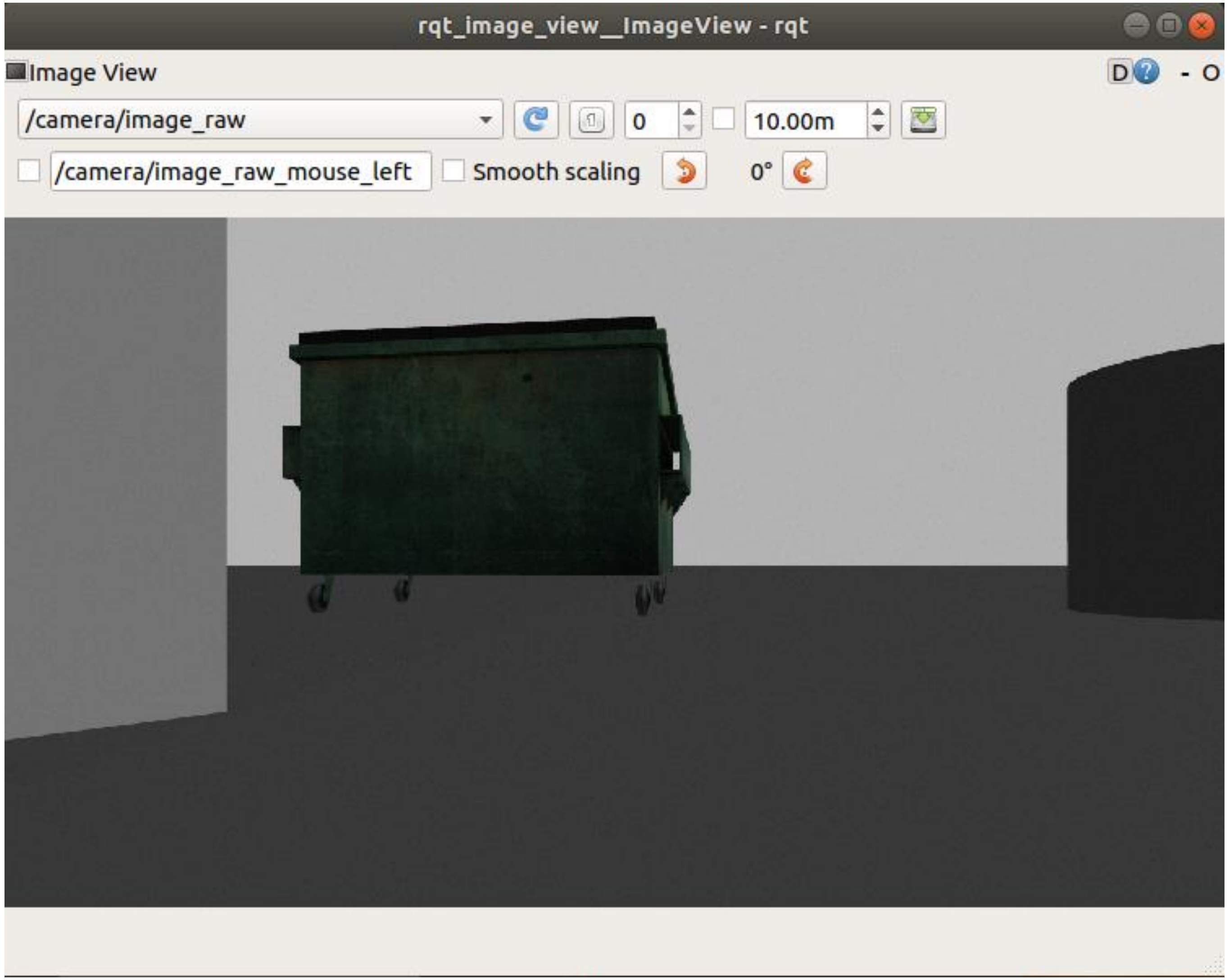
```
hcx@hcx-pc:~$ rostopic list
/camera/camera_info
/camera/image_raw
/camera/image_raw/compressed
/camera/image_raw/compressed/parameter_descriptions
/camera/image_raw/compressed/parameter_updates
/camera/image_raw/compressedDepth
/camera/image_raw/compressedDepth/parameter_descriptions
/camera/image_raw/compressedDepth/parameter_updates
/camera/image_raw/theora
/camera/image_raw/theora/parameter_descriptions
/camera/image_raw/theora/parameter_updates
/camera/parameter_descriptions
/camera/parameter_updates
/clock
/cmd_vel
/gazebo/link_states
/gazebo/model_states
/gazebo/parameter_descriptions
/gazebo/parameter_updates
/gazebo/set_link_state
/gazebo/set_model_state
/joint_states
/odom
/rosout
/rosout_agg
/tf
/tf_static
```

启动仿真环境 roslaunch mbot_gazebo view_mbot_with_camera_gazebo.launch

3. 传感器仿真及应用

查看摄像头仿真图像

$ rqt_image_view



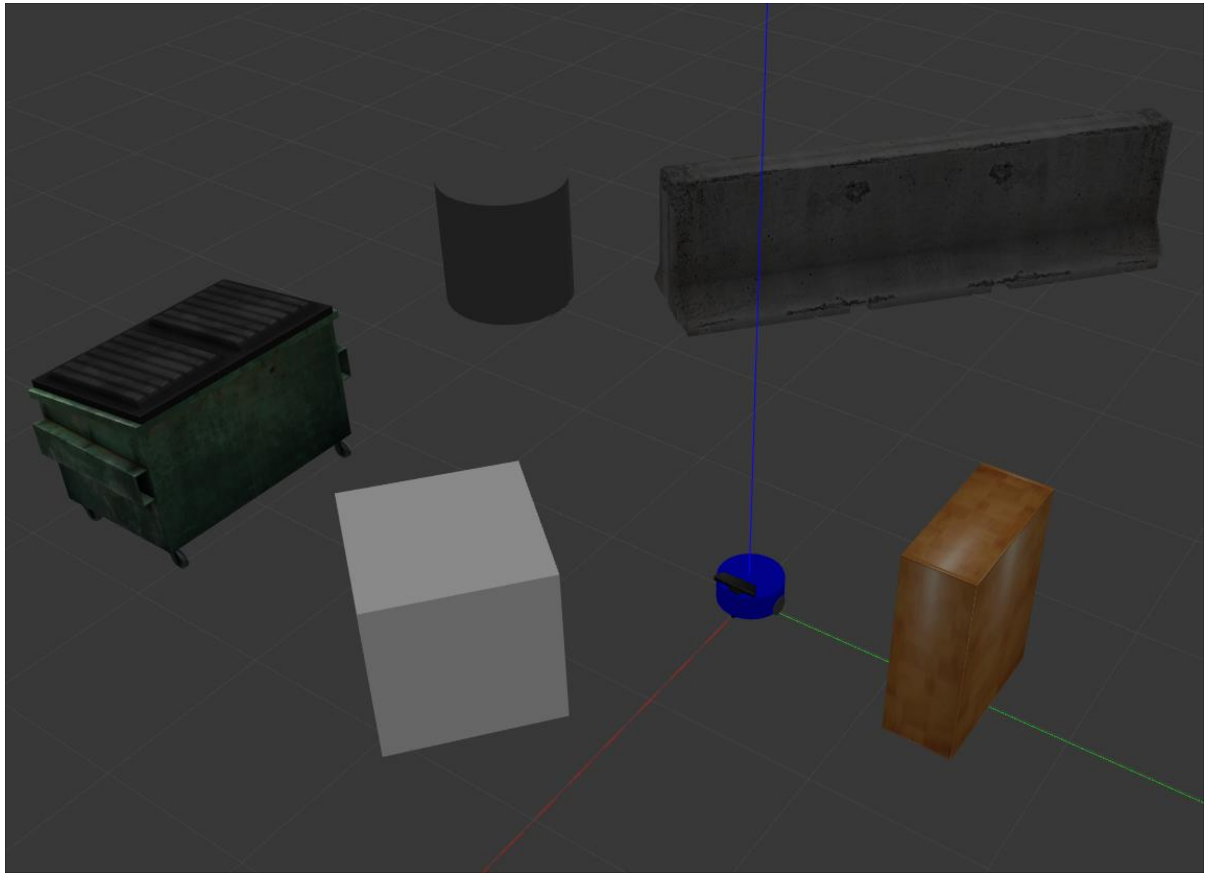
3. 传感器仿真及应用

RGB-D摄像头仿真（kinect）

```xml
<gazebo reference="${prefix}_link">
    <sensor type="depth" name="${prefix}">
        <always_on>true</always_on>
        <update_rate>20.0</update_rate>
        <camera>
            <horizontal_fov>${60.0*M_PI/180.0}</horizontal_fov>
            <image>
                <format>R8G8B8</format>
                <width>640</width>
                <height>480</height>
            </image>
            <clip>
                <near>0.05</near>
                <far>8.0</far>
            </clip>
        </camera>
        <plugin name="kinect_${prefix}_controller" filename="libgazebo_ros_openni_kinect.so">
            <cameraName>${prefix}</cameraName>
            <alwaysOn>true</alwaysOn>
            <updateRate>10</updateRate>
            <imageTopicName>rgb/image_raw</imageTopicName>
            <depthImageTopicName>depth/image_raw</depthImageTopicName>
            <pointCloudTopicName>depth/points</pointCloudTopicName>
            <cameraInfoTopicName>rgb/camera_info</cameraInfoTopicName>
            <depthImageCameraInfoTopicName>depth/camera_info</depthImageCameraInfoTopicName>
            <frameName>${prefix}_frame_optical</frameName>
            <baseline>0.1</baseline>
            <distortion_k1>0.0</distortion_k1>
            <distortion_k2>0.0</distortion_k2>
            <distortion_k3>0.0</distortion_k3>
            <distortion_t1>0.0</distortion_t1>
            <distortion_t2>0.0</distortion_t2>
            <pointCloudCutoff>0.4</pointCloudCutoff>
        </plugin>
    </sensor>
</gazebo>
```

kinect_gazebo.xacro

3. 传感器仿真及应用

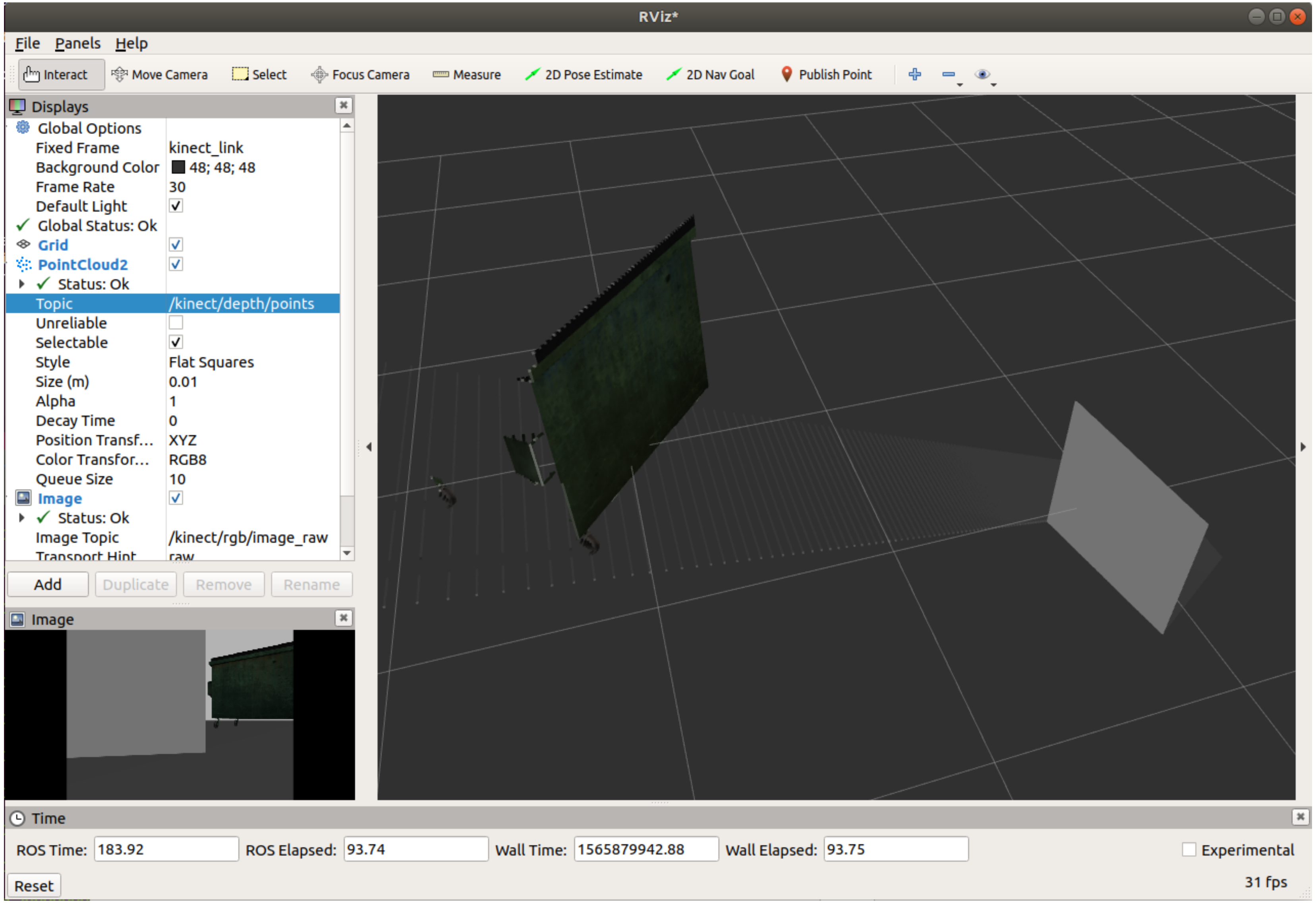


```
hcx@hcx-pc:~$ rostopic list
/clock
/cmd_vel
/gazebo/link_states
/gazebo/model_states
/gazebo/parameter_descriptions
/gazebo/parameter_updates
/gazebo/set_link_state
/gazebo/set_model_state
/joint_states
/kinect/depth/camera_info
/kinect/depth/image_raw
/kinect/depth/points
/kinect/parameter_descriptions
/kinect/parameter_updates
/kinect/rgb/camera_info
/kinect/rgb/image_raw
/kinect/rgb/image_raw/compressed
/kinect/rgb/image_raw/compressed/parameter_descriptions
/kinect/rgb/image_raw/compressed/parameter_updates
/kinect/rgb/image_raw/compressedDepth
/kinect/rgb/image_raw/compressedDepth/parameter_descriptions
/kinect/rgb/image_raw/compressedDepth/parameter_updates
/kinect/rgb/image_raw/theora
/kinect/rgb/image_raw/theora/parameter_descriptions
/kinect/rgb/image_raw/theora/parameter_updates
/odom
/rosout
/rosout_agg
/tf
/tf_static
```

启动仿真环境　roslaunch mbot_gazebo view_mbot_with_kinect_gazebo.launch

3. 传感器仿真及应用

在rviz中查看Kinect信息



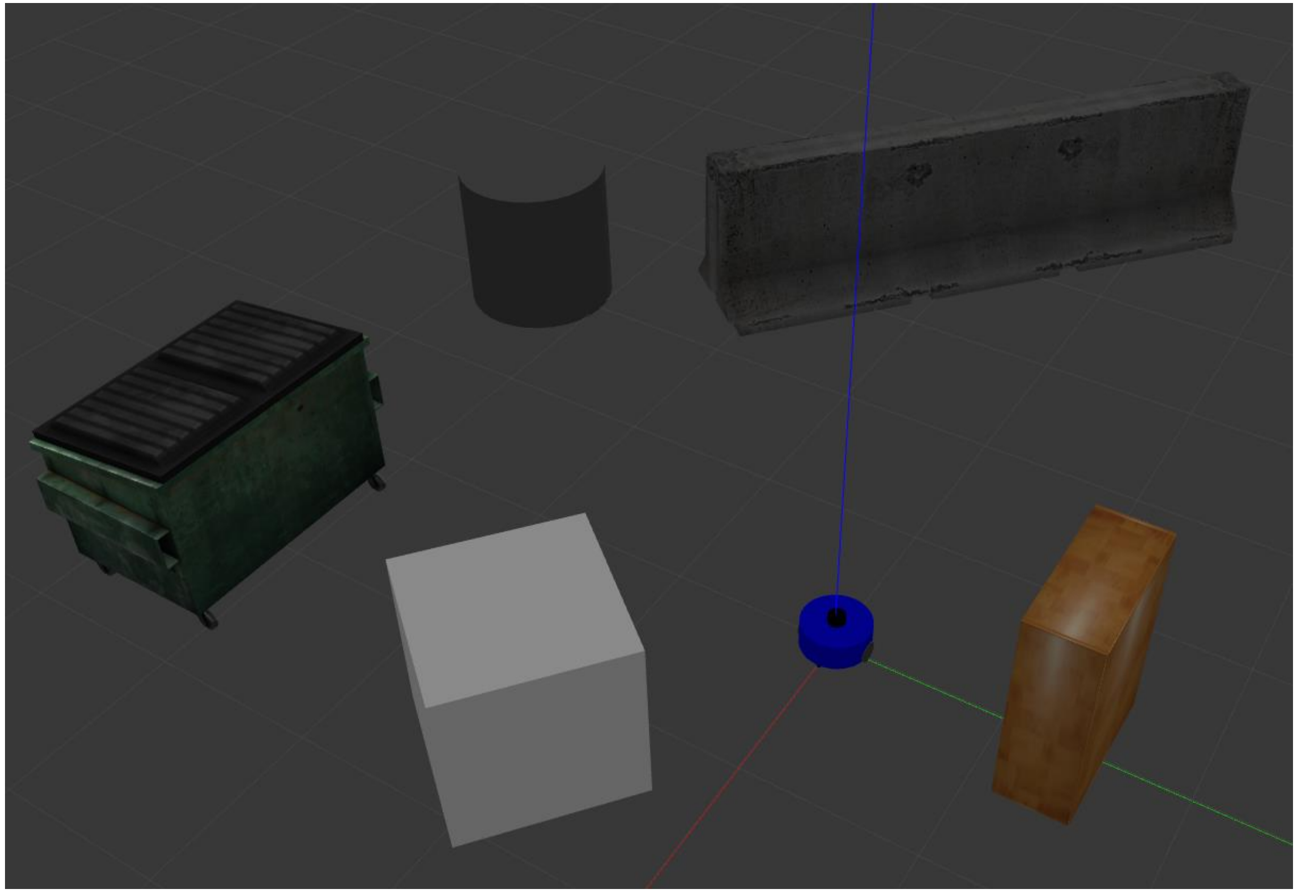
3. 传感器仿真及应用

激光雷达仿真

```xml
<gazebo reference="${prefix}_link">
    <sensor type="ray" name="rplidar">
        <pose>0 0 0 0 0 0</pose>
        <visualize>false</visualize>
        <update_rate>5.5</update_rate>
        <ray>
            <scan>
              <horizontal>
                <samples>360</samples>
                <resolution>1</resolution>
                <min_angle>-3</min_angle>
                <max_angle>3</max_angle>
              </horizontal>
            </scan>
            <range>
              <min>0.10</min>
              <max>6.0</max>
              <resolution>0.01</resolution>
            </range>
            <noise>
              <type>gaussian</type>
              <mean>0.0</mean>
              <stddev>0.01</stddev>
            </noise>
        </ray>
        <plugin name="gazebo_rplidar" filename="libgazebo_ros_laser.so">
            <topicName>/scan</topicName>
            <frameName>laser_link</frameName>
        </plugin>
    </sensor>
</gazebo>
```

lidar_gazebo.xacro

3. 传感器仿真及应用

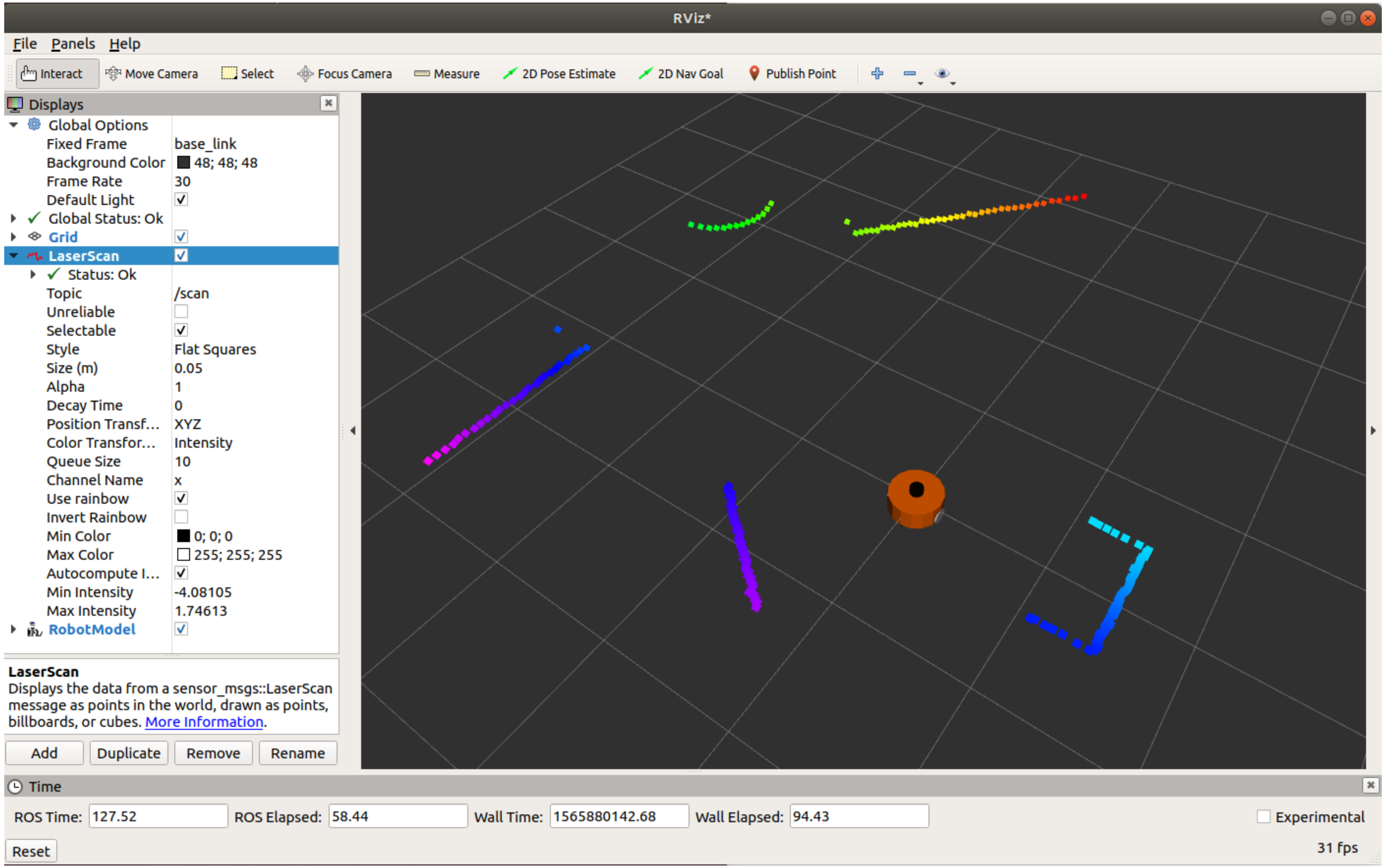


```
hcx@hcx-pc:~$ rostopic list
/clock
/cmd_vel
/gazebo/link_states
/gazebo/model_states
/gazebo/parameter_descriptions
/gazebo/parameter_updates
/gazebo/set_link_state
/gazebo/set_model_state
/joint_states
/odom
/rosout
/rosout_agg
/scan
/tf
/tf_static
```

启动仿真环境 roslaunch mbot_gazebo view_mbot_with_laser_gazebo.launch

3. 传感器仿真及应用

在rviz中查看激光雷达信息



本讲小结

优化物理仿真模型	• 为link添加惯性参数和碰撞属性 • 为link添加gazebo标签 • 为joint添加传动装置 • 添加gazebo控制器插件
创建物理仿真环境	• 直接添加环境模型 • 使用Building Editor
传感器仿真及应用	摄像头、RGBD、激光雷达

本讲作业

1. 将上讲作业创建的机器人URDF模型，改写成xacro文件，创建仿真环境，将机器人模型加载到Gazebo仿真环境中，完成运动控制的仿真；

2. 在机器人模型上添加摄像头和激光雷达，将机器人模型加载到Gazebo中，完成传感器的仿真，并在rviz中显示传感器数据。

扩展阅读

- ROS xacro使用方法
http://wiki.ros.org/xacro

- rviz与Gazebo的区别
https://www.zhihu.com/question/268658280/answer/340190866

- Gazebo仿真教程
http://gazebosim.org/tutorials

- ROS探索总结（三十一）—— ros_control
http://www.guyuehome.com/890

- ROS探索总结（二十四）—— 使用gazebo中的插件
http://www.guyuehome.com/388

Thank You

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