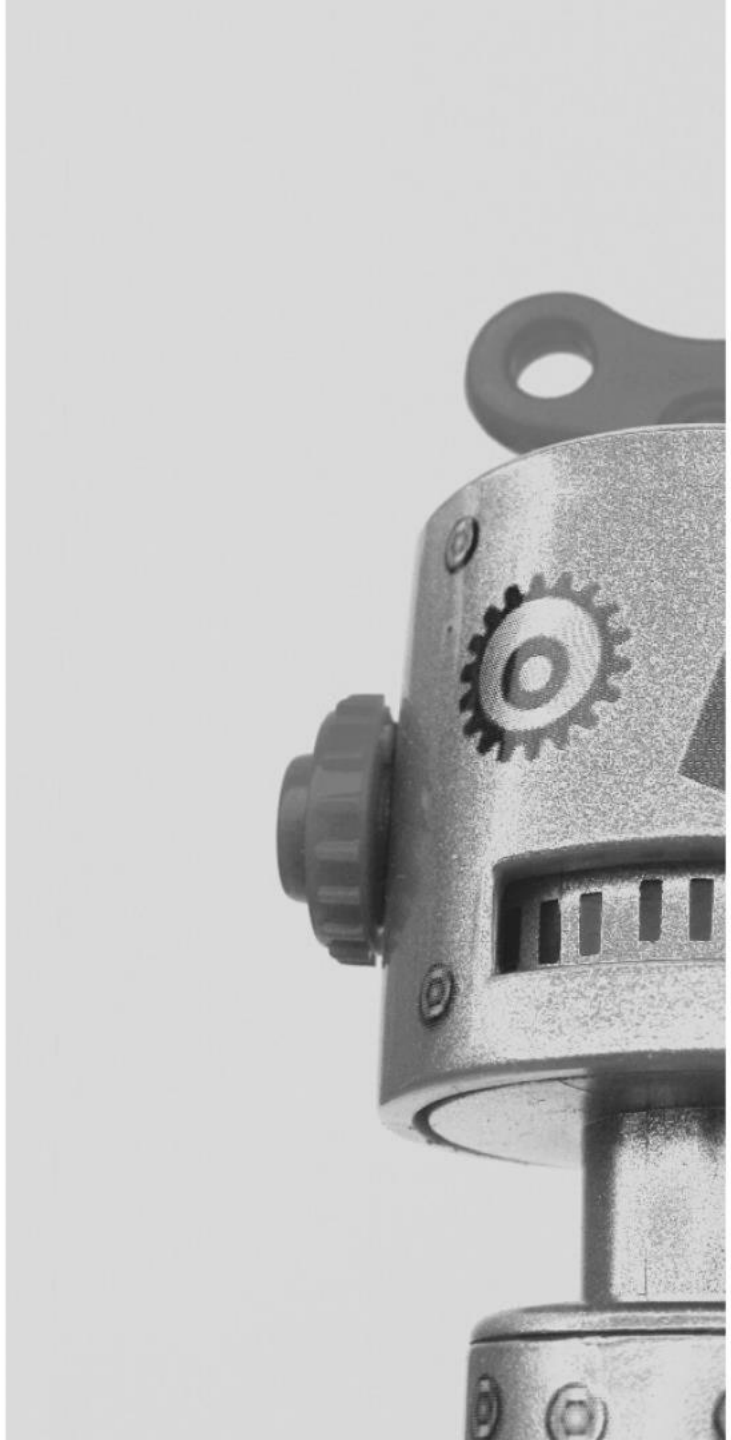


Real Robot & 3D sensor

OVERVIEW

Real Robot

- Understanding robot hardware
- Setup Software Environment
- Control the Robot
  - With Controller
  - With Simple Script

Understanding 3D sensor

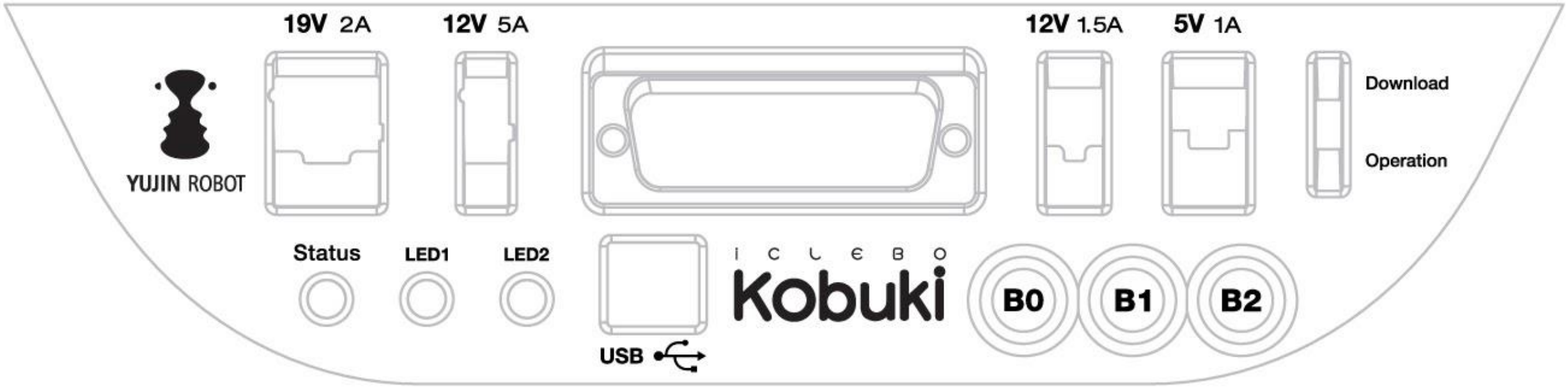
- Concept of 3D sensor
- Install and testing Kinect (3D sensor)
- Human Follower Experiment

Robot Hardware

Turtlebot 2

http://kobuki.yujinrobot.com/about2/

Robot Hardware



19V/2A: Laptop power supply
12V/5A: Arm power supply
12v/1.5A: Microsoft Kinect power supply
5V/1A: General power supply
Status LED: Indicates Kobuki's status
Green: Kobuki is turned on and battery at high voltage level
Orange: On - Low battery voltage level (please charge soon)
Green blinking: On - Battery charging
Off: Kobuki is turned off.
LED1/2: Programmable LEDs
USB: Data connection
BO/1/2: Buttons
Firmware switch: Enable/disables the firmware update mode

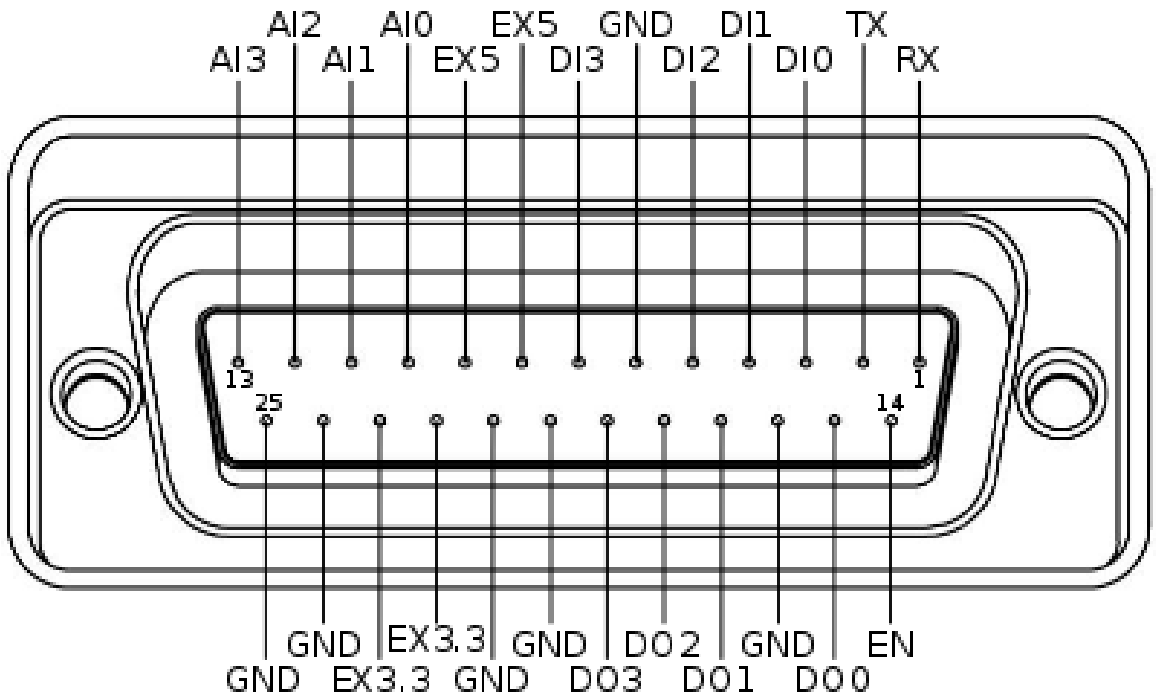
http://kobuki.yujinrobot.com/about2/

Robot Hardware

Power

- 5V@1A Molex PN : 43650-0218 – for custom boards
- 12V@1.5A : Molex PN : 43045-0224 – specially supporting the Kinect
- 12V@5A : Molex PN : 3929-9023 – for high powered accessories (e.g. robotic arm)
- 19V@2A : Molex PN : 3928-9068 – for recharging netbooks

Robot Hardware

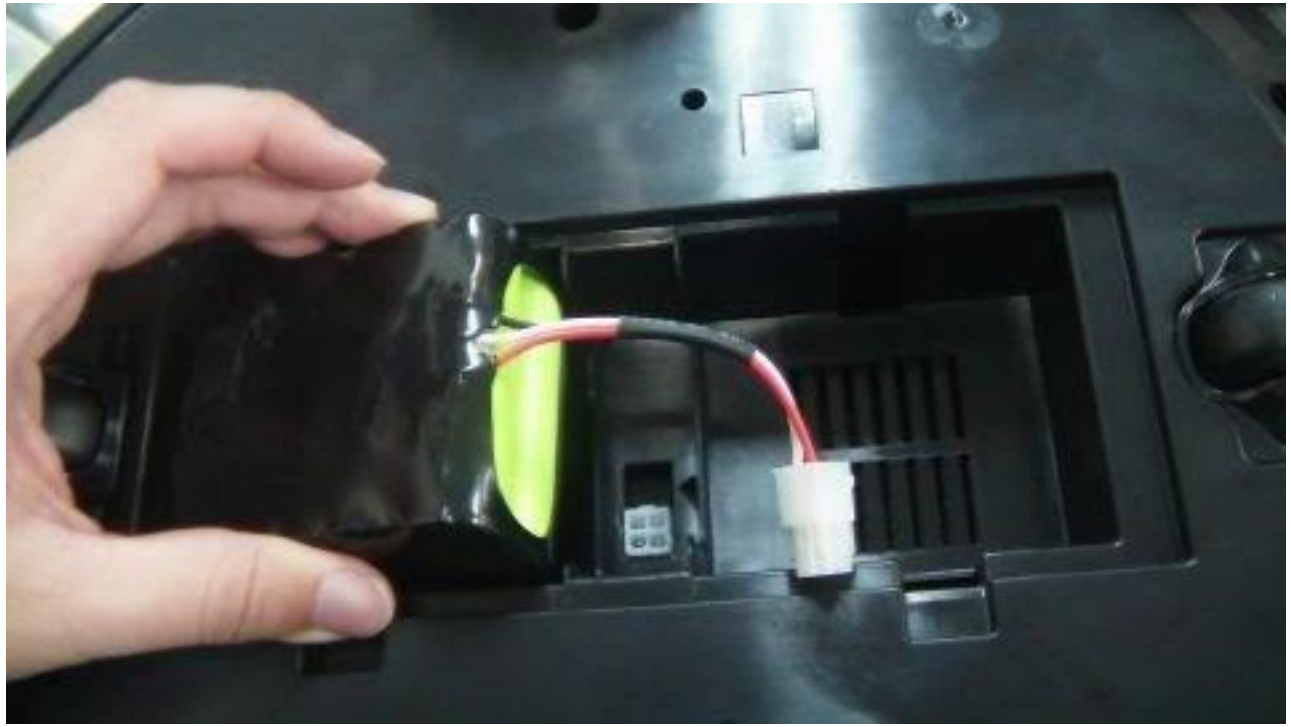


I/O Port

- DB25 pin D-SUB Female connector

RX / TX: Serial data connection (RS232; used voltage level is 3.3V!)
EX3.3 / EX5: 3.3V/1A and 5V/1A power supply
DI0 – 3: 4 x Digital input (high: 3.3 - 5V, low: 0V)
DO0 – 3: 4 x Digital output (open-drain, pull-up resistor required)
AI0-3: 4 x Analog input (12bit ADC: 0 - 4095, 0 - 3.3V)
GND: Ground
EN: Used for detecting an external board (connect to external ground)

Robot Hardware



Battery

- 4S1P/4S2P Battery Pack Connector

Robot Hardware

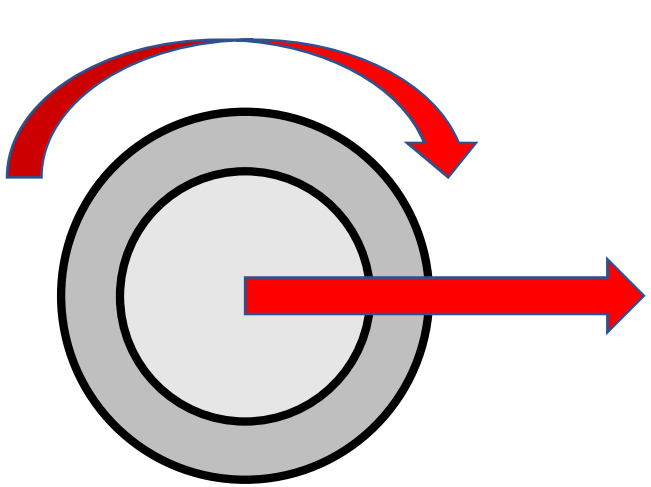
Cables

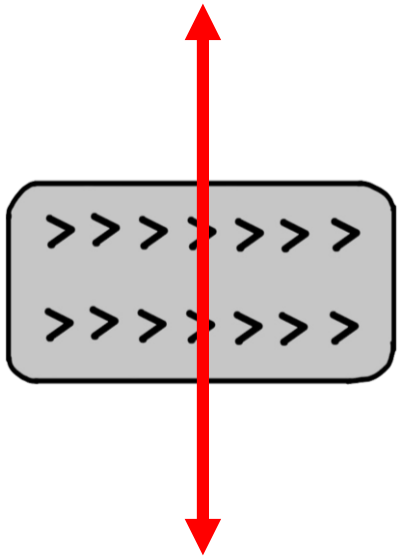
- **12V@1.5A :** Molex PN : 43025-0200 – specially supporting the Kinect

Wheel Locomotion

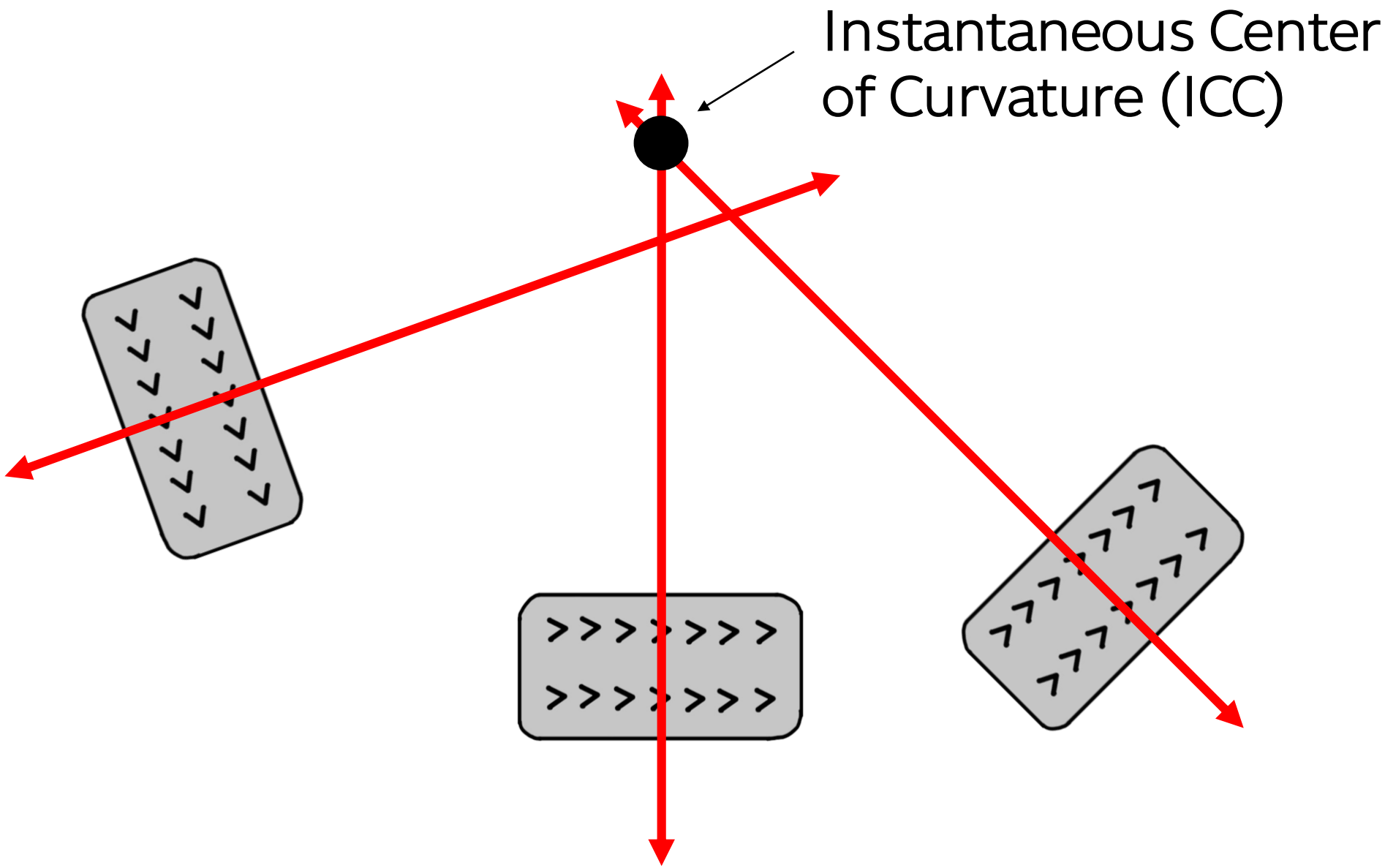
Locomotion : Power of motion from place to place

- Differential Drive (turtlebot)
- Car Drive (Ackerman steering)
- Mecanum Wheel Drive

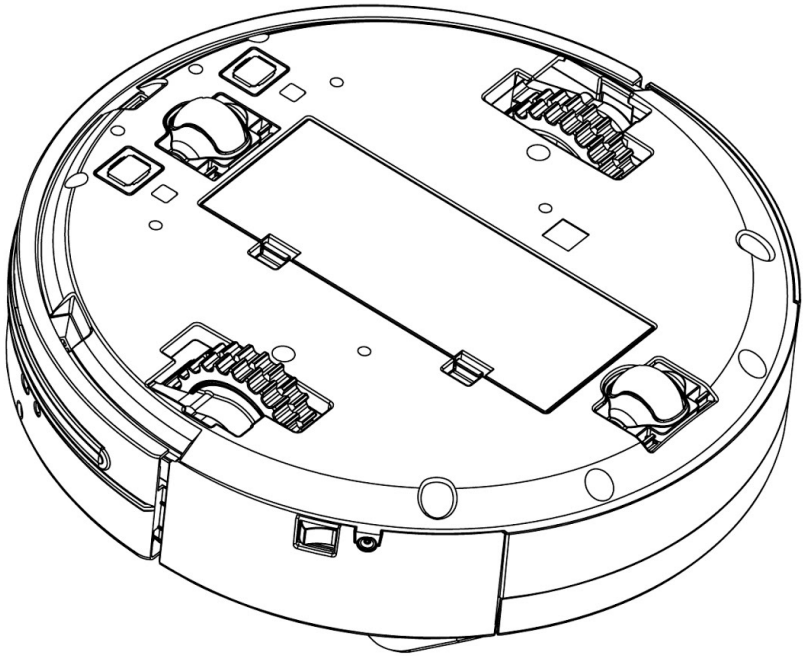


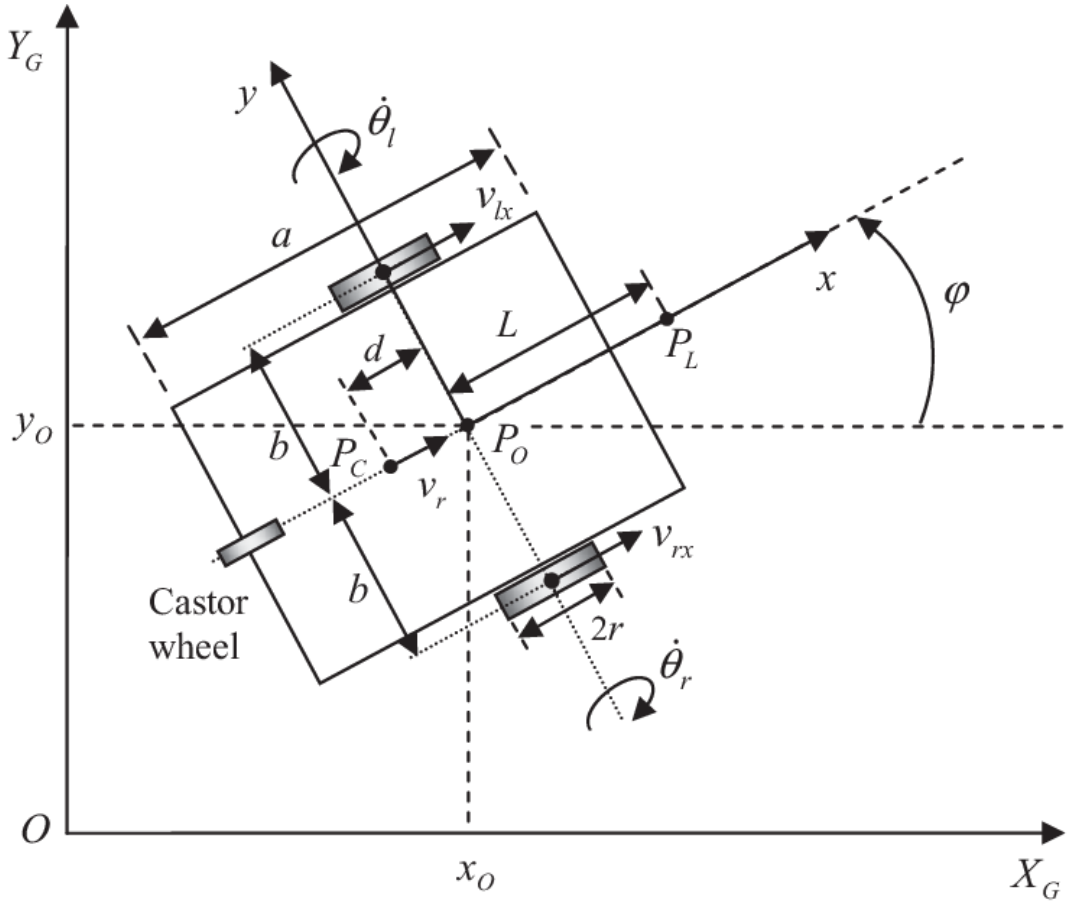


Wheel Locomotion



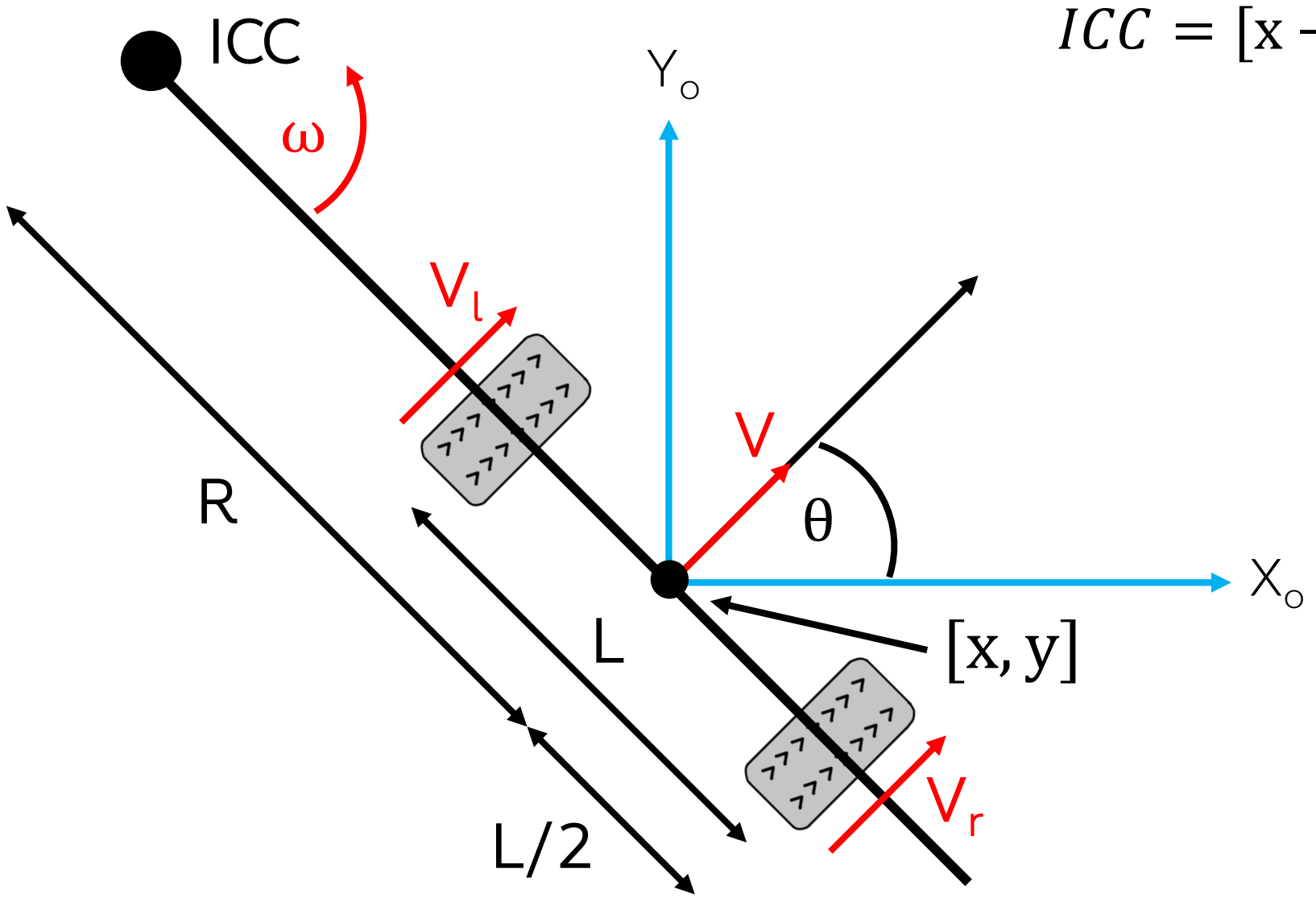
Wheel Locomotion
(Differential Drive)





Differential Drive robot

Wheel Locomotion
(Differential Drive)



$$ICC = [x - R\sin(\theta), y + R\cos(\theta)]$$

$$\omega\left(R + \frac{L}{2}\right) = V_r$$

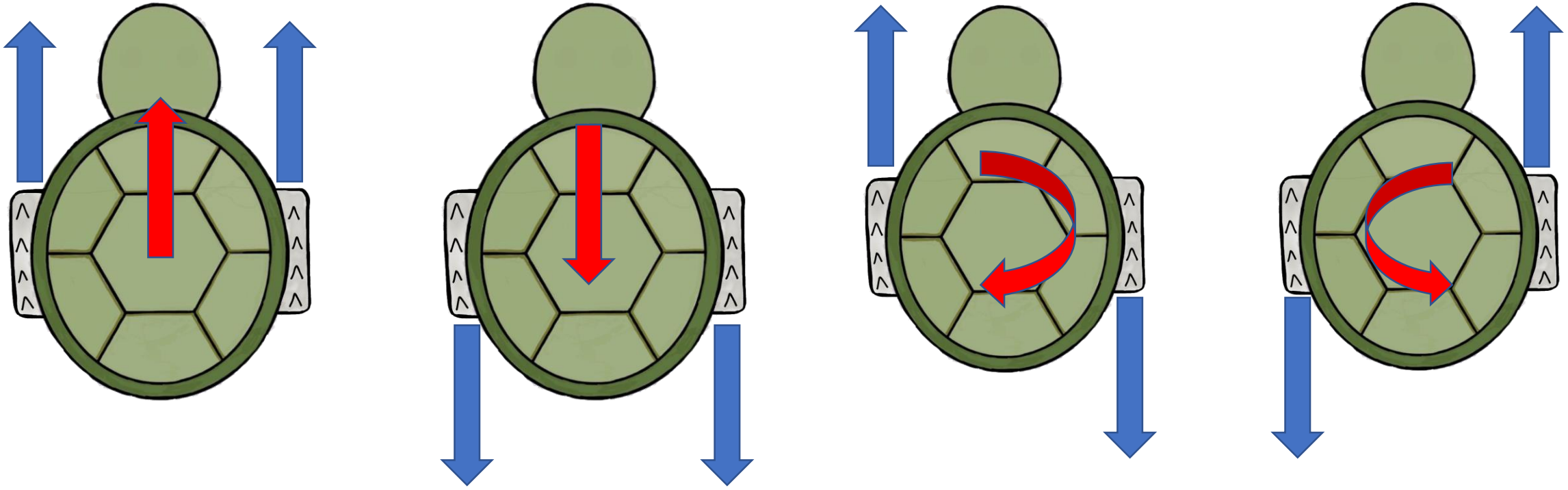
$$\omega\left(R - \frac{L}{2}\right) = V_l$$

$$R = \frac{L}{2}\frac{(V_l + V_r)}{(V_r - V_l)}$$

$$\omega = \frac{(V_r - V_l)}{L}$$

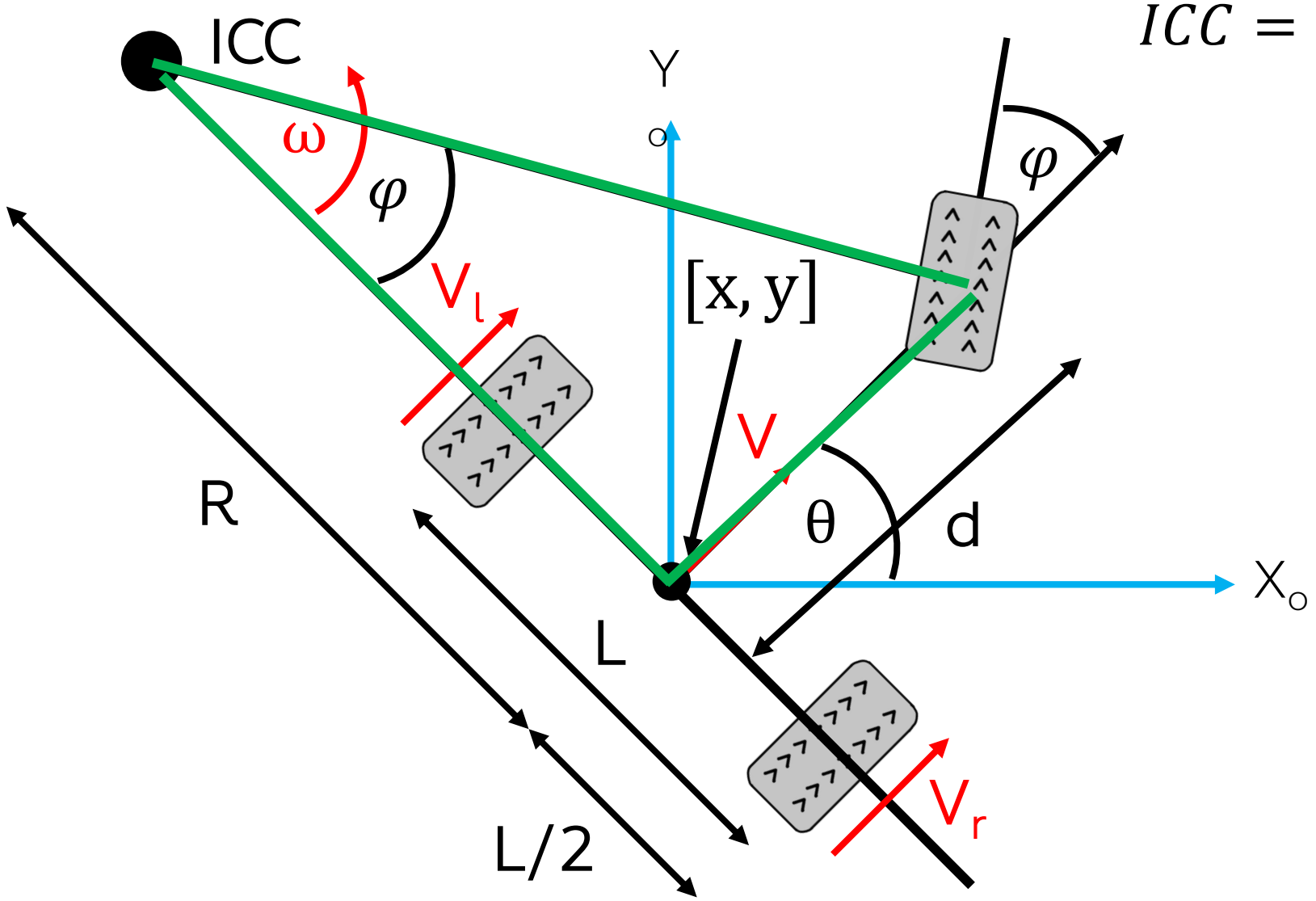
$$V = \frac{(V_r + V_l)}{2}$$

Wheel Locomotion



Differential Drive Robot Motion

Wheel Locomotion
(Ackermann (car) Drive)



$$ICC = [x - R\sin(\theta), y + R\cos(\theta)]$$

$$R = \frac{d}{\tan(\varphi)}$$

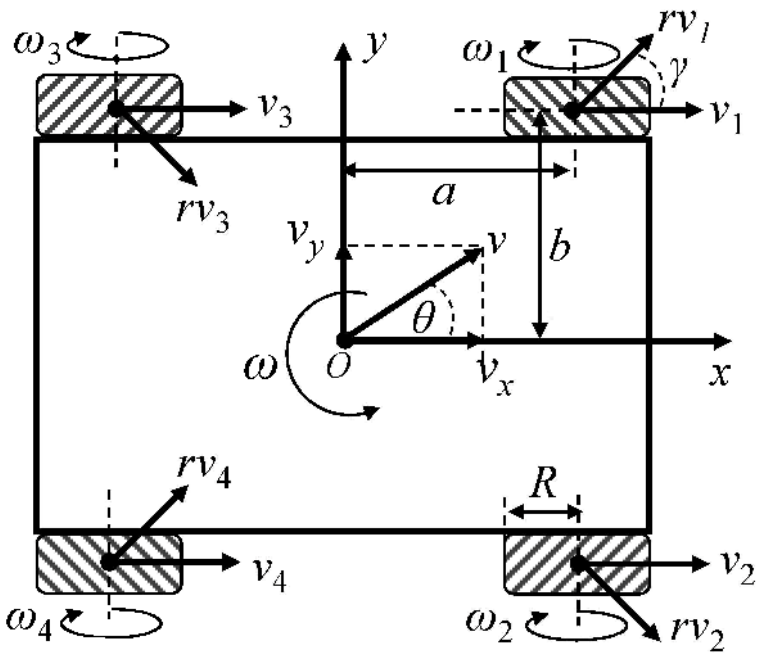
$$\omega\left(R + \frac{L}{2}\right) = V_r$$

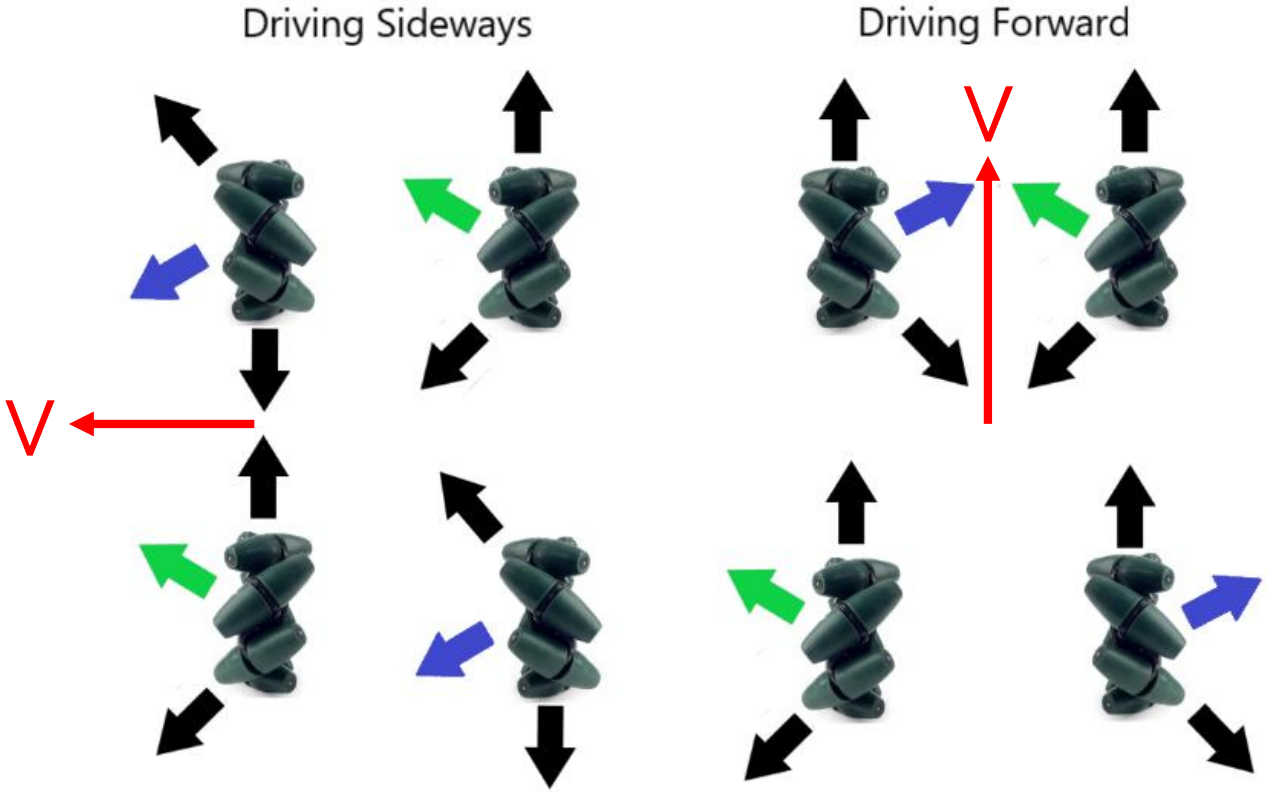
$$\omega\left(R - \frac{L}{2}\right) = V_l$$

$$R = \frac{L}{2}\frac{(V_l + V_r)}{(V_r - V_l)}$$

$$\omega = \frac{(V_r - V_l)}{L}$$

Wheel Locomotion
(Mecanum Wheel Drive)

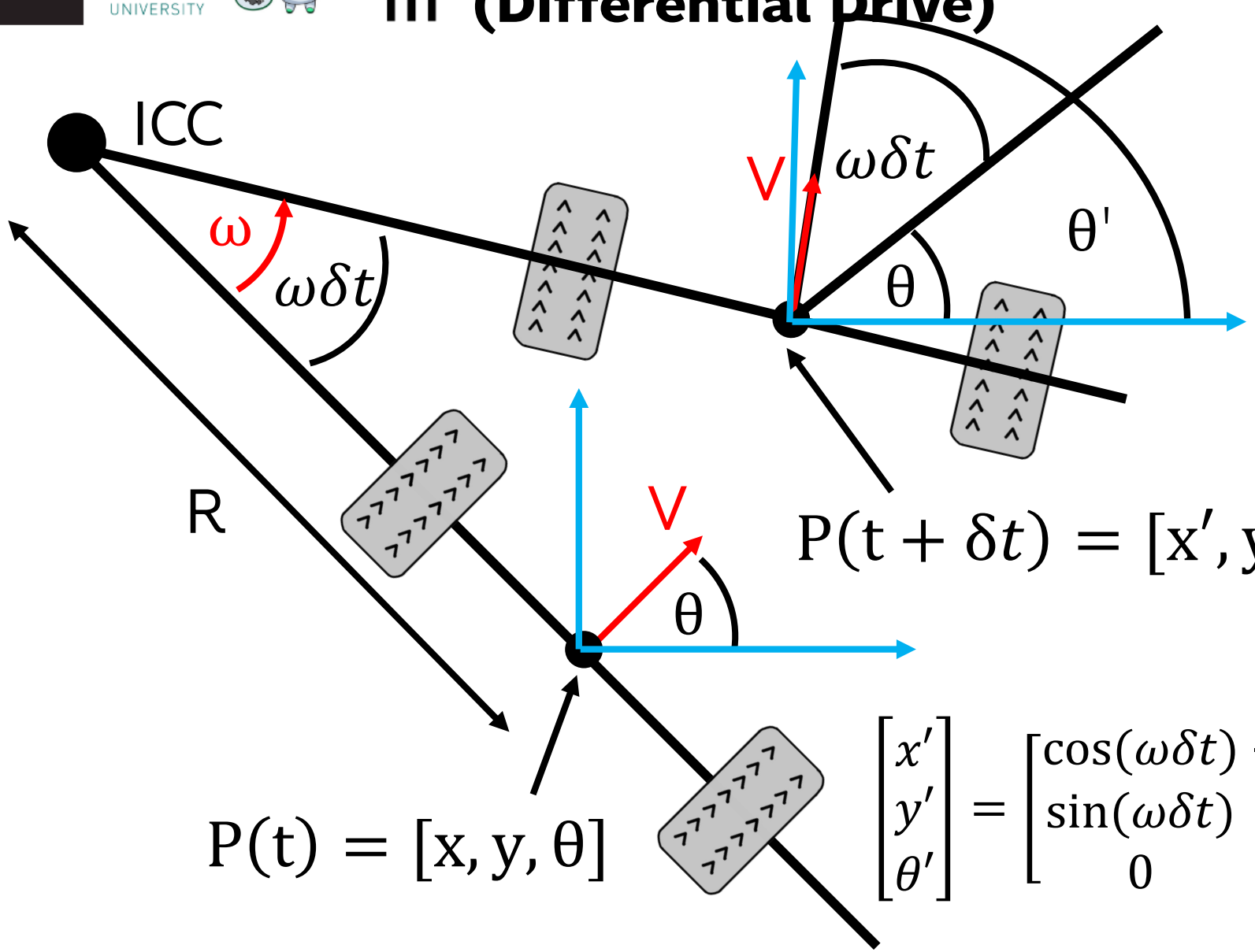




$$\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_3\\ \omega_4\end{bmatrix} = \frac{1}{R}\begin{bmatrix}1 & -1 & -(a+b)\\ 1 & 1 & (a+b)\\ 1 & 1 & -(a+b)\\ 1 & -1 & (a+b)\end{bmatrix}\begin{bmatrix}v_x\\ v_y\\ v_\theta\end{bmatrix}$$

Ref :
[1] Maulana, E., Muslim, M.A., & Hendrayawan, V. (2015). Inverse kinematic implementation of four- wheels mecanum drive mobile robot using stepper motors.
[2] https://ftccats.github.io/software/ProgrammingMecanumWheels.html

Wheel Locomotion
(Differential Drive)



$$x(t) = \int_0^t v(t')\ \cos[\theta(t')]dt'$$

$$y(t) = \int_0^t v(t')\ \sin[\theta(t')]dt'$$

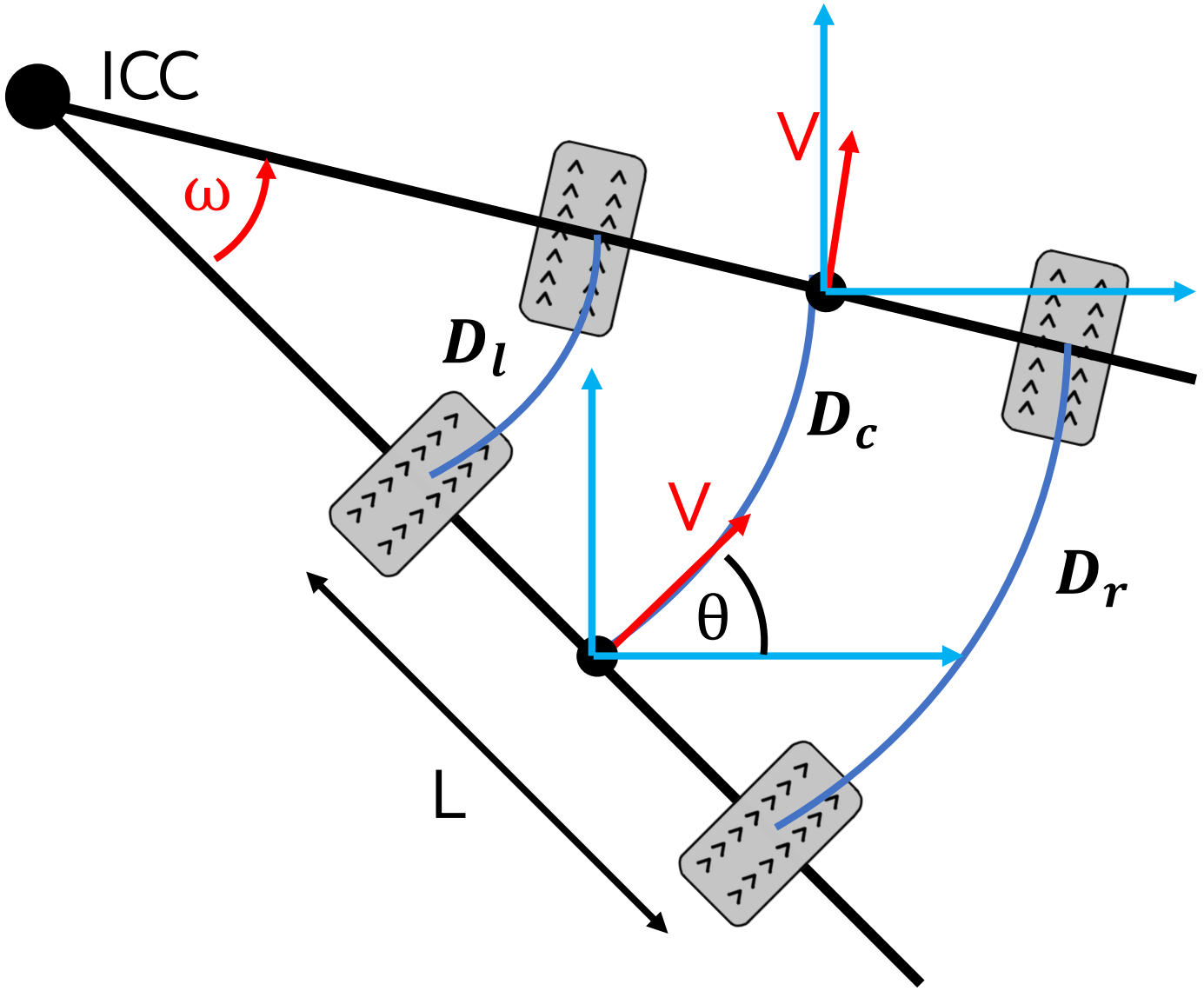
$$\theta(t) = \int_0^t \omega(t')\ dt'$$

$$P(t + \delta t) = [x', y', \theta']$$

$$P(t) = [x, y, \theta]$$

$$\begin{bmatrix} x' \\ y' \\ \theta' \end{bmatrix} = \begin{bmatrix} \cos(\omega\delta t) & -\sin(\omega\delta t) & 0 \\ \sin(\omega\delta t) & \cos(\omega\delta t) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x - ICC_x \\ y - ICC_y \\ \theta \end{bmatrix} + \begin{bmatrix} ICC_x \\ ICC_y \\ \omega\delta t \end{bmatrix}$$

Wheel Locomotion
(Differential Drive)



$$V\delta t = D_c$$

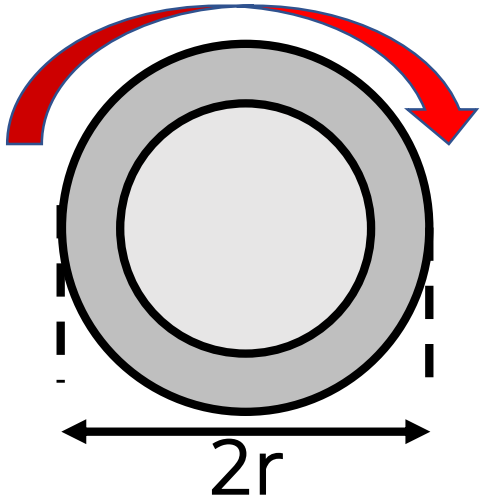
$$D_c = \frac{(D_l + D_r)}{2}$$

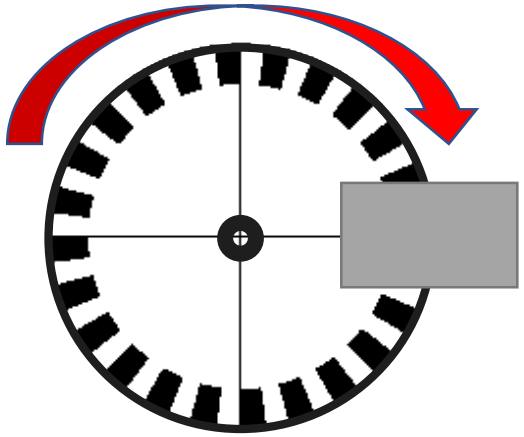
$$x' = x + D_c\cos(\theta)$$

$$y' = y + D_c\sin(\theta)$$

$$\theta' = \theta + \frac{(D_r - D_l)}{L}$$

Encoder





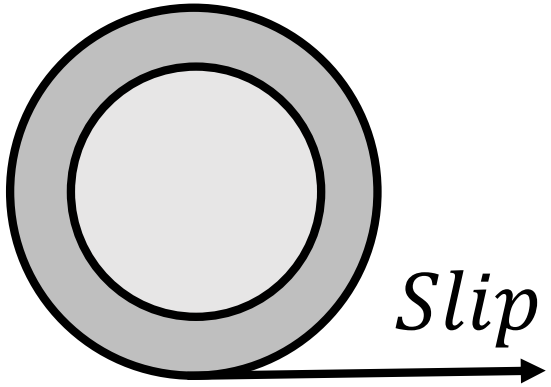
- Encoder has N “ticks” per revolution
- Most wheel Encoder give the total tick count since the beginning (Increment Encoder)

For Each Wheel

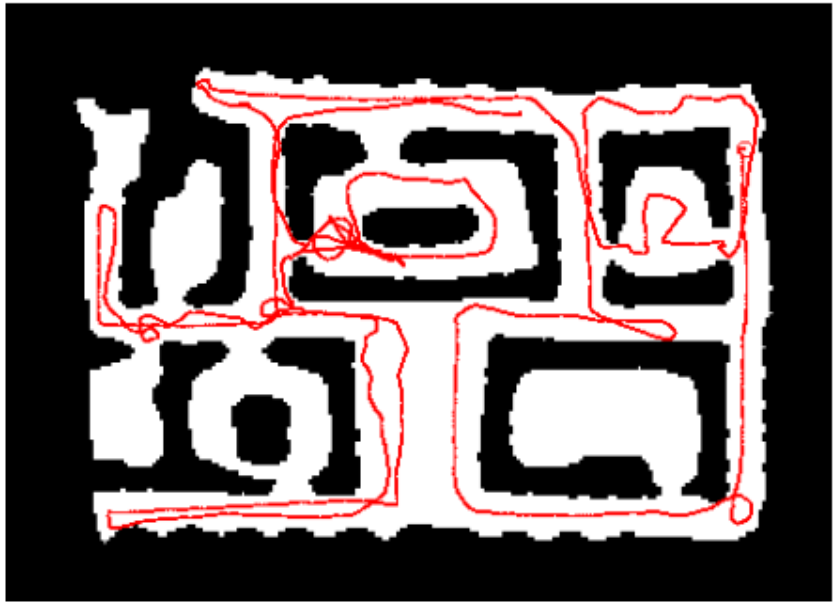
$$\Delta\text{tick} = \text{tick}' - \text{tick}$$

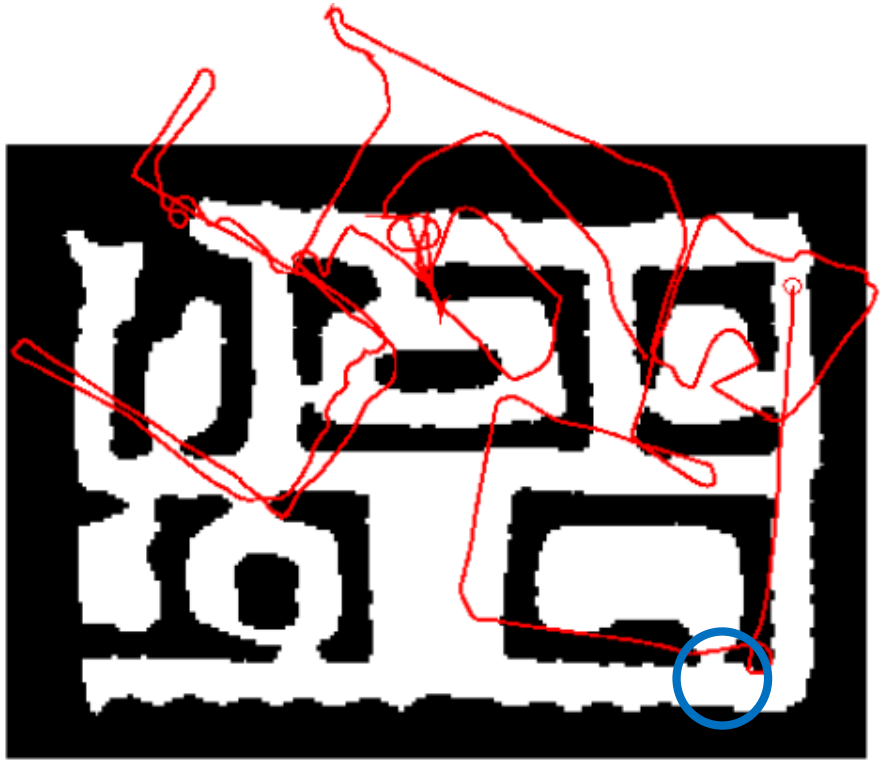
$$D = 2\pi\text{r}\frac{\Delta\text{tick}}{N}$$

Dead Reckoning and Odometry



- Estimating the motion based on the issued controls/wheel encoder readings
- Integrated over time (Cumulative Error)
- Drift





Software Setup

Install all kobuki package

```
$ sudo apt-get install ros-kinetic-kobuki*
```

Install turtlebot package

```
$ sudo apt-get install ros-kinetic-turtlebot
$ sudo apt-get install ros-kinetic-turtlebot-*
```

Ref : https://robots.ros.org/kobuki/
http://wiki.ros.org/turtlebot/Tutorials/indigo

Software Setup

Environment Setup

Add following command in ~/.bashrc file

```
export TURTLEBOT_BASE=kobuki
export TURTLEBOT_STACKS=hexagons
export TURTLEBOT_3D_SENSOR=kinect
export TURTLEBOT_SERIAL_PORT=/dev/kobuki
```

Software Setup

Verify software setup

1) Turn ON Kobuki

2) Connect computer to Kobuki via USB

3) Run following command:

```
$ roscore
```

4) Open new terminal

```
$ roslaunch turtlebot_bringup minimal.launch
```

Control The Robot

Control with the Controller

```
$ roslaunch turtlebot_teleop logitech.launch
```

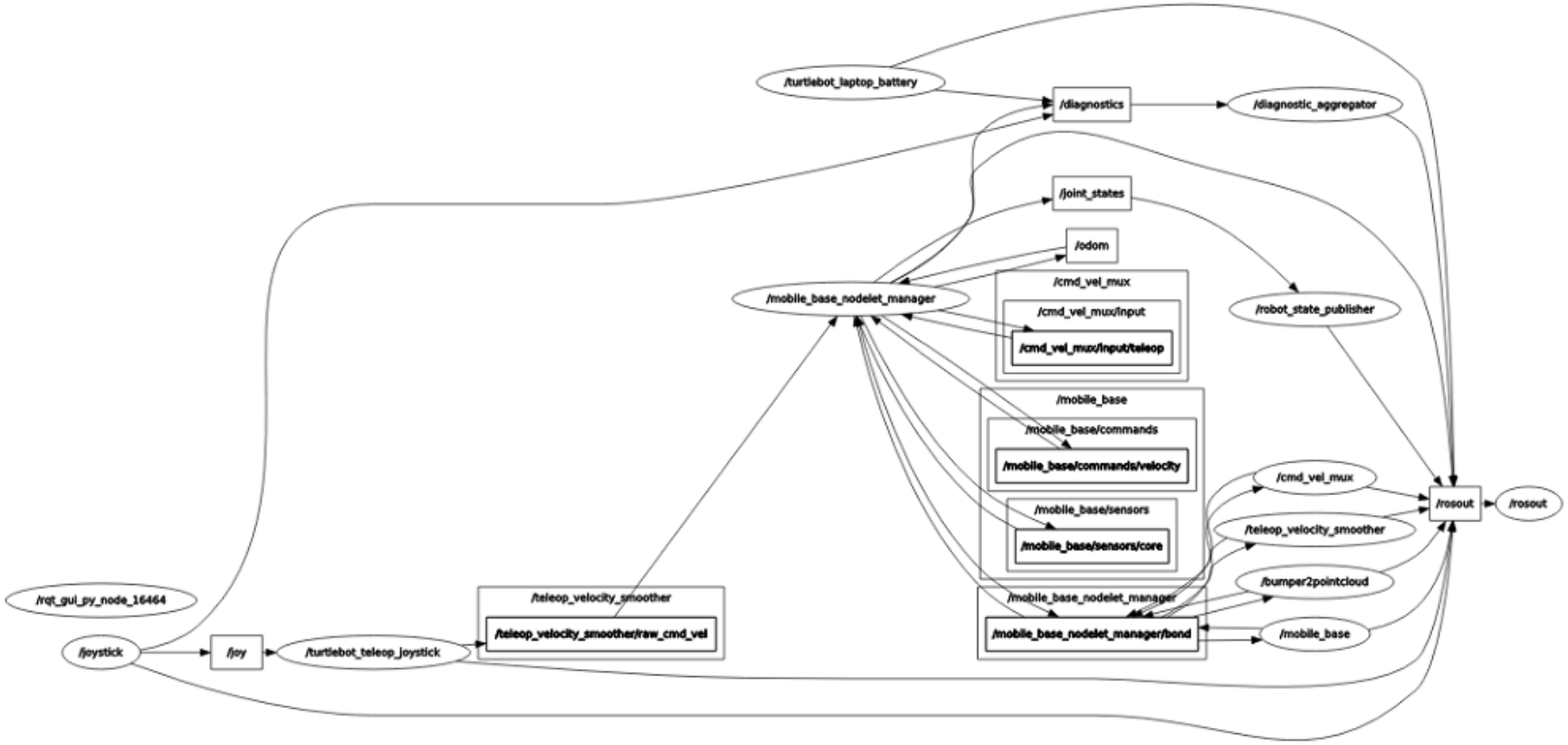
LB : Hold to Enable

Using Left Analog to Control

Control The Robot

To create a dynamic graph of what's going on in the system run:

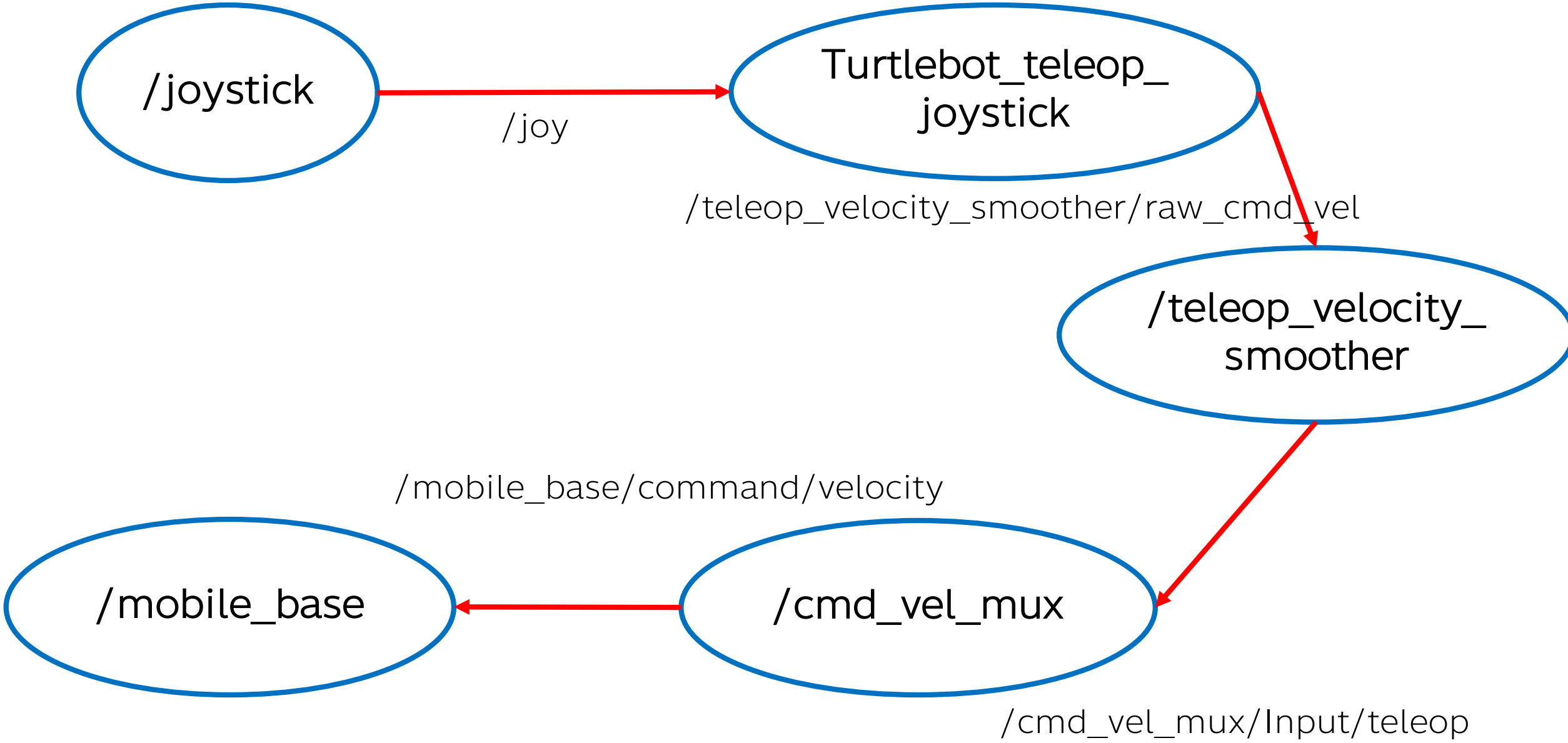
```
$ rosrun rqt_graph rqt_graph
```



Display the results as:

Node/Topics (active)

Control The Robot



Control The Robot

```
user@ros-workshop:~$ rostopic type /joy
sensor_msgs/Joy
user@ros-workshop:~$ rostopic type /teleop_velocity_smoother/raw_cmd_vel
geometry_msgs/Twist
user@ros-workshop:~$ rostopic type /cmd_vel_mux/input/teleop
geometry_msgs/Twist
user@ros-workshop:~$ rostopic type /mobile_base/commands/velocity
geometry_msgs/Twist
```

Raw Message Definition

```
# This expresses velocity in free space broken into its linear and angular parts.
Vector3  linear
Vector3  angular
```

Compact Message Definition

```
geometry_msgs/Vector3 linear
geometry_msgs/Vector3 angular
```

Control The Robot

File: `geometry_msgs/Vector3.msg`

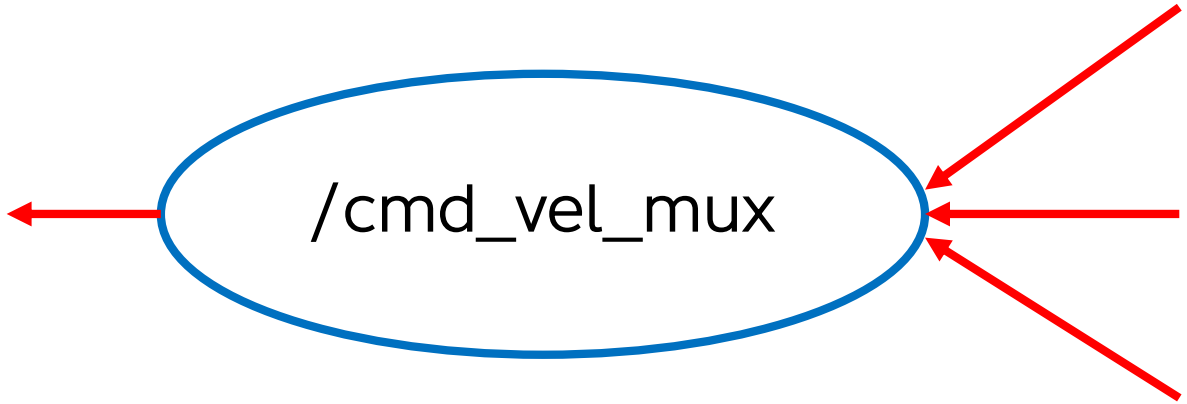
Raw Message Definition

```
# This represents a vector in free space.
# It is only meant to represent a direction. Therefore, it does not
# make sense to apply a translation to it (e.g., when applying a
# generic rigid transformation to a Vector3, tf2 will only apply the
# rotation). If you want your data to be translatable too, use the
# geometry_msgs/Point message instead.

float64 x
float64 y
float64 z
```

Control The Robot

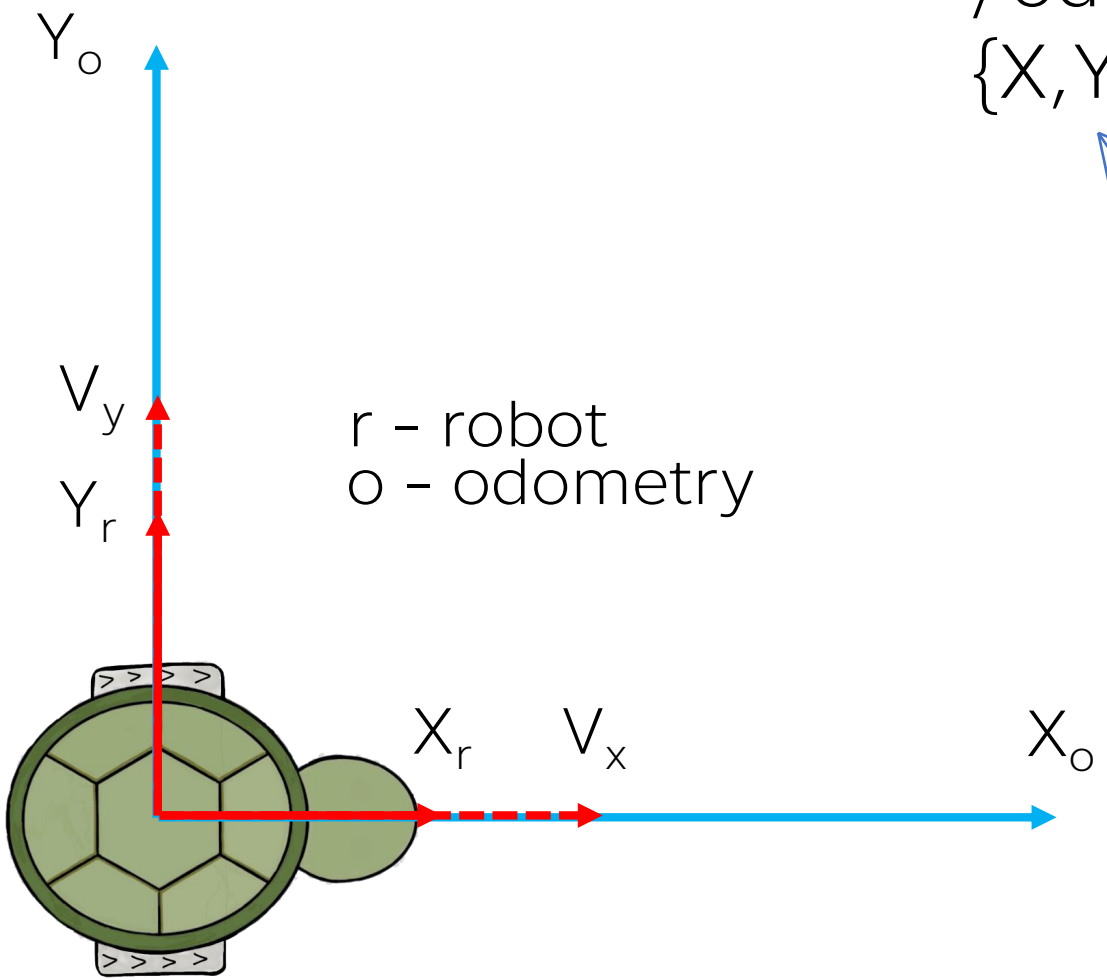
/opt/ros/kinetic/share/turtlebot_bringup/param/mux.yaml

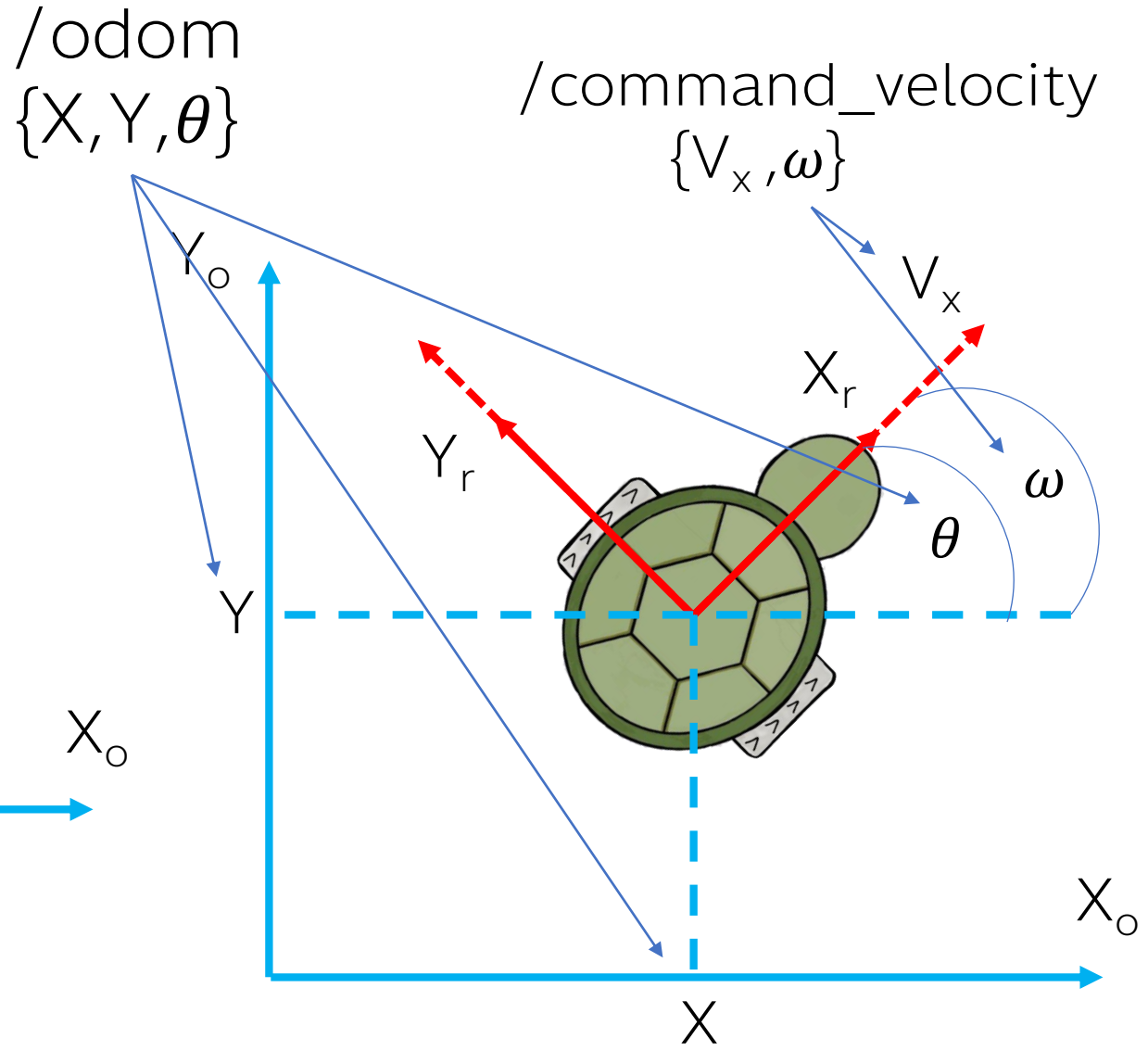
```
subscribers:
  - name:        "Safe reactive controller"
    topic:       "input/safety_controller"
    timeout:     0.2
    priority:    10
  - name:        "Teleoperation"
    topic:       "input/teleop"
    timeout:     1.0
    priority:    7
  - name:        "Switch"
    topic:       "input/switch"
    timeout:     1.0
    priority:    6
  - name:        "Navigation"
    topic:       "input/navi"
    timeout:     1.0
    priority:    5
```



https://github.com/yujinrobot/yujin_ocs/tree/devel/yocs_cmd_vel_mux

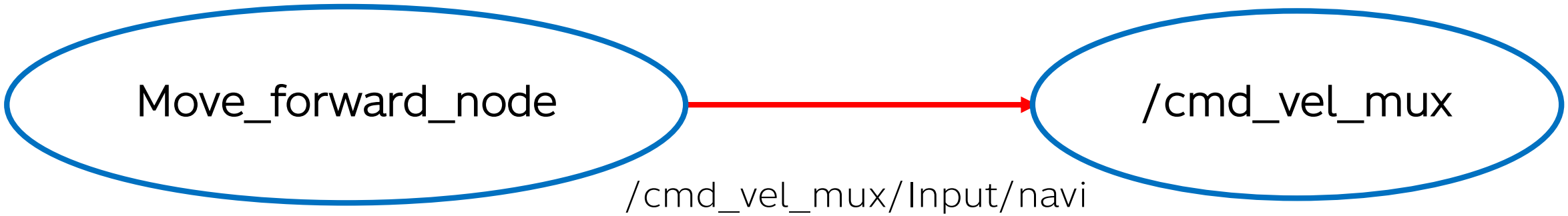
Control The Robot





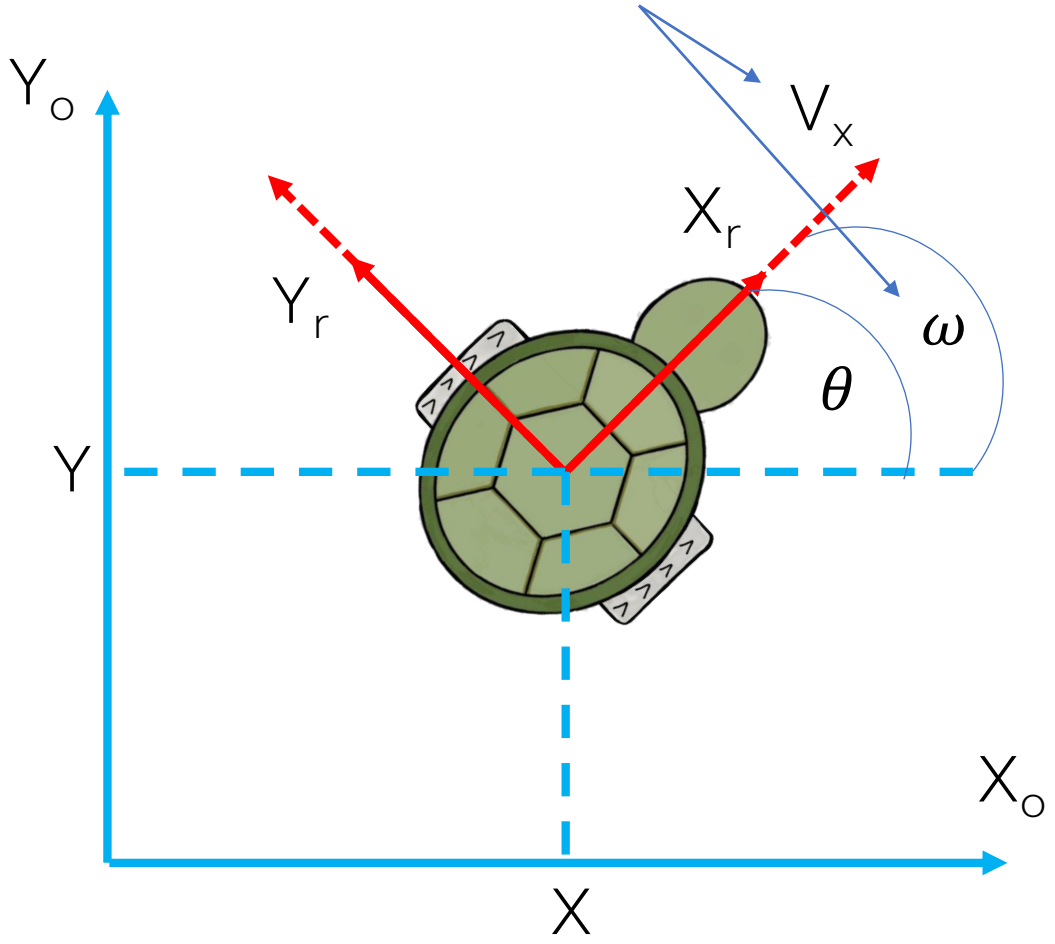
Control The Robot

1. Control robot velocity without feedback



Control The Robot

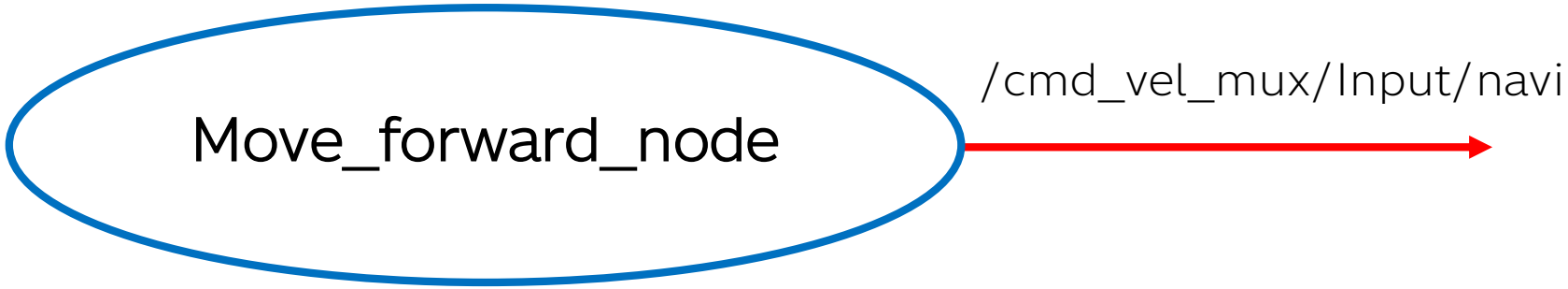
/command_velocity
$\{V_x, \omega\}$



geometry_msgs/Vector3 linear
geometry_msgs/Vector3 angular

Twist
- linear
  - x ← V_x
  - y
  - z
- angular
  - x
  - y
  - z ← ω

Control The Robot




```
#!/usr/bin/env python
import rospy
from geometry_msgs.msg import Twist

if __name__ == '__main__':
    try:
        MoveForward()
    except:
        rospy.loginfo(" MoveForward node terminated.")
```

Control The Robot

```
class MoveForward():
    def __init__(self):
        rospy.init_node('move_forward_node', anonymous=False)
        rospy.loginfo("To stop Turtlebot press CTRL + C")
        rospy.on_shutdown(self.shutdown)
        self.cmd_vel_pub =  rospy.Publisher('cmd_vel_mux/input/navi', Twist,
queue_size=10)
        self.move_forward(0.05, 0.0)
```

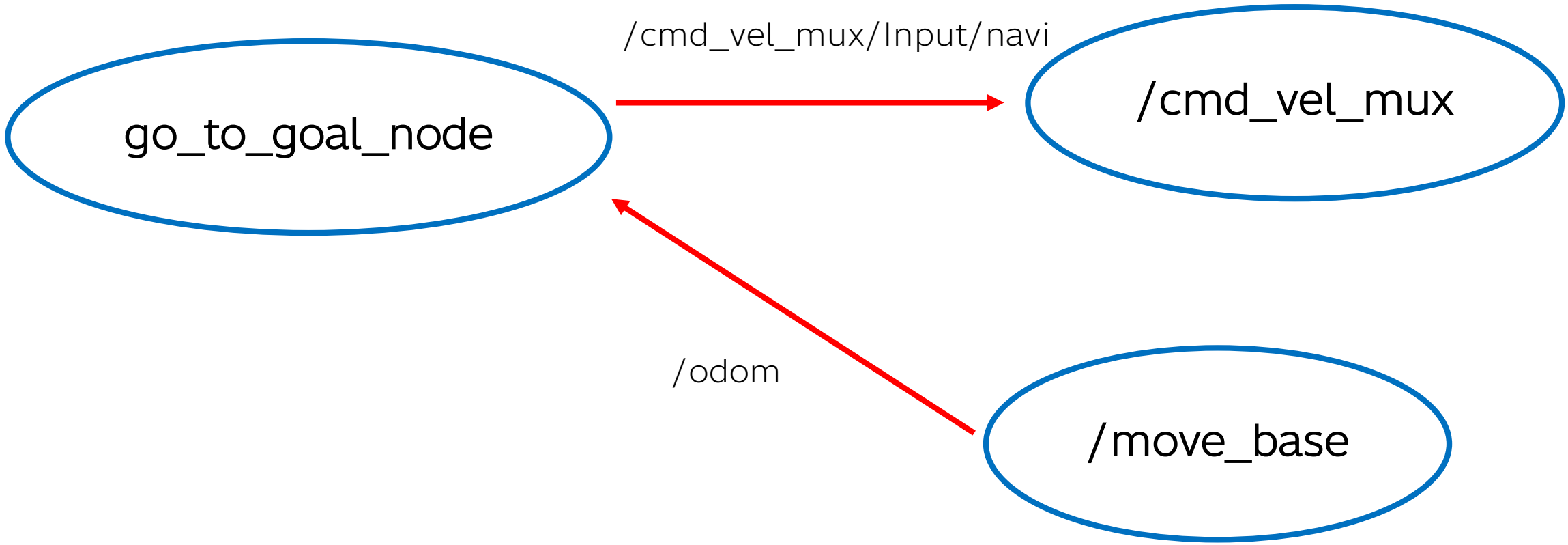
```
    def move_forward(self, vel_x, vel_z):
        r = rospy.Rate(10)
        move_cmd = Twist()
        move_cmd.linear.x = vel_x
        move_cmd.angular.z = vel_z
        while not rospy.is_shutdown():
            self.cmd_vel_pub.publish(move_cmd)
            r.sleep()
```

Control The Robot

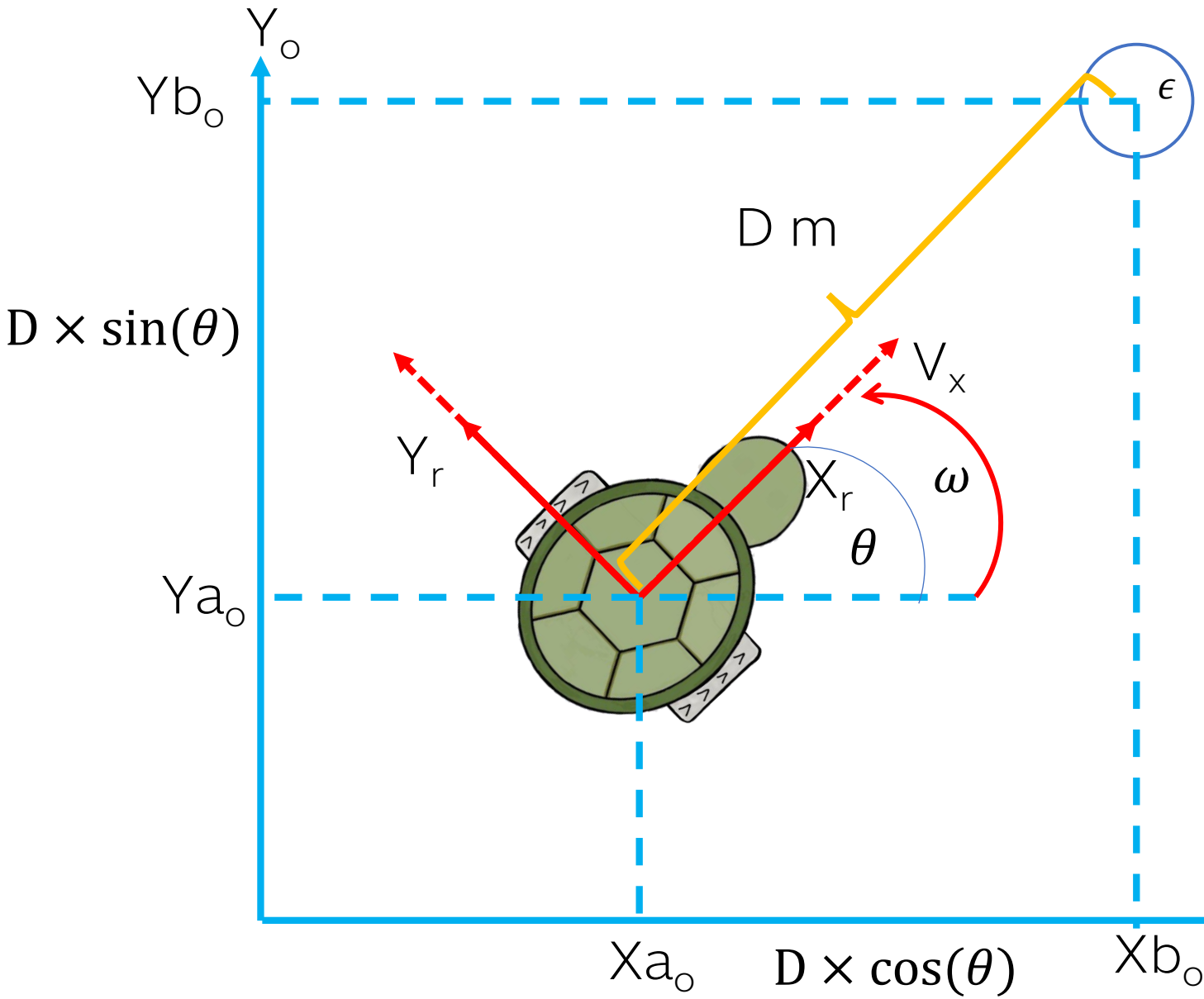
```
def shutdown(self):
    # stop turtlebot
    rospy.loginfo("Stop TurtleBot")
    # a default Twist has linear.x of 0 and angular.z of 0.  So it'll
 stop TurtleBot
    self.cmd_vel_pub.publish(Twist())
    # sleep just makes sure TurtleBot receives the stop command prior
 to shutting down the script
    rospy.sleep(1)
```

Control The Robot

2. Control robot velocity with feedback



Control The Robot



Goal :

$$Xb_o = Xa_o + Dcos(\theta)$$
$$Yb_o = Ya_o + Dsin(\theta)$$

Stop criteria:

$$\sqrt{(X_o - Xb_o)^2 + (Y_o - Yb_o)^2} \leq \epsilon$$

Current Position

Control The Robot

```
#!/usr/bin/env python
import rospy
from geometry_msgs.msg import Twist
from nav_msgs.msg import Odometry
from tf.transformations import euler_from_quaternion
from math import cos, sin, sqrt
class GoToGoal():
    def __init__(self):
        rospy.init_node('go_to_goal_node', anonymous=False, log_level=rospy.DEBUG)
        rospy.loginfo("To stop Turtlebot press CTRL + C")
        rospy.on_shutdown(self.shutdown)
        self.cmd_vel_pub = rospy.Publisher('cmd_vel_mux/input/navi' , Twist, queue_size=10)
        self.odom_sub = rospy.Subscriber('odom', Odometry, self.odom_callback)
        self.goal_pose_x = 0
        self.goal_pose_y = 0
        self.current_pose_x = 0
        self.current_pose_y = 0
        self.current_theta = 0
        self.vel_x = 0
        self.tol = 0.1
        self.move_cmd = Twist()
        rospy.wait_for_message("odom", Odometry) # wait for odometry data
```

Control The Robot

```
def odom_callback(self, odom_data):
    self.current_pose_x = odom_data.pose.pose.position.x
    self.current_pose_y = odom_data.pose.pose.position.y
    orientation_q = odom_data.pose.pose.orientation # orientation data
    orientation_list = [orientation_q.x, orientation_q.y, orientation_q.z, orientation_q.w]

    # change orientation data to radius
   (roll, pitch, yaw) = euler_from_quaternion(orientation_list)
    self.current_theta = yaw # currently radius of robot

def go_to_goal(self, vel_x):
    self.move_cmd.linear.x = vel_x  # set velocity
    while not rospy.is_shutdown():
        if self.check_stop():
            self.shutdown()
            break
        else:
            self.cmd_vel_pub.publish(self.move_cmd)
```

Control The Robot

```
def set_goal(self, distance, tol):
    self.goal_pose_x = self.current_pose_x + (distance * cos(self.current_theta))
    self.goal_pose_y = self.current_pose_y + (distance * sin(self.current_theta))
    self.tol = tol
    rospy.logdebug(" Current Pose : " + str([self.current_pose_x,self.current_pose_y]))
    rospy.logdebug("Move Distance : " + str(distance) + " m with TOL : " + str(tol) + "m")
    rospy.logdebug("    Goal Pose : " + str([self.goal_pose_x,self.goal_pose_y]))

def check_stop(self):
    delta_x = self.goal_pose_x - self.current_pose_x
    delta_y = self.goal_pose_y - self.current_pose_y
    error = sqrt(delta_x ** 2 + delta_y ** 2)
    rospy.logdebug(error)
    if error <= self.tol:
        return True
    else:
        return False
```

Goal :

$$Xb_o = Xa_o + Dcos(\theta)$$
$$Yb_o = Ya_o + Dsin(\theta)$$

Stop criteria:

$$\sqrt{(X_o - Xb_o)^2 + (Y_o - Yb_o)^2} \leq \epsilon$$

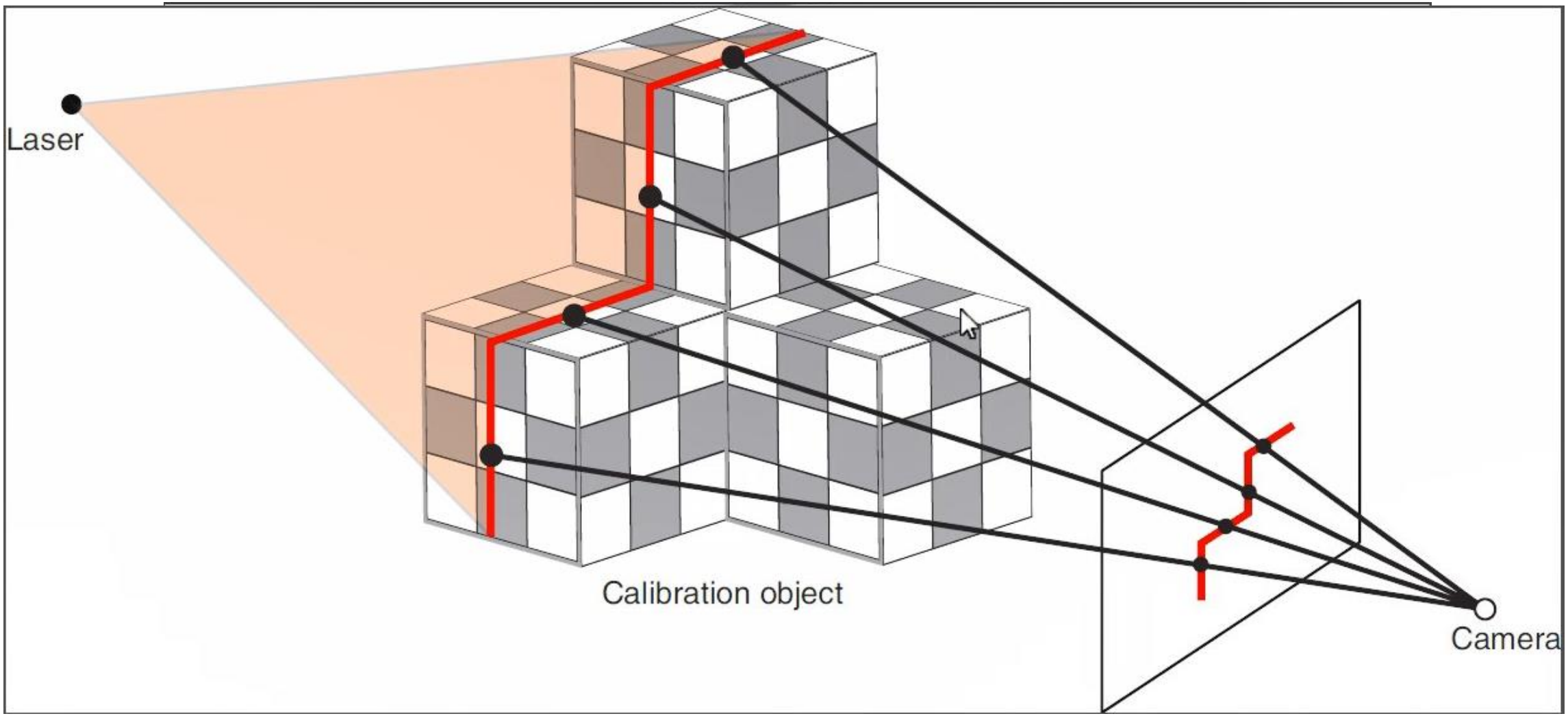
Control The Robot

```
    def shutdown(self):
        rospy.loginfo("Stop TurtleBot")
        self.cmd_vel_pub.publish(Twist())
        rospy.sleep(1)

if __name__ == "__main__":
    try:
        go_to_goal = GoToGoal()
        # Set go at 1m ahead with 0.05m tolerant
        go_to_goal.set_goal(1, 0.05)
        # Start moving forward at speed 0.1 m/s
        go_to_goal.go_to_goal(0.1)

    except rospy.ROSInterruptException:
        rospy.loginfo("GoToGoal Forward node terminated")
```

3D sensor

KU
KASETSART
UNIVERSITY

Type of 3D sensor



Laser triangulation: one of the most common types of 3D sensing, laser triangulation works by projecting a laser onto a part or other surface. Depth is measured by the deformation of the laser, making this technology good for large depth of field applications

Type of 3D sensor

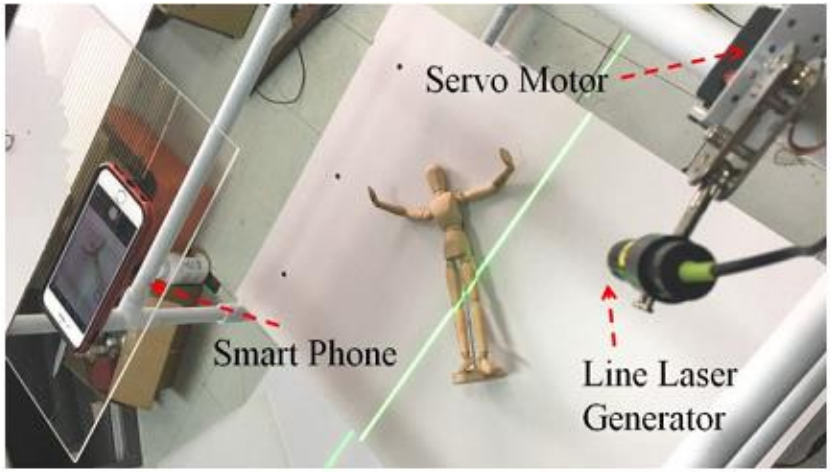


Fig. 1. Low Cost Smart Phone 3D Scanner.

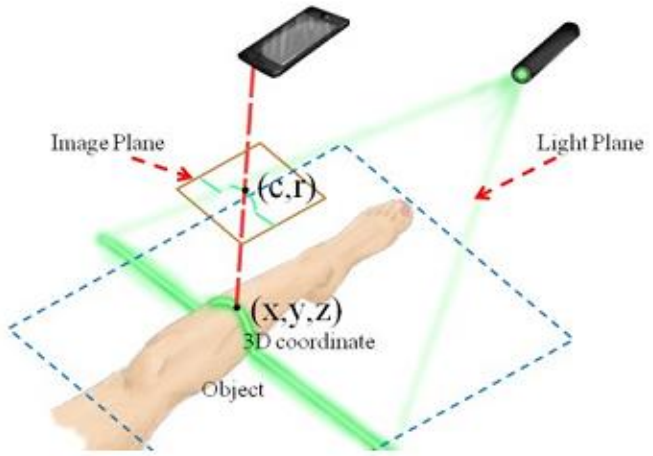


Fig. 2. Triangulation scanning method

3. Splint Reconstruction Method

Lanman [3] is not used because it is complex to a non-technical user. Therefore, the calibration is done simpler way by placing a smart phone camera to a scanning surface at fixed distance, then, they are perpendicular to each others. Each pixel point on the detected line is calculated for corresponding 3D point. This process is repeated for every frame in recorded video and the point cloud image is generated. The noise and unnecessary point cloud can be removed by using Statistical Outlier Removal or Mean distance to k-NN and Voxel grid uniform sampling respectively. Figure 3 shows the output point cloud image from this step.

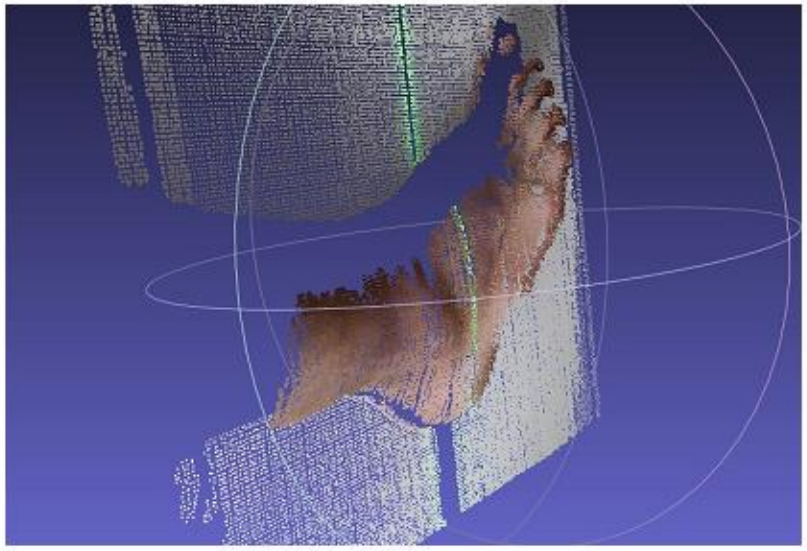
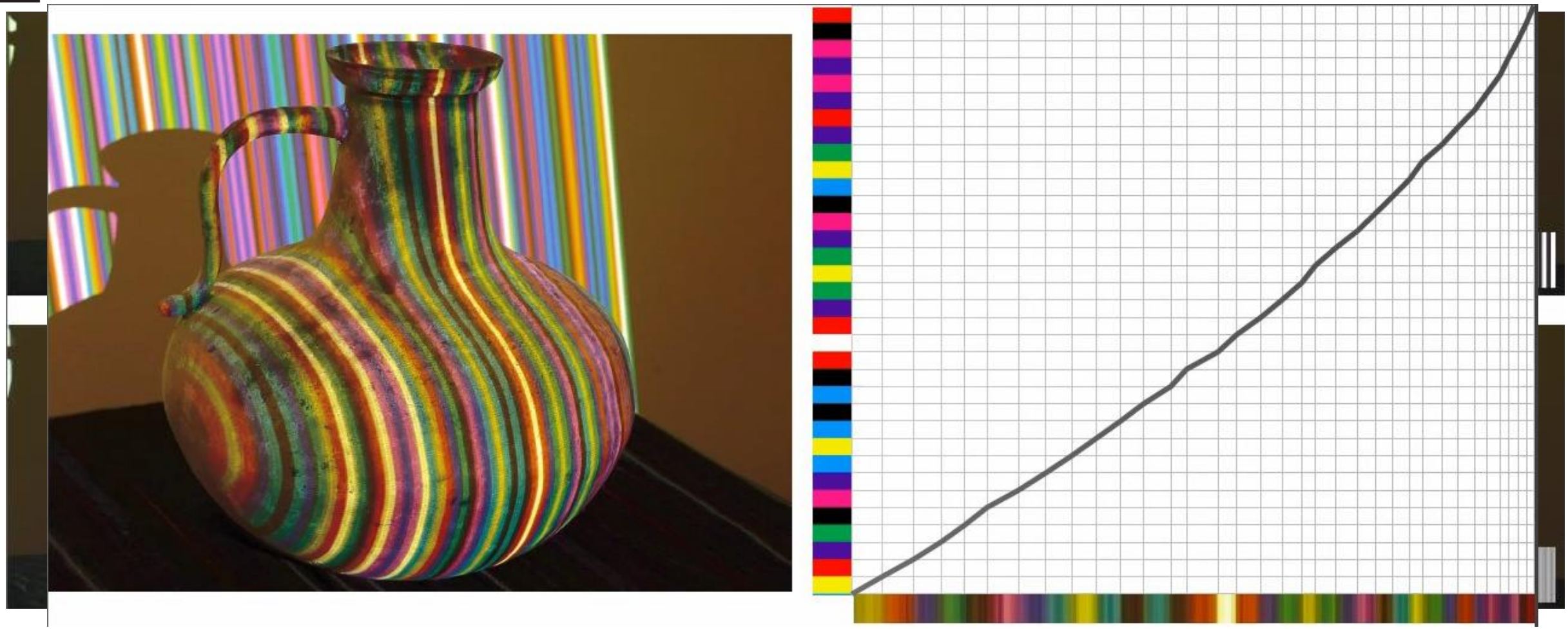


Fig. 3. 3D point cluod image from the scanner.

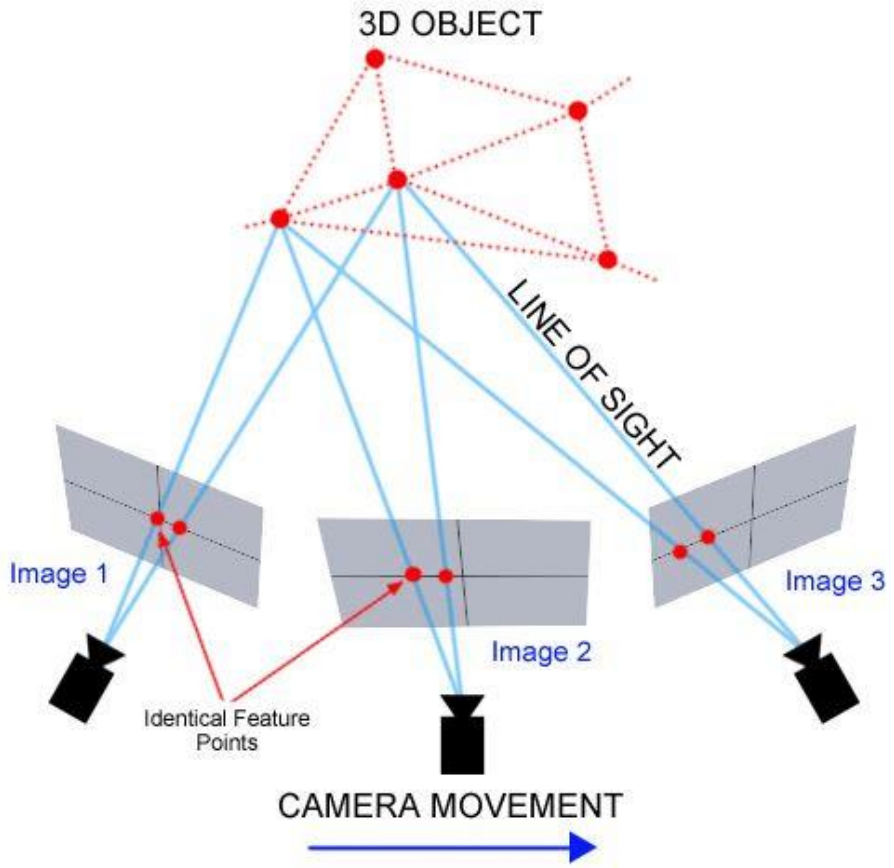
Type of 3D sensor

Type of 3D sensor



Structured light: with no need for moving parts, structured light 3D sensing systems are some of the most sophisticated solutions out there. They leverage an innovative projection technique to encode 3D information directly on the scene. **(Apple face id, Kinect v1)**

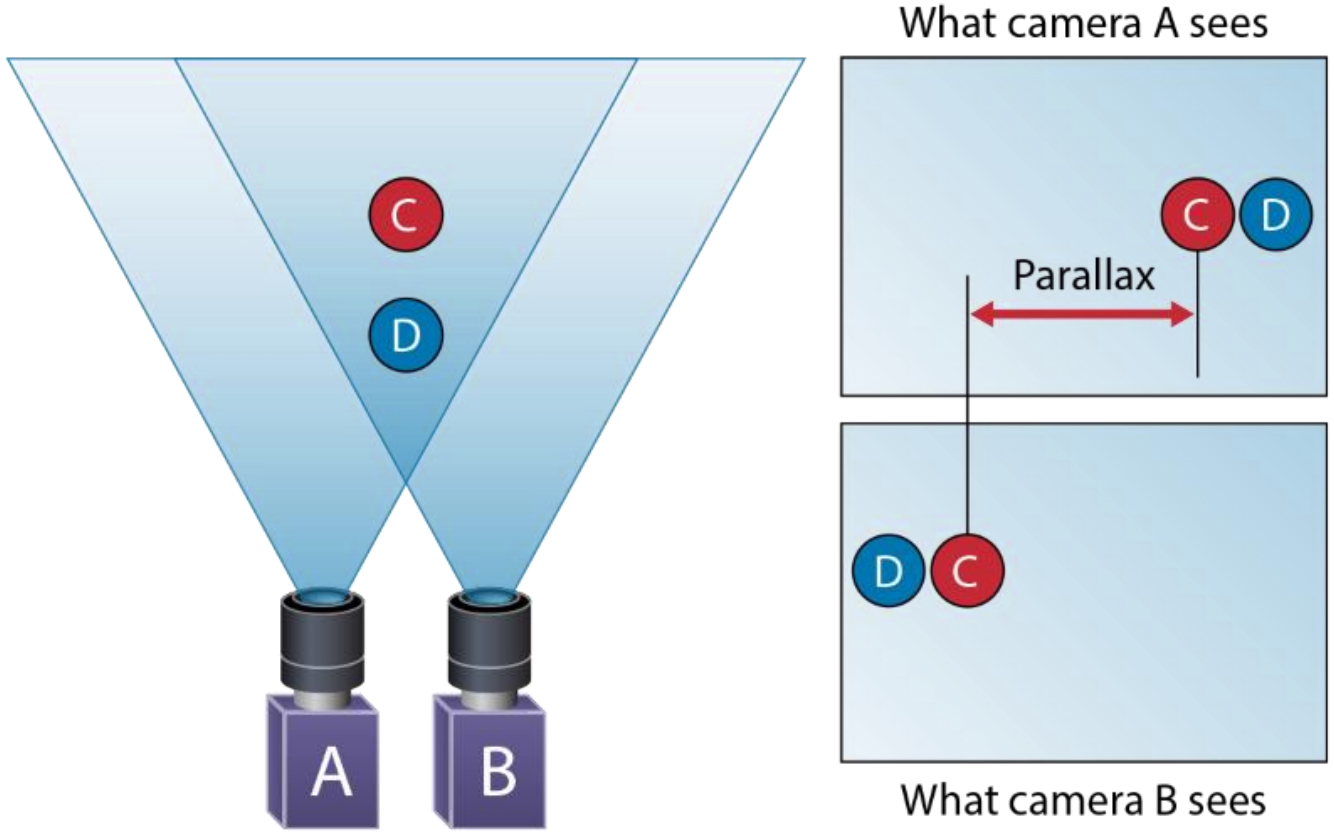
Type of 3D sensor



Photogrammetry: a method of computing a 3D reconstruction based on a large number of 2D images of an object. Photogrammetry is a common alternative to LIDAR systems.

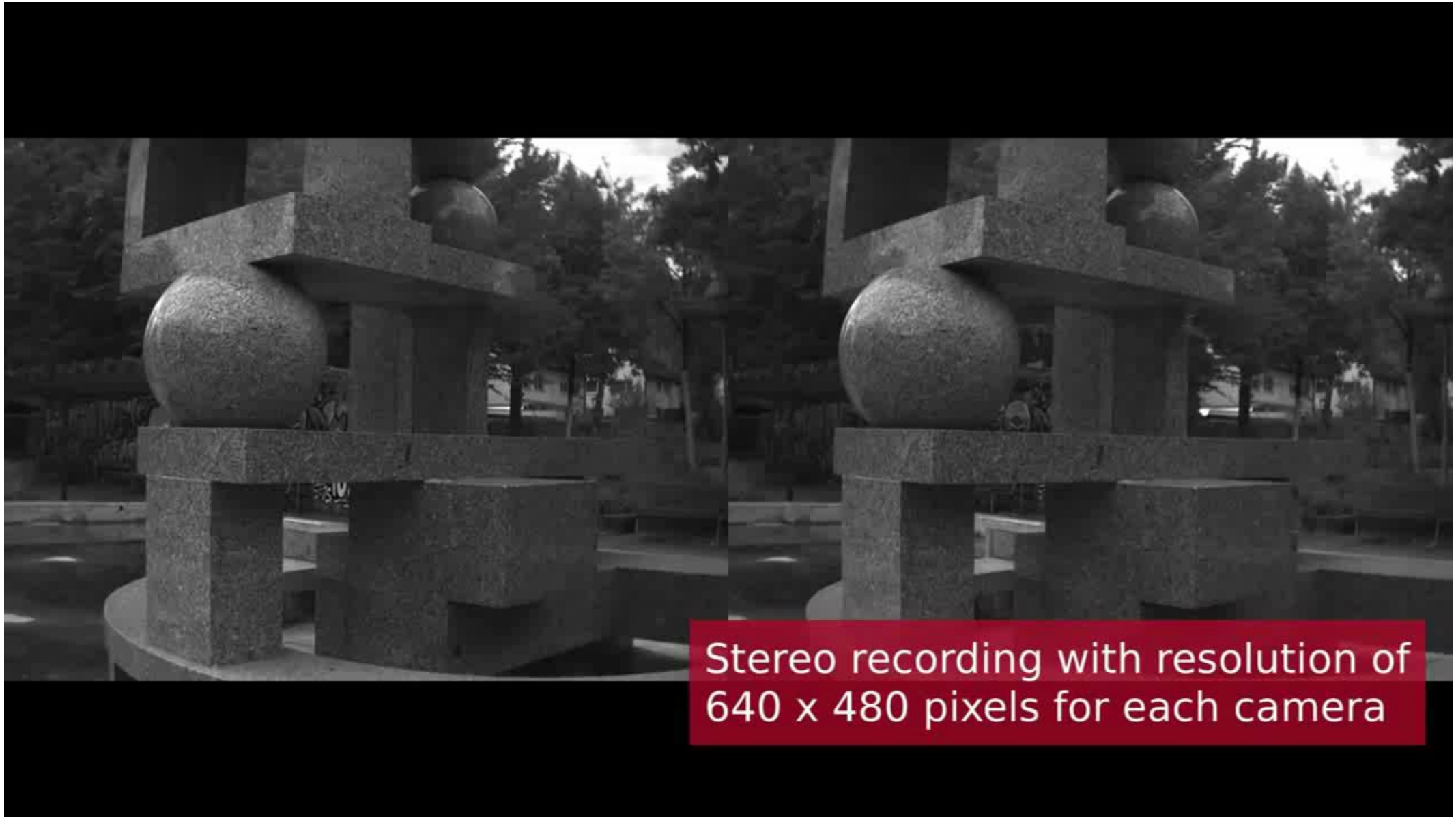
Type of 3D sensor

Type of 3D sensor

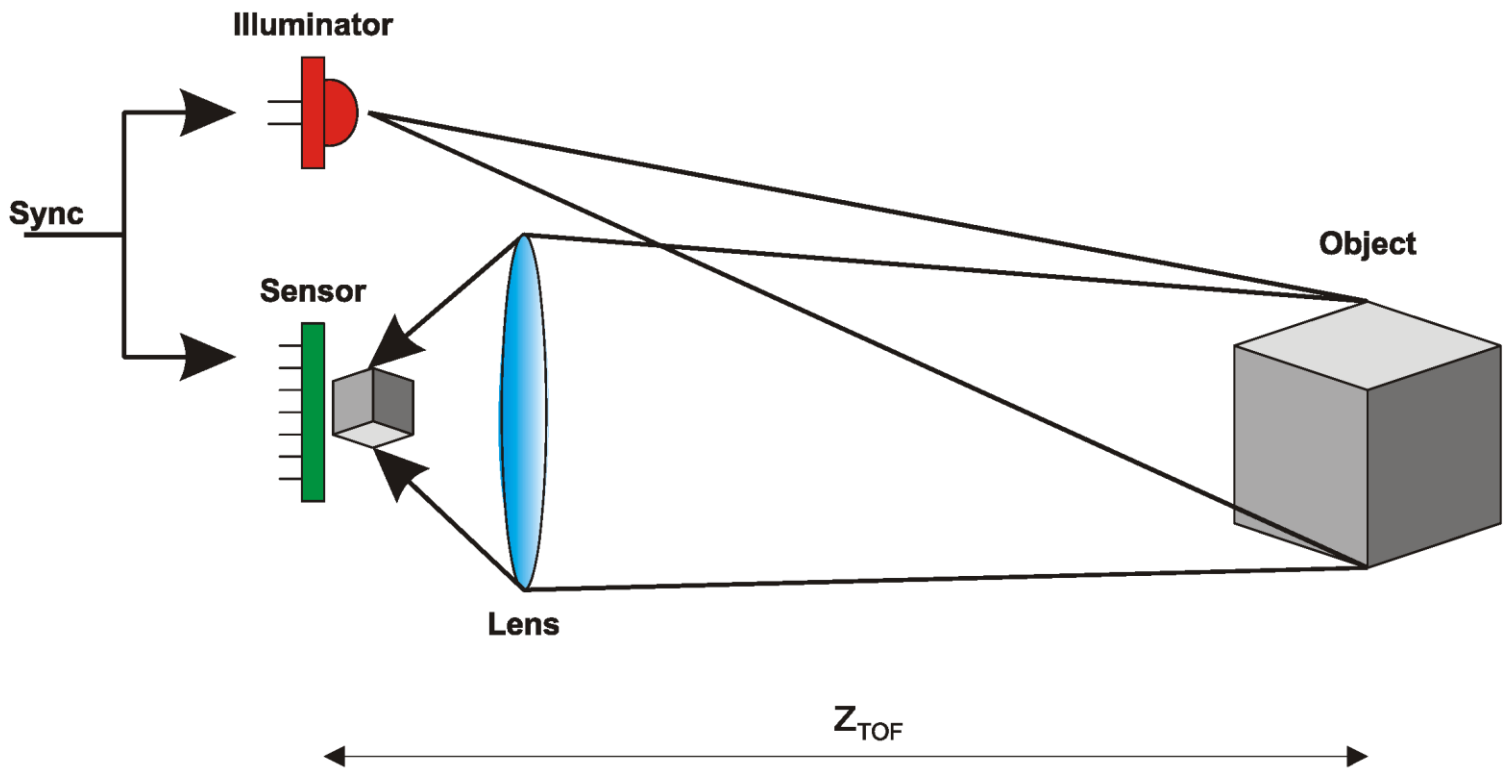


Stereo vision: this type of 3D imaging mimics the way humans perceive 3D images – two sensors are used at different angles to calculate and represent depth. Typically stereo vision is used for applications that don't require measurements, such as counting people.

Type of 3D sensor



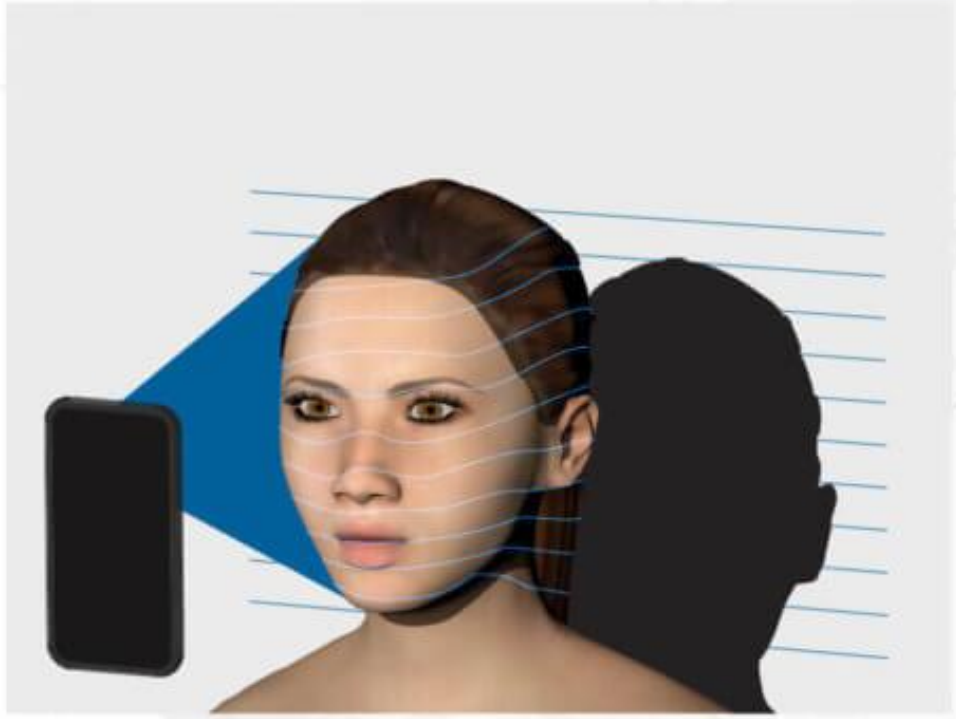
Type of 3D sensor



Time-of-flight: these systems detect the time of light travel between the light emitter, an inspected object, and back to the detector. Time-of-flight systems are either area sensing or LIDAR systems. (Apple is considering using ToF sensors for 2020's phones)

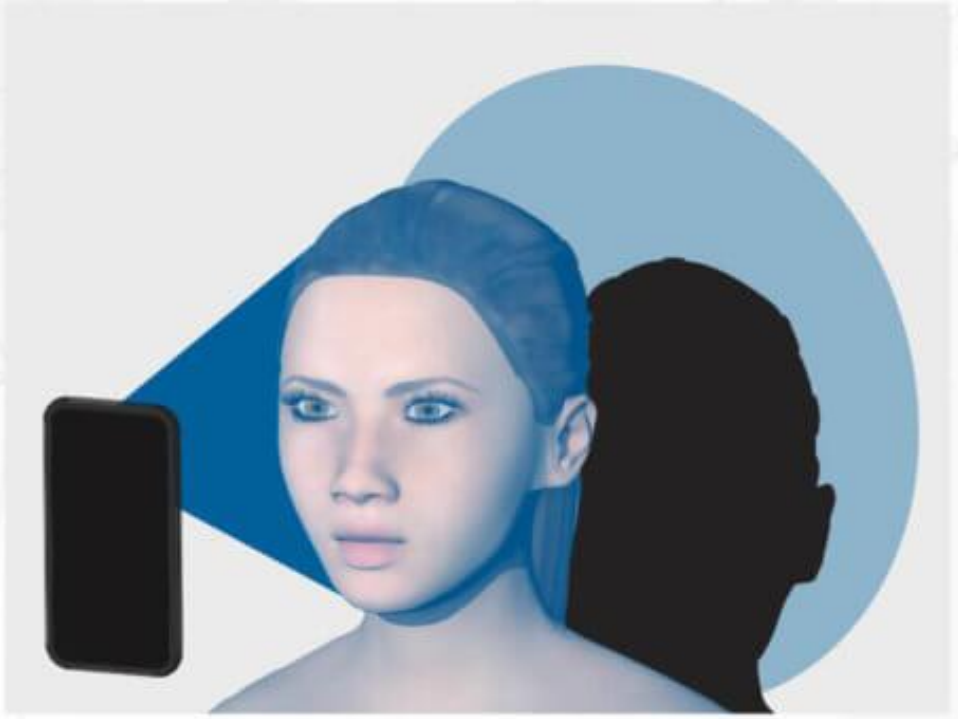
Type of 3D sensor

HOW STRUCTURED LIGHT SYSTEMS WORK



Structured light emitter projects patterns in infrared light.
The patterns are projected in pulses.
By understanding how the pattern distorts on each object, depth can be calculated.

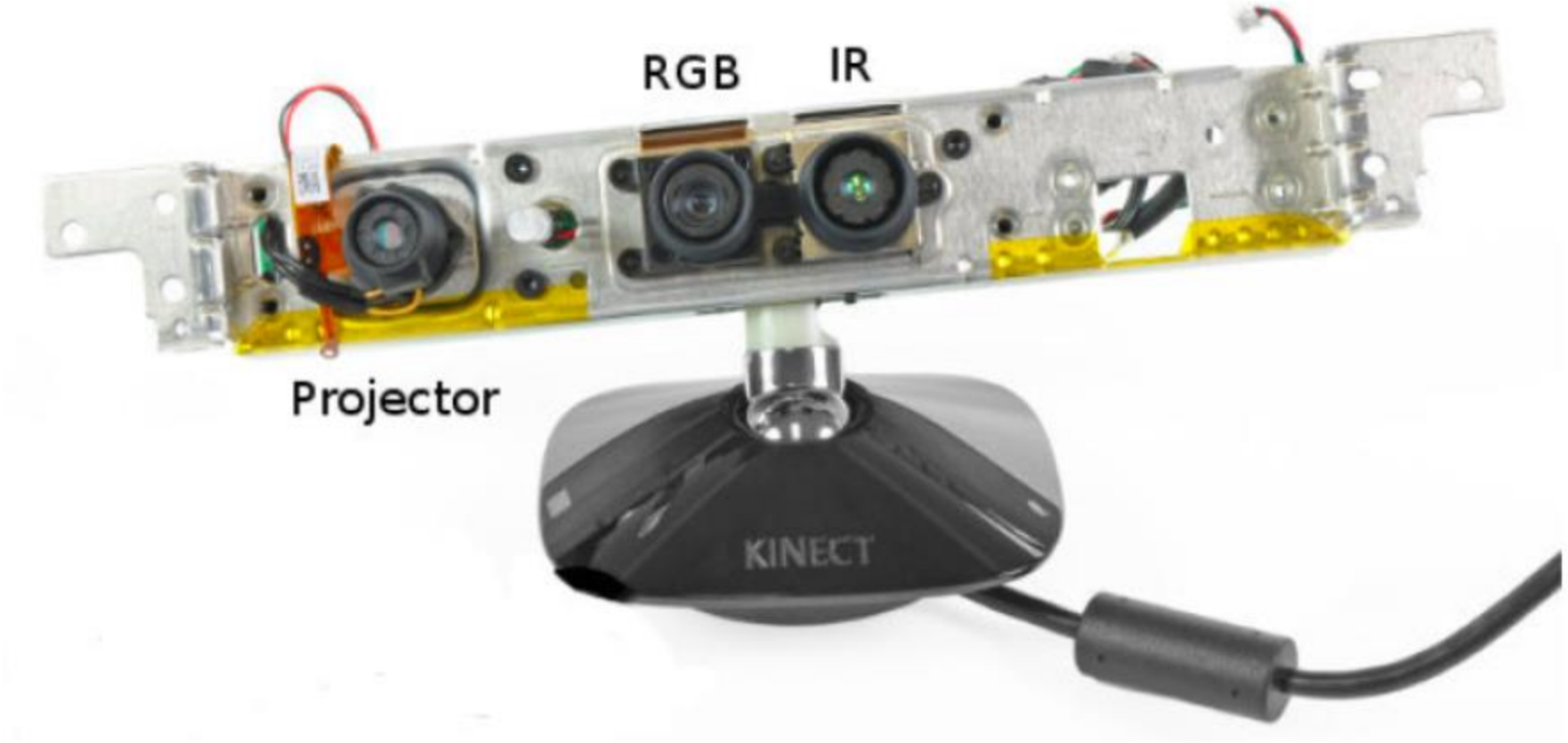
HOW TIME OF FLIGHT SYSTEMS WORK



Time-of-flight emitter floods the scene with infrared light.
By measuring the time it takes for the light to return from each pixel, the depth map of the scene is computed.

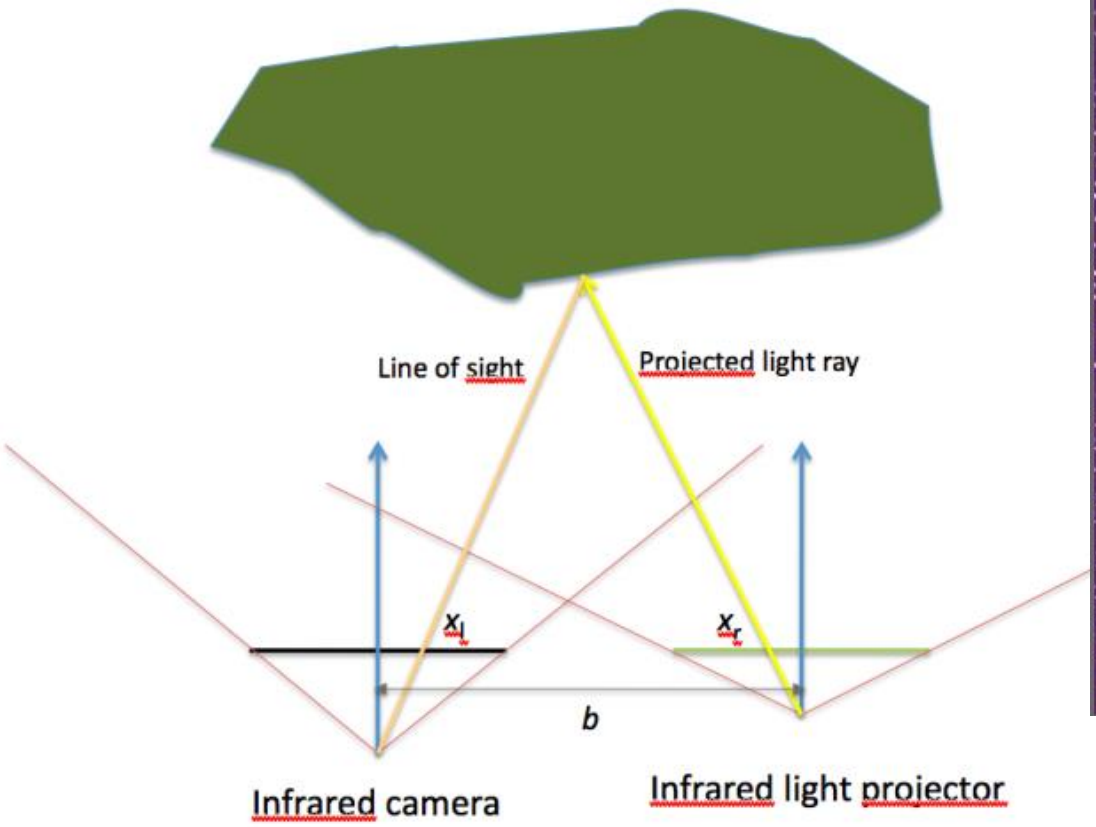
Kinect

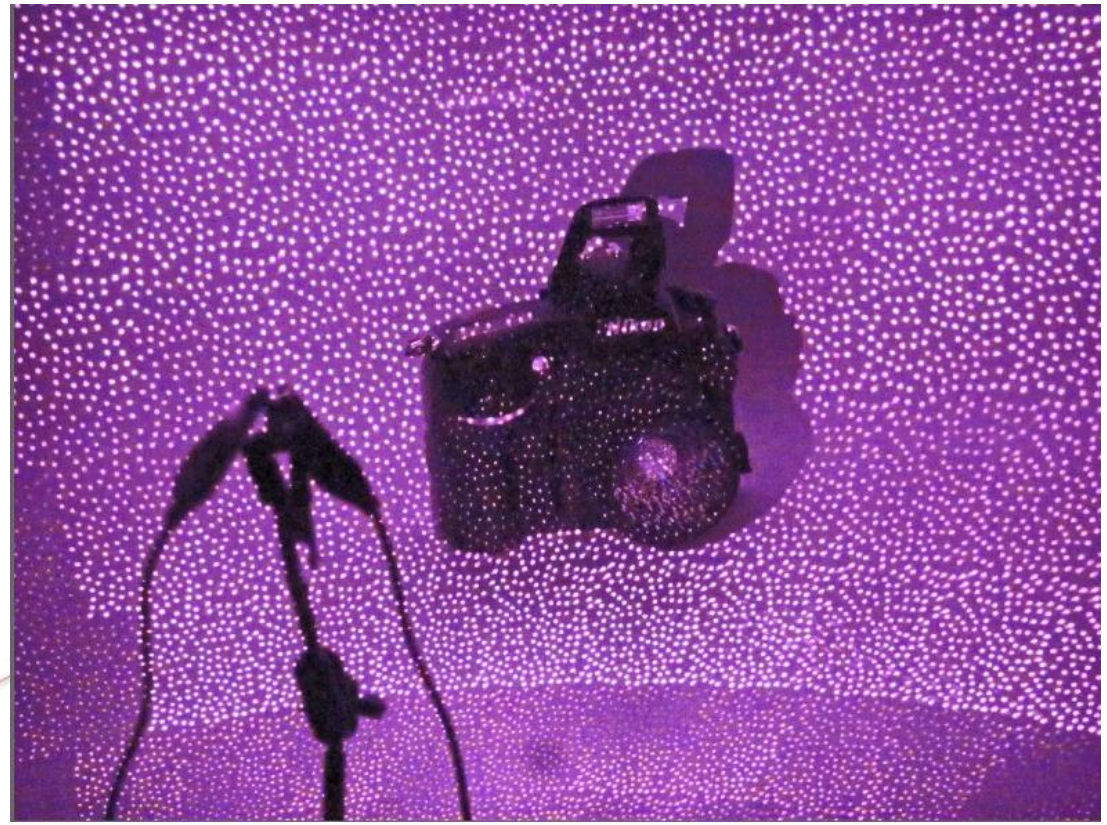
Inside Kinect



Kinect

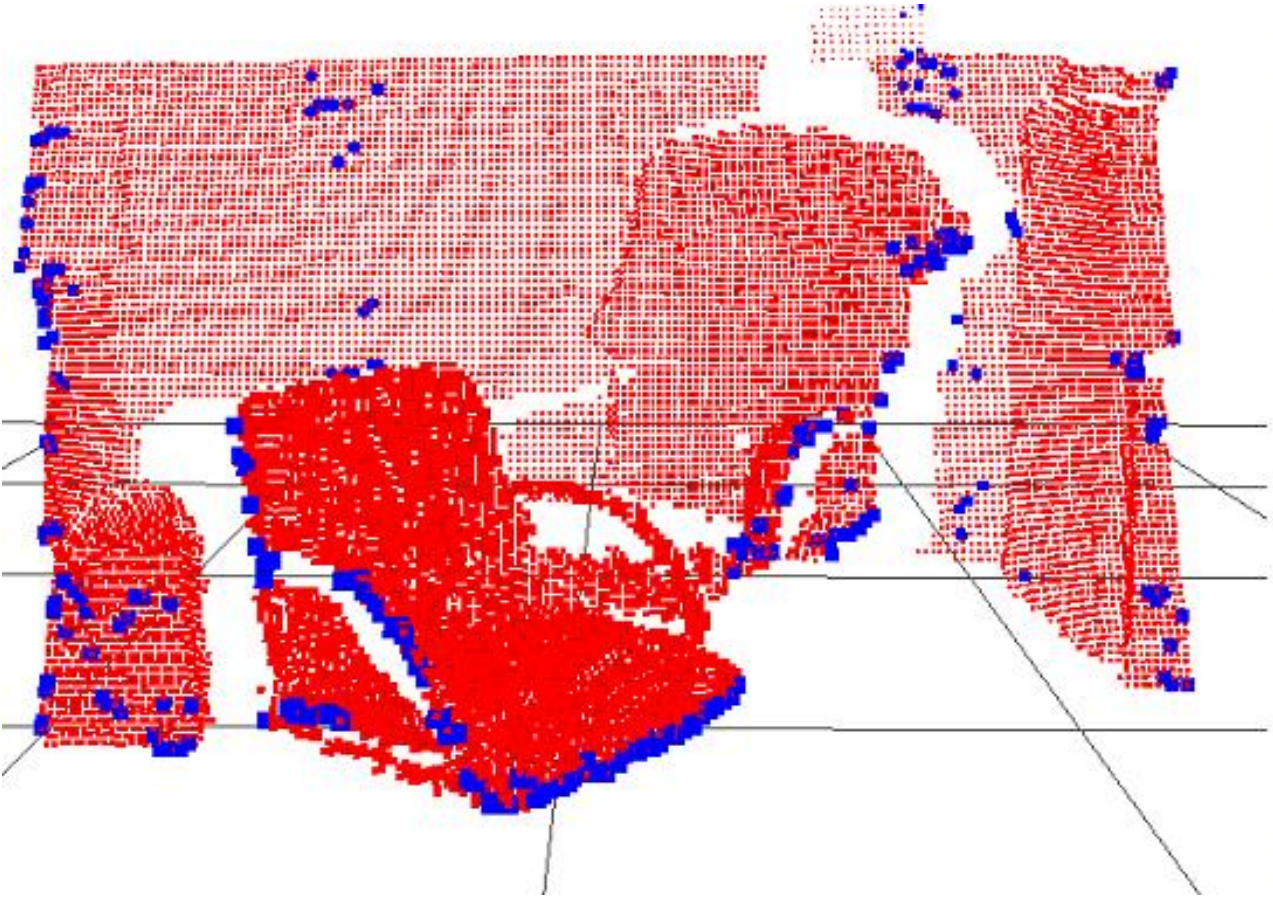
Geometry of Kinect (Rectified)





Kinect

Point Cloud = Output of the 3D sensor



Install and testing Kinect (3D sensor)

1) Connect Kinect to Computer (USB)

2) Connect Kinect power wire to Kobuki base

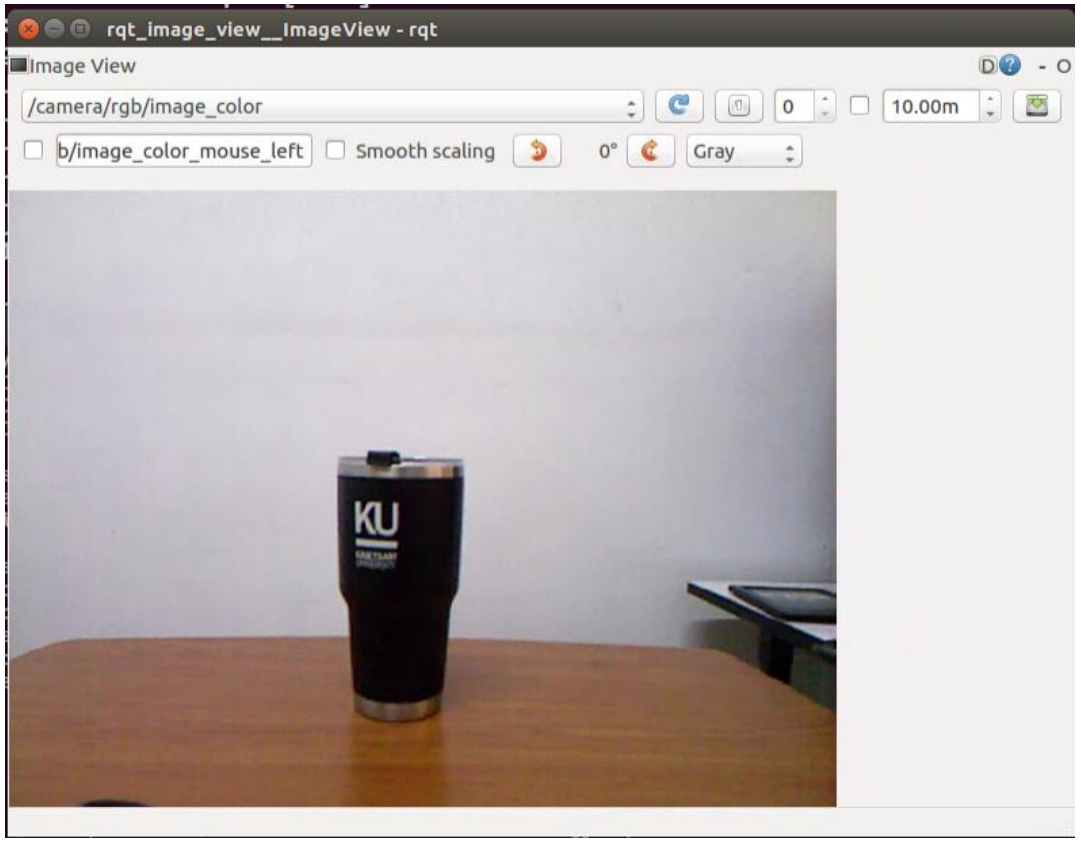
3) Run:

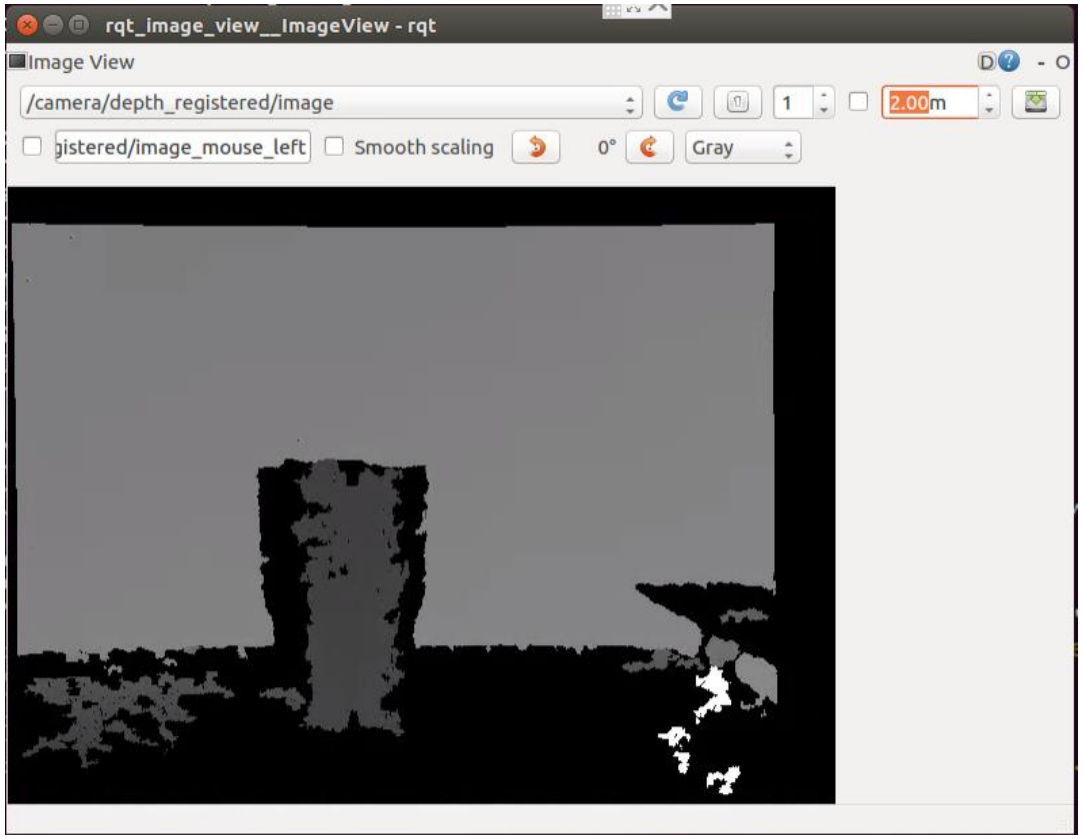
```
$ roslaunch turtlebot_bringup 3dsensor.launch
```

```
[ INFO] [1588910795.024392227]: Searching for device with index = 1
[ INFO] [1588910795.194397100]: Starting a 3s RGB and Depth stream flush.
[ INFO] [1588910795.194562060]: Opened 'Xbox NUI Camera' on bus 0:0 with serial number 'B003627068880428'
```

Install and testing Kinect (3D sensor)

```
$rosrun rqt_image_view rqt_image_view
```





Install and testing Kinect (3D sensor)

View Depth image in 3D with robot visualization (Rviz)

```
$ roslaunch turtlebot_bringup minimal.launch
```

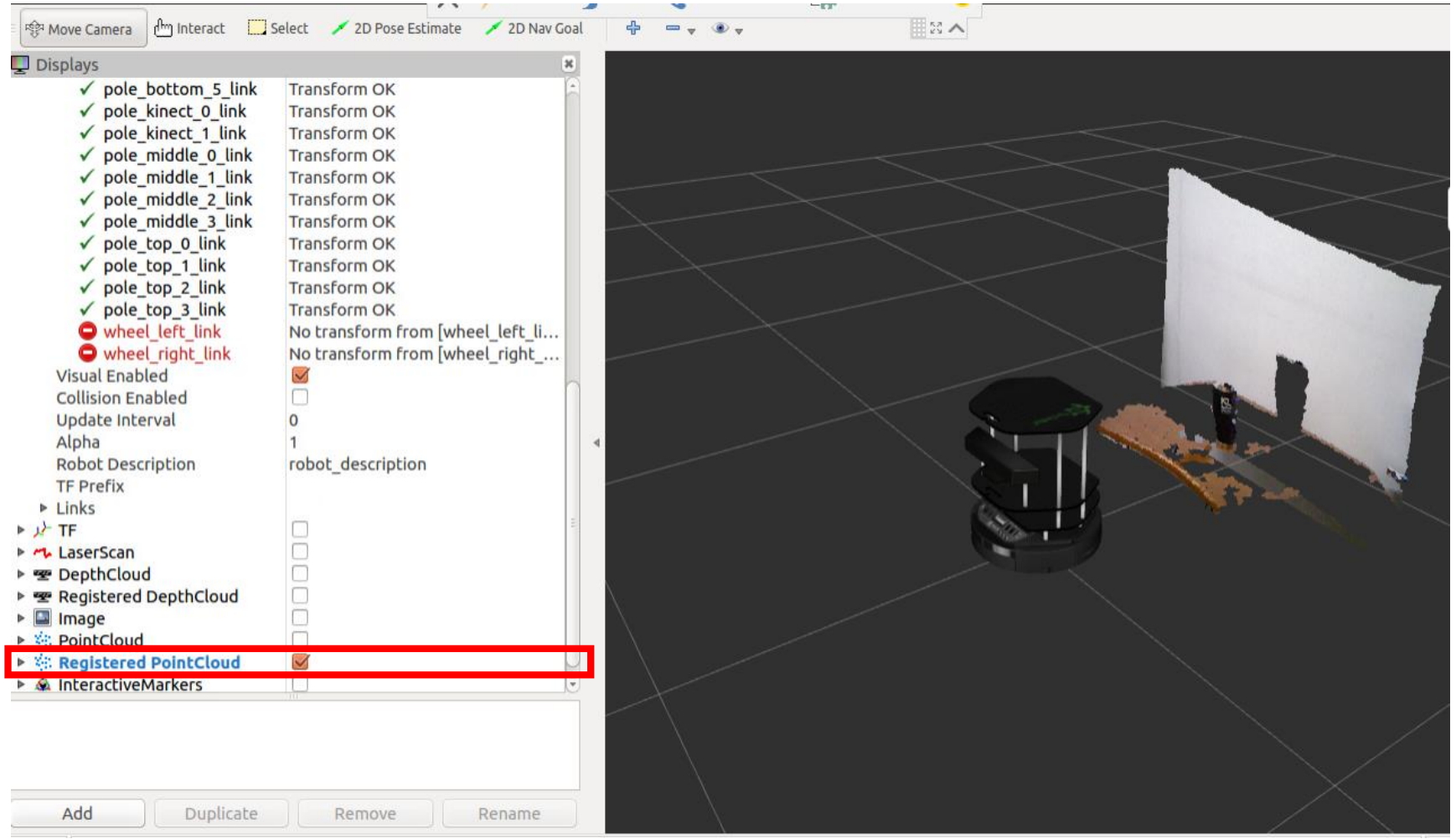
```
$ roslaunch turtlebot_bringup 3dsensor.launch
```

Run RVIZ

```
$ roslaunch turtlebot_rviz_launchers view_robot.launch
```

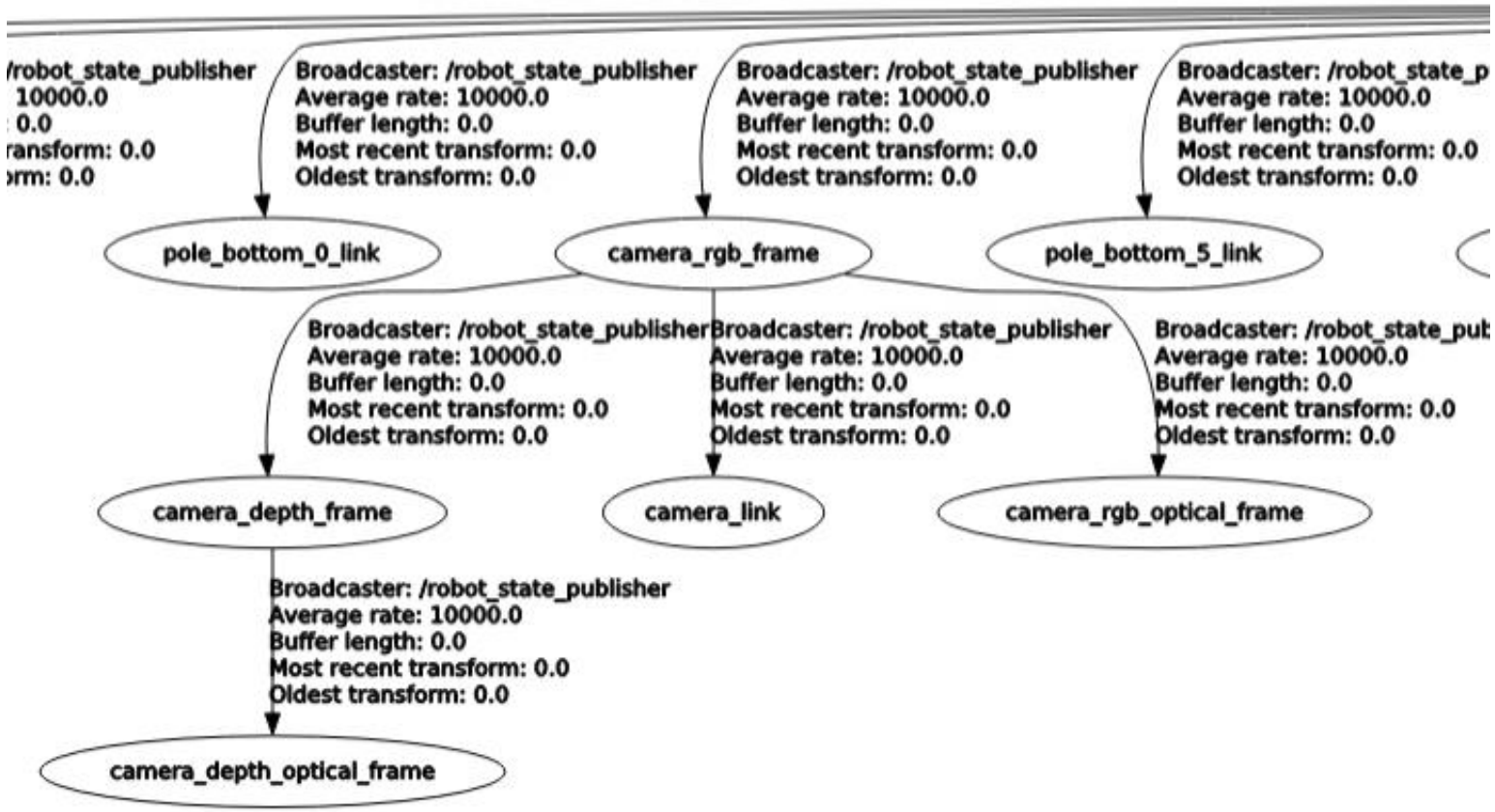
Install and testing Kinect (3D sensor)

Check the Registered PointClound in menu



Install and testing Kinect (3D sensor)

```
$ rosrun rqt_tf_tree rqt_tf_tree
```



Human Follower Experiment

Start the follower demo

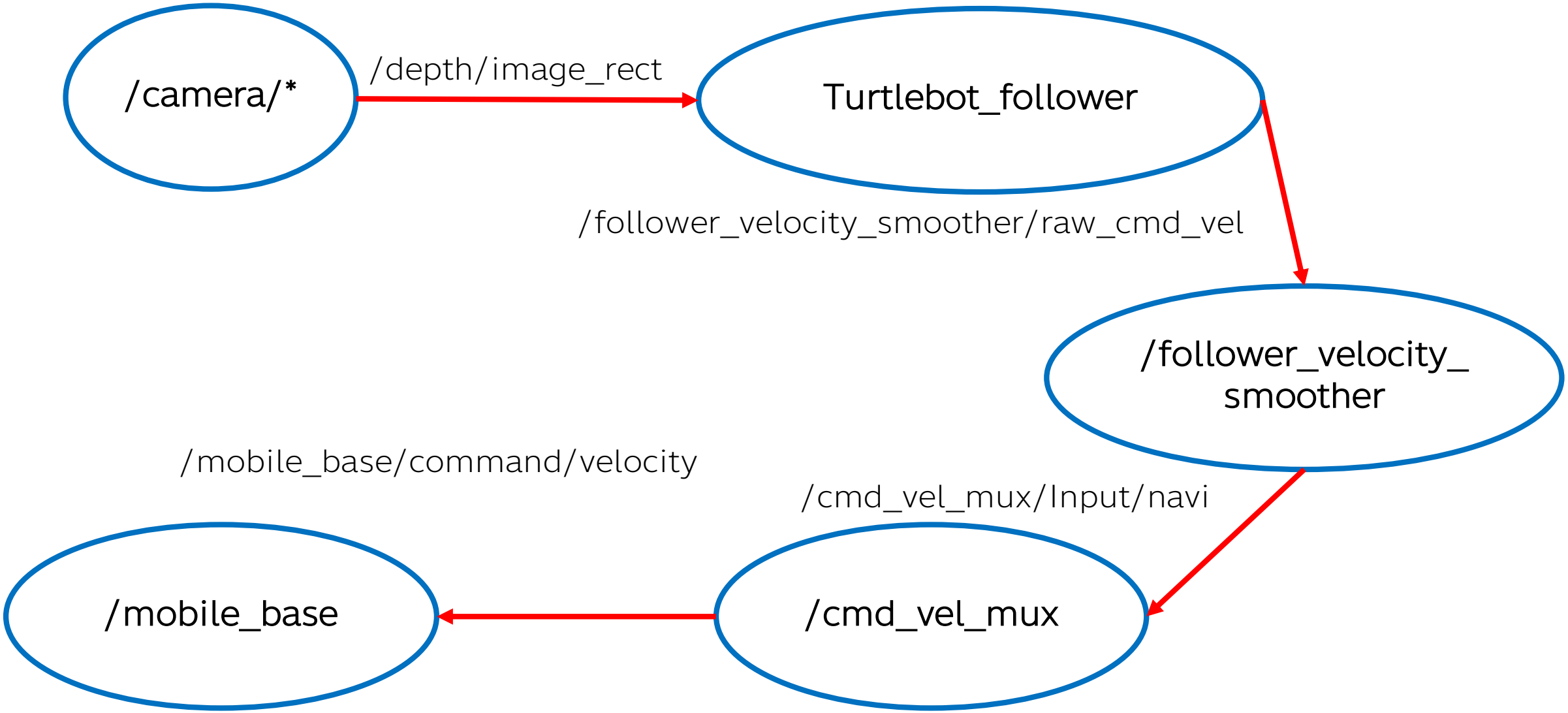
```
$ roslaunch turtlebot_bringup minimal.launch
```

```
$ roslaunch turtlebot_follower follower.launch
```

Changing Follower Parameters

```
$ rosrun rqt_reconfigure rqt_reconfigure
```

Human Follower Experiment



Human Follower Experiment

How it works:

```
uint32_t image_width = depth_msg->width;
float x_radians_per_pixel = 60.0/57.0/image_width;
float sin_pixel_x[image_width];
for (int x = 0; x < image_width; ++x) {
  sin_pixel_x[x] = sin((x - image_width/ 2.0)  * x_radians_per_pixel);
}
uint32_t image_height = depth_msg->height;
float y_radians_per_pixel = 45.0/57.0/image_width;
float sin_pixel_y[image_height];

for (int y = 0; y < image_height; ++y) { // Sign opposite x for y up values
    sin_pixel_y[y] = sin((image_height/ 2.0 - y)  * y_radians_per_pixel);
}
```

Note:
radians = degrees * π / 180°
= degree / 57.2957

Kinect	Specifications
Viewing angle	Field of View (FoV): 43° vertical x 57° horizontal

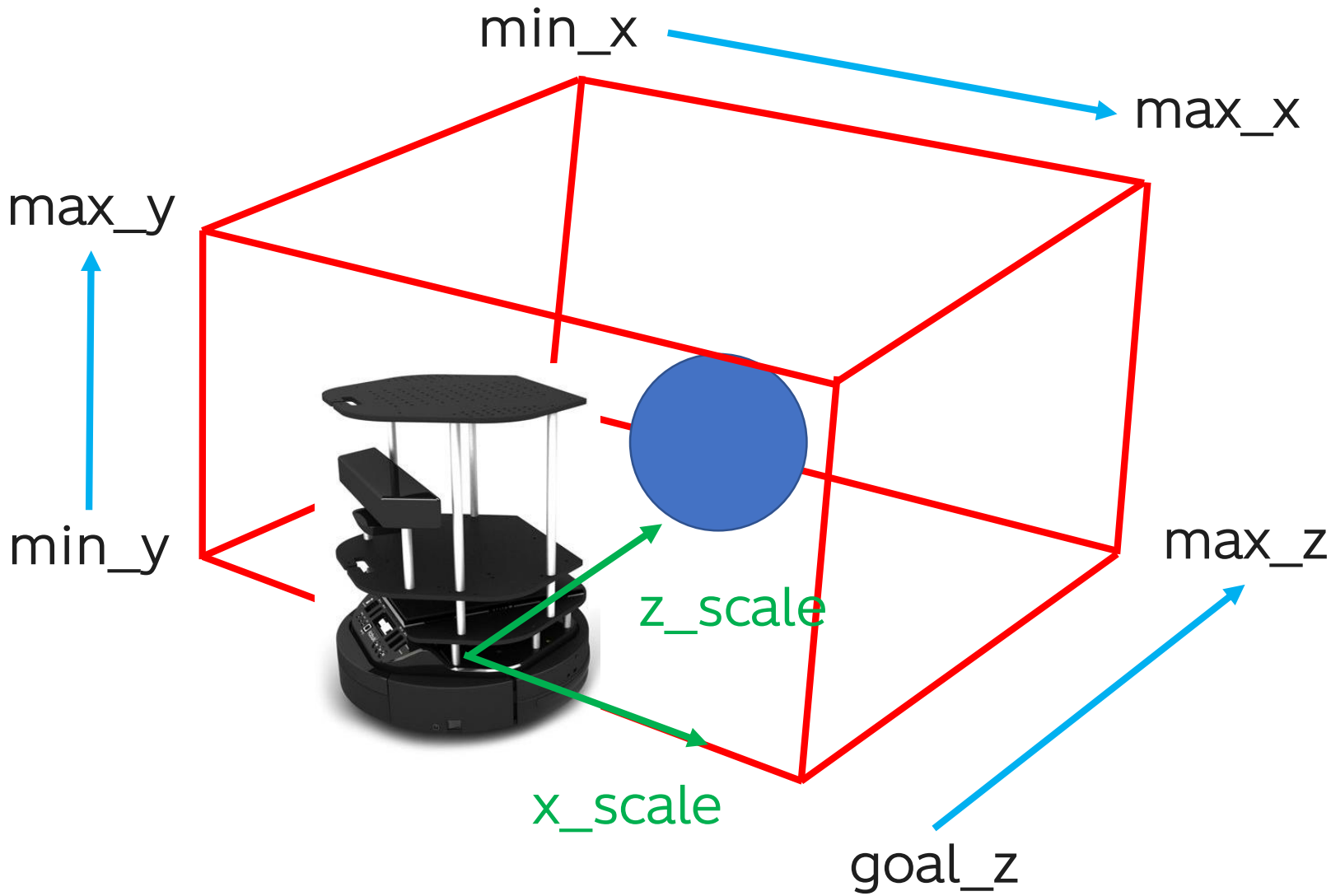
Human Follower Experiment

```
for (int v = 0; v < (int)depth_msg->height; ++v, depth_row += row_step)
{
    for (int u = 0; u < (int)depth_msg->width; ++u)
    {
        float depth = depth_image_proc::DepthTraits<float>::toMeters(depth_row[u]);
        if (!depth_image_proc::DepthTraits<float>::valid(depth) || depth > max_z_)
            continue;
        float y_val = sin_pixel_y[v] * depth;
        float x_val = sin_pixel_x[u] * depth;
        if ( y_val > min_y_ && y_val < max_y_ &&
            x_val > min_x_ && x_val < max_x_)
        {
            x += x_val;
            y += y_val;
            z = std::min(z, depth); //approximate depth as forward.
            n++;
        }
    }
}
```

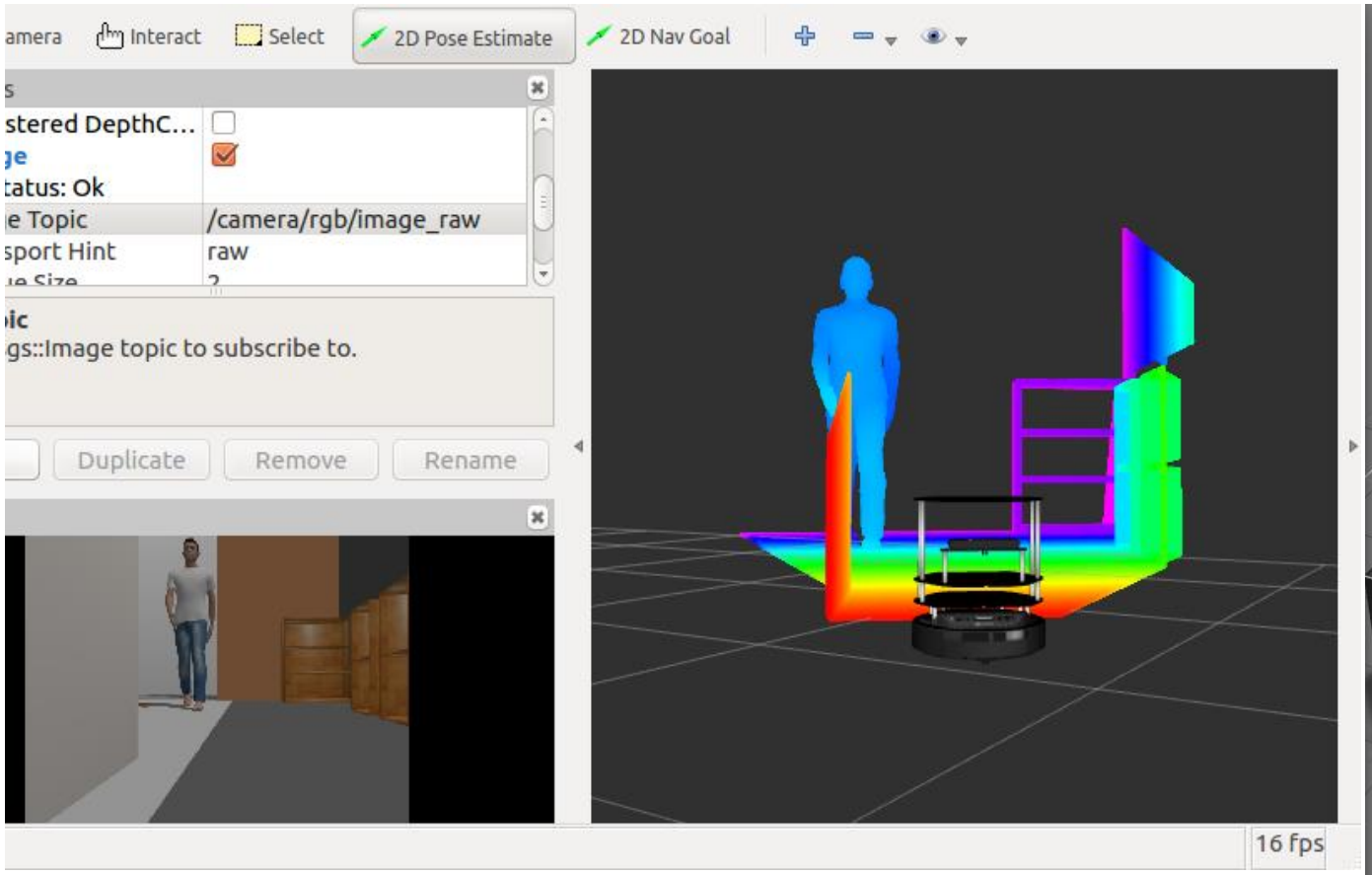
Human Follower Experiment

Changing Follower Parameters

Human Follower Experiment



World Simulation



Setup a ROS catkin workspace → Create a ROS package for the robot → Create a ROS node to launch the robot with Rviz → Create a node to publish joint state instructions to the robot → Launch these ROS nodes with roslaunch

World Simulation

Place gazebo_models.tar.gz to home directory

```
$ tar -zxvf gazebo_models.tar.gz
$ cd gazebo_models
$ cp -fR * $HOME/.gazebo/models/
```

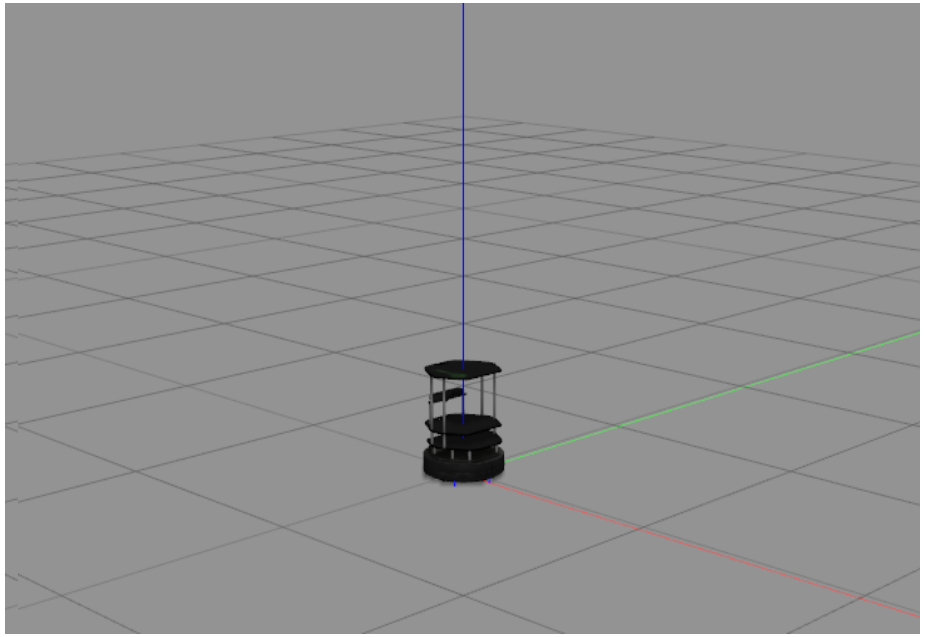
```
ku@ku:~/myROS$ cp -fR fitness $HOME/.gazebo/models
ku@ku:~/myROS$ ls $HOME/.gazebo/models
ambulance  cube_20k  fitness        jersey_barrier  living  person_standing  sun  table
bookshelf  dumpster  ground_plane   kitchen_dining  oak_tree  person_walking  suv
ku@ku:~/myROS$
```

World Simulation

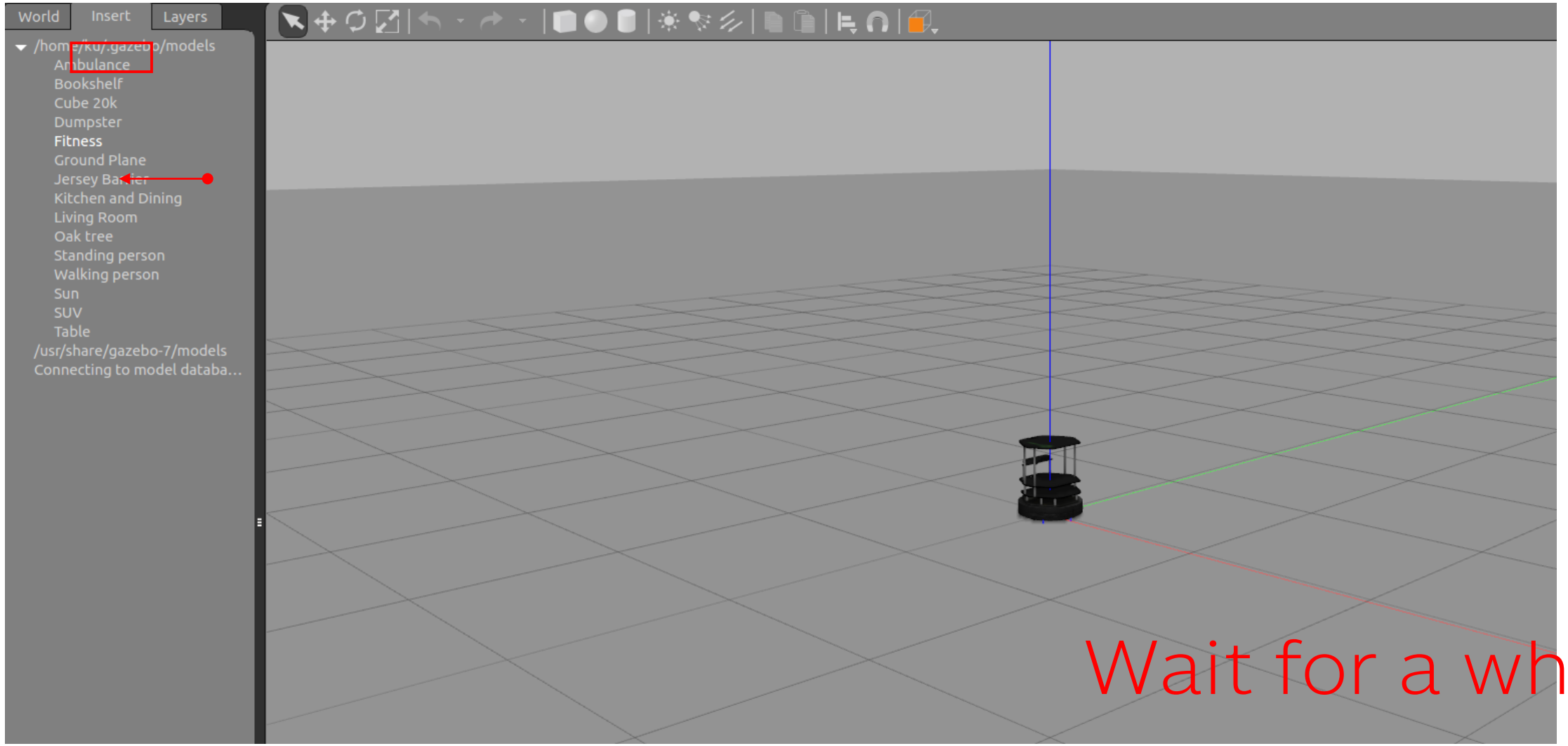
Launch gazebo turtlebot simulator with empty world

```
$ roscore
```

```
$ roslaunch turtlebot_gazebo turtlebot_world.launch
world_file:=/opt/ros/kinetic/share/turtlebot_gazebo/worlds/empty.world
```

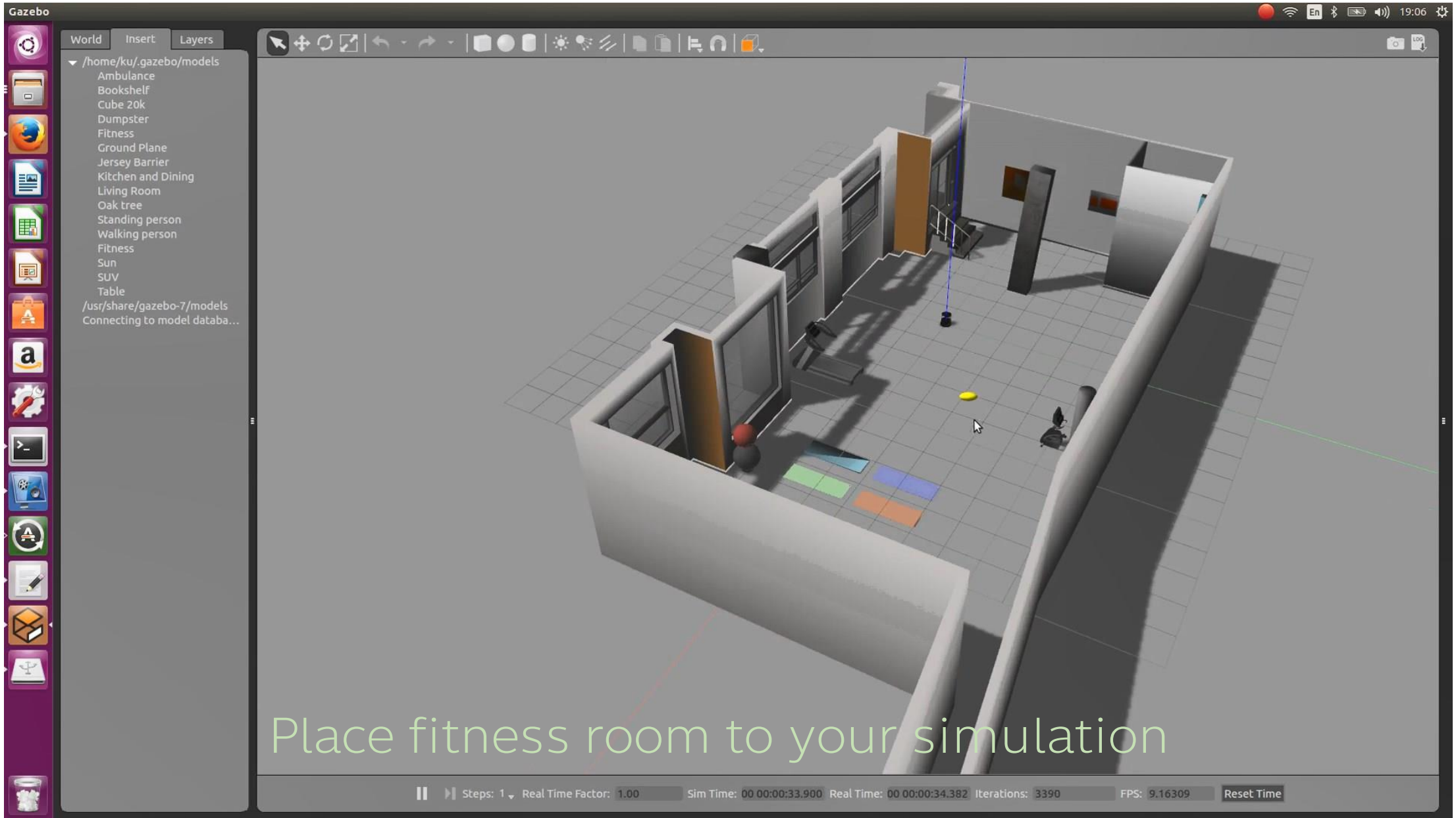


World Simulation



Wait for a while

World Simulation



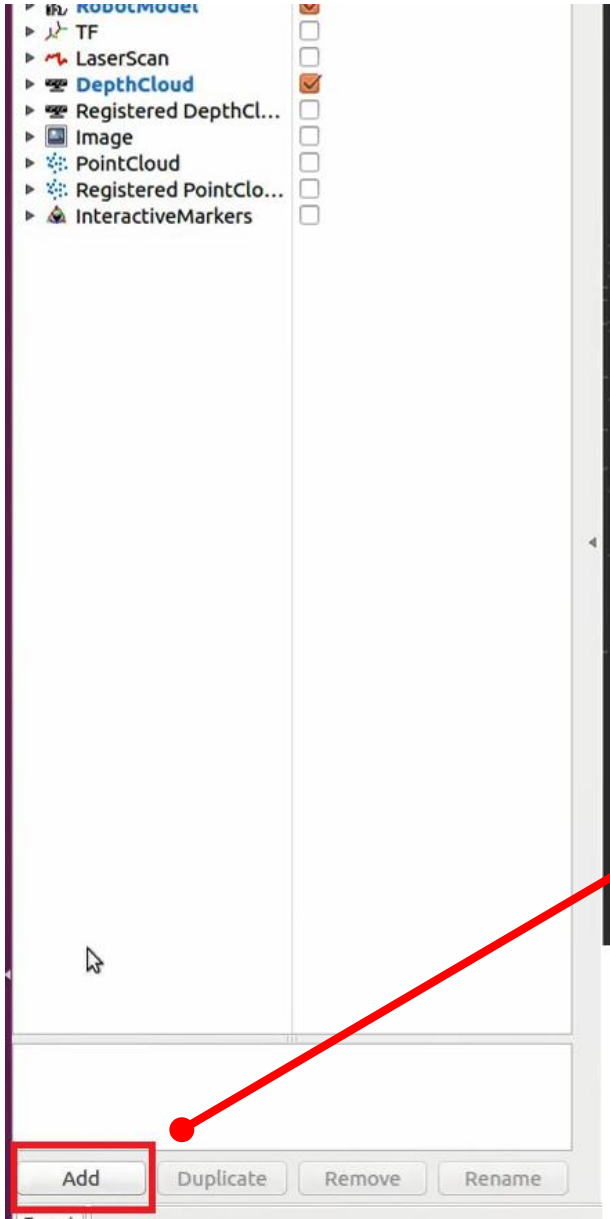
World Simulation

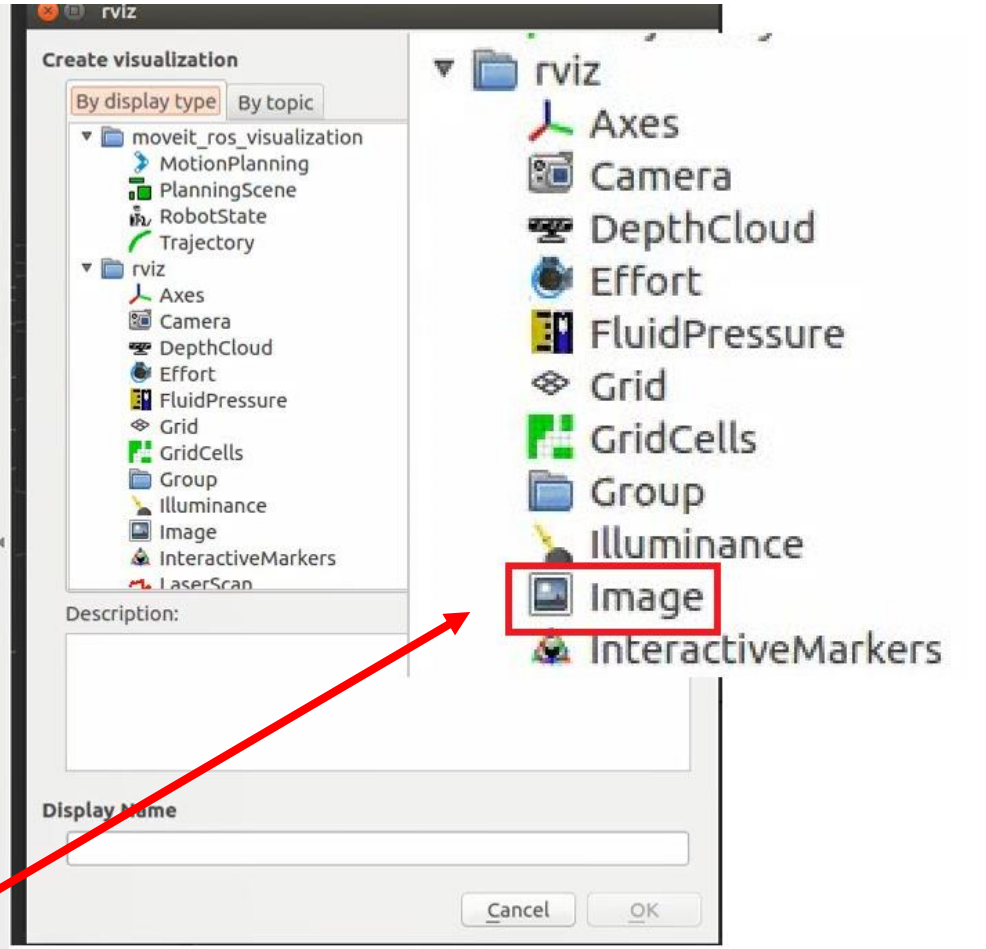
Launch turtlebot rviz

```
$ roslaunch turtlebot_rviz_launchers view_robot.launch
```

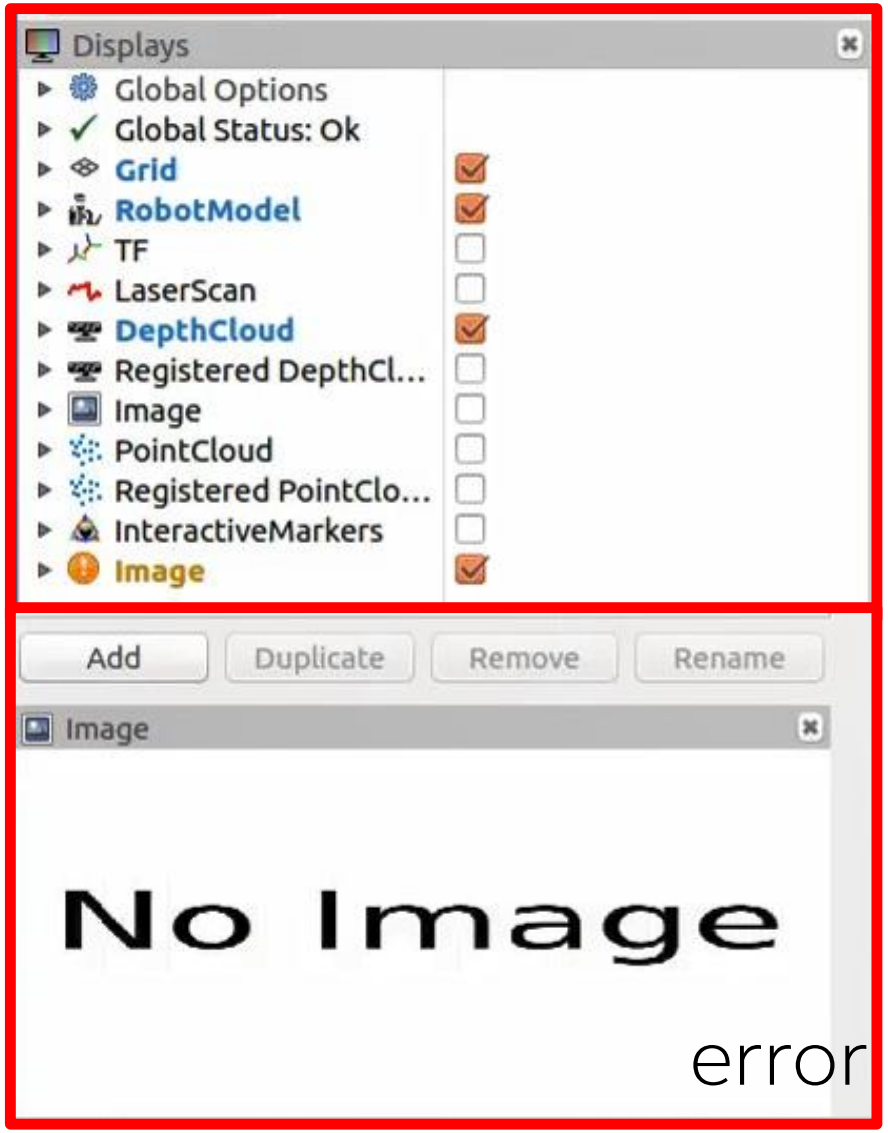
Enable DepthCloud

World Simulation



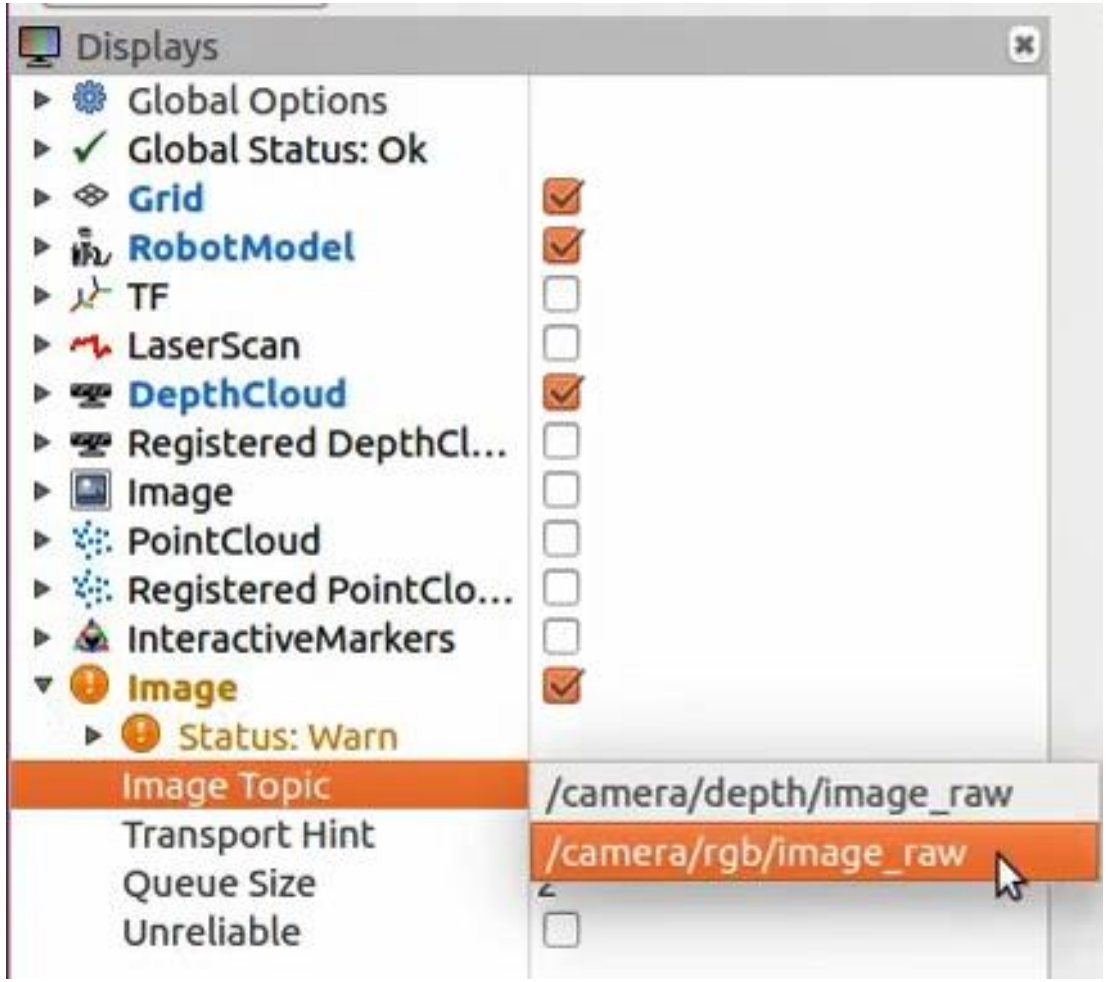


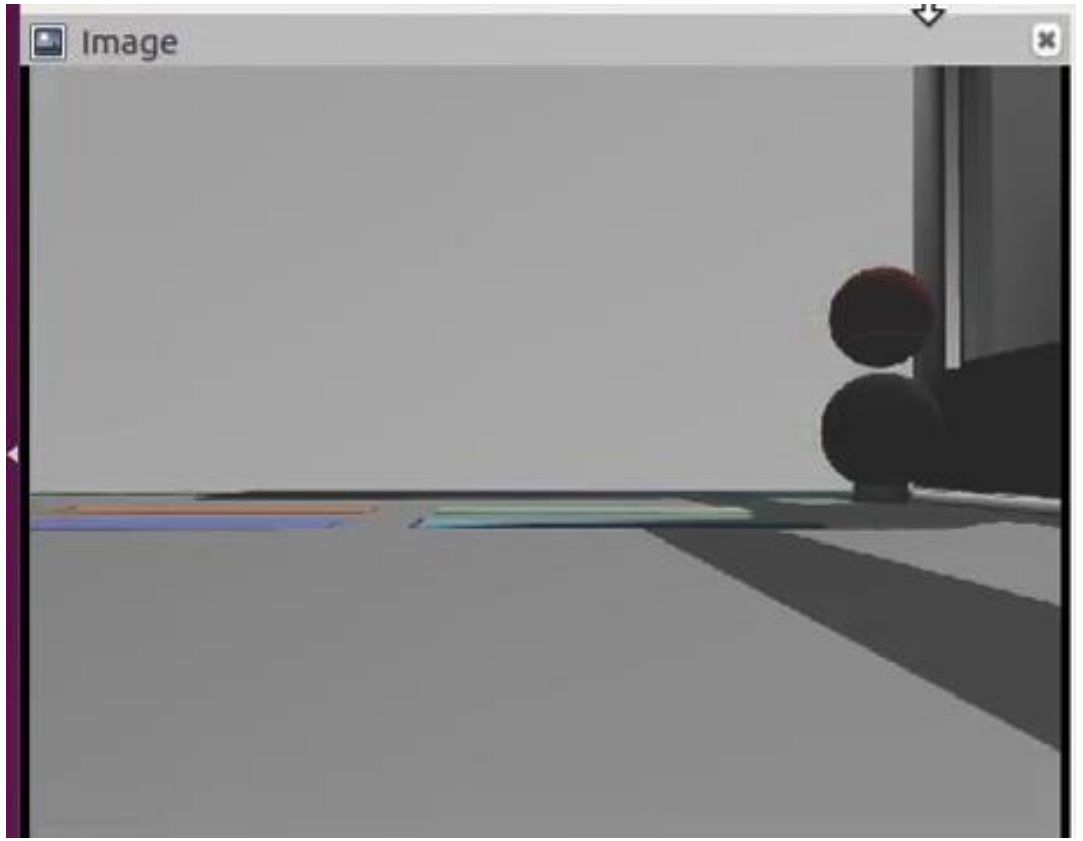
Add image



error

World Simulation





World Simulation

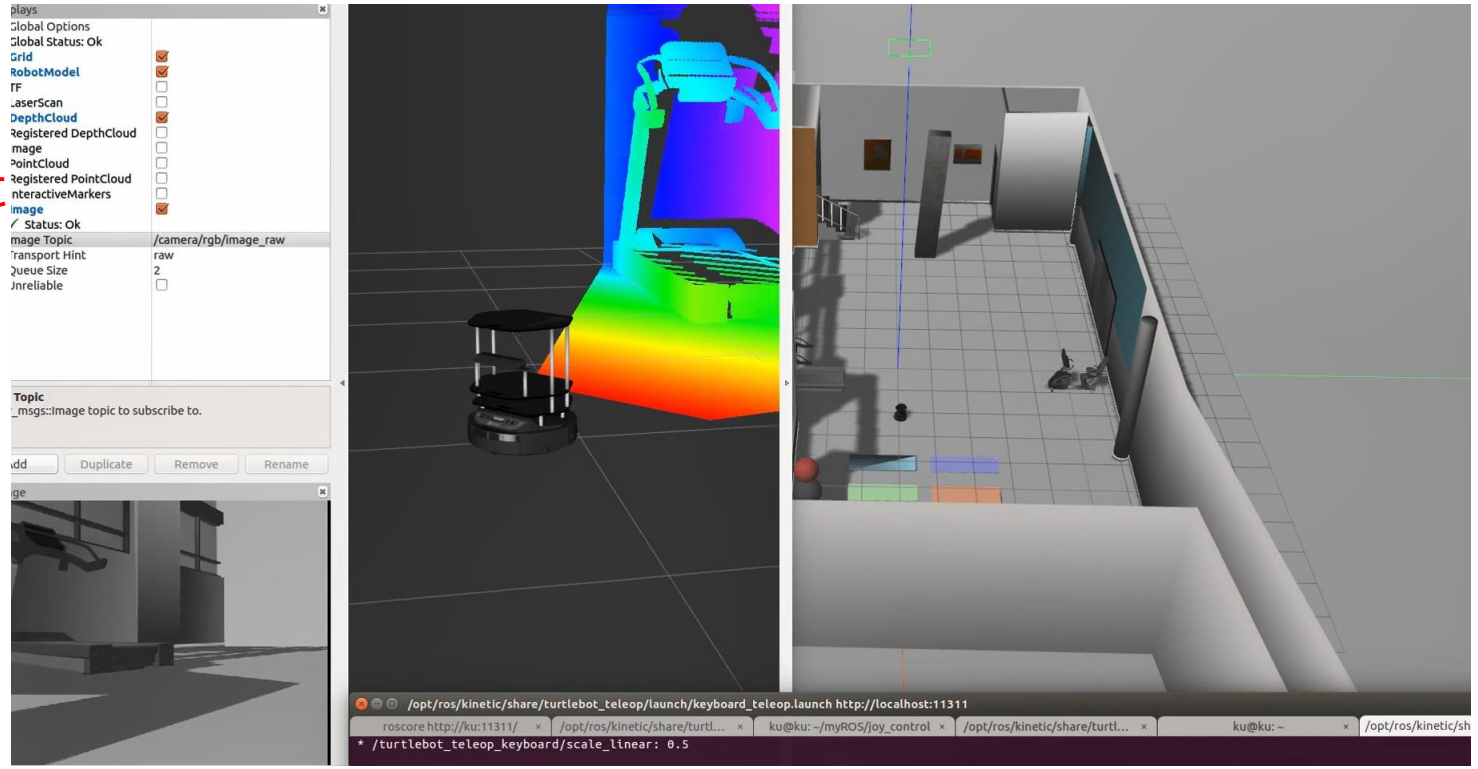
Test turtlebot in environment

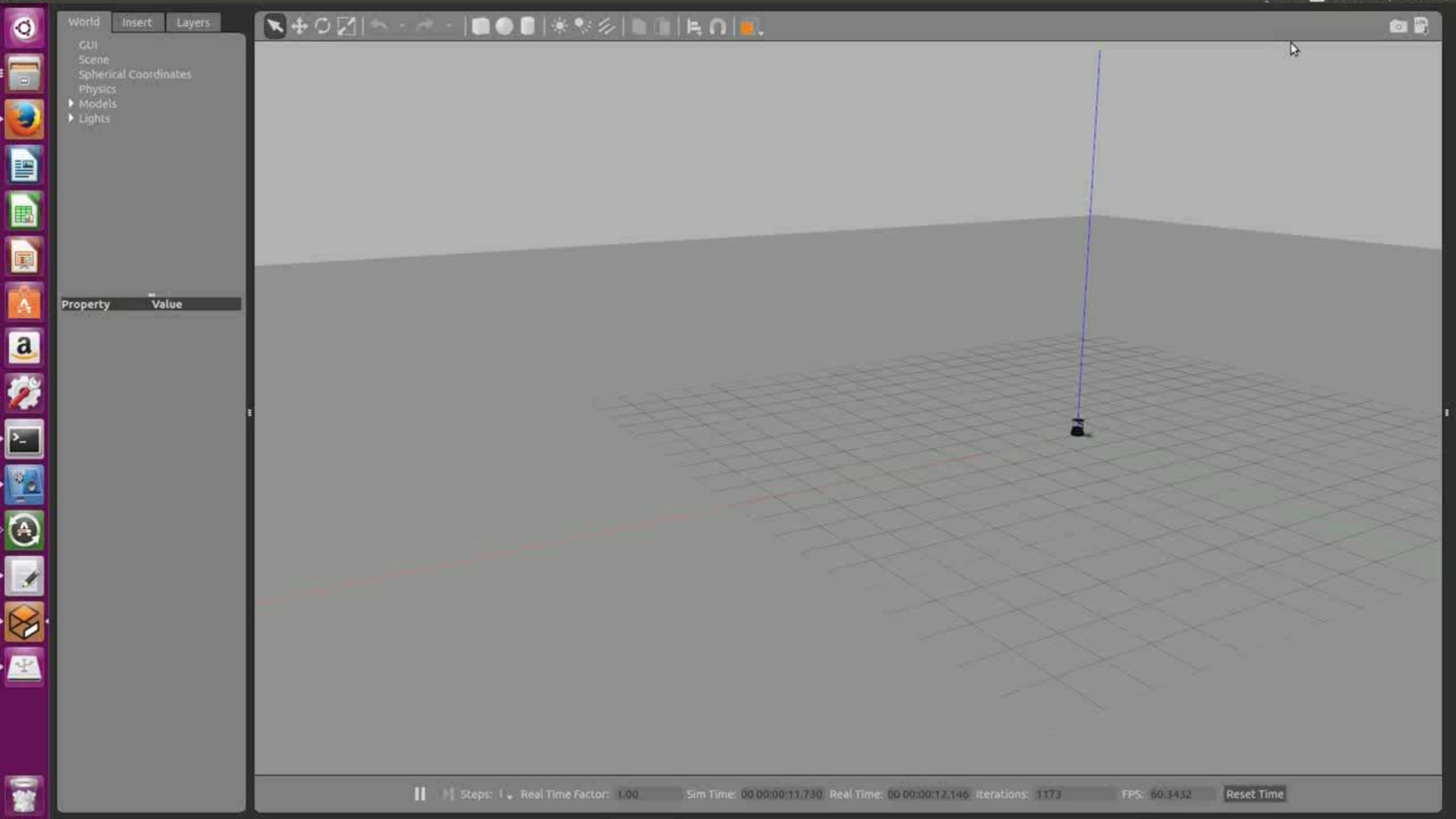
```
$ roslaunch turtlebot_teleop keyboard_teleop.launch
```

```
$ roslaunch turtlebot_teleop logitech.launch
```

You can get image directly to test your image processing algorithm

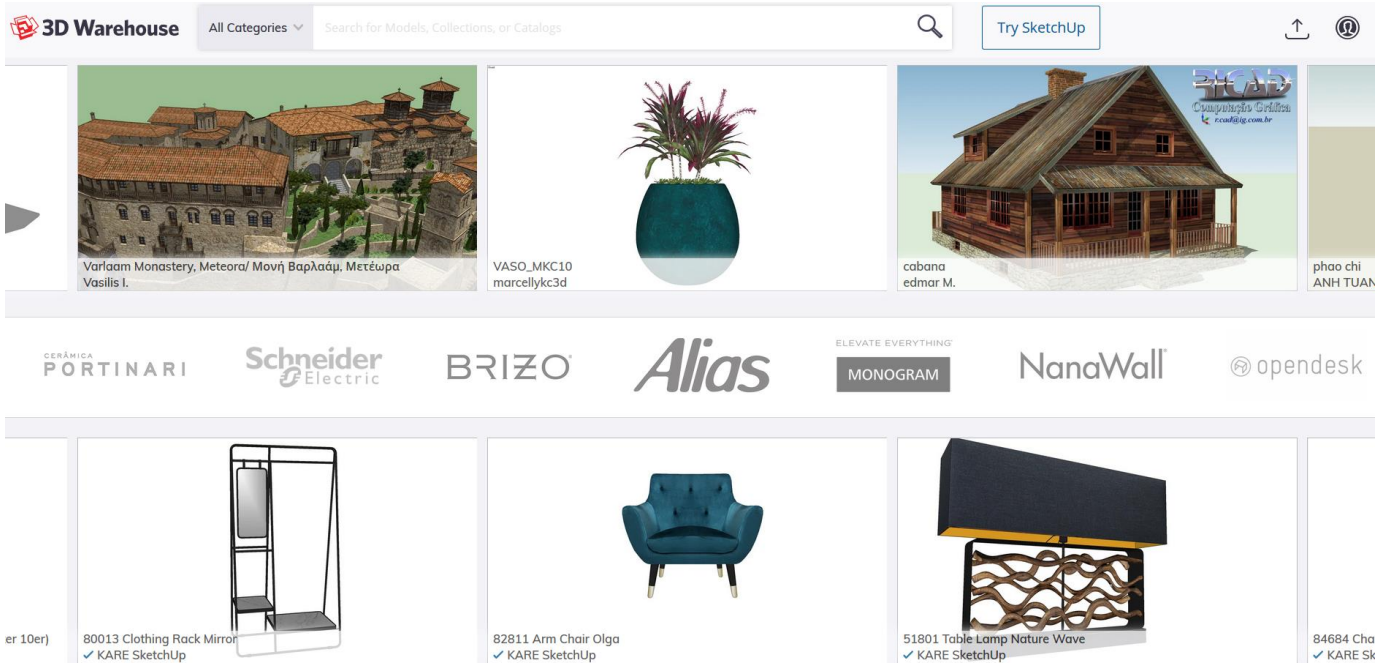
Save .world to use in the future




World
Insert
Layers
GUI
Scene
Spherical Coordinates
Physics
Models
Lights
Property
Value
Steps:
Real Time Factor:
1.00
Sim Time:
00 00:00:11.730
Real Time:
00 00:00:12.146
Iterations:
1173
FPS:
60.3432
Reset Time

Where can we get environment ?

skp export to Collada file
convert solidwork to Collada file via MeshLab



or create by yourself

http://gazebosim.org/tutorials?tut=build_model

https://3dwarehouse.sketchup.com/

THANK YOU