GLOSSARY

AMR (Autonomouus Mobile Robot)

ROS (Robot Operating System)

SLAM (Simultaneous Localization and Mapping)

URDF (Unified Robot Description Format)

IMU (Inertial Measurement Unit)

LiDAR (Light Detection and Ranging)

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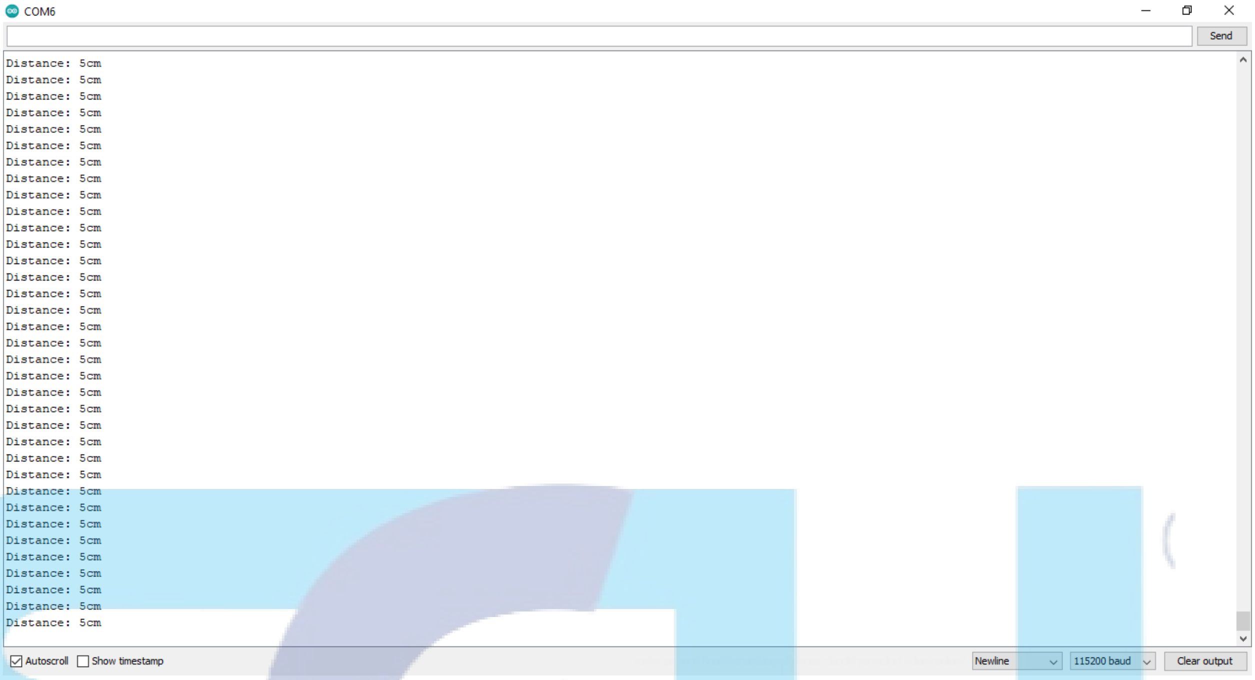
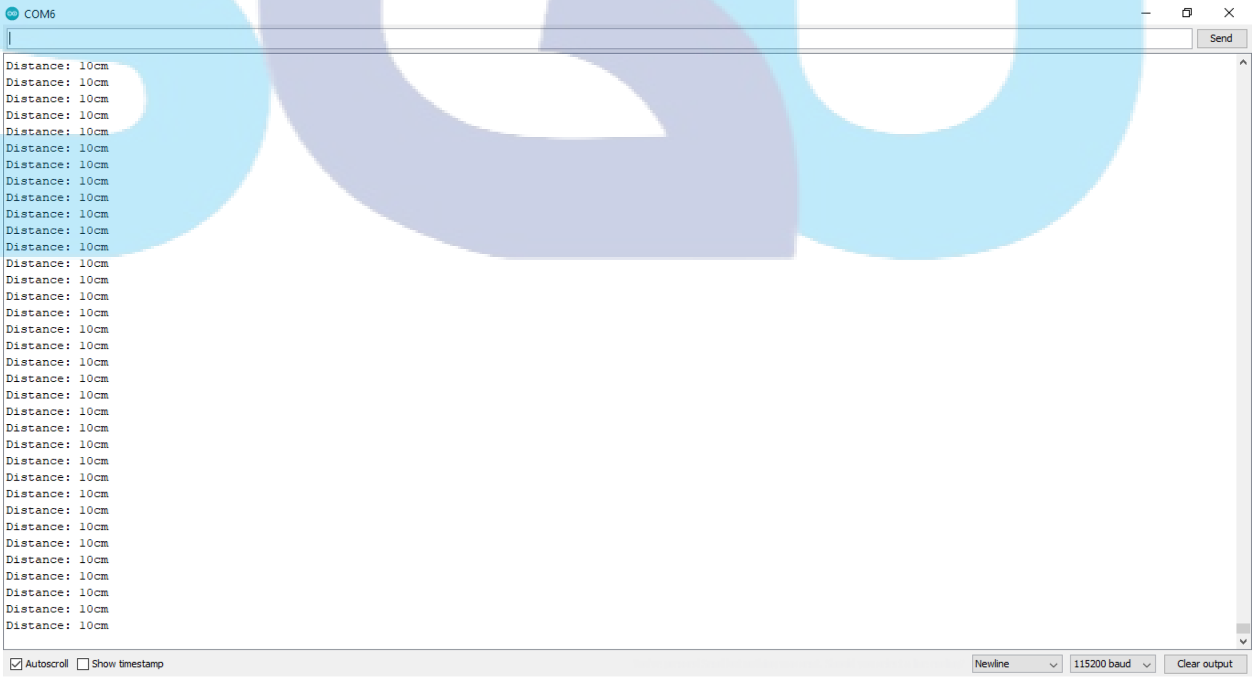
APPENDICES

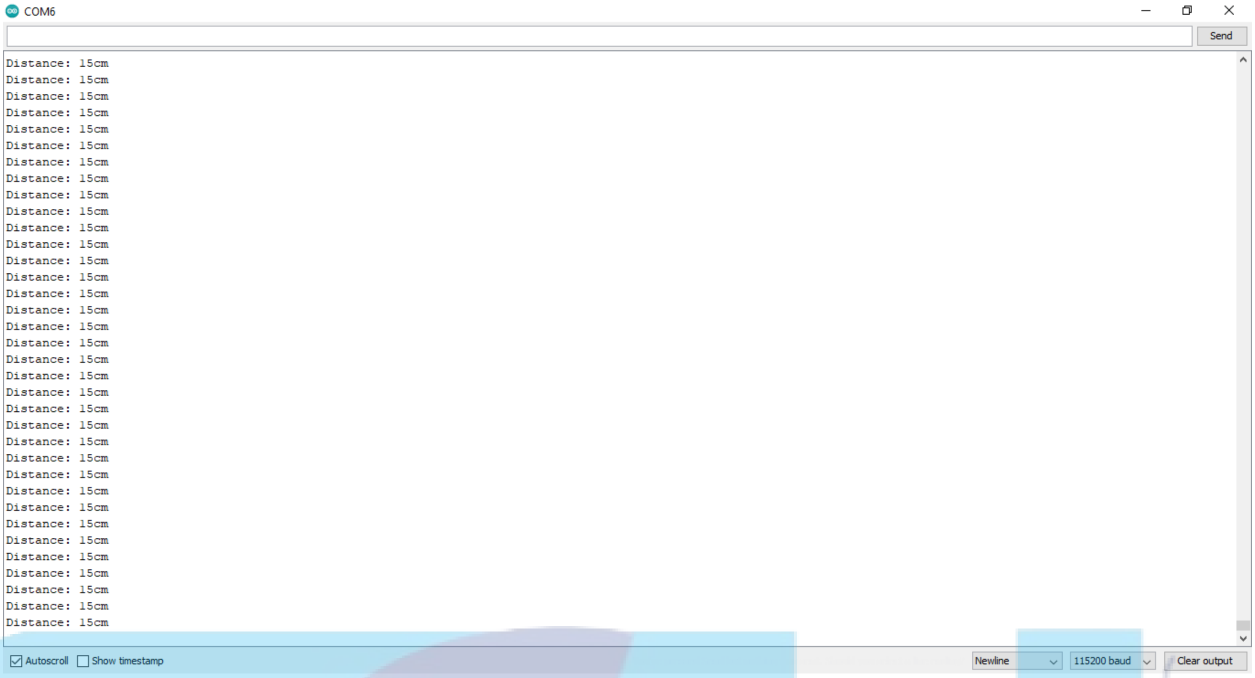
Appendix 1 Data Testing of Ultrasonic Sensor



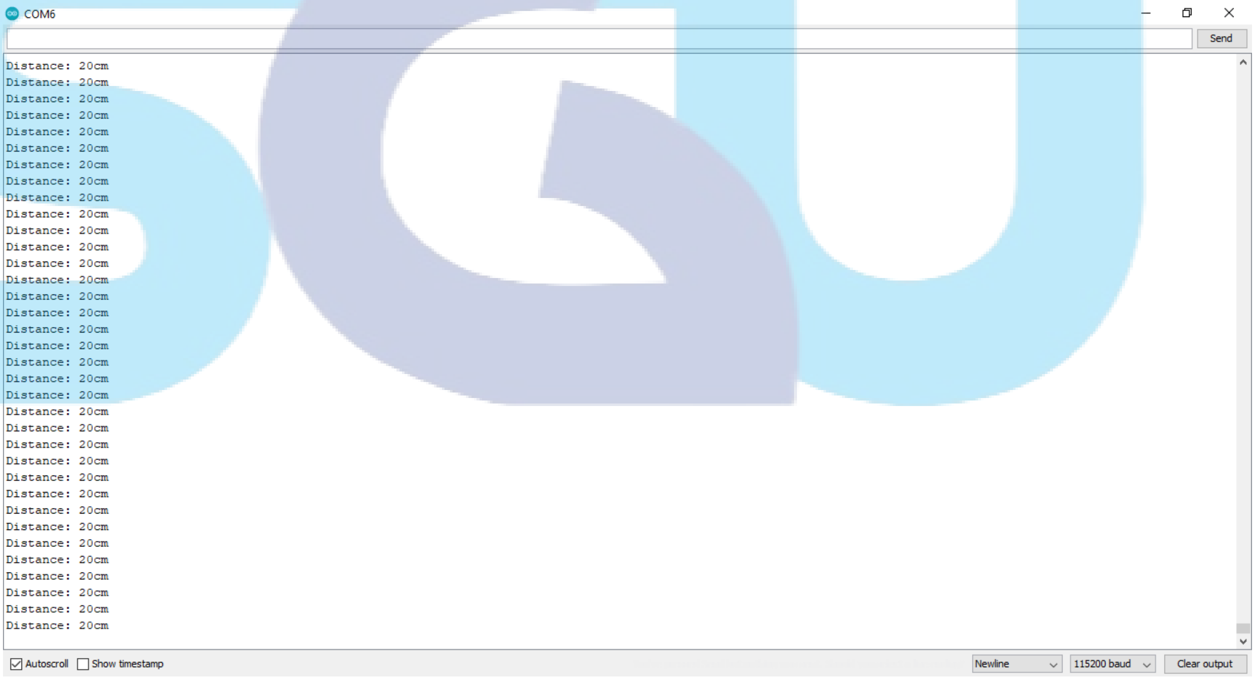
distance 5 cm



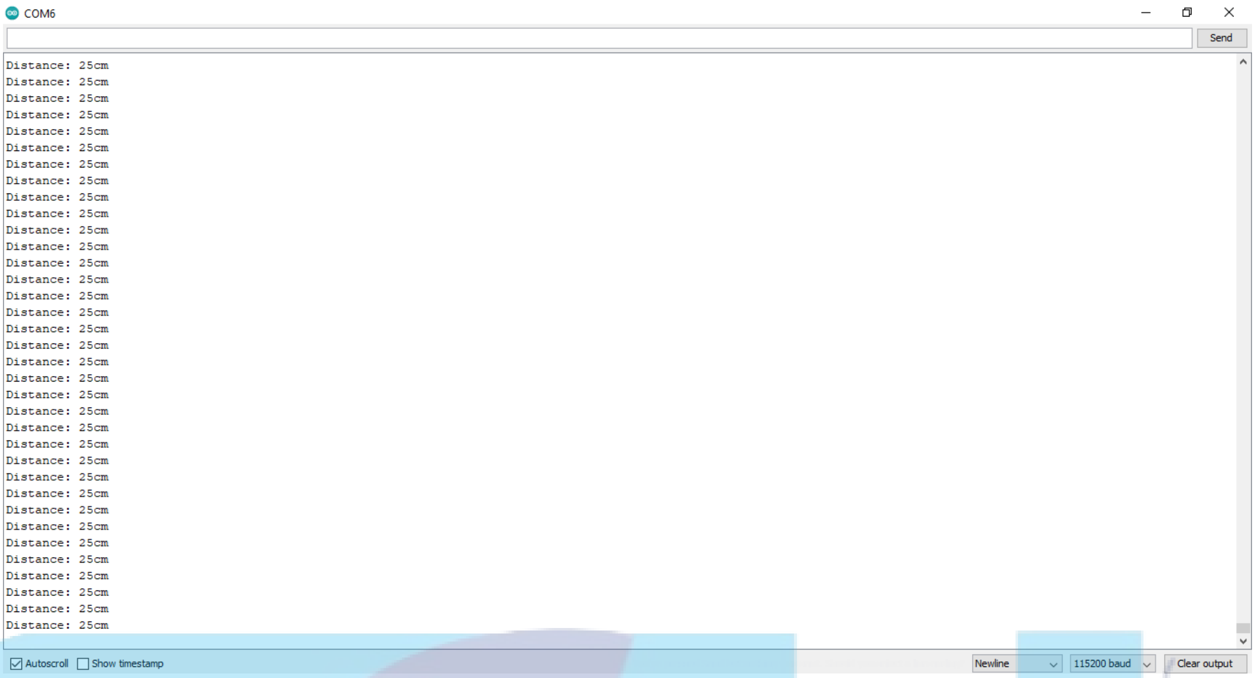
distance 10 cm



Distance 15 cm

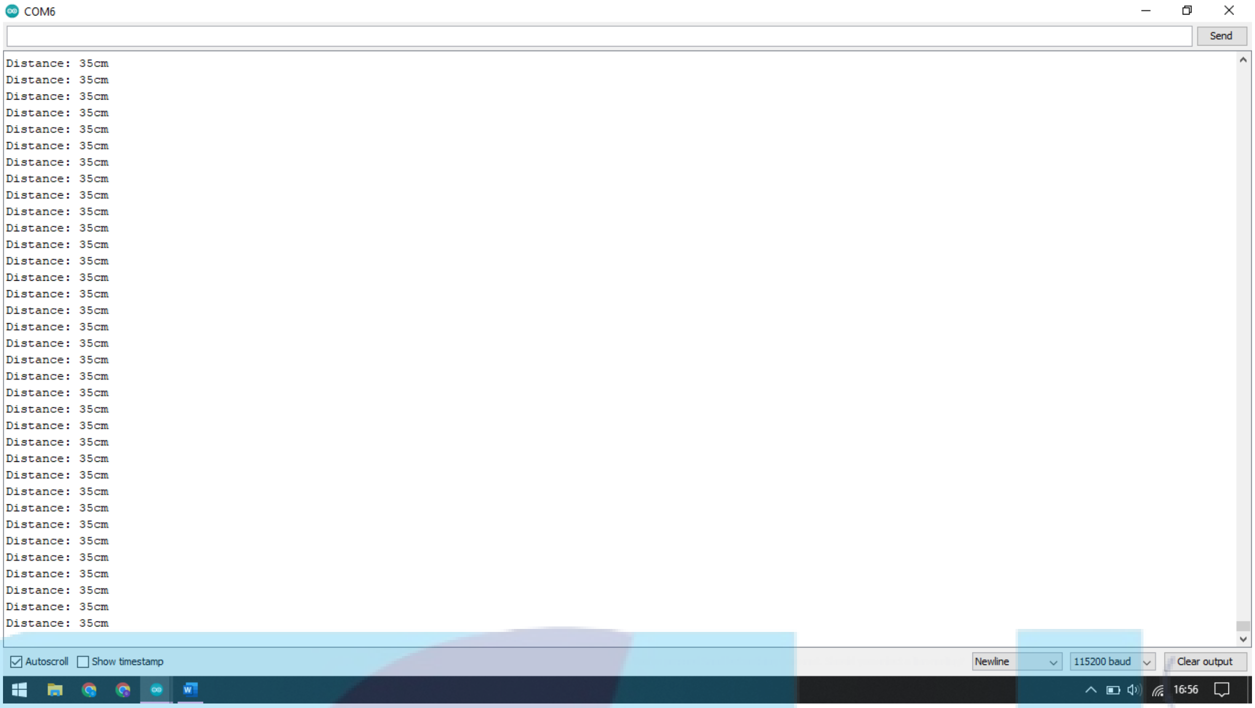


Distance 20 cm

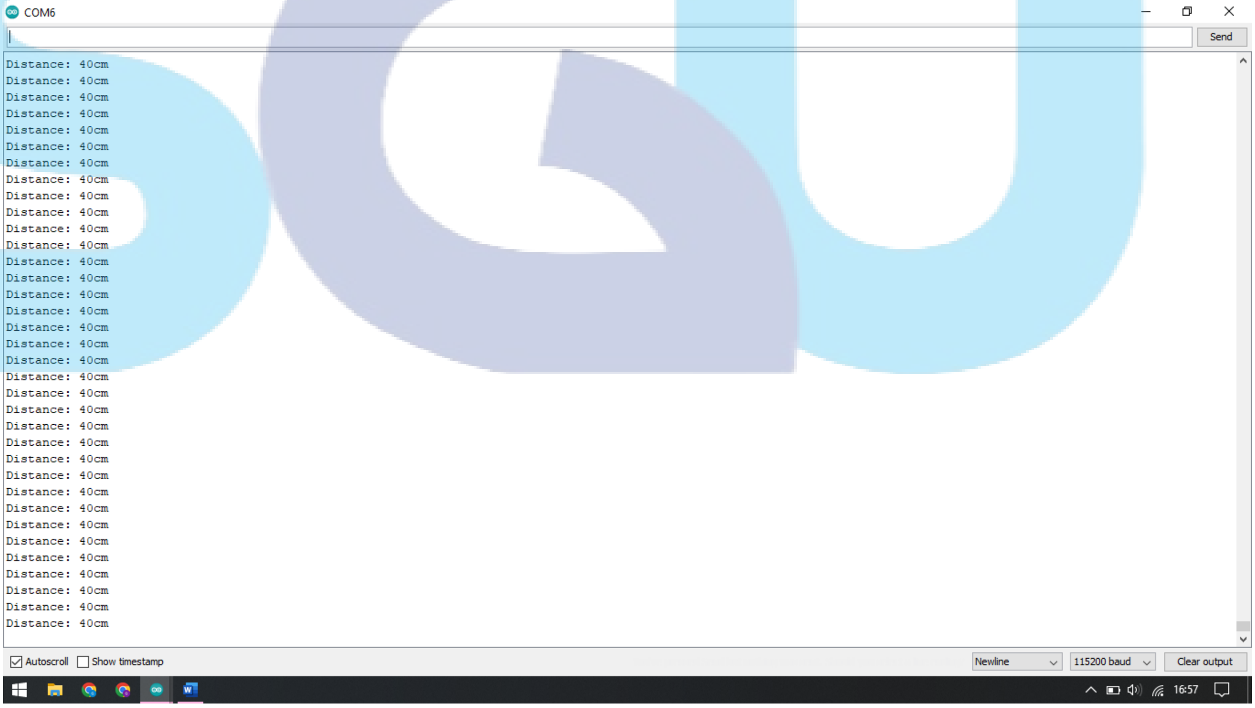


Distance 25 cm

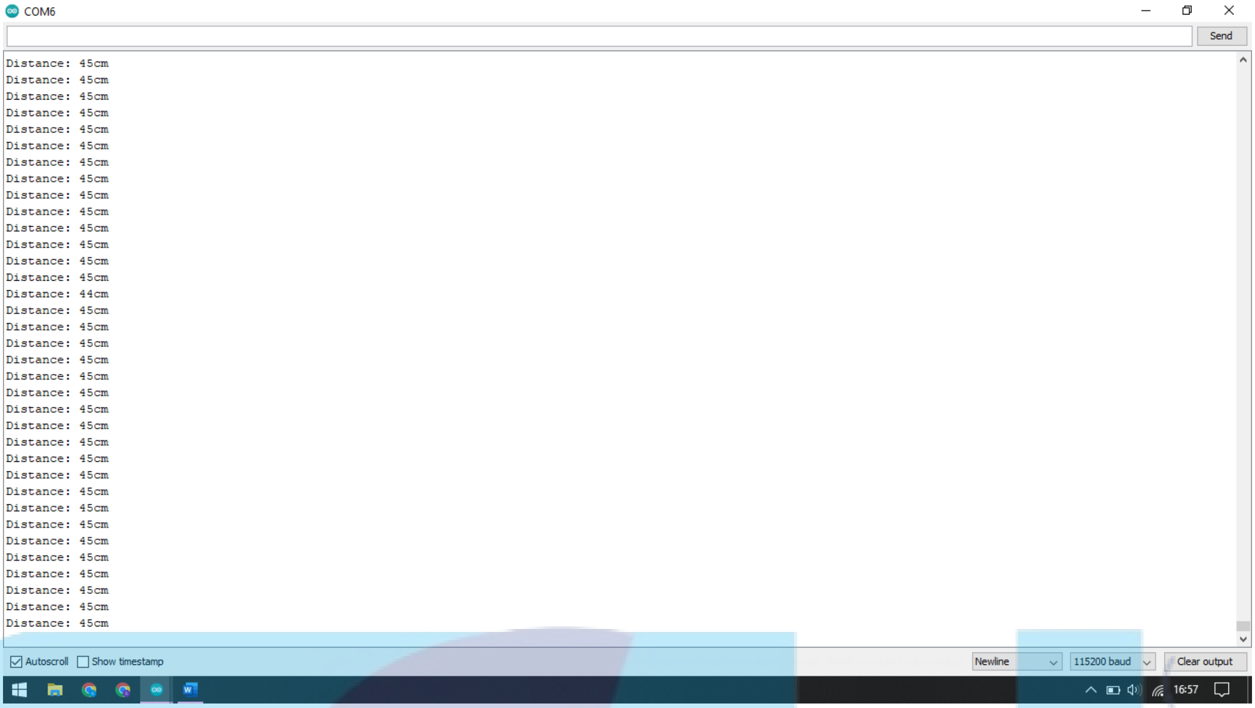
distance 30 cm



Distance 35 cm



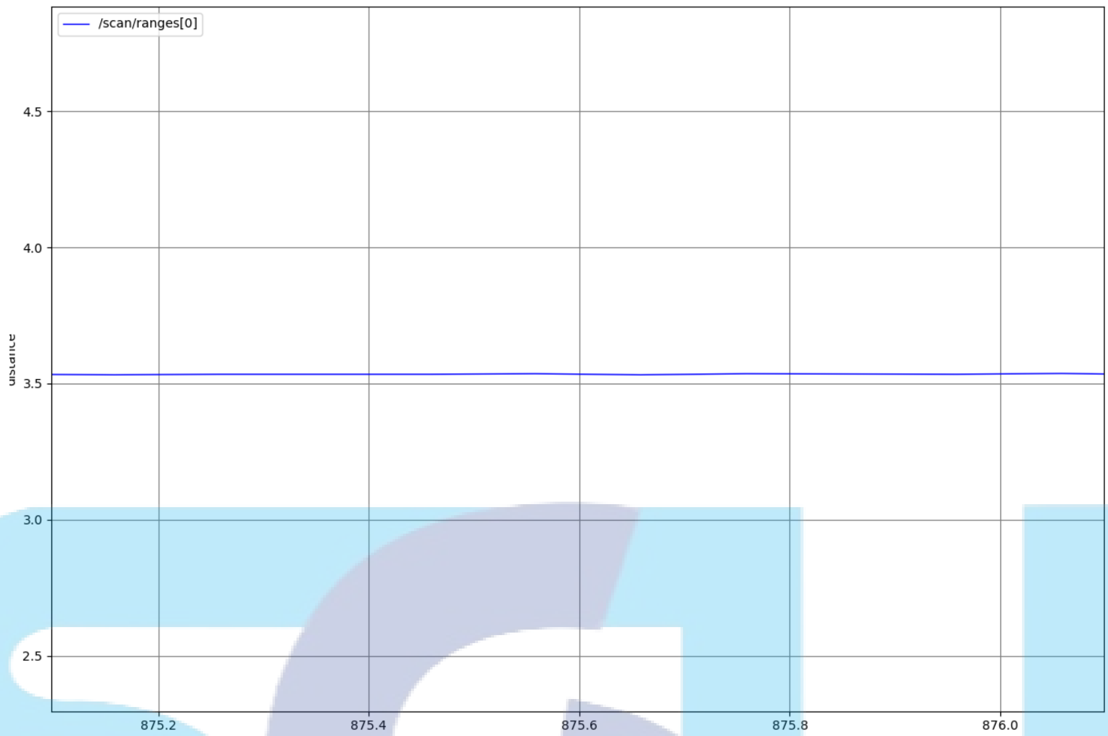
Distance 40 cm

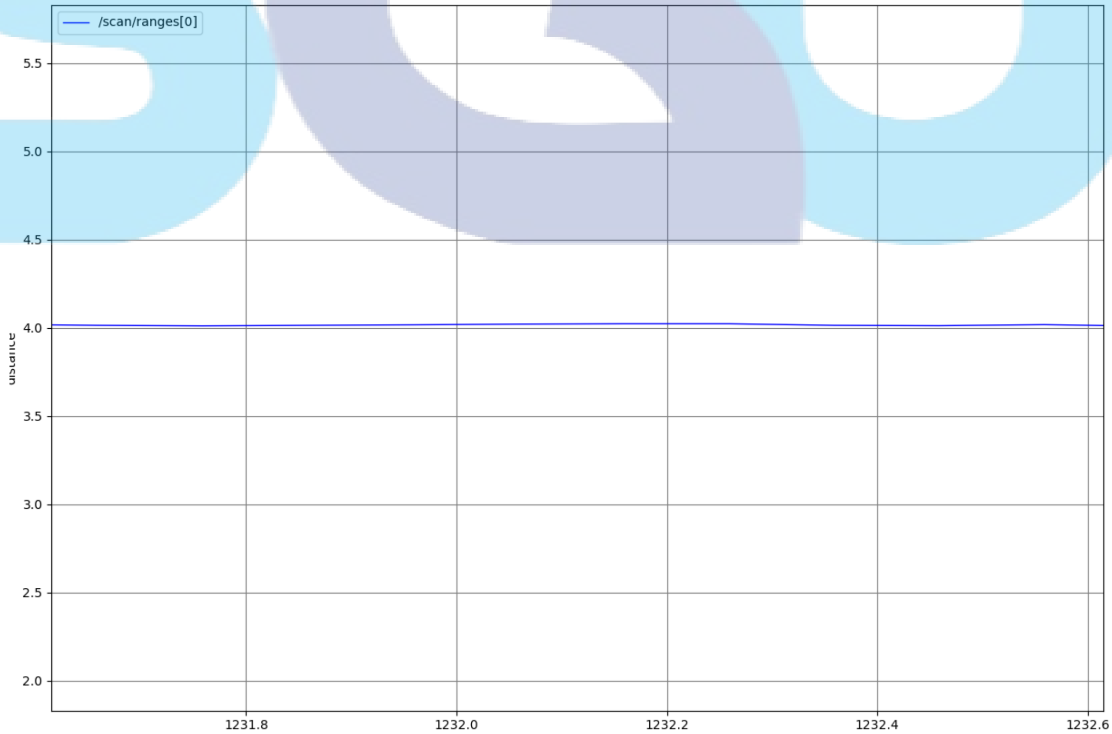


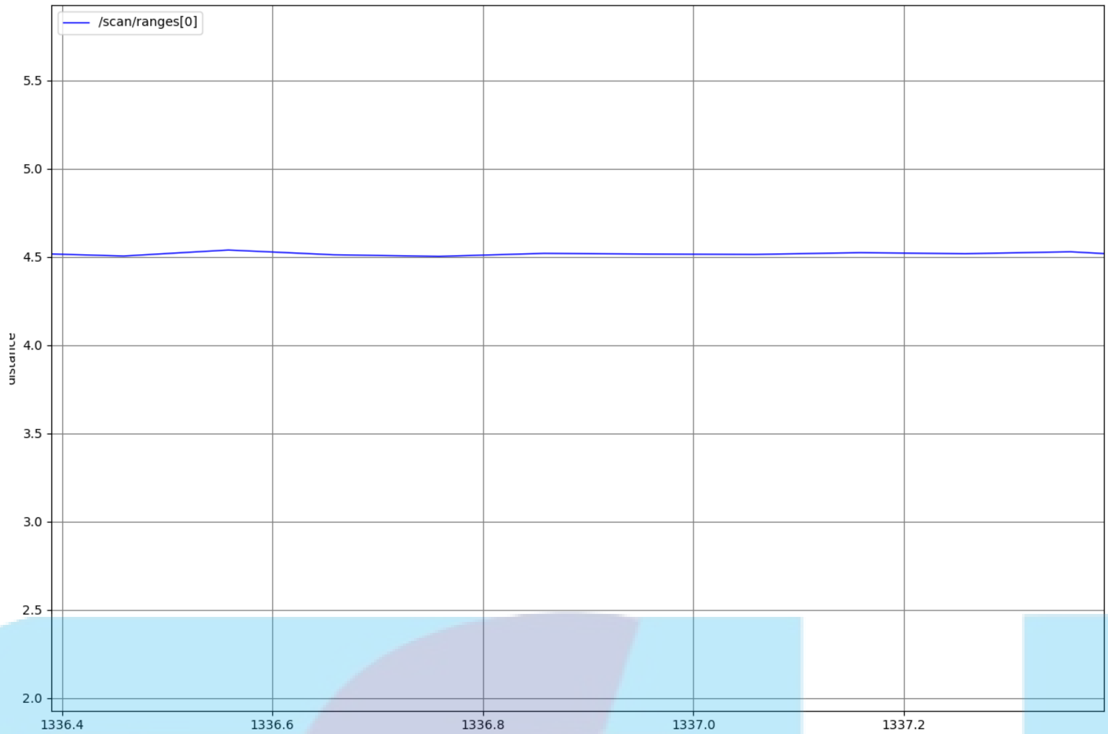
Distance 45 cm

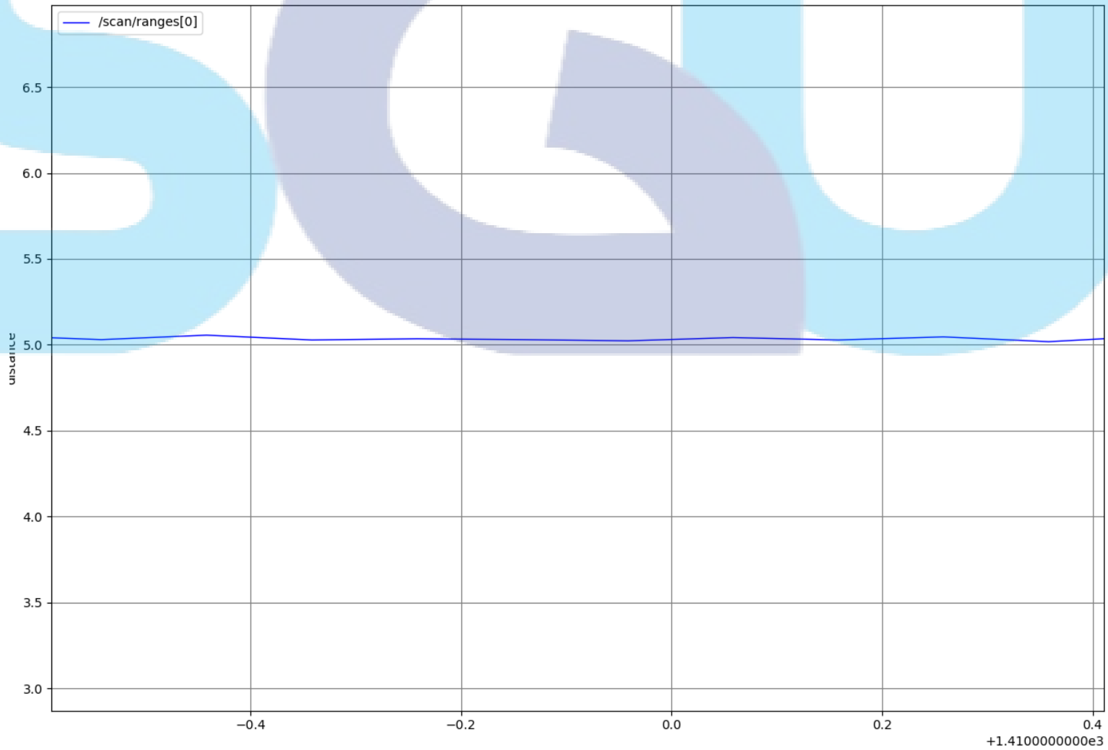
Distance 50 cm

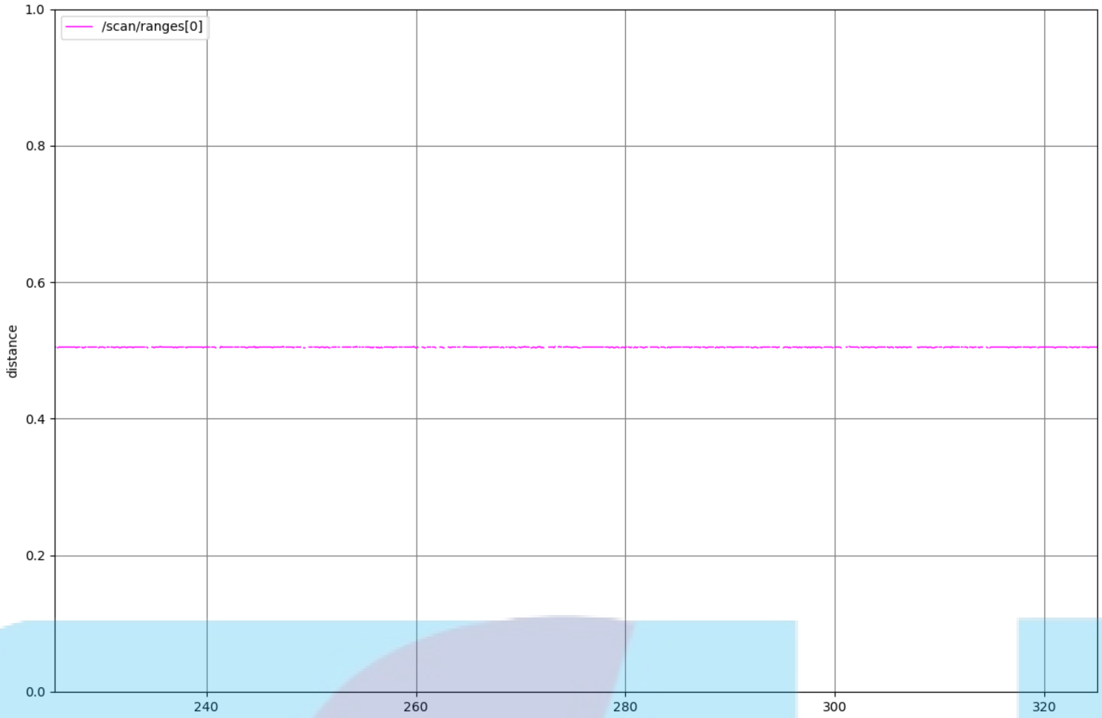
Appendix 2 Data Testing of LiDAR

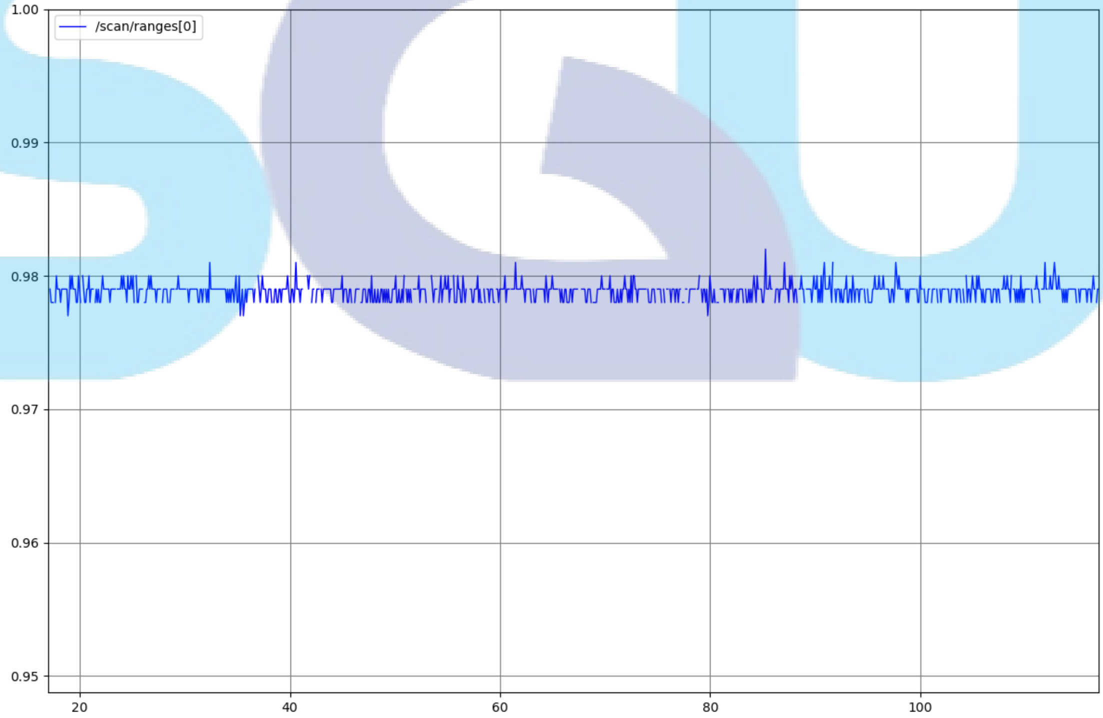


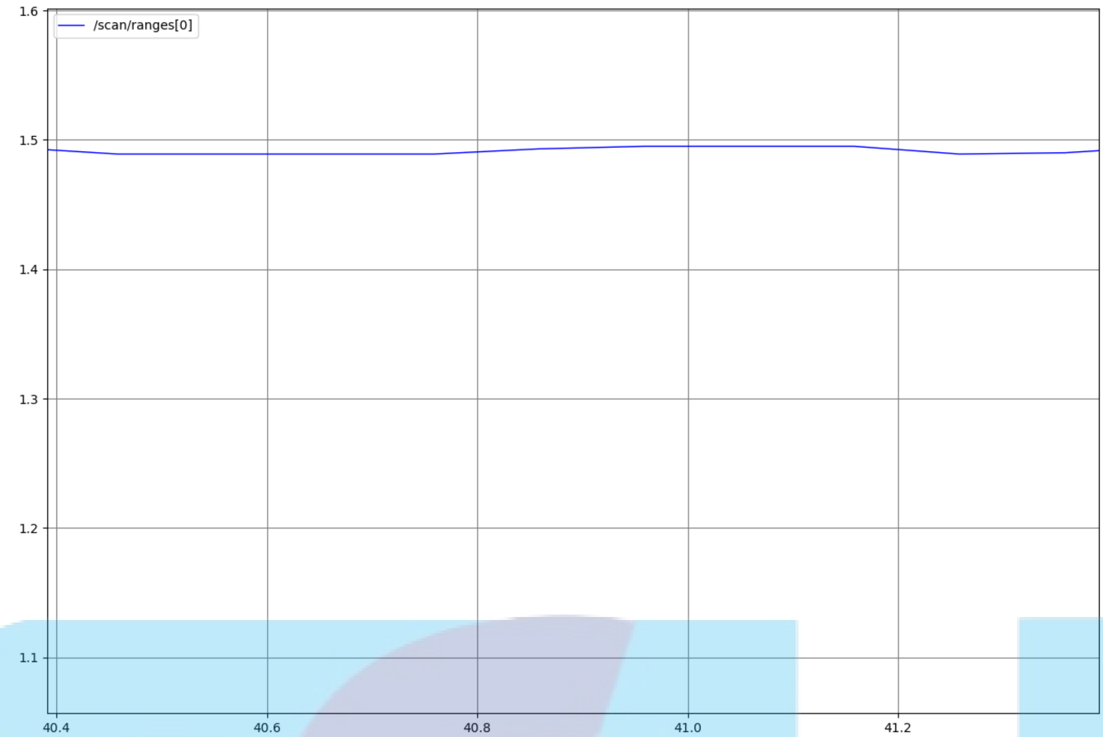


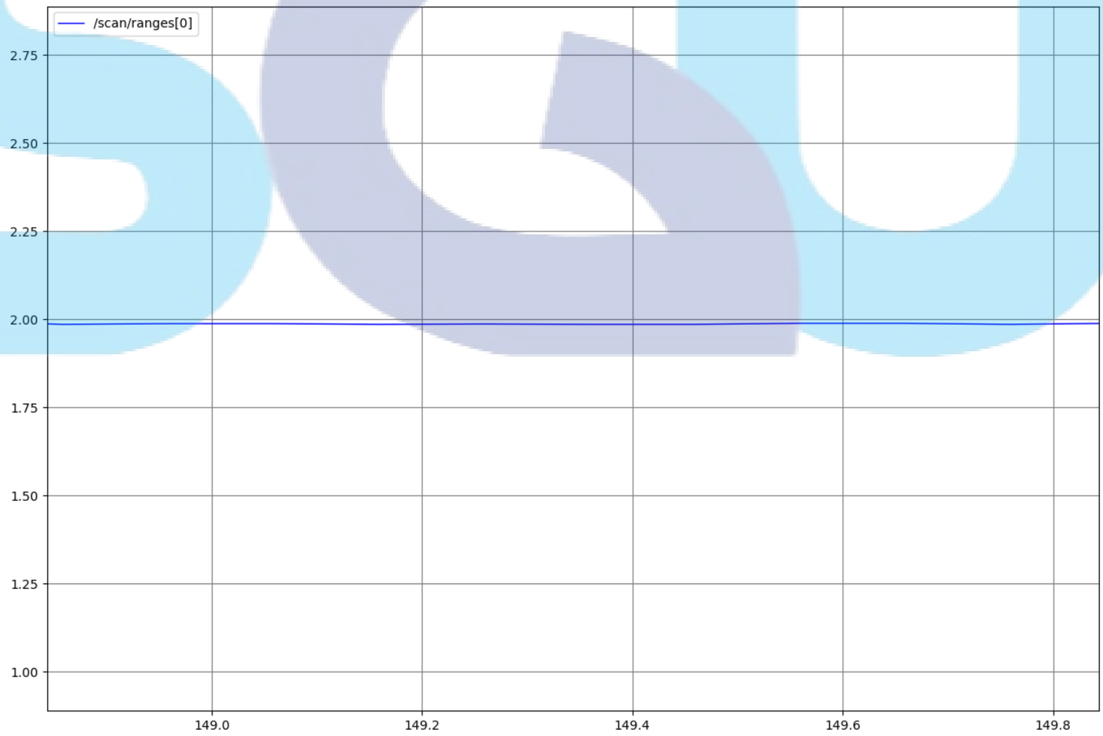

/scan/ranges[0]
distance
1336.4
1336.6
1336.8
1337.0
1337.2


/scan/ranges[0]
distance
−0.4
−0.2
0.0
0.2
0.4
+1.4100000000e3


/scan/ranges[0]
distance
1.0
0.8
0.6
0.4
0.2
0.0
240
260
280
300
320


/scan/ranges[0]
1.00
0.99
0.98
0.97
0.96
0.95
20
40
60
80
100


/scan/ranges[0]
1.6
1.5
1.4
1.3
1.2
1.1
40.4
40.6
40.8
41.0
41.2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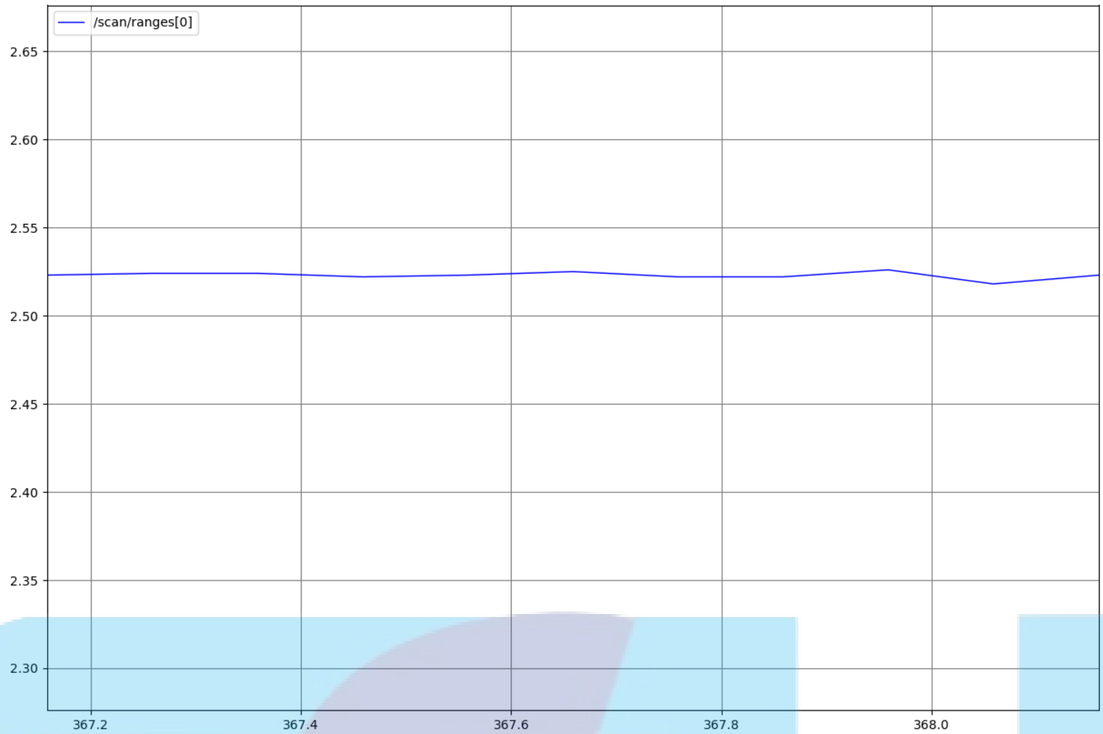
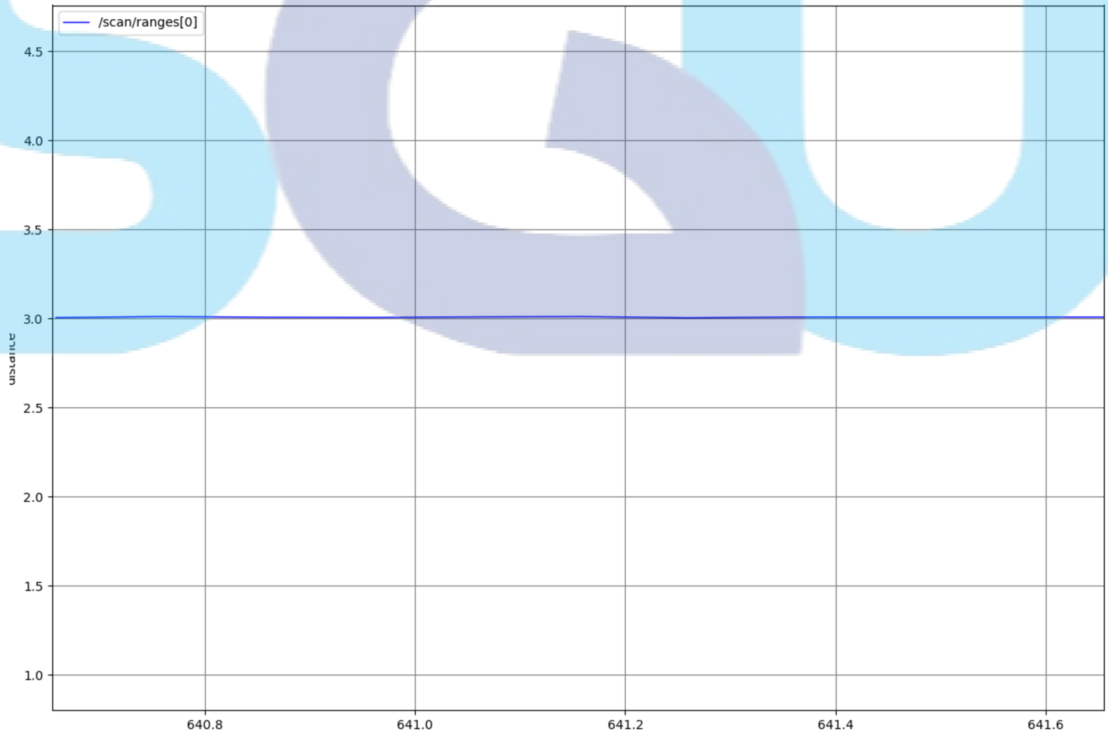
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
149.0
149.2
149.4
149.6
149.8


/scan/ranges[0]
2.65
2.60
2.55
2.50
2.45
2.40
2.35
2.30
367.2
367.4
367.6
367.8
368.0


/scan/ranges[0]
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
640.8
641.0
641.2
641.4
641.6

0,5 m	0,75 m	1m	1,25m	1,5m	1,75m	2m	2,25	2,5 m	3m	3,5	4m	4,5m	5m
0,504999995	0,749000013	1,018000007	1,256000042	1,50999999	1,751000047	2,013999939	2,256999969	2,513999939	3,051000118	3,53399992	4,014999866	4,524000168	5,065000057
0,504999995	0,749000013	1,018000007	1,256000042	1,511000037	1,756999969	2,016000032	2,255000114	2,513999939	3,046999931	3,530999899	4,028999805	4,534999847	5,065000057
0,504000008	0,749000013	1,018000007	1,254999995	1,511000037	1,761999965	2,013999939	2,255000114	2,515000105	3,052000046	3,53399992	4,034999847	4,534999847	5,077000141
0,504000008	0,749000013	1,019000053	1,256000042	1,506999969	1,761999965	2,016000032	2,256999969	2,515000105	3,051000118	3,536999941	4,014999866	4,524000168	5,077000141
0,504000008	0,749000013	1,019000053	1,256000042	1,511000037	1,756999969	2,013999939	2,257999897	2,515000105	3,051000118	3,532000065	4,028999805	4,539000034	5,041999817
0,504000008	0,748000026	1,018000007	1,256000042	1,511999965	1,751000047	2,016000032	2,257999897	2,513999939	3,049999952	3,536000013	4,026000023	4,547999859	5,048999786
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0,504999995	0,749000013	1,019000053	1,253000021	1,506999969	1,763000011	2,015000105	2,255000114	2,513000011	3,048000097	3,526000023	4,020999908	4,534999847	5,072000027
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0,504999995	0,748000026	1,019000053	1,254999995	1,511000037	1,758000016	2,015000105	2,256000042	2,519000053	3,049000025	3,530999899	4,022999763	4,531000137	5,058000088
0,504999995	0,748000026	1,018000007	1,256000042	1,511999965	1,751000047	2,013999939	2,256000042	2,520999908	3,046000004	3,530999899	4,032000065	4,534999847	5,070000172
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0,504000008	0,749000013	1,019000053	1,256000042	1,508999944	1,756999969	2,013999939	2,256000042	2,516000032	3,049000025	3,532000065	4,014999866	4,528999805	5,078999996
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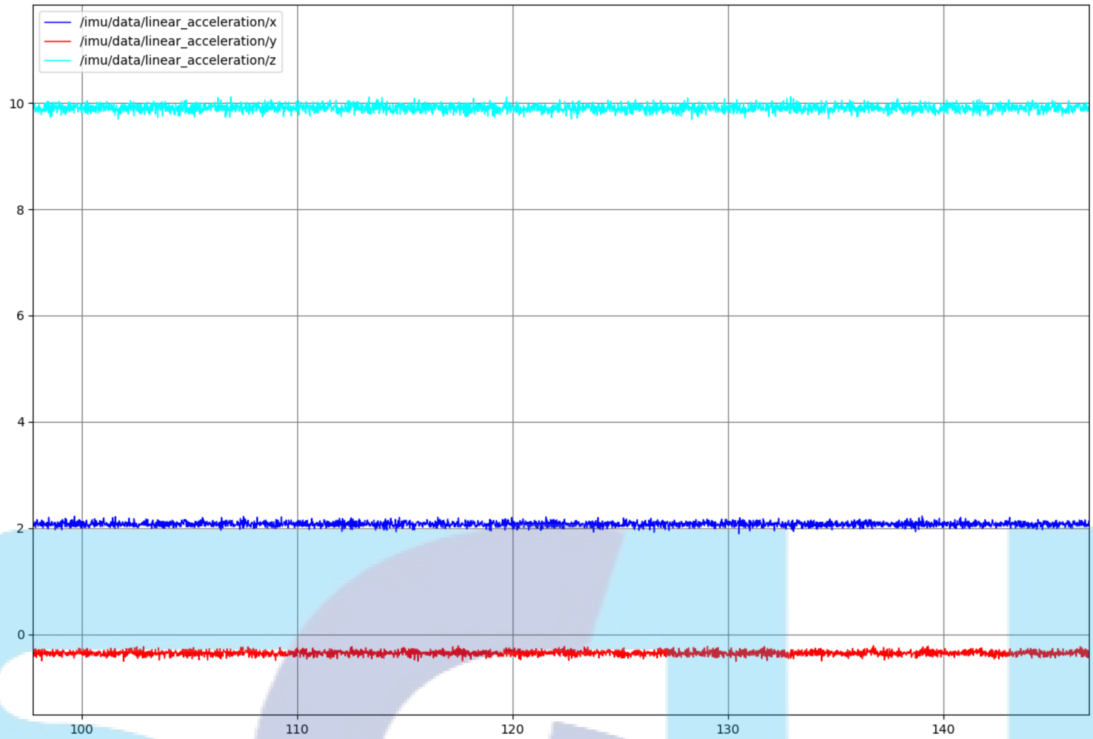
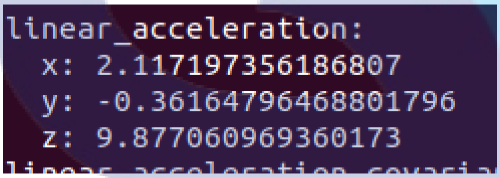
0,504999995	0,749000013	1,01699996	1,253999949	1,508000016	1,756999969	2,015000105	2,256999969	2,519999981	3,051000118	3,532999992	4,02699995	4,539999962	5,063000202
0,504999995	0,749000013	1,019000053	1,254999995	1,511999965	1,758999944	2,015000105	2,256999969	2,517999887	3,049000025	3,528000116	4,020999908	4,539999962	5,063000202
0,504000008	0,749000013	1,01699996	1,254999995	1,508999944	1,758999944	2,013999939	2,256999969	2,513999939	3,049000025	3,535000086	4,022999763	4,532999992	5,09100008
0,504000008	0,749000013	1,01699996	1,254999995	1,508999944	1,756000042	2,013999939	2,253999949	2,516000032	3,052000046	3,528000116	4,024000168	4,532999992	5,059999943

data	std dv	average	ERROR
0,5	0,000496512	0,504719999	0,943999728
0,75	0,000388083	0,748820015	0,157331288
1	0,000754883	1,017960005	1,796000486
1,25	0,001030374	1,255140014	0,41120109
1,5	0,001479673	1,510119991	0,67466608
1,75	0,003970092	1,756439993	0,367999611
2	0,001015206	2,015100021	0,755001065
2,25	0,002106923	2,256639995	0,295110908
2,5	0,002828133	2,515960007	0,63840026
3	0,004992092	3,048240037	1,608001228
3,5	0,004060742	3,531000013	0,885714664
4	0,00684822	4,023999967	0,599991184
4,5	0,008524298	4,535899992	0,797777596
5	0,01323822	5,065880041	1,317600824

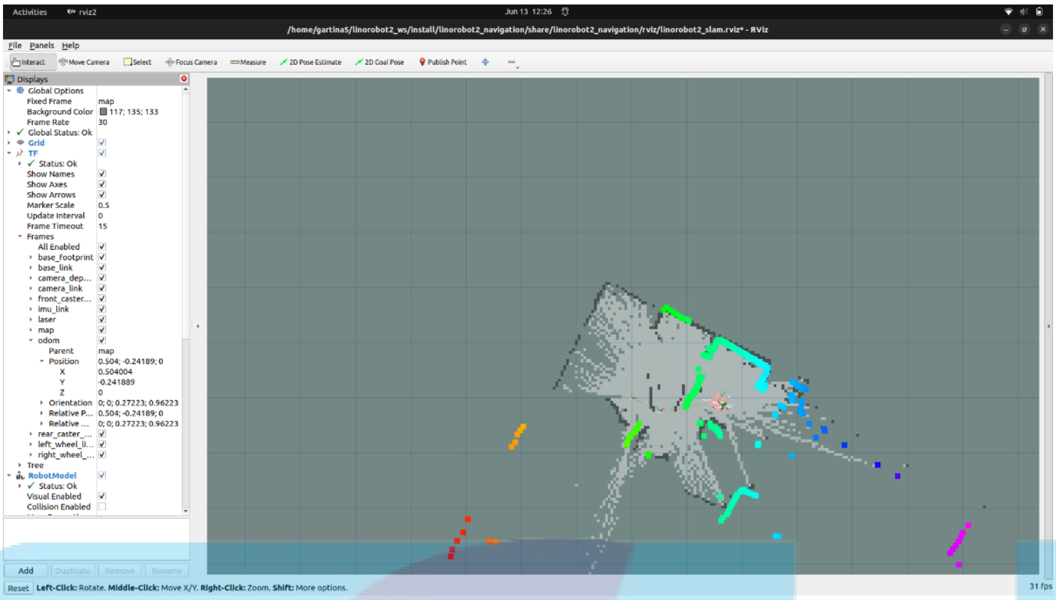
Appendix 3 Data Tesing of IMU

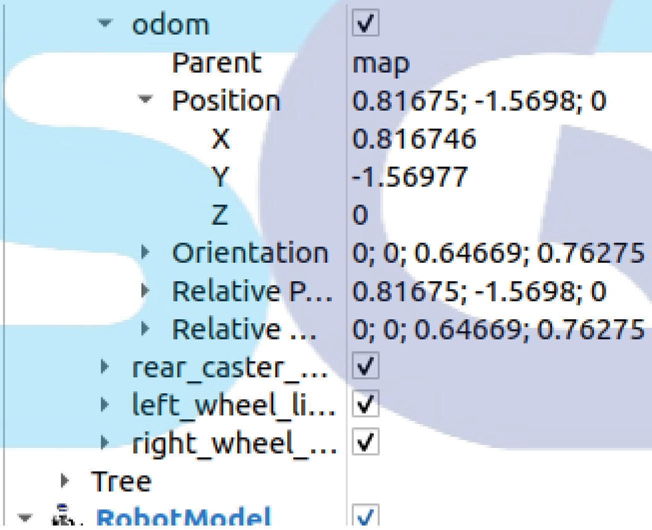


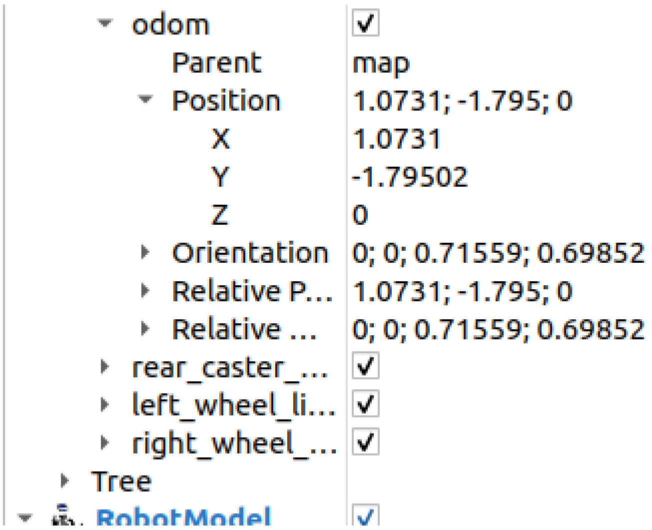


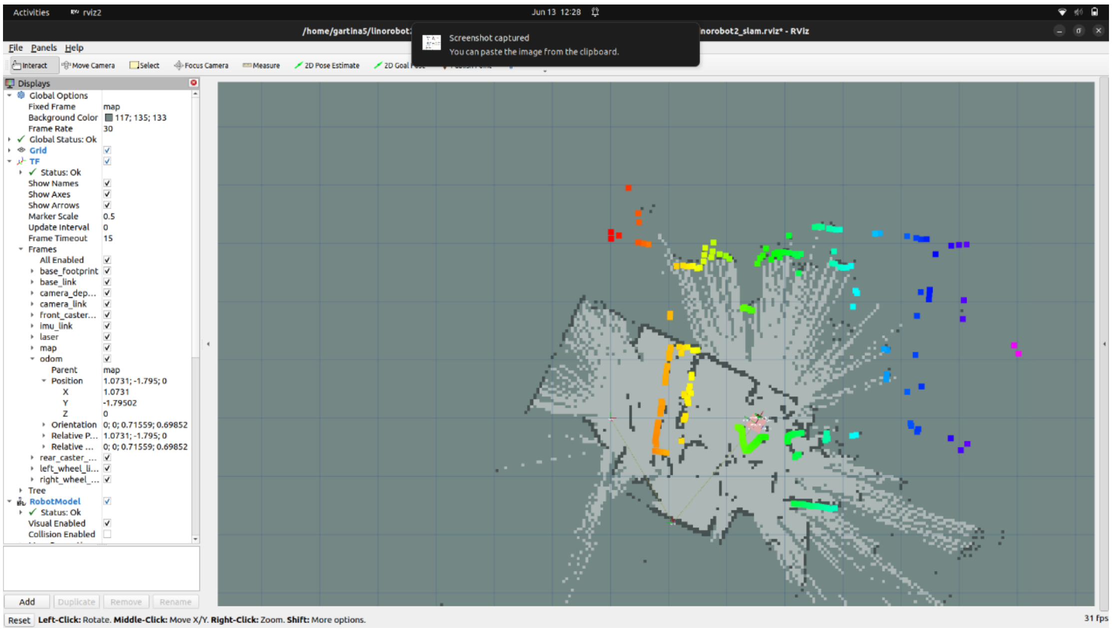
```
linear_acceleration:
  x: 2.117197356186807
  y: -0.36164796468801796
  z: 9.877060969360173
```

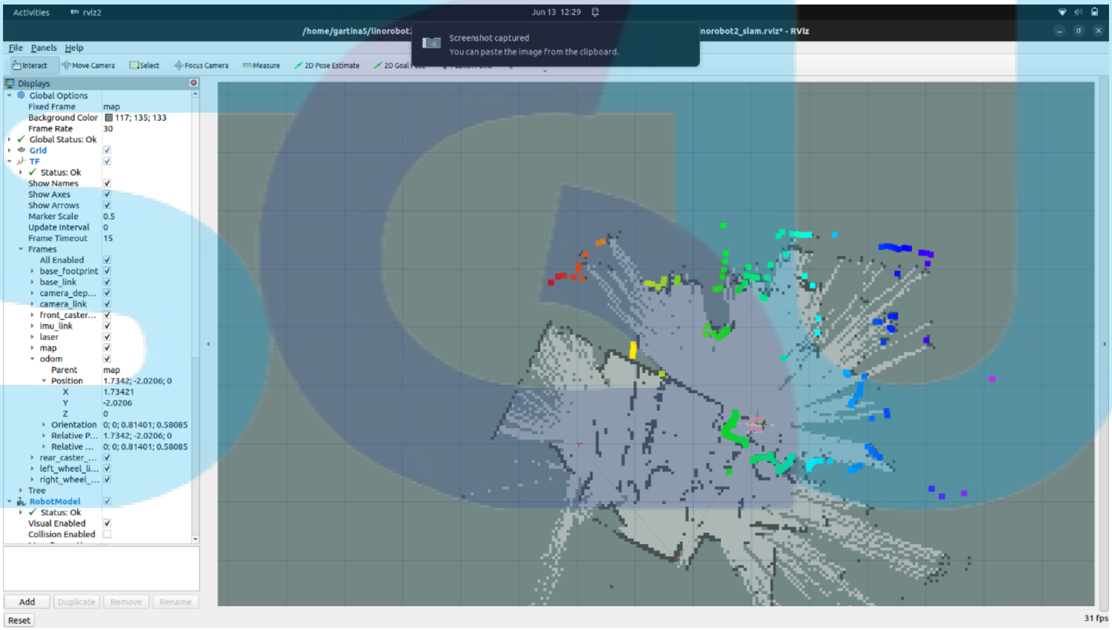
Appendix 4 Data Testing of Encoder

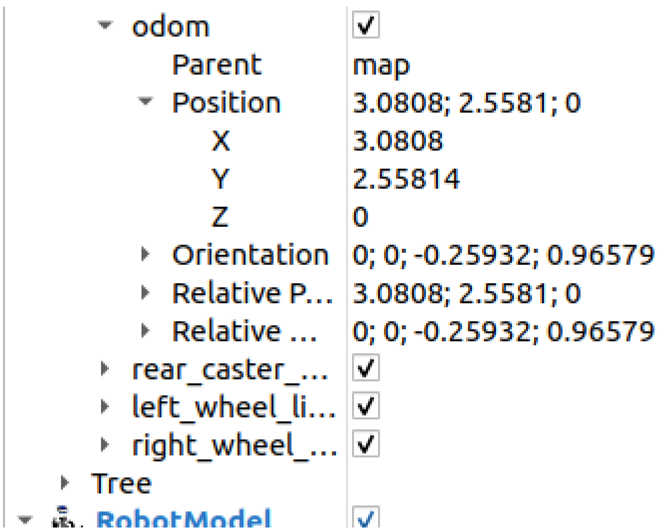


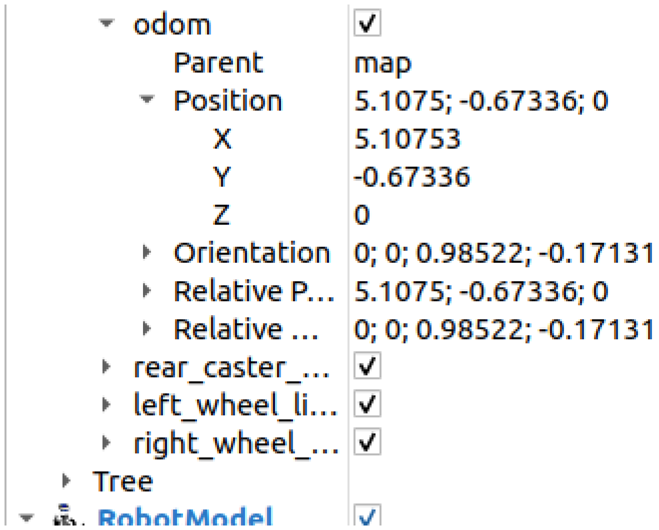


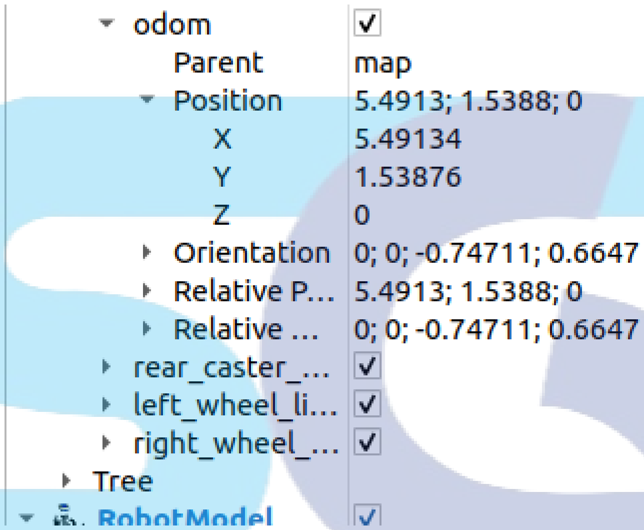


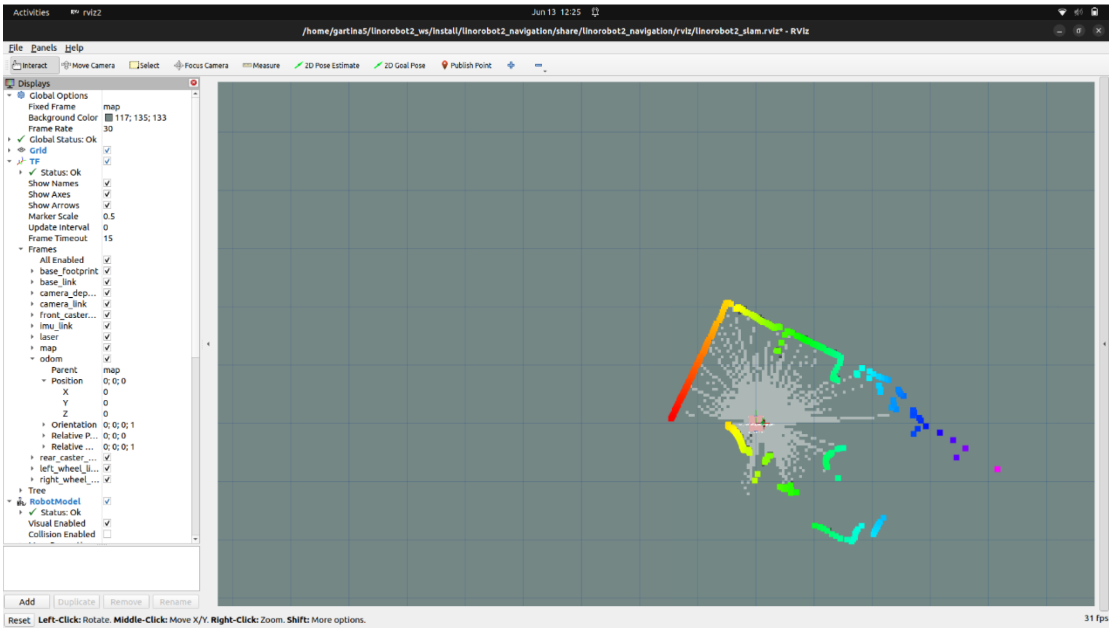


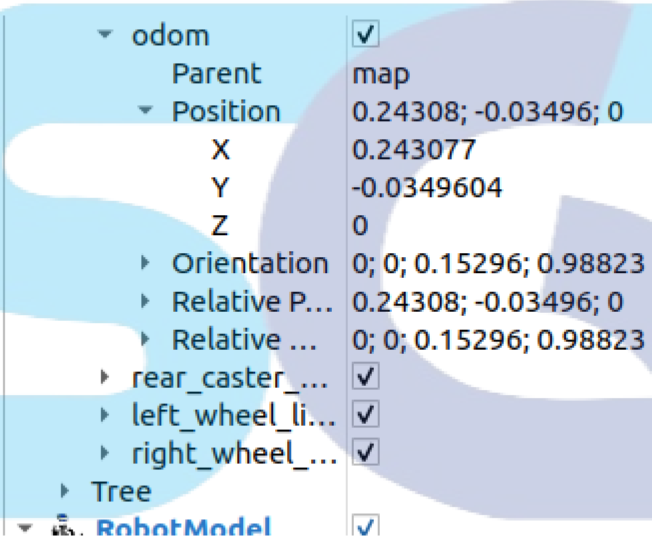



odom
Parent map
Position 3.0808; 2.5581; 0
X 3.0808
Y 2.55814
Z 0
Orientation 0; 0; -0.25932; 0.96579
Relative P... 3.0808; 2.5581; 0
Relative ... 0; 0; -0.25932; 0.96579
rear_caster_...
left_wheel_li...
right_wheel_...
Tree
RobotModel

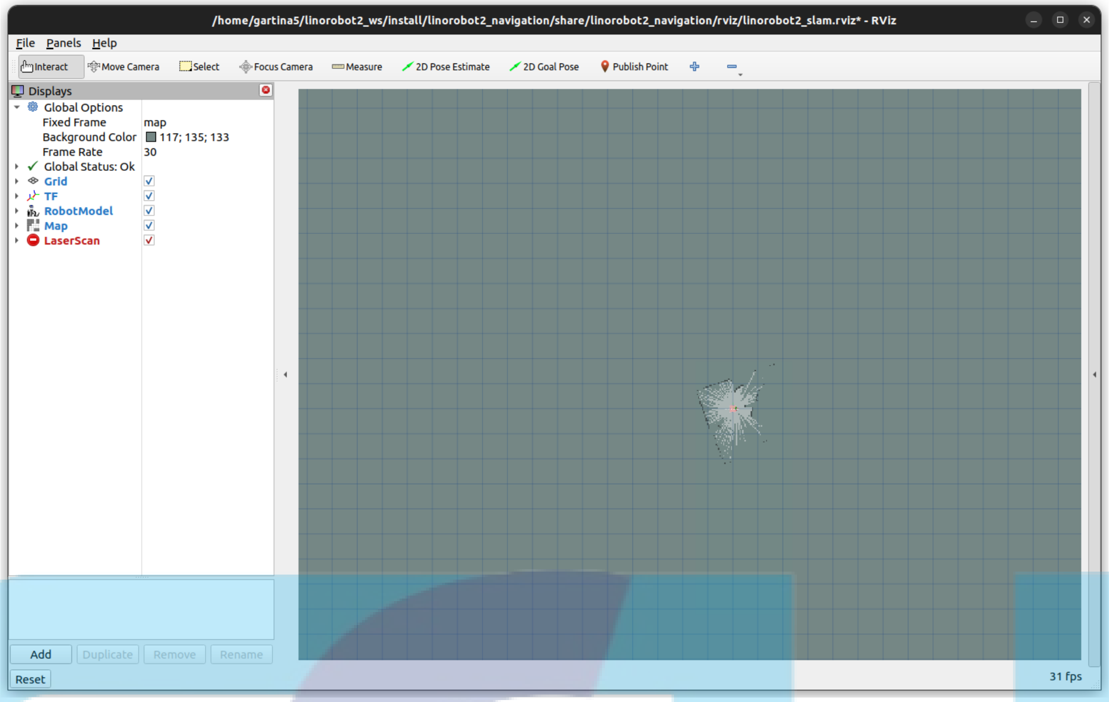

odom
Parent
map
Position
5.1075; -0.67336; 0
X
5.10753
Y
-0.67336
Z
0
Orientation
0; 0; 0.98522; -0.17131
Relative P...
5.1075; -0.67336; 0
Relative ...
0; 0; 0.98522; -0.17131
rear_caster_...
left_wheel_li...
right_wheel_...
Tree
RobotModel

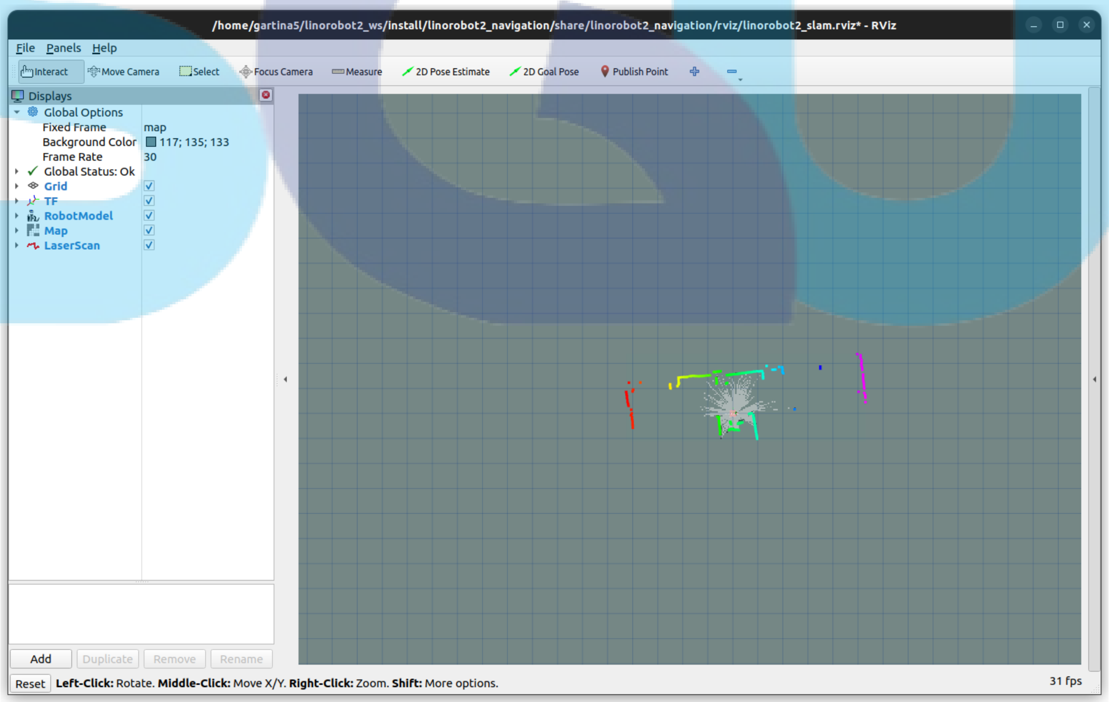

odom
Parent
map
Position
5.4913; 1.5388; 0
X
5.49134
Y
1.53876
Z
0
Orientation
0; 0; -0.74711; 0.6647
Relative P...
5.4913; 1.5388; 0
Relative ...
0; 0; -0.74711; 0.6647
rear_caster_...
left_wheel_li...
right_wheel_...
Tree
RobotModel

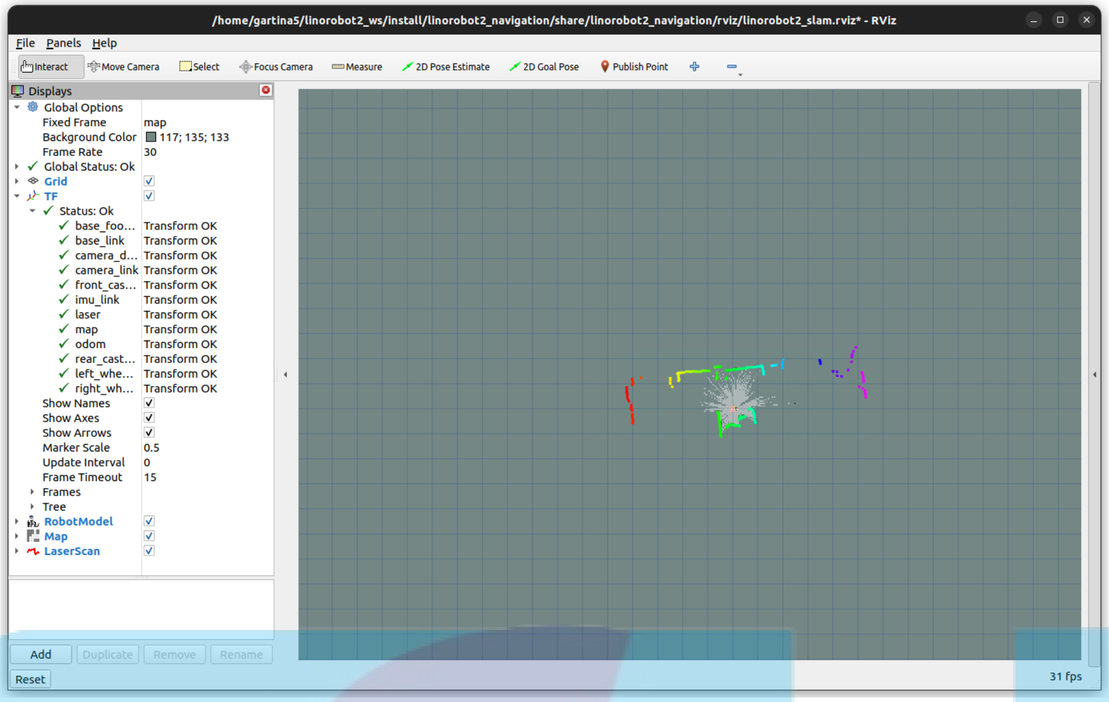

/home/gartina5/linorobot2_ws/install/linorobot2_navigation/share/linorobot2_navigation/rviz/linorobot2_slam.rviz* - RViz
Displays
Global Options
Fixed Frame
map
Background Color
117; 135; 133
Frame Rate
30
Global Status: Ok
Grid
TF
Reset
Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click: Zoom. Shift: More options.
31 fps

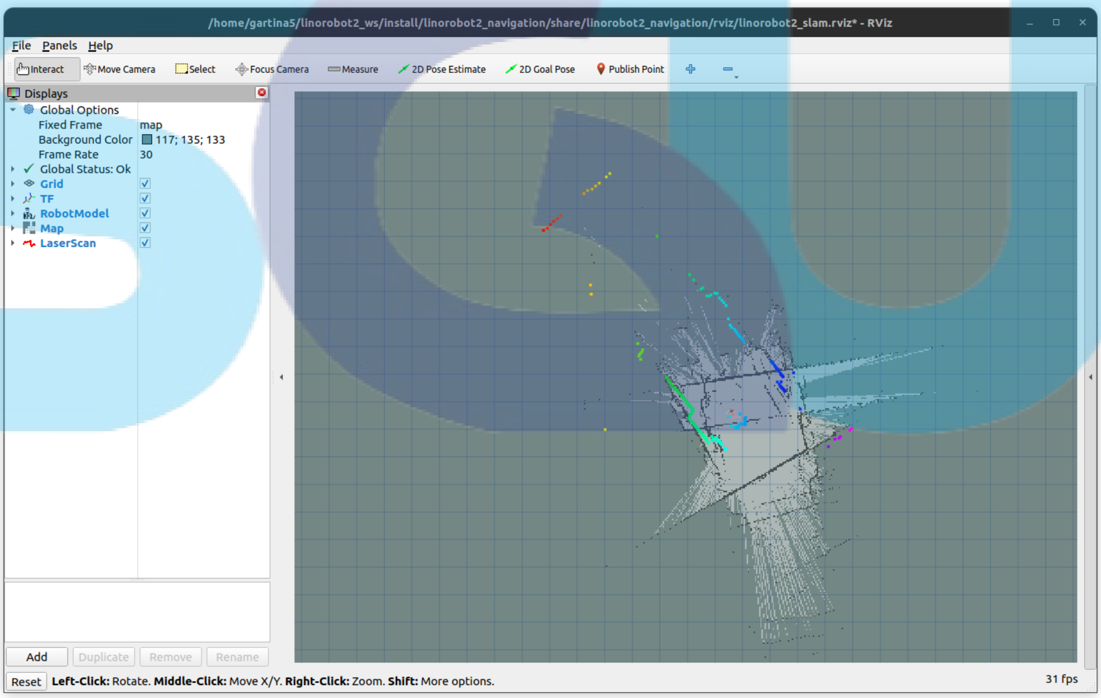

odom
Parent
map
Position
0.24308; -0.03496; 0
X
0.243077
Y
-0.0349604
Z
0
Orientation
0; 0; 0.15296; 0.98823
Relative P...
0.24308; -0.03496; 0
Relative ...
0; 0; 0.15296; 0.98823
rear_caster_...
left_wheel_li...
right_wheel_...
Tree

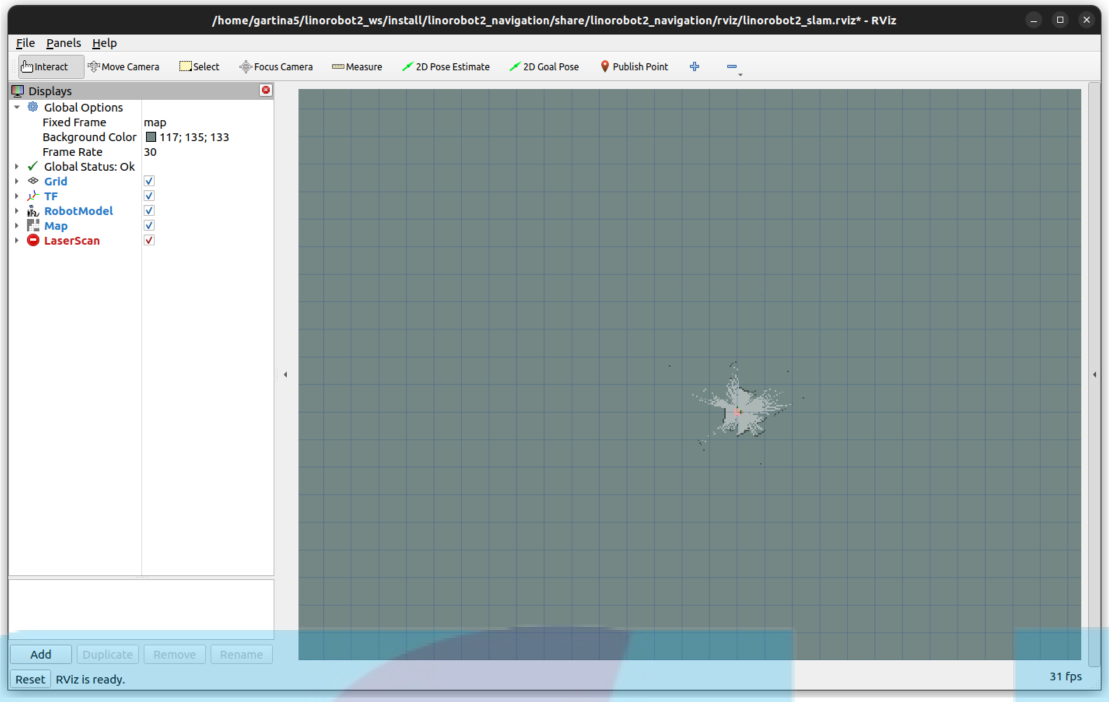
Appendix 4 Data Testing of Mapping

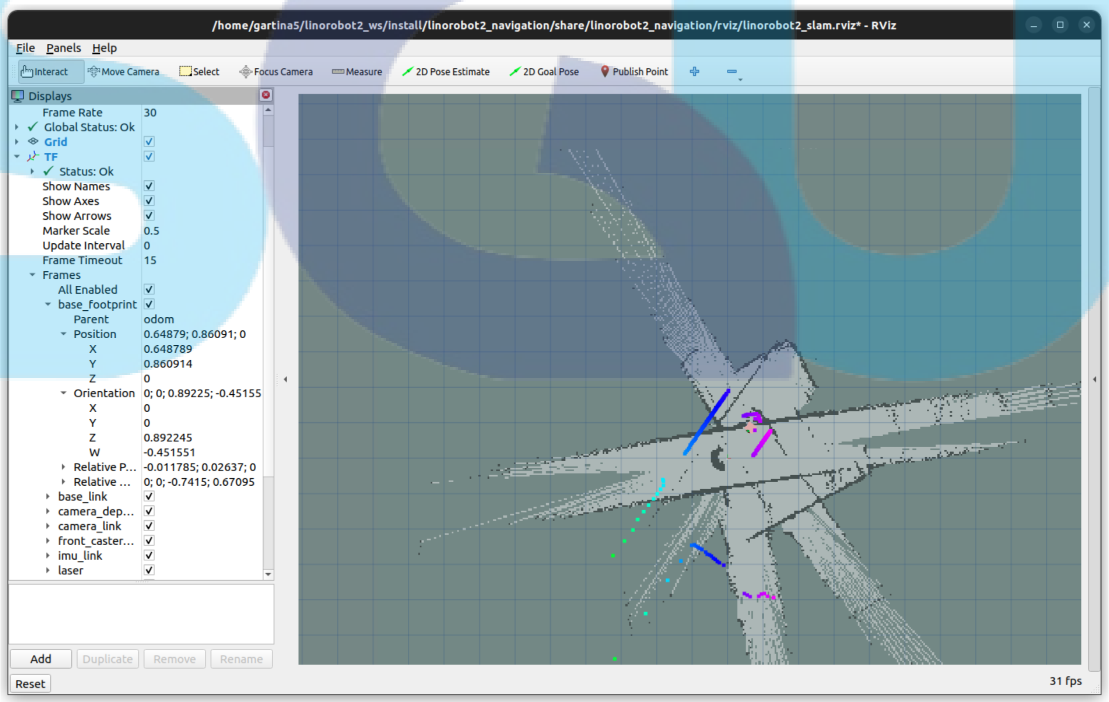


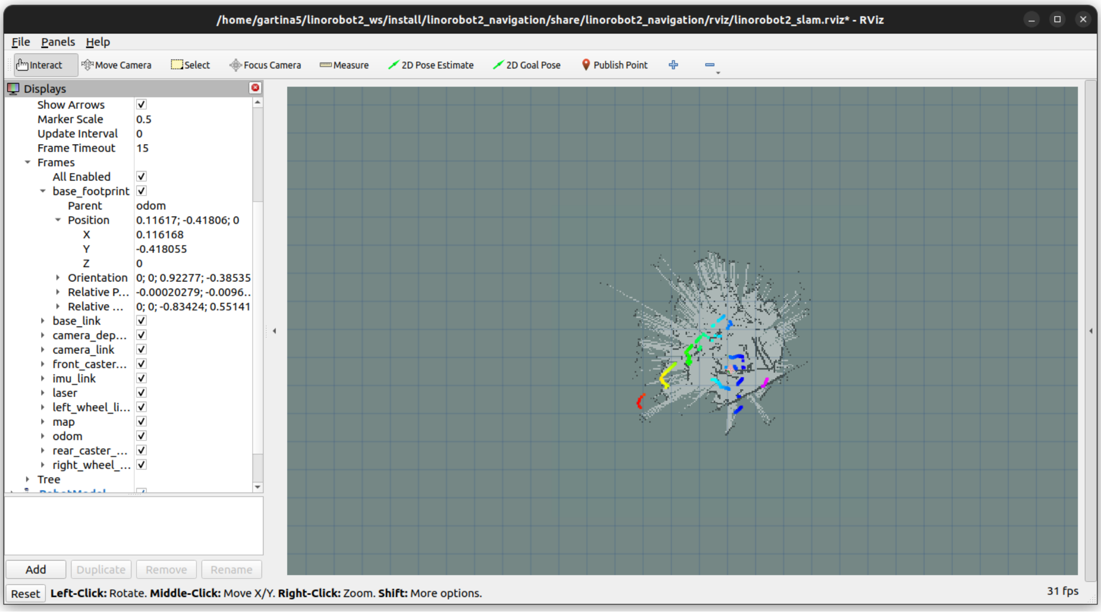



/home/gartina5/linorobot2_ws/install/linorobot2_navigation/share/linorobot2_navigation/rviz/linorobot2_slam.rviz* - RViz
File Panels Help
Interact Move Camera Select Focus Camera Measure 2D Pose Estimate 2D Goal Pose Publish Point
Displays
Global Options
Fixed Frame map
Background Color 117; 135; 133
Frame Rate 30
Global Status: Ok
Grid
TF
Status: Ok
base_foo… Transform OK
base_link Transform OK
camera_d… Transform OK
camera_link Transform OK
front_cas… Transform OK
imu_link Transform OK
laser Transform OK
map Transform OK
odom Transform OK
rear_cast… Transform OK
left_whe… Transform OK
right_wh… Transform OK
Show Names
Show Axes
Show Arrows
Marker Scale 0.5
Update Interval 0
Frame Timeout 15
Frames
Tree
RobotModel
Map
LaserScan
Add Duplicate Remove Rename
Reset
31 fps


/home/gartina5/linorobot2_ws/install/linorobot2_navigation/share/linorobot2_navigation/rviz/linorobot2_slam.rviz* - RViz
File Panels Help
Interact Move Camera Select Focus Camera Measure 2D Pose Estimate 2D Goal Pose Publish Point
Displays
Global Options
Fixed Frame map
Background Color 117; 135; 133
Frame Rate 30
Global Status: Ok
Grid
TF
RobotModel
Map
LaserScan
Add Duplicate Remove Rename
Reset Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click: Zoom. Shift: More options.
31 fps


/home/gartina5/linorobot2_ws/install/linorobot2_navigation/share/linorobot2_navigation/rviz/linorobot2_slam.rviz* - RViz
File Panels Help
Interact
Move Camera
Select
Focus Camera
Measure
2D Pose Estimate
2D Goal Pose
Publish Point
Displays
Global Options
Fixed Frame map
Background Color 117; 135; 133
Frame Rate 30
Global Status: Ok
Grid
TF
RobotModel
Map
LaserScan
Add
Duplicate
Remove
Rename
Reset
RViz is ready.
31 fps


/home/gartina5/linorobot2_ws/install/linorobot2_navigation/share/linorobot2_navigation/rviz/linorobot2_slam.rviz* - RViz
File Panels Help
Interact
Move Camera
Select
Focus Camera
Measure
2D Pose Estimate
2D Goal Pose
Publish Point
Displays
Frame Rate 30
Global Status: Ok
Grid
TF
Status: Ok
Show Names
Show Axes
Show Arrows
Marker Scale 0.5
Update Interval 0
Frame Timeout 15
Frames
All Enabled
base_footprint
Parent odom
Position 0.64879; 0.86091; 0
X 0.648789
Y 0.860914
Z 0
Orientation 0; 0; 0.89225; -0.45155
X 0
Y 0
Z 0.892245
W -0.451551
Relative P... -0.011785; 0.02637; 0
Relative ... 0; 0; -0.7415; 0.67095
base_link
camera_dep...
camera_link
front_caster...
imu_link
laser
Add
Duplicate
Remove
Rename
Reset
31 fps


/home/gartina5/linorobot2_ws/install/linorobot2_navigation/share/linorobot2_navigation/rviz/linorobot2_slam.rviz* - RViz
File
Panels
Help
Interact
Move Camera
Select
Focus Camera
Measure
2D Pose Estimate
2D Goal Pose
Publish Point
Displays
Show Arrows
Marker Scale 0.5
Update Interval 0
Frame Timeout 15
Frames
All Enabled
base_footprint
Parent odom
Position 0.11617; -0.41806; 0
X 0.116168
Y -0.418055
Z 0
Orientation 0; 0; 0.92277; -0.38535
Relative P... -0.00020279; -0.0096..
Relative ... 0; 0; -0.83424; 0.55141
base_link
camera_dep...
camera_link
front_caster...
imu_link
laser
left_wheel_li...
map
odom
rear_caster_...
right_wheel_...
Tree
Add
Duplicate
Remove
Rename
Reset
Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click: Zoom. Shift: More options.
31 fps

Appendix 5 Program

firmware.ino
~/linorobot2_hardware/firmware/src

```
    bool imu_ok = imu.init();
    if(!imu_ok)
    {
        while(1)
        {
            flashLED(3);
        }
    }

    Serial.begin(115200);
    set_microros_serial_transports(Serial);
}

void loop() {

    switch (state)
    {
        case WAITING_AGENT:
            EXECUTE_EVERY_N_MS(500, state = (RMW_RET_OK == rmw_uros_ping_agent(100, 1)) ? AGENT_AVAILABLE : WAITING_AGENT;);
            break;
        case AGENT_AVAILABLE:
            state = (true == createEntities()) ? AGENT_CONNECTED : WAITING_AGENT;
            if (state == WAITING_AGENT)
            {
                destroyEntities();
            }
            break;
        case AGENT_CONNECTED:
            EXECUTE_EVERY_N_MS(200, state = (RMW_RET_OK == rmw_uros_ping_agent(100, 1)) ? AGENT_CONNECTED : AGENT_DISCONNECTED;);
            if (state == AGENT_CONNECTED)
            {
                rclc_executor_spin_some(&executor, RCL_MS_TO_NS(100));
            }
            break;
        case AGENT_DISCONNECTED:
            destroyEntities();
            state = WAITING_AGENT;
            break;
        default:
            break;
    }
}

void controlCallback(rcl_timer_t * timer, int64_t last_call_time)
{
    RCLC_UNUSED(last_call_time);
    if (timer != NULL)
    {
       moveBase();
       publishData();
    }
}
```

C Tab Width: 8 Ln 37, Col 1 INS

firmware.ino
~/linorobot2_hardware/firmware/src

```
}

void twistCallback(const void * msgin)
{
    (LED_PIN, !digitalRead(LED_PIN));

    prev_cmd_time = millis();
}

bool createEntities()
{
    allocator = rcl_get_default_allocator();
    //create init_options
    RCCHECK(rclc_support_init(&support, 0, NULL, &allocator));
    // create node
    RCCHECK(rclc_node_init_default(&node, "linorobot_base_node", "", &support));
    // create odometry publisher
    RCCHECK(rclc_publisher_init_default(
        &odom_publisher,
        &node,
        ROSIDL_GET_MSG_TYPE_SUPPORT(nav_msgs, msg, Odometry),
        "odom/unfiltered"
    ));
    // create IMU publisher
    RCCHECK(rclc_publisher_init_default(
        &imu_publisher,
        &node,
        ROSIDL_GET_MSG_TYPE_SUPPORT(sensor_msgs, msg, Imu),
        "imu/data"
    ));
    // create twist command subscriber
    RCCHECK(rclc_subscription_init_default(
        &twist_subscriber,
        &node,
        ROSIDL_GET_MSG_TYPE_SUPPORT(geometry_msgs, msg, Twist),
        "cmd_vel"
    ));
    // create timer for actuating the motors at 50 Hz (1000/20)
    const unsigned int control_timeout = 20;
    RCCHECK(rclc_timer_init_default(
        &control_timer,
        &support,
        RCL_MS_TO_NS(control_timeout),
        controlCallback
    ));
    executor = rclc_executor_get_zero_initialized_executor();
    RCCHECK(rclc_executor_init(&executor, &support.context, 2, & allocator));
    RCCHECK(rclc_executor_add_subscription(
        &executor,
        &twist_subscriber,
        &twist_msg,
        &twistCallback,
        ON_NEW_DATA
    ));
```

C   Tab Width: 8   Ln 37, Col 1   INS

firmware.ino
~/linorobot2_hardware/firmware/src

```
    ));
    RCCHECK(rclc_executor_add_timer(&executor, &control_timer));

    // synchronize time with the agent
    syncTime();
    digitalWrite(LED_PIN, HIGH);

    return true;
}

bool destroyEntities()
{
    rmw_context_t * rmw_context = rcl_context_get_rmw_context(&support.context);
    (void) rmw_uros_set_context_entity_destroy_session_timeout(rmw_context, 0);

    rcl_publisher_fini(&odom_publisher, &node);
    rcl_publisher_fini(&imu_publisher, &node);
    rcl_subscription_fini(&twist_subscriber, &node);
    rcl_node_fini(&node);
    rcl_timer_fini(&control_timer);
    rclc_executor_fini(&executor);
    rclc_support_fini(&support);

    digitalWrite(LED_PIN, HIGH);

    return true;
}

void fullStop()
{
    twist_msg.linear.x = 0.0;
    twist_msg.linear.y = 0.0;
    twist_msg.angular.z = 0.0;

    motor1_controller.brake();
    motor2_controller.brake();
    motor3_controller.brake();
    motor4_controller.brake();
}

void moveBase()
{
    // brake if there's no command received, or when it's only the first command sent
    if(((millis() - prev_cmd_time) >= 200))
    {
        twist_msg.linear.x = 0.0;
        twist_msg.linear.y = 0.0;
        twist_msg.angular.z = 0.0;

        digitalWrite(LED_PIN, HIGH);
    }
    // get the required rpm for each motor based on required velocities, and base used
    Kinematics::rpm req_rpm = kinematics.getRPM(
        twist_msg.linear.x,
```

C Tab Width: 8 Ln 37, Col 1 INS

firmware.ino
~/linorobot2_hardware/firmware/src

```
        twist_msg.linear.x,
        twist_msg.linear.y,
        twist_msg.angular.z
    );

    // get the current speed of each motor
    float current_rpm1 = motor1_encoder.getRPM();
    float current_rpm2 = motor2_encoder.getRPM();
    float current_rpm3 = motor3_encoder.getRPM();
    float current_rpm4 = motor4_encoder.getRPM();

    // the required rpm is capped at -/+ MAX_RPM to prevent the PID from having too much error
    // the PWM value sent to the motor driver is the calculated PID based on required RPM vs measured RPM
    motor1_controller.spin(motor1_pid.compute(req_rpm.motor1, current_rpm1));
    motor2_controller.spin(motor2_pid.compute(req_rpm.motor2, current_rpm2));
    motor3_controller.spin(motor3_pid.compute(req_rpm.motor3, current_rpm3));
    motor4_controller.spin(motor4_pid.compute(req_rpm.motor4, current_rpm4));

    Kinematics::velocities current_vel = kinematics.getVelocities(
        current_rpm1,
        current_rpm2,
        current_rpm3,
        current_rpm4
    );

    unsigned long now = millis();
    float vel_dt = (now - prev_odom_update) / 1000.0;
    prev_odom_update = now;
    odometry.update(
        vel_dt,
        current_vel.linear_x,
        current_vel.linear_y,
        current_vel.angular_z
    );
}

void publishData()
{
    odom_msg = odometry.getData();
    imu_msg = imu.getData();

    struct timespec time_stamp = getTime();

    odom_msg.header.stamp.sec = time_stamp.tv_sec;
    odom_msg.header.stamp.nanosec = time_stamp.tv_nsec;

    imu_msg.header.stamp.sec = time_stamp.tv_sec;
    imu_msg.header.stamp.nanosec = time_stamp.tv_nsec;

    RCSOFTCHECK(rcl_publish(&imu_publisher, &imu_msg, NULL));
    RCSOFTCHECK(rcl_publish(&odom_publisher, &odom_msg, NULL));
}
```

C Tab Width: 8 Ln 37, Col 1 INS

```
    RCSOFTCHECK(rcl_publish(&imu_publisher, &imu_msg, NULL));
    RCSOFTCHECK(rcl_publish(&odom_publisher, &odom_msg, NULL));
}

void syncTime()
{
    // get the current time from the agent
    unsigned long now = millis();
    RCCHECK(rmw_uros_sync_session(10));
    unsigned long long ros_time_ms = rmw_uros_epoch_millis();
    // now we can find the difference between ROS time and uC time
    time_offset = ros_time_ms - now;
}

struct timespec getTime()
{
    struct timespec tp = {0};
    // add time difference between uC time and ROS time to
    // synchronize time with ROS
    unsigned long long now = millis() + time_offset;
    tp.tv_sec = now / 1000;
    tp.tv_nsec = (now % 1000) * 1000000;

    return tp;
}

void rclErrorLoop()
{
    while(true)
    {
        flashLED(2);
    }
}

void flashLED(int n_times)
{
    for(int i=0; i<n_times; i++)
    {
        digitalWrite(LED_PIN, HIGH);
        delay(150);
        digitalWrite(LED_PIN, LOW);
        delay(150);
    }
    delay(1000);
}
```

C Tab Width: 8 Ln 37, Col 1 INS

```ini
; PlatformIO Project Configuration File
;
;   Build options: build flags, source filter
;   Upload options: custom upload port, speed and extra flags
;   Library options: dependencies, extra library storages
;   Advanced options: extra scripting
;
; Please visit documentation for the other options and examples
; https://docs.platformio.org/page/projectconf.html

[env]
framework = arduino
upload_port = /dev/ttyACM0
platform = teensy
board = teensy40
upload_protocol = teensy-cli
lib_extra_dirs = ../firmware/lib
build_flags =
    -I ../config

[env:teensy41]
board = teensy41

[env:teensy40]
board = teensy40

[env:teensy36]
//board = teensy36

[env:teensy35]
//board = teensy35

[env:teensy31]
board = teensy31

[env:dev]
board = teensy40
build_flags =
    -I ../config
    -D USE_DEV_CONFIG

[env:beebo]
board = teensy31
board_build.f_cpu = 96000000L
build_flags =
    -I ../config
    -D USE_BEEBO_CONFIG

[env:beebo_m]
board = teensy31
board_build.f_cpu = 96000000L
build_flags =
    -I ../config
    -D USE_BEEBO_M_CONFIG
```

.ini Tab Width: 8 Ln 24, Col 16 INS

gartina5@GartinaROG: ~

```
gartina5@GartinaROG:~$ wget https://www.pjrc.com/teensy/00-teensy.rules
--2023-06-14 17:59:26--  https://www.pjrc.com/teensy/00-teensy.rules
Resolving www.pjrc.com (www.pjrc.com)... 162.254.150.250
Connecting to www.pjrc.com (www.pjrc.com)|162.254.150.250|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 2062 (2.0K)
Saving to: '00-teensy.rules.5'

00-teensy.rules.5   100%[===================>]   2.01K  --.-KB/s    in 0s

2023-06-14 17:59:28 (348 MB/s) - '00-teensy.rules.5' saved [2062/2062]
```

```
gartina5@GartinaROG:~$ sudo cp 00-teensy.rules /etc/udev/rules.d/
[sudo] password for gartina5:
```

```
//uncomment the motor driver you're using
//#define USE_GENERIC_2_IN_MOTOR_DRIVER      // Motor drivers with 2 Direction Pins(INA, INB) and 1
PWM(ENABLE) pin ie. L298, L293, VNH5019
 #define USE_GENERIC_1_IN_MOTOR_DRIVER   // Motor drivers with 1 Direction Pin(INA) and 1 PWM(ENABLE)
pin.
  // #define USE_BTS7960_MOTOR_DRIVER        // BTS7970 Motor Driver
 //#define USE_ESC_MOTOR_DRIVER            // Motor ESC for brushless motors

//uncomment the IMU you're using
// #define USE_GY85_IMU
 #define USE_MPU6050_IMU
// #define USE_MPU9150_IMU
// #define USE_MPU9250_IMU
```

```
         FRONT
    MOTOR1  MOTOR2  (2WD/ACKERMANN)
    MOTOR3  MOTOR4  (4WD/MECANUM)
         BACK
*/

//define your robot' specs here
#define MOTOR_MAX_RPM 60                   // motor's max RPM
#define MAX_RPM_RATIO 0.95                      // max RPM allowed for each MAX_RPM_ALLOWED =
MOTOR_MAX_RPM * MAX_RPM_RATIO
#define MOTOR_OPERATING_VOLTAGE 12              // motor's operating voltage (used to calculate max RPM)
#define MOTOR_POWER_MAX_VOLTAGE 12              // max voltage of the motor's power source (used to
calculate max RPM)
#define MOTOR_POWER_MEASURED_VOLTAGE 12         // current voltage reading of the power connected to the
motor (used for calibration)
#define COUNTS_PER_REV1 45                  // wheel1 encoder's no of ticks per rev
#define COUNTS_PER_REV2 45                 // wheel2 encoder's no of ticks per rev
#define COUNTS_PER_REV3 45                  // wheel3 encoder's no of ticks per rev
#define COUNTS_PER_REV4 60                  // wheel4 encoder's no of ticks per rev
#define WHEEL_DIAMETER 0.21                    // wheel's diameter in meters
#define LR_WHEELS_DISTANCE 0.27                // distance between left and right wheels
#define PWM_BITS 8                              // PWM Resolution of the microcontroller
#define PWM_FREQUENCY 2000                    // PWM Frequency
```

```
// ENCODER PINS
#define MOTOR1_ENCODER_A 16
#define MOTOR1_ENCODER_B 17

#define MOTOR2_ENCODER_A 14
#define MOTOR2_ENCODER_B 15

#define MOTOR3_ENCODER_A 30
#define MOTOR3_ENCODER_B 31

#define MOTOR4_ENCODER_A 32
#define MOTOR4_ENCODER_B 33

// MOTOR PINS
#ifdef USE_GENERIC_1_IN_MOTOR_DRIVER
  #define MOTOR1_PWM 7 //Pin no 21 is not a PWM pin on Teensy 4.x, you can swap it with pin no 1
instead.
  #define MOTOR1_IN_A 1
  #define MOTOR1_IN_B 1

  #define MOTOR2_PWM 6
  #define MOTOR2_IN_A 1
  #define MOTOR2_IN_B 1

  #define MOTOR3_PWM 22
  #define MOTOR3_IN_A 23
  #define MOTOR3_IN_B 0

  #define MOTOR4_PWM 4
  #define MOTOR4_IN_A 3
  #define MOTOR4_IN_B 2
```

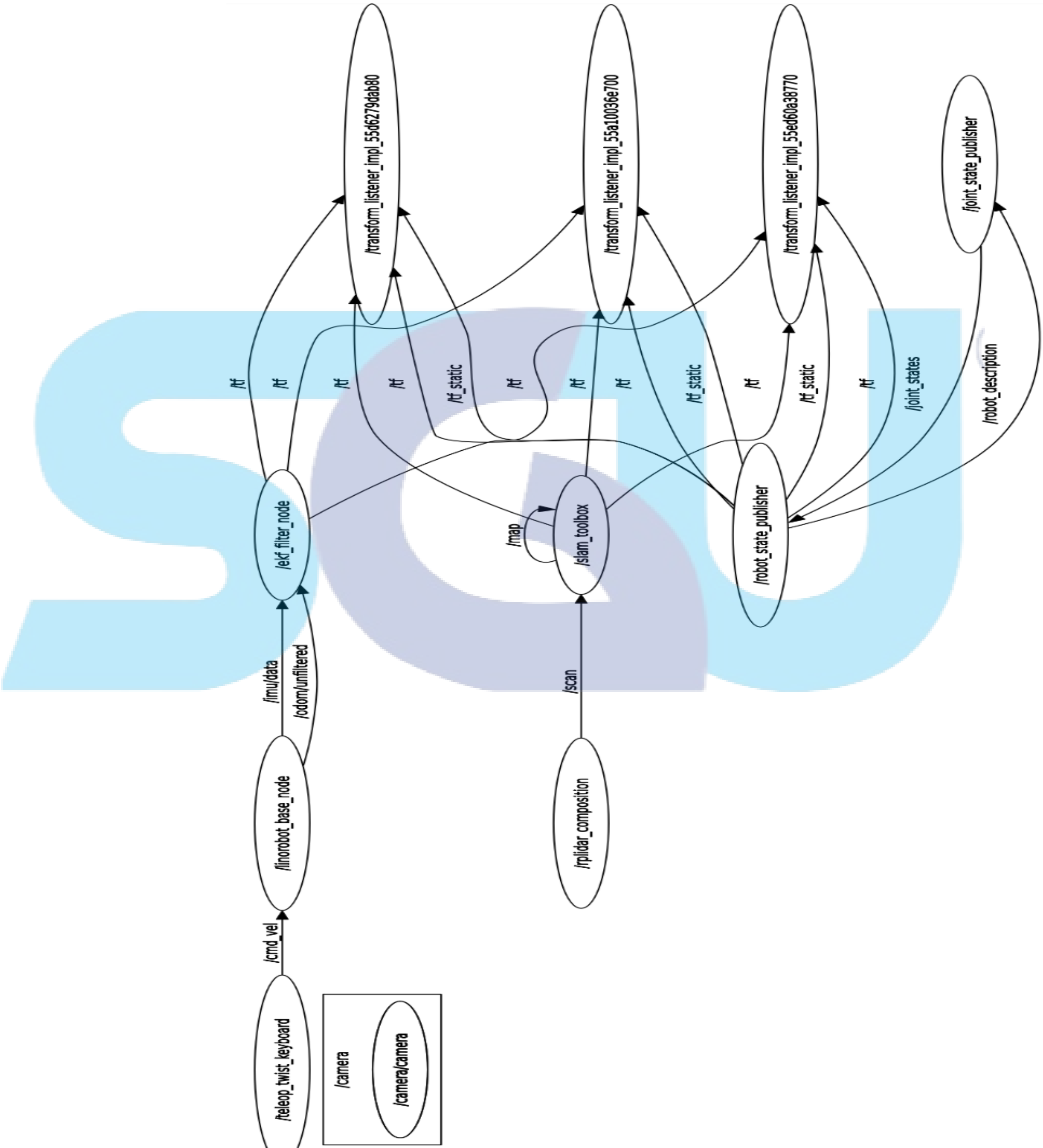
firmware.ino
~/linorobot2_hardware/firmware/src

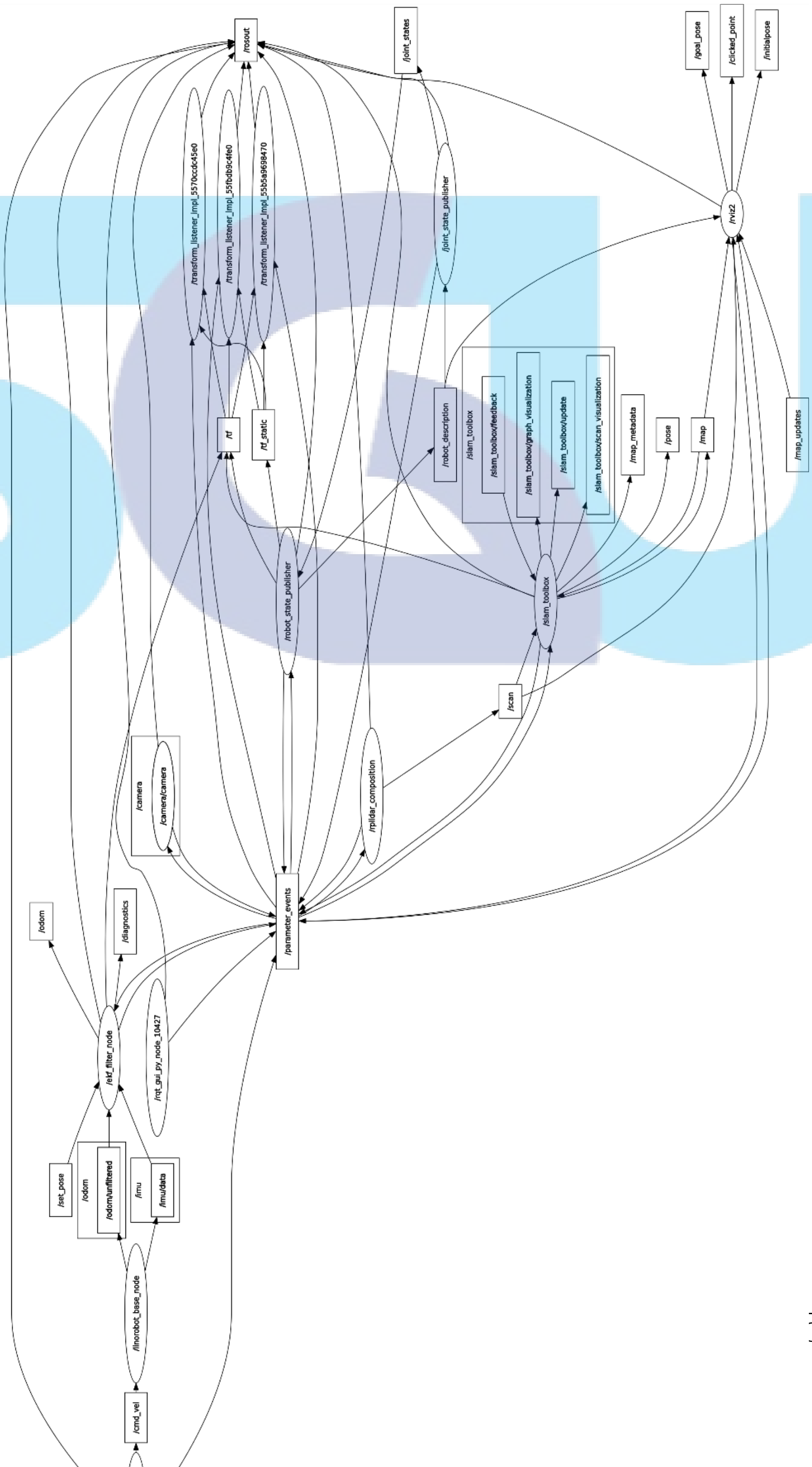
```
// Copyright (c) 2021 Juan Miguel Jimeno
//
// Licensed under the Apache License, Version 2.0 (the "License");
// you may not use this file except in compliance with the License.
// You may obtain a copy of the License at
//
//     http://www.apache.org/licenses/LICENSE-2.0
//
// Unless required by applicable law or agreed to in writing, software
// distributed under the License is distributed on an "AS IS" BASIS,
// WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
// See the License for the specific language governing permissions and
// limitations under the License.
#include <Arduino.h>
#include <micro_ros_platformio.h>
#include <stdio.h>

#include <rcl/rcl.h>
#include <rcl/error_handling.h>
#include <rclc/rclc.h>
#include <rclc/executor.h>

#include <nav_msgs/msg/odometry.h>
#include <sensor_msgs/msg/imu.h>
#include <geometry_msgs/msg/twist.h>
#include <geometry_msgs/msg/vector3.h>

#include "config.h"
#include "motor.h"
#include "kinematics.h"
#include "pid.h"
#include "odometry.h"
#include "imu.h"
#define ENCODER_USE_INTERRUPTS
#define ENCODER_OPTIMIZE_INTERRUPTS
#include "encoder.h"

#define RCCHECK(fn) { rcl_ret_t temp_rc = fn; if((temp_rc != RCL_RET_OK)){rclErrorLoop();}}
#define RCSOFTCHECK(fn) { rcl_ret_t temp_rc = fn; if((temp_rc != RCL_RET_OK)){}}
#define EXECUTE_EVERY_N_MS(MS, X)  do { \
  static volatile int64_t init = -1; \
  if (init == -1) { init = uxr_millis();} \
  if (uxr_millis() - init > MS) { X; init = uxr_millis();} \
} while (0)

rcl_publisher_t odom_publisher;
rcl_publisher_t imu_publisher;
rcl_subscription_t twist_subscriber;

nav_msgs__msg__Odometry odom_msg;
sensor_msgs__msg__Imu imu_msg;
geometry_msgs__msg__Twist twist_msg;

rclc_executor_t executor;
```

C   Tab Width: 8   Ln 37, Col 1   INS

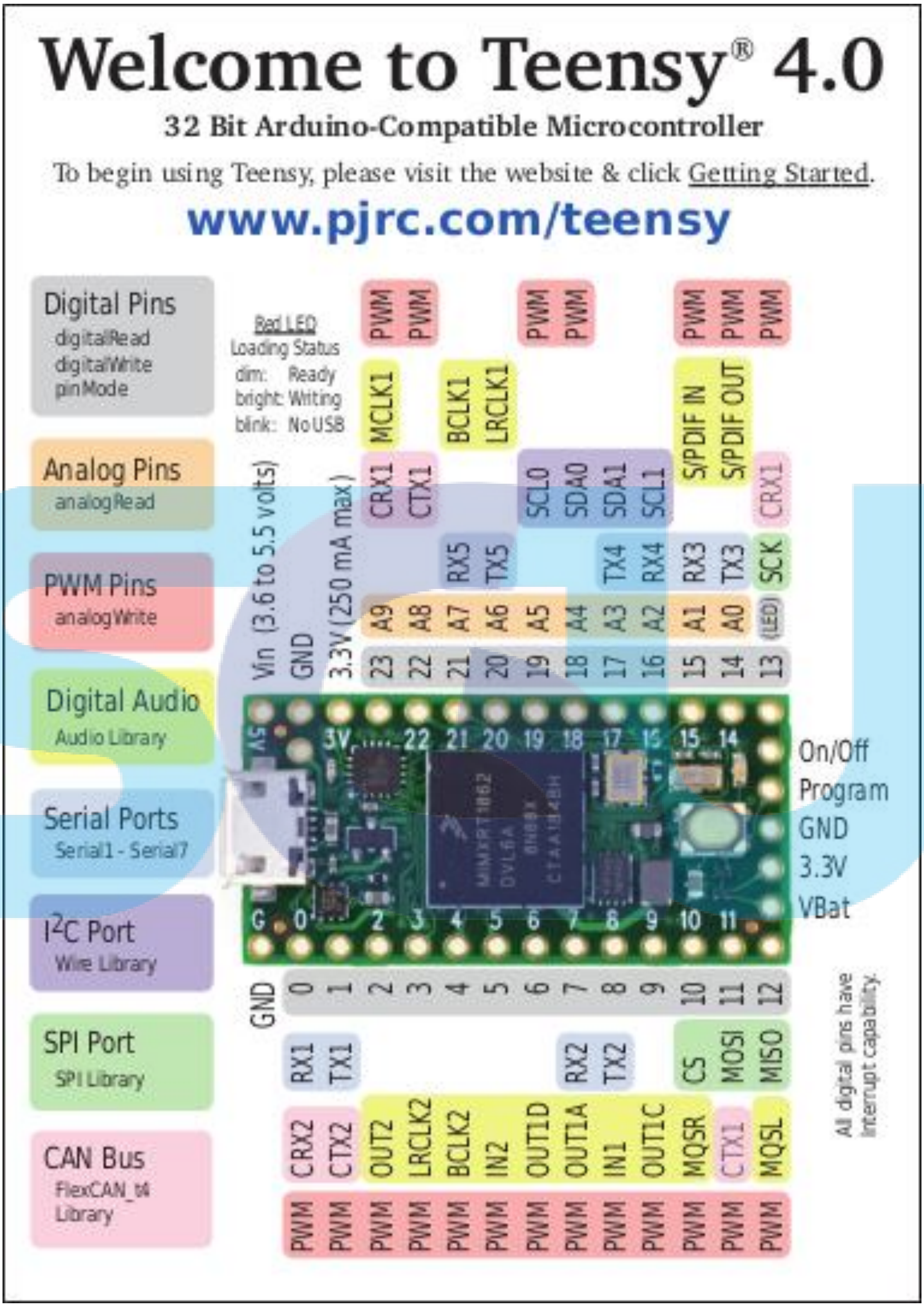

```
rclc_executor_t executor;
rclc_support_t support;
rcl_allocator_t allocator;
rcl_node_t node;
rcl_timer_t control_timer;

unsigned long long time_offset = 0;
unsigned long prev_cmd_time = 0;
unsigned long prev_odom_update = 0;

enum states
{
  WAITING_AGENT,
  AGENT_AVAILABLE,
  AGENT_CONNECTED,
  AGENT_DISCONNECTED
} state;

Encoder motor1_encoder(MOTOR1_ENCODER_A, MOTOR1_ENCODER_B, COUNTS_PER_REV1, MOTOR1_ENCODER_INV);
Encoder motor2_encoder(MOTOR2_ENCODER_A, MOTOR2_ENCODER_B, COUNTS_PER_REV2, MOTOR2_ENCODER_INV);
Encoder motor3_encoder(MOTOR3_ENCODER_A, MOTOR3_ENCODER_B, COUNTS_PER_REV3, MOTOR3_ENCODER_INV);
Encoder motor4_encoder(MOTOR4_ENCODER_A, MOTOR4_ENCODER_B, COUNTS_PER_REV4, MOTOR4_ENCODER_INV);

Motor motor1_controller(PWM_FREQUENCY, PWM_BITS, MOTOR1_INV, MOTOR1_PWM, MOTOR1_IN_A, MOTOR1_IN_B);
Motor motor2_controller(PWM_FREQUENCY, PWM_BITS, MOTOR2_INV, MOTOR2_PWM, MOTOR2_IN_A, MOTOR2_IN_B);
Motor motor3_controller(PWM_FREQUENCY, PWM_BITS, MOTOR3_INV, MOTOR3_PWM, MOTOR3_IN_A, MOTOR3_IN_B);
Motor motor4_controller(PWM_FREQUENCY, PWM_BITS, MOTOR4_INV, MOTOR4_PWM, MOTOR4_IN_A, MOTOR4_IN_B);

PID motor1_pid(PWM_MIN, PWM_MAX, K_P, K_I, K_D);
PID motor2_pid(PWM_MIN, PWM_MAX, K_P, K_I, K_D);
PID motor3_pid(PWM_MIN, PWM_MAX, K_P, K_I, K_D);
PID motor4_pid(PWM_MIN, PWM_MAX, K_P, K_I, K_D);

Kinematics kinematics(
    Kinematics::LINO_BASE,
    MOTOR_MAX_RPM,
    MAX_RPM_RATIO,
    MOTOR_OPERATING_VOLTAGE,
    MOTOR_POWER_MAX_VOLTAGE,
    WHEEL_DIAMETER,
    LR_WHEELS_DISTANCE
);

Odometry odometry;
IMU imu;

void setup()
{
    //set_microros_transports();
    pinMode(LED_PIN, OUTPUT);

    bool imu_ok = imu.init();
    if(!imu_ok)
    {
```

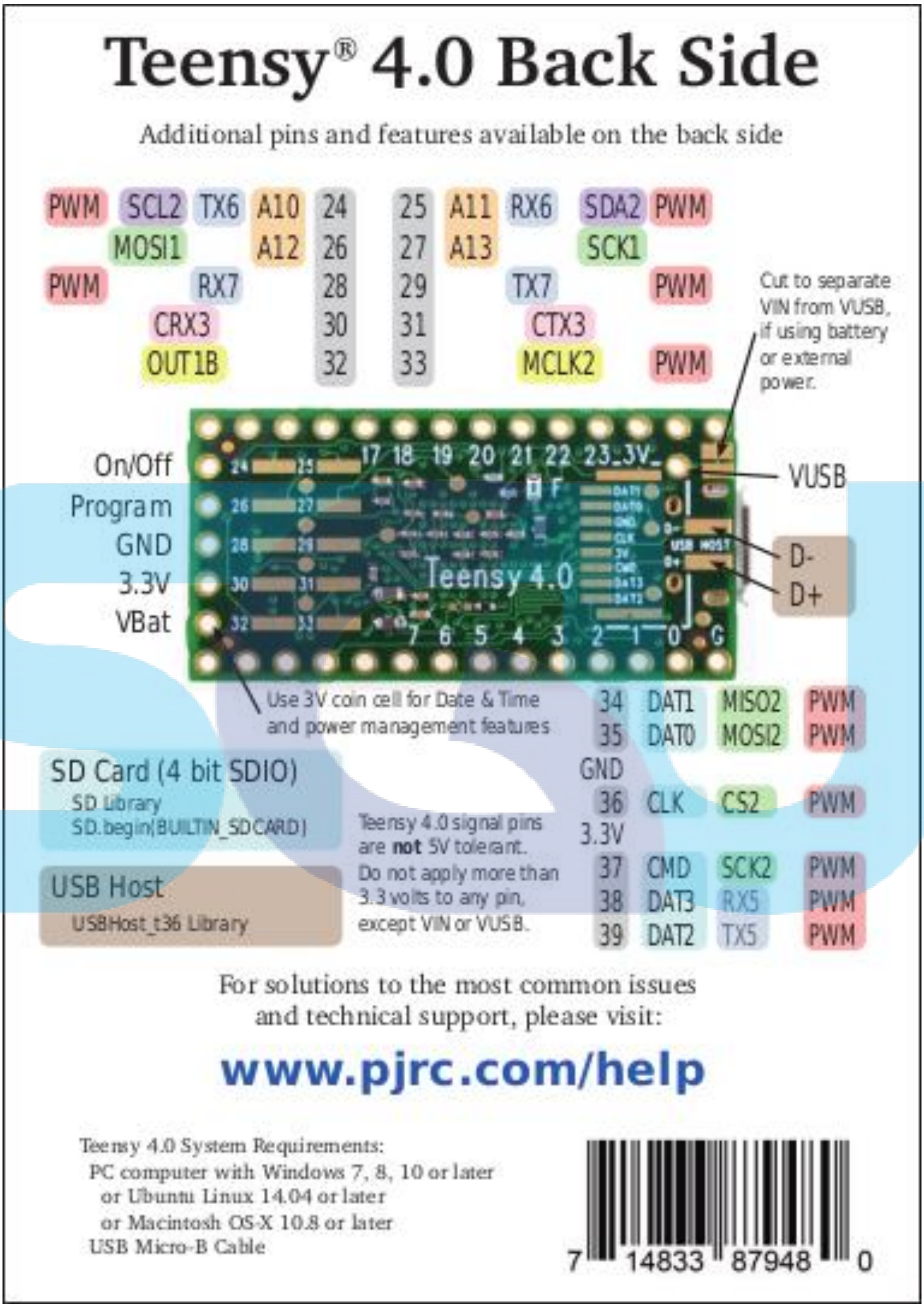
Appendix 6 RQT Graph


/teleop_twist_keyboard
/cmd_vel
/linorobot_base_node
/imu/data
/odom/unfiltered
/ekf_filter_node
/rplidar_composition
/scan
/slam_toolbox
/map
/robot_state_publisher
/transform_listener_impl_55d6279dab80
/transform_listener_impl_55a10036e700
/transform_listener_impl_55ed60a38770
/joint_state_publisher
/tf
/tf_static
/joint_states
/robot_description
/camera
/camera/camera

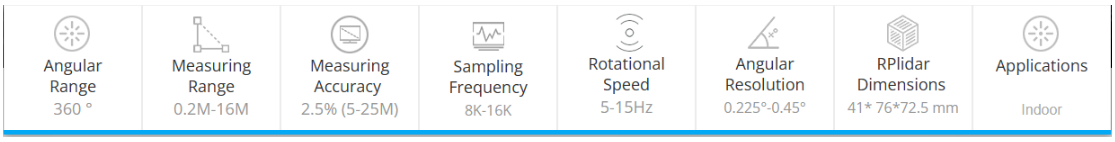

/rosout
/joint_states
/goal_pose
/clicked_point
/initialpose
/transform_listener_impl_5570ccdc45e0
/transform_listener_impl_55fbdb9c4fe0
/transform_listener_impl_55b5a9698470
/joint_state_publisher
/rviz2
/tf
/tf_static
/robot_description
/slam_toolbox
/slam_toolbox/feedback
/slam_toolbox/graph_visualization
/slam_toolbox/update
/slam_toolbox/scan_visualization
/map_metadata
/pose
/map
/map_updates
/robot_state_publisher
/slam_toolbox
/scan
/camera
/camera/camera
/rplidar_composition
/parameter_events
/odom
/diagnostics
/ekf_filter_node
/rqt_gui_py_node_10427
/set_pose
/odom
/odom/unfiltered
/imu
/imu/data
/linorobot_base_node
/cmd_vel

Appendix 7 Data Sheet of Teensy 4.0




Teensy® 4.0 Back Side
Additional pins and features available on the back side
PWM SCL2 TX6 A10 24 25 A11 RX6 SDA2 PWM
MOSI1 A12 26 27 A13 SCK1
PWM RX7 28 29 TX7 PWM
CRX3 30 31 CTX3
OUT1B 32 33 MCLK2 PWM
Cut to separate VIN from VUSB, if using battery or external power.
On/Off
Program
GND
3.3V
VBat
VUSB
D-
D+
Teensy 4.0
Use 3V coin cell for Date & Time and power management features
34 DAT1 MISO2 PWM
35 DAT0 MOSI2 PWM
GND
36 CLK CS2 PWM
3.3V
37 CMD SCK2 PWM
38 DAT3 RX5 PWM
39 DAT2 TX5 PWM
SD Card (4 bit SDIO)
SD Library
SD.begin(BUILTIN_SDCARD)
USB Host
USBHost_t36 Library
Teensy 4.0 signal pins are not 5V tolerant. Do not apply more than 3.3 volts to any pin, except VIN or VUSB.
For solutions to the most common issues and technical support, please visit:
www.pjrc.com/help
Teensy 4.0 System Requirements:
PC computer with Windows 7, 8, 10 or later
or Ubuntu Linux 14.04 or later
or Macintosh OS-X 10.8 or later
USB Micro-B Cable
7 14833 87948 0

Appendix 8 Data Sheet of RPLiDAR A2



Item	Unit	Min	Typical	Max	Comments
Distance Range	Meter(m)	0.15	-	8	Based om white objects with 70% reflectivity
Angular Range	Degree	-	0-360	-	-
Distance Resolution	mm	-	<0.5	-	<1.5 meters
			<1% of the distance		All distance range*
Angular Resolution	Degree	0.45	0.9	1.35	10Hz scan rate
Sample Duration	Millisecond(ms)	-	0.25	-	-
Sample Frequency	Hz	2000	4000	4100	
Scan Rate	Hz	5	10	15	The rate is for a round of scan. The typical value is measured when RPLIDAR takes 400 samples per scan

RPLiDAR Performance

Item	Unit	Min	Typical	Max	Comments
Laser wavelength	Nanometer(nm)	775	785	795	Infrared Light Band
Laser power	Milliwatt (mW)	-	3	5	Peak power
Pulse length	Microsecond(us)	60	87	90	-
Laser Safety Class	-	-	FDA Class I	-	-

RPLiDAR Optical Specification

Color	Signal Name	Type	Description	Min	Typical	Max
Red	VCC	Power	Total Power	4.9V	5V	5.5V
Yellow	TX	Output	Serial port output of the scanner core	0V	3.3V	3.5V
Green	RX	Input	Serial port input of the scanner core	0V	3.3V	3.5V
Black	GND	Power	GND	0V	0V	0V
Blue	MOTOCTL	Input	Scan motor /PWM Control Signal (active high, internal pull down)	0V	3.3V	5V

RPLiDAR External Interface Signal Definition

Item	Unit	Min	Typical	Max	Remark
Power Voltage	V	4.9	5	5.5	If the voltage exceeds the max value, it may damage the core
Power Voltage Ripple	mV	-	20	50	High ripple may cause the core working failure.
System Start Current	mA	-	1200	1500	The system startup requires relatively higher current.
Power Current	mA	TBD	200	220	5V Power，power off
		TBD	450	600	5V Power，power on

RPLiDAR Power Supply Specification

Item	Unit	Min	Typical	Max	Comments
Band rate	bps	-	115200	-	-
Working mode	-	-	8N1	-	8n1
Output high voltage	Volt (V)	2.9	-	3.5	Logic High
Output low voltage	Volt (V)	-	-	0.4	Logic Low
Input high voltage	Volt (V)	1.6*	-	3.5	Logic High
Input low voltage	Volt (V)	-0.3	-	0.4	Logic Low

RPLiDAR Serial Port Interface

Item	Unit	Min	Typical	Max	Comments
Weight	Gram (g)	TBD	190	TBD	
Temperature range	Degree Celsius (°C)	0	20	45	

RPLiDAR MISC Specification

Appendix 9 Data Sheet of IMU

2 Features

2.1 Gyroscope Features

The triple-axis MEMS gyroscope in the MPU-9250 includes a wide range of features:

- Digital-output X-, Y-, and Z-Axis angular rate sensors (gyroscopes) with a user-programmable full-scale range of ±250, ±500, ±1000, and ±2000°/sec and integrated 16-bit ADCs
- Digitally-programmable low-pass filter
- Gyroscope operating current: 3.2mA
- Sleep mode current: 8µA
- Factory calibrated sensitivity scale factor
- Self-test

2.2 Accelerometer Features

The triple-axis MEMS accelerometer in MPU-9250 includes a wide range of features:

- Digital-output triple-axis accelerometer with a programmable full scale range of ±2*g*, ±4*g*, ±8*g* and ±16*g* and integrated 16-bit ADCs
- Accelerometer normal operating current: 450µA
- Low power accelerometer mode current: 8.4µA at 0.98Hz, 19.8µA at 31.25Hz
- Sleep mode current: 8µA
- User-programmable interrupts
- Wake-on-motion interrupt for low power operation of applications processor
- Self-test

2.3 Magnetometer Features

The triple-axis MEMS magnetometer in MPU-9250 includes a wide range of features:

- 3-axis silicon monolithic Hall-effect magnetic sensor with magnetic concentrator
- Wide dynamic measurement range and high resolution with lower current consumption.
- Output data resolution of 14 bit (0.6µT/LSB)
- Full scale measurement range is ±4800µT
- Magnetometer normal operating current: 280µA at 8Hz repetition rate
- Self-test function with internal magnetic source to confirm magnetic sensor operation on end products

2.4 Additional Features

The MPU-9250 includes the following additional features:

- Auxiliary master I²C bus for reading data from external sensors (e.g. pressure sensor)
- 3.5mA operating current when all 9 motion sensing axes and the DMP are enabled
- VDD supply voltage range of 2.4 – 3.6V
- VDDIO reference voltage for auxiliary I²C devices
- Smallest and thinnest QFN package for portable devices: 3x3x1mm
- Minimal cross-axis sensitivity between the accelerometer, gyroscope and magnetometer axes
- 512 byte FIFO buffer enables the applications processor to read the data in bursts
- Digital-output temperature sensor
- User-programmable digital filters for gyroscope, accelerometer, and temp sensor
- 10,000 *g* shock tolerant
- 400kHz Fast Mode I²C for communicating with all registers
- 1MHz SPI serial interface for communicating with all registers

3 Electrical Characteristics

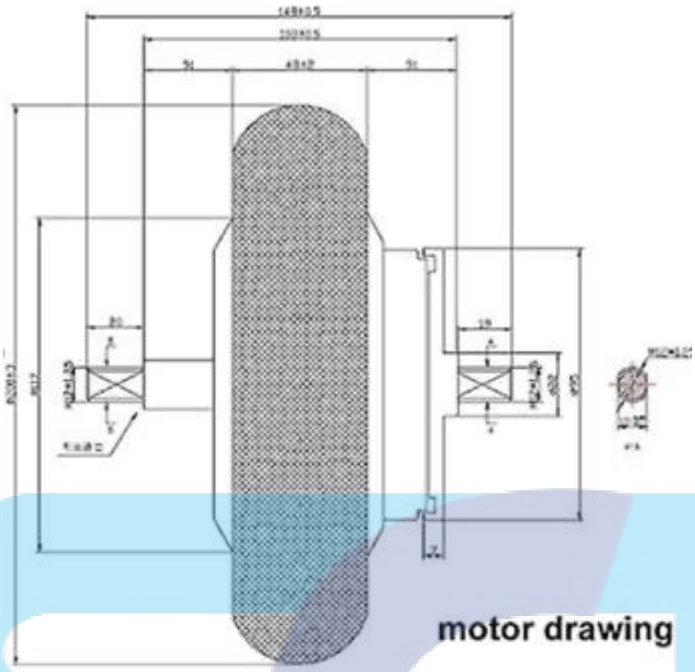
3.1 Gyroscope Specifications

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Full-Scale Range	FS_SEL=0		±250		°/s
	FS_SEL=1		±500		°/s
	FS_SEL=2		±1000		°/s
	FS_SEL=3		±2000		°/s
Gyroscope ADC Word Length			16		bits
Sensitivity Scale Factor	FS_SEL=0		131		LSB/(°/s)
	FS_SEL=1		65.5		LSB/(°/s)
	FS_SEL=2		32.8		LSB/(°/s)
	FS_SEL=3		16.4		LSB/(°/s)
Sensitivity Scale Factor Tolerance	25°C		±3		%
Sensitivity Scale Factor Variation Over Temperature	-40°C to +85°C		±4		%
Nonlinearity	Best fit straight line; 25°C		±0.1		%
Cross-Axis Sensitivity			±2		%
Initial ZRO Tolerance	25°C		±5		°/s
ZRO Variation Over Temperature	-40°C to +85°C		±30		°/s
Total RMS Noise	DLPFCFG=2 (92 Hz)		0.1		°/s-rms
Rate Noise Spectral Density			0.01		°/s/√Hz
Gyroscope Mechanical Frequencies		25	27	29	KHz
Low Pass Filter Response	Programmable Range	5		250	Hz
Gyroscope Startup Time	From Sleep mode		35		ms
Output Data Rate	Programmable, Normal mode	4		8000	Hz

Table 1 Gyroscope Specifications

Appendix 10 BLDC motor data sheet



motor drawing

This is a gearless brushless hub motor. It is designed for high speed electric scooter, or other high speed electric vehicle.

The current power is 350W, max loading is 75KG.

Please noted it is hall sensor motor, which has total 8 wires.

Specification

Model: L-BHM
Voltage: 36 Volt
Output: 350 Watt
Max Speed: 35 KM/H
Rated Efficiency: ≥75%
Rated Current: 7A
Rated Torque: 5 N.m
Max Loading: 75 KG
Wheel Size: 8 inch
This motor has hall sensor (total has 8 wires):

Appendix 11 Motor Driver data sheet

Specification and model:

Model	Maximum Output current	Maximum Output voltage	Directvoltage Working range
	DC: (A)	DC: (V)	DC: (V)
DC10/50DPW15BL	15	10-50	10-50 (95%)

I: Features:

◆ This produce has three manners of working: speed control, current control and open-loop control.
◆ Control functions of braking, direction, enable, first-magnification, dual speed setting, etc. can be realized.
◆ Maximum current limit can be adjusted.
0-5V signal control mode for external potentiometer, interior potentiometer and external analog quantity and soft start function.
◆ Time setting function for soft start.
◆ Overcurrent protection function and locked-rotor protection.
◆ High-speed control, which has a full speed of one pole pair motor can reach 120000RPM.
Details refer to relevant contents.

II: Performance Indexes:

1. Power supply voltage VCC: 10—50VDC (error <5% is better).
2. Maximum output voltage: Vout=0.95 VCC.

3. Maximum output current: 15A.
4. Switching frequency: 39KHz.
5. Maximum speed (one pole pair motor): 120, 000rpm.
6. Hall power supply voltage range: 7—12VDC Maximum output current is 30mA.
7. Locked-rotor protection time: 1.5 seconds.
8. Ambient temperature: -10-- +600C.
Ambient humidity: relative humidity ≤ 80RH.
9. Analog quantity output: 0-- +5VDC.
10. Soft start time: 20ms—10S.
11. Regulation voltage of external potentiometer: 0-- +5V potentiometer (10KΩ/2W).
10. Overall dimension (including radiator): 122*35*72mm.
11. Weight: approximate 300g.

III: Overall dimension: see Figure 1

Figure 1

4

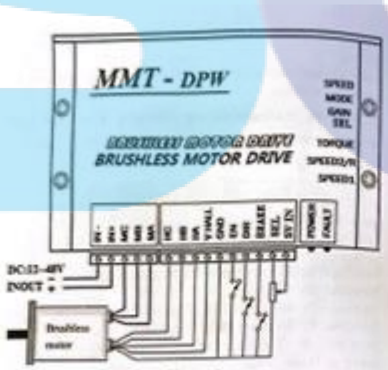


Figure 2

VII. Connection for fuse, power switch and motor

1. It must be equipped with a fast fuse and electromagnetic relay contactor between power input end of driver and power (storage battery) to realize emergency power off in case of suddenly power cut. See Figure 3
(Note: selection for fast fuse and electromagnetic relay contactor: rated current value should be bigger or equal to 150-200% of motor rated current.)

8

Note: please confirm if the voltage rated value of motor matches with the output voltage of the driver.
2. Motor connecting: see Figure 3

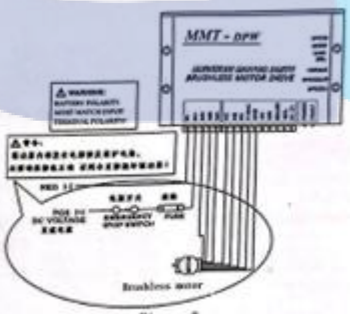


Figure 3

3. Power input connection

> **⚠ Warning**
> There is no storage battery polarity transposition for power input end inside the driver to protect circuit. Please ensure the POS (+) be connected with B+ terminal and NEG (-) with B- terminal.

9

CURRICULUM VITAE

PERSONAL INFORMATION

Name : Mohammad Rizky Gartina

Place & date of birth : Tangerang, 5 November 2001

Address : Depark Denaara F2 no 10, BSD

Telephone : 081312343638

Email : gartina5@gmail.com

EDUCATION

2019 – Now Swiss German University, Mechatronics Department

2016 – 2019 Al-Azhar BSD Senior High School

2014 – 2016 Al-Azhar BSD Junior High School

2007 – 2013 Al-Azhar BSD

TRAINING AND INTERNSHIP

2022 **Intership at PT Resyana Andata Cipta, Indonesia**

- Car ECU programming
- Fabricated car parts

2020 – 2022 **Training at ATMI Cikarang, Indonesia**

- Reverse Engineering
- Milling
- Turning
- Welding
- Safety technic
- Assembly

- BW Electro
- BW Mechanic

2021 **Internship at PT Multi Teknologi Persada, Indonesia**

- Learning about scrara robot mechanism
- Integrating scrara robot into the project

2020 **Training PT Yaskawa Electric, Indonesia**

- Training arm robot

LANGUAGE SKILLS

INDONESIA – Mother Language

English – fluent in speaking and writing

Deutch – basic understanding (A2)

COMPUTER SKILLS

Microsoft Office: Word, Excel, Power Point

C++Coding, Arduino, SolidWorks, AutoCAD, Adobe Photoshop, Fusion 360, ROS

INTEREST AND HOBBYS

Football, Travelling, listening music