```
% ======
% ROB521_assignment2.m
% ======
%
% This assignment will introduce you to the idea of estimating the
 motion
% of a mobile robot using wheel odometry, and then also using that
 wheel
% odometry to make a simple map.  It uses a dataset previously
 gathered in
% a mobile robot simulation environment called Gazebo. Watch the
 video,
% 'gazebo.mp4' to visualize what the robot did, what its environment
% looks like, and what its sensor stream looks like.
%
% There are three questions to complete (5 marks each):
%
%    Question 1: code (noise-free) wheel odometry algorithm
%    Question 2: add noise to data and re-run wheel odometry algorithm
%    Question 3: build a map from ground truth and noisy wheel
 odometry
%
% Fill in the required sections of this script with your code, run it
 to
% generate the requested plots, then paste the plots into a short
 report
% that includes a few comments about what you've observed.  Append
 your
% version of this script to the report.  Hand in the report as a PDF
 file.
%
% requires: basic Matlab, 'ROB521_assignment2_gazebo_data.mat'
%
% T D Barfoot, December 2015
%
clear all;
clc

% set random seed for repeatability
rng(1);

% ==========================
% load the dataset from file
% ==========================
%
%    ground truth poses: t_true x_true y_true theta_true
% odometry measurements: t_odom v_odom omega_odom
%           laser scans: t_laser y_laser
%    laser range limits: r_min_laser r_max_laser
%    laser angle limits: phi_min_laser phi_max_laser
%
load ROB521_assignment2_gazebo_data.mat;
```

=== Question 1: code (noise-free) wheel odometry algorithm ===

Write an algorithm to estimate the pose of the robot throughout motion using the wheel odometry data (t_odom, v_odom, omega_odom) and assuming a differential-drive robot model. Save your estimate in the variables (x_odom y_odom theta_odom) so that the comparison plots can be generated below. See the plot 'ass1_q1_soln.png' for what your results should look like.

```
% variables to store wheel odometry pose estimates
numodom = size(t_odom,1);
x_odom = zeros(numodom,1);
y_odom = zeros(numodom,1);
theta_odom = zeros(numodom,1);

% set the initial wheel odometry pose to ground truth
x_odom(1) = x_true(1);
y_odom(1) = y_true(1);
theta_odom(1) = theta_true(1);

% ------insert your wheel odometry algorithm here-------
for i=2:numodom
    theta_new = omega_odom(i)*(t_odom(i) - t_odom(i-1)) +
 theta_odom(i-1);

    if theta_new > pi
        theta_new = theta_new - 2*pi;
    elseif theta_new < -pi
        theta_new = theta_new + 2*pi;
    end

    x_new     = v_odom(i)*cos(theta_new)*(t_odom(i) - t_odom(i-1)) +
 x_odom(i-1);
    y_new     = v_odom(i)*sin(theta_new)*(t_odom(i) - t_odom(i-1)) +
 y_odom(i-1);

    x_odom(i) = x_new;
    y_odom(i) = y_new;
    theta_odom(i) = theta_new;
end
% ------end of your wheel odometry algorithm-------

% plot the results for verification
figure(1)
clf;

subplot(2,2,1);
hold on;
plot(x_true,y_true,'b');
plot(x_odom, y_odom, 'r');
legend('true', 'odom');
xlabel('x [m]');
ylabel('y [m]');
title('path');
```

```
axis equal;

subplot(2,2,2);
hold on;
plot(t_true,theta_true,'b');
plot(t_odom,theta_odom,'r');
legend('true', 'odom');
xlabel('t [s]');
ylabel('theta [rad]');
title('heading');

subplot(2,2,3);
hold on;
pos_err = zeros(numodom,1);
for i=1:numodom
    pos_err(i) = sqrt((x_odom(i)-x_true(i))^2 + (y_odom(i)-
y_true(i))^2);
end
plot(t_odom,pos_err,'b');
xlabel('t [s]');
ylabel('distance [m]');
title('position error (odom-true)');

subplot(2,2,4);
hold on;
theta_err = zeros(numodom,1);
for i=1:numodom
    phi = theta_odom(i) - theta_true(i);
    while phi > pi
        phi = phi - 2*pi;
    end
    while phi < -pi
        phi = phi + 2*pi;
    end
    theta_err(i) = phi;
end
plot(t_odom,theta_err,'b');
xlabel('t [s]');
ylabel('theta [rad]');
title('heading error (odom-true)');
print -dpng self_ass1_q1.png

% =================================================================
% Question 2: add noise to data and re-run wheel odometry algorithm
% =================================================================
%
% Now we're going to deliberately add some noise to the linear and
% angular velocities to simulate what real wheel odometry is like.
 Copy
% your wheel odometry algorithm from above into the indicated place
 below
% to see what this does.  The below loops 100 times with different
 random
```

```
% noise.  See the plot 'ass1_q2_soln.pdf' for what your results should
 look
% like.

% save the original odometry variables for later use
v_odom_noisefree = v_odom;
omega_odom_noisefree = omega_odom;

% set up plot
figure(2);
clf;
hold on;

% loop over random trials
for n=1:100

    % add noise to wheel odometry measurements (yes, on purpose to see
 effect)
    v_odom = v_odom_noisefree + 0.2*randn(numodom,1);
    omega_odom = omega_odom_noisefree + 0.04*randn(numodom,1);

    % ------insert your wheel odometry algorithm here-------
    for i=2:numodom
        theta_new = omega_odom(i)*(t_odom(i) - t_odom(i-1)) +
 theta_odom(i-1);

    if theta_new > pi
        theta_new = theta_new - 2*pi;
    elseif theta_new < -pi
        theta_new = theta_new + 2*pi;
    end

    x_new     = v_odom(i)*cos(theta_new)*(t_odom(i) - t_odom(i-1)) +
 x_odom(i-1);
    y_new     = v_odom(i)*sin(theta_new)*(t_odom(i) - t_odom(i-1)) +
 y_odom(i-1);

    x_odom(i) = x_new;
    y_odom(i) = y_new;
    theta_odom(i) = theta_new;


    end
    % ------end of your wheel odometry algorithm-------

    % add the results to the plot
    plot(x_odom, y_odom, 'r');
end

% plot ground truth on top and label
plot(x_true,y_true,'b');
xlabel('x [m]');
ylabel('y [m]');
title('path');
```

```
axis equal;
print -dpng self_ass1_q2.png
```

== Question 3: build a map from noisy and noise-free wheel odometry ==

Now we're going to try to plot all the points from our laser scans in the robot's initial reference frame. This will involve first figuring out how to plot the points in the current frame, then transforming them back to the initial frame and plotting them. Do this for both the ground truth pose (blue) and also the last noisy odometry that you calculated in Question 2 (red). At first even the map based on the ground truth may not look too good. This is because the laser timestamps and odometry timestamps do not line up perfectly and you'll need to interpolate. Even after this, two additional patches will make your map based on ground truth look as crisp as the one in 'ass1_q3_soln.png'. The first patch is to only plot the laser scans if the angular velocity is less than 0.1 rad/s; this is because the timestamp interpolation errors have more of an effect when the robot is turning quickly. The second patch is to account for the fact that the origin of the laser scans is about 10 cm behind the origin of the robot. Once your ground truth map looks crisp, compare it to the one based on the odometry poses, which should be far less crisp, even with the two patches applied.

```
% set up plot
figure(3);
clf;
hold on;

% precalculate some quantities
npoints = size(y_laser,2);
angles = linspace(phi_min_laser, phi_max_laser,npoints);
cos_angles = cos(angles);
sin_angles = sin(angles);

for n=1:2
    if n==2
        % interpolate the noisy odometry at the laser timestamps
        t_interp = linspace(t_odom(1),t_odom(numodom),numodom);
        x_interp = interp1(t_interp,x_odom,t_laser);
        y_interp = interp1(t_interp,y_odom,t_laser);
        theta_interp = interp1(t_interp,theta_odom,t_laser);
        omega_interp = interp1(t_interp,omega_odom,t_laser);
    else
        % interpolate the noise-free odometry at the laser timestamps
        t_interp = linspace(t_true(1),t_true(numodom),numodom);
        x_interp = interp1(t_interp,x_true,t_laser);
        y_interp = interp1(t_interp,y_true,t_laser);
        theta_interp = interp1(t_interp,theta_true,t_laser);
        omega_interp = interp1(t_interp,omega_odom,t_laser);
    end

    x_map = [];
    y_map = [];
    laser_angles = linspace(phi_min_laser, phi_max_laser,
 size(y_laser, 2))';

    % loop over laser scans
    for i=1:size(t_laser,1)
```

```
        % ------insert your point transformation algorithm here------
        for j=1:size(y_laser, 2)
            if omega_interp(i)<0.1
                if ~isnan(y_laser(i, j))

                    x_botframe = (y_laser(i,
 j)-0.1)*cos(theta_interp(i) + laser_angles(j));
                    y_botframe = (y_laser(i,
 j)-0.1)*sin(theta_interp(i) + laser_angles(j));

                    x_inerframe = x_interp(i) + x_botframe;
                    y_inerframe = y_interp(i) + y_botframe;

                    x_map = [x_map x_inerframe];
                    y_map = [y_map y_inerframe];

                end
            end
        end
        % ------end of your point transformation algorithm-------
    end

    if n==1
        scatter(x_map,y_map, 6,'b', 'filled');
        print -dpng self_ass1_q3_gt.png
        hold on
    else
        axis equal;
        scatter(x_map,y_map, 6,'r', 'filled');
    end
end

legend('groundtruth pose','noisyodometry pose')
xlabel('x [m]');
ylabel('y [m]');
title('map');
print -dpng self_ass1_q3_both.png
```

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