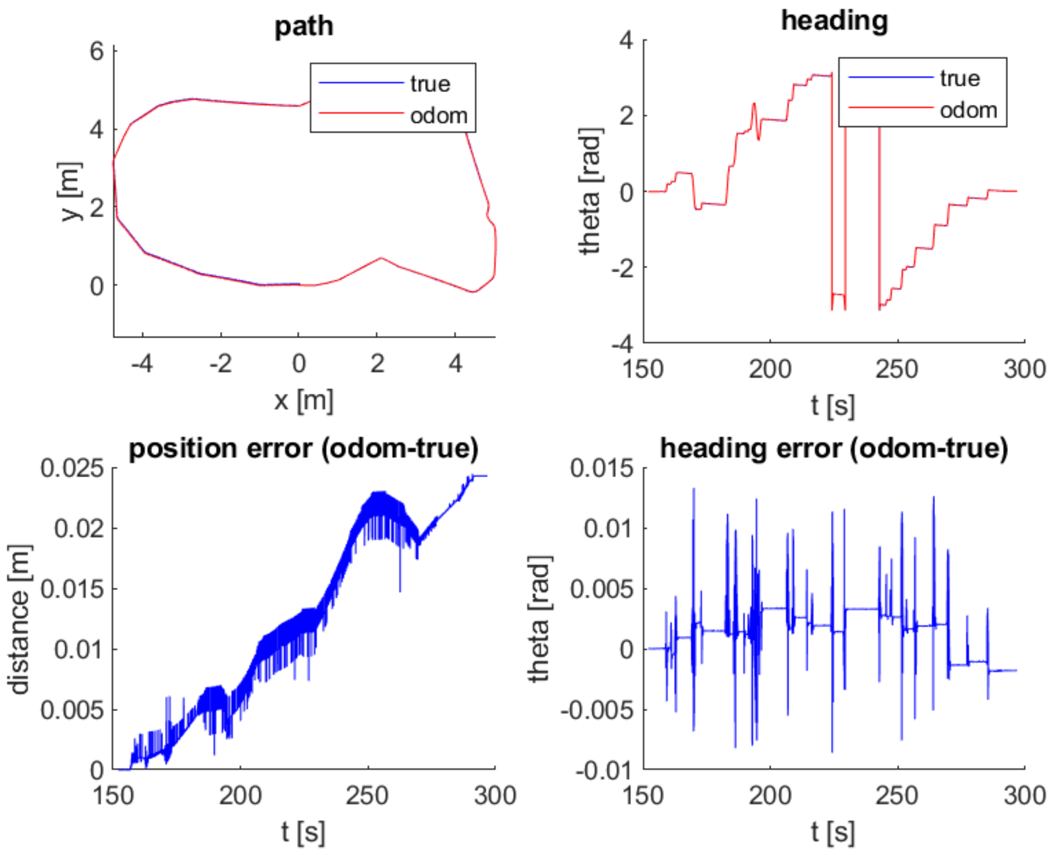
Assignment 1 Report
ROB521: Mobile Robotics and Perception

Name: Malcolm MacKay **Student number: 1002423308**

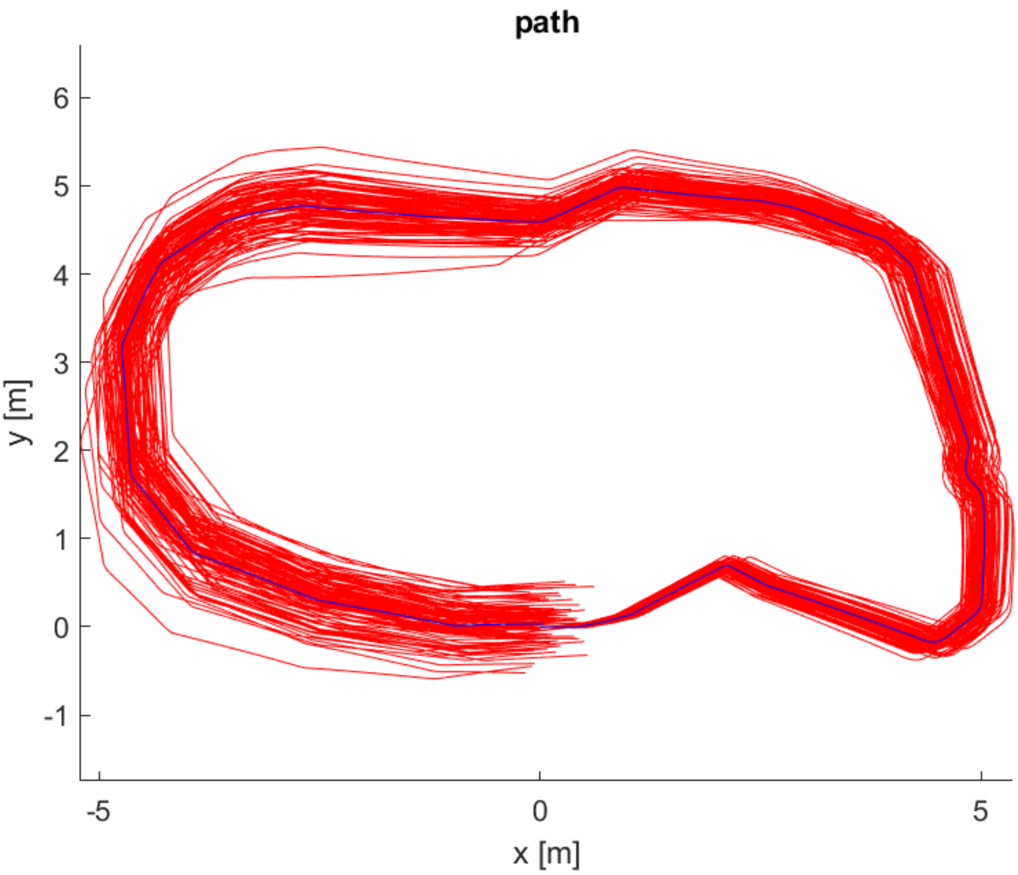
Question 1:

My results for question 1 look identical to the solution. It can be seen that with no noise, that the error isn't that that far off once the path is completed, however the position error is steadily growing over time. The error in this questoin is caused by the numberical integration of the odometry data.



Question 2:

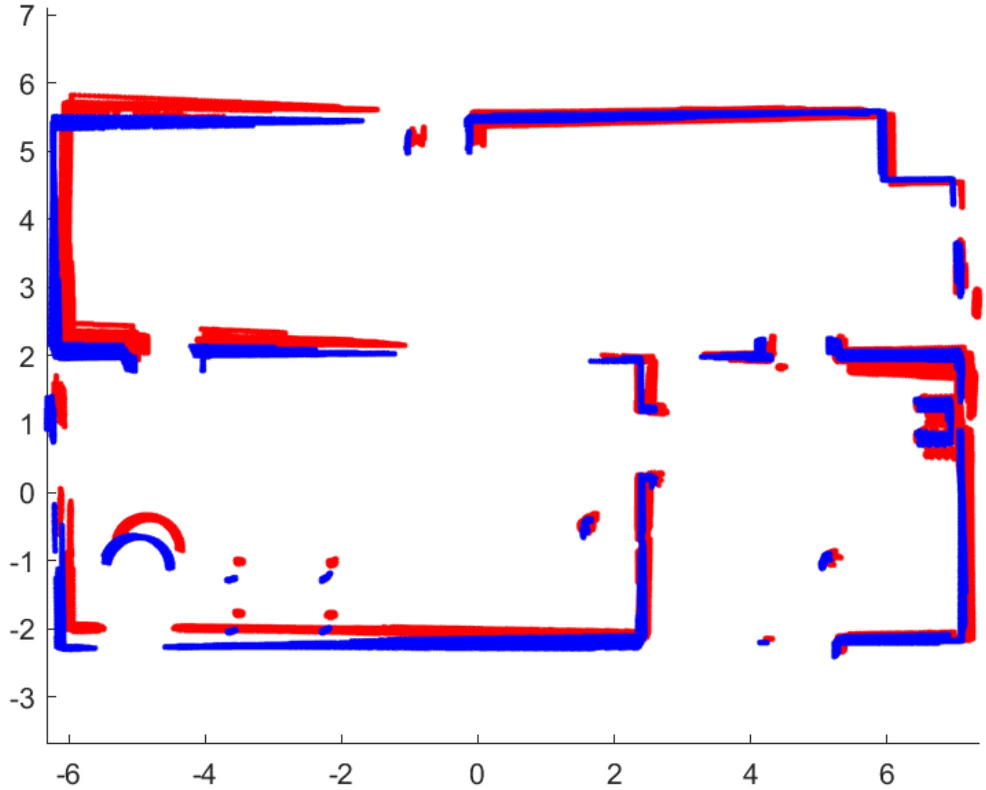
My results for question 2 look identical to the solution. The results make sense, as you can clearly see the cart is very sure of its starting area (ground truth) but over time becomes less sure as the noise error propagates the farther it gets. This is exactly why we don't use wheel odometry over large distances.

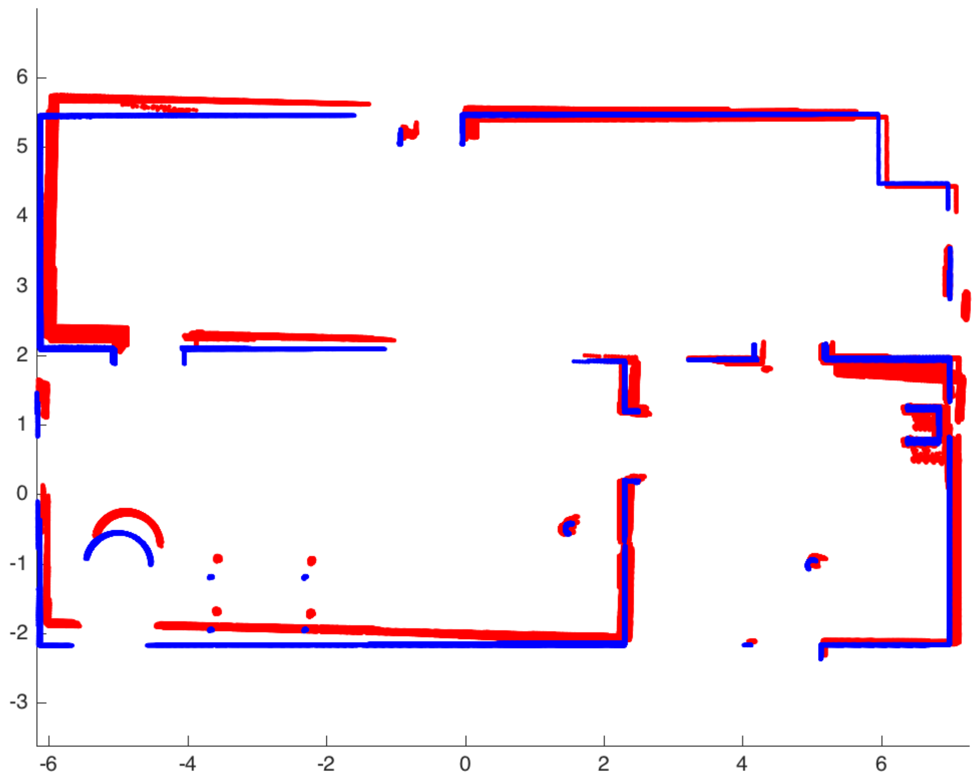


Question 3:

My results for question 3 look similar to the solution given, but vary slightly. The general shape of the map is the same, and the maps produced by true odometry vs the noisy odometry seem to be related in the same way. Because of this, I think this was a matter of graphing tool used in matlab, it appears as though the dots used for my solution are simply thicker.

In regards to what I noticed about the actual map, it appears as though sections on the left side of the map diverge more than sections on the right side of the map. This makes sense, due to the path of the robot. The left side of the map has noisier odometry, and it's later in time so more error has propagated (think the path in question 2), resulting to a noisier map.


7
6
5
4
3
2
1
0
-1
-2
-3
-6
-4
-2
0
2
4
6


6
5
4
3
2
1
0
-1
-2
-3
-6
-4
-2
0
2
4
6

Appendix (Code)

```
    % ======
% ass1.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, 'gazebo.mat'
%
% T D Barfoot, December 2015
%
clear all;

% 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 gazebo.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

    %calculate change in distance, angle, and time
    dt = t_odom(i) - t_odom(i-1);
    dist = v_odom(i)*dt;
    angle = omega_odom(i)*dt;

    %update the odometry measurements
    x_odom(i) = x_odom(i-1) + dist * cos(theta_odom(i-1)) ;
    y_odom(i) = y_odom(i-1) + dist * sin(theta_odom(i-1));
    theta_odom(i) = wrapToPi(theta_odom(i-1) + angle);

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 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 effec
    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
        %calculate change in distance, angle, and time
        dt = t_odom(i) - t_odom(i-1);
        dist = v_odom(i)*dt;
        angle = omega_odom(i)*dt;

        %update the odometry measurements
        x_odom(i) = x_odom(i-1) + dist * cos(theta_odom(i-1)) ;
        y_odom(i) = y_odom(i-1) + dist * sin(theta_odom(i-1));
        theta_odom(i) = wrapToPi(theta_odom(i-1) + angle);

    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 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==1
        % 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

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

        % ------insert your point transformation algorithm here------

        %create rotation matrix and vector that go from the initial frame to
        %robot frame
        theta = wrapToPi(theta_interp(i) - theta_interp(1));
        C_ib = [cos(theta) -sin(theta);
                sin(theta) cos(theta)];
        r_ib = [x_interp(i) - x_interp(1);
```

```
                y_interp(i) - y_interp(1)];


        %loop through laser points transform each of them
        for j = 1:npoints
            %calculate vector from robot to end of laser
            r_b = [y_laser(i,j) * cos_angles(j);
                   y_laser(i,j) * sin_angles(j)];
            %transform laser vector back to initial frame
            r_i = C_ib * r_b + r_ib;

            %record these points
            if n == 1
                xpoints_true(i,j) = r_i(1);
                ypoints_true(i,j) = r_i(2);
            else
                xpoints_odom(i,j) = r_i(1);
                ypoints_odom(i,j) = r_i(2);
            end
        end
        % ------end of your point transformation algorithm-------
    end
end

axis equal;
%did these backwards
scatter(reshape(xpoints_true, 1, []), reshape(ypoints_true, 1, []), '.', 'r'
scatter(reshape(xpoints_odom, 1, []), reshape(ypoints_odom, 1, []), '.', 'b'
print -dpng ass1_q3.png
```