Rob521 - Assignment 2
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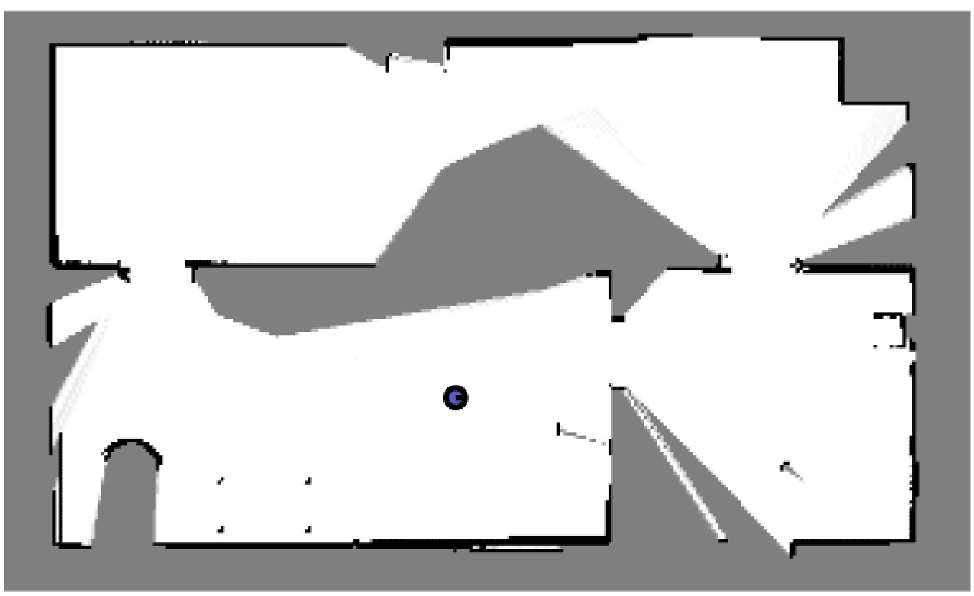
Question #1 -build an occupancy grid map
In this part, we had to implement an occupancy grip mapping algorithm that builds the map from perfect ground-truth localization.This is completely identical to the ROB521 Lab3 mapping that we had to complete and thus I implemented the method that my team used in that lab.

By iterating through all of the lidar scans, and proceeding if the lidar measurement is within the laser range limits (r_min and r_max) and if it wasn't a nan value. We converted the robot pose and the lidar end position to the map frame. Ray traced to see where the lidar did not find an obstacle with the end of the lidar scan being an obstacle. We then updated the log map with the beta and alpha values for free and occupied space (0.5 for beta and 3 for alpha). And then put that through the log-odds to recover the map at that time frame. Do that for all time frames.

In the below map, black is occupied (alpha) and white is free (beta), while grey are unknown.

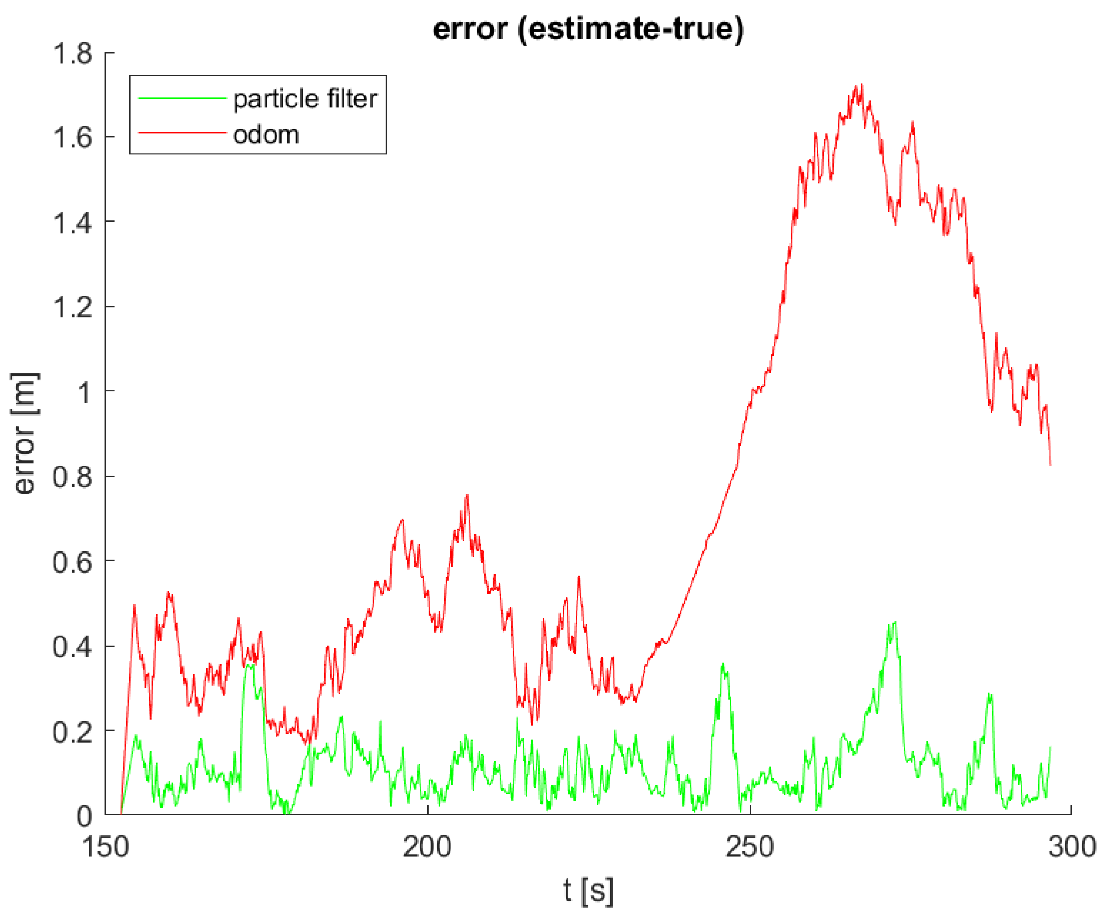


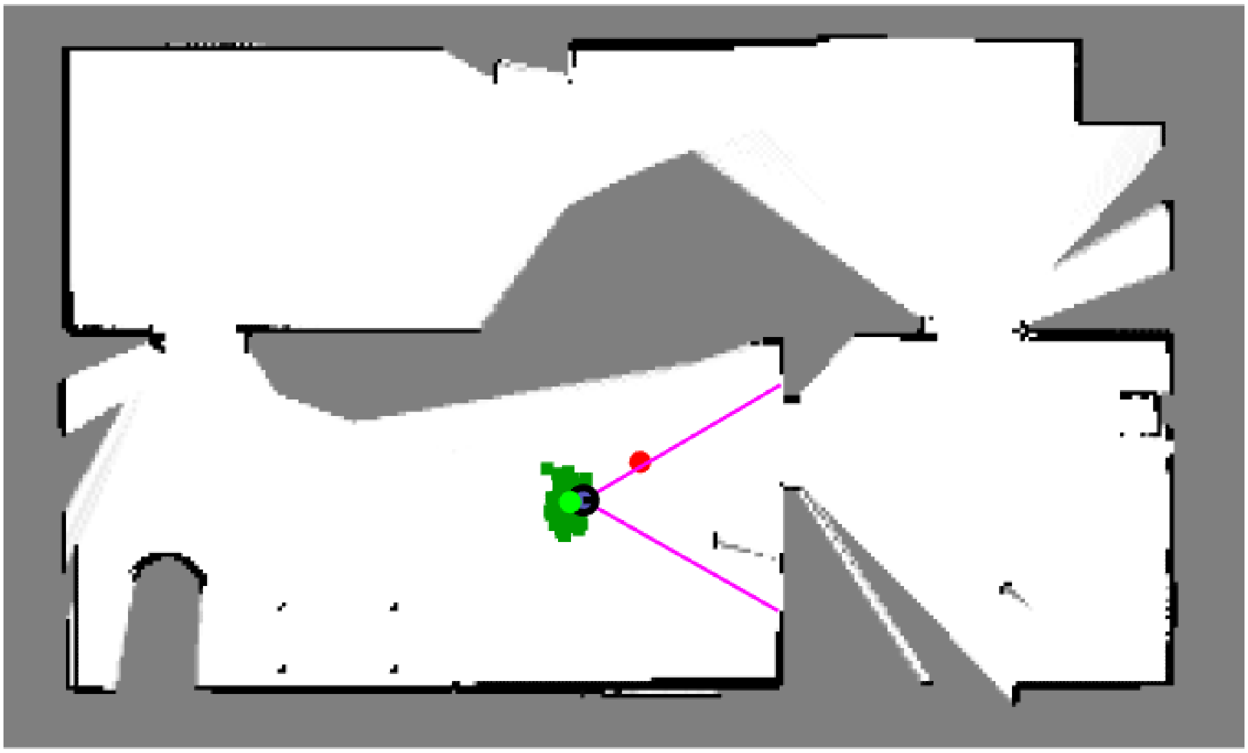
Question #2 - localization from an occupancy grid map using particle filter

In this part, we had to implement a particle filter localization algorithm to localize the robot. We only used two scans as this was outlined in the doc and was sufficient to localize. Noise was added to the wheel odometry and to the laser scan. We first estimated the y_laser given the particle pose and information on the laser and occupancy map. To do so we just propagated and found the first occupied cell from the ray.

The next thing was to calculate the weight of the particle given a normal distribution with the mean of the predicted and a given variance. This was done using normpdf.

The below graph shows the error of the particle filter and error of odom.





CODE BELOW

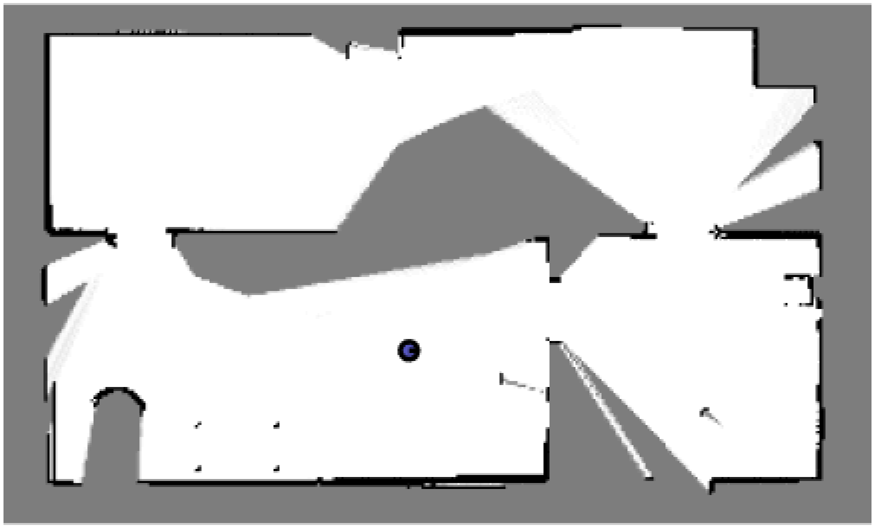
```
% =========
% ass3_q1.m
% =========
%
% This assignment will introduce you to the idea of first building an
% occupancy grid then using that grid to estimate a robot's motion using a
% particle filter.
%
% There are two questions to complete (5 marks each):
%
%    Question 1: code occupancy mapping algorithm
%    Question 2: see ass3_q2.m
%
% Fill in the required sections of this script with your code, run it to
% generate the requested plot/movie, 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
% and the two resulting AVI files from Questions 1 and 2.
%
% requires: basic Matlab, 'gazebo.mat'
%
% T D Barfoot, January 2016
%
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: build an occupancy grid map
% =======================================
%
% Write an occupancy grid mapping algorithm that builds the map from the
% perfect ground-truth localization.  Some of the setup is done for you
% below.  The resulting map should look like "ass2_q1_soln.png".  You can
% watch the movie "ass2_q1_soln.mp4" to see what the entire mapping process
% should look like.  At the end you will save your occupancy grid map to
% the file "occmap.mat" for use in Question 2 of this assignment.

% allocate a big 2D array for the occupancy grid
```

```
ogres = 0.05;                   % resolution of occ grid
ogxmin = -7;                    % minimum x value
ogxmax = 8;                     % maximum x value
ogymin = -3;                    % minimum y value
ogymax = 6;                     % maximum y value
ognx = (ogxmax-ogxmin)/ogres;   % number of cells in x direction
ogny = (ogymax-ogymin)/ogres;   % number of cells in y direction
oglo = zeros(ogny,ognx);        % occupancy grid in log-odds format
ogp = zeros(ogny,ognx);         % occupancy grid in probability format

% precalculate some quantities
numodom = size(t_odom,1);
npoints = size(y_laser,2);
angles = linspace(phi_min_laser, phi_max_laser, npoints);
dx = ogres*cos(angles);
dy = ogres*sin(angles);

% interpolate the noise-free ground-truth 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);

% set up the plotting/movie recording
vid = VideoWriter('ass2_q1.avi');
open(vid);
figure(1);
clf;
pcolor(ogp);
colormap(1-gray);
shading('flat');
axis equal;
axis off;
M = getframe;
writeVideo(vid,M);

BETA = 0.5;
ALPHA = 3;


% loop over laser scans (every fifth)
for t=1:5:size(t_laser,1)

    % ------insert your occupancy grid mapping algorithm here------




    for i = 1:npoints

        if ~isnan(y_laser(t,i)) && r_min_laser < y_laser(t,i) && y_laser(t,i)
 < r_max_laser
```

```
            %convert to map frame
            x_start = (x_interp(t)-ogxmin);
            y_start = (y_interp(t)-ogymin);

            range_mes = y_laser(t,i);
            cur_angle = angles(i) + theta_interp(t);

            % x_end and y_end calculation
            x_end = x_start + range_mes * cos(cur_angle);
            y_end = y_start + range_mes * sin(cur_angle);



            % convert to map coordinates
            x_start = round(x_start/ogres);
            y_start = round(y_start/ogres);
            x_end = round(x_end/ogres);
            y_end = round(y_end/ogres);


            % ray trace
            [rr, cc] = ray_trace(x_start, y_start, x_end, y_end);

            % shape
            [row_bound, col_bound] = size(oglo);


                    % iterate over each cell index pair
            for j=1:size(rr, 1)

                % skip over any instances where index is outside map
                if rr(j) > row_bound || cc(j) > col_bound || rr(j) <= 0 || ...
                        cc(j) <= 0
                    continue
                end
                % update log-odds
                if j < (size(rr,1))
                    % all cells except last cell are set as free
                    oglo(rr(j),cc(j)) = oglo(rr(j),cc(j)) - BETA;
                else
                    % last cell is set as occupied
                    oglo(rr(j),cc(j)) = oglo(rr(j),cc(j)) + ALPHA;
                end

            end

        end

    end
    oglo;
    % recovering probabilities from log-odds
    ogp = exp(oglo)./(1 + exp(oglo));
```

```
    % ------end of your occupancy grid mapping algorithm-------

    % draw the map
    clf;
    pcolor(ogp);
    colormap(1-gray);
    shading('flat');
    axis equal;
    axis off;

    % draw the robot
    hold on;
    x = (x_interp(t)-ogxmin)/ogres;
    y = (y_interp(t)-ogymin)/ogres;
    th = theta_interp(t);
    r = 0.15/ogres;
    set(rectangle( 'Position', [x-r y-r 2*r 2*r], 'Curvature', [1
 1]),'LineWidth',2,'FaceColor',[0.35 0.35 0.75]);
    set(plot([x x+r*cos(th)]', [y y+r*sin(th)]', 'k-'),'LineWidth',2);

    % save the video frame
    M = getframe;
    writeVideo(vid,M);

    pause(0.1);

end

close(vid);
print -dpng ass2_q1.png

save occmap.mat ogres ogxmin ogxmax ogymin ogymax ognx ogny oglo ogp;


% given two points in a matrix, returns the diagonal indices
function [rr, cc] = ray_trace(x1, y1, x2, y2)
    % Initialize the return arrays
    rr = [];
    cc = [];

    % Calculate the x and y distances between the two points
    dx = abs(x2 - x1);
    dy = abs(y2 - y1);

    % Calculate the step size for the x and y axes
    if x1 < x2
        sx = 1;
    else
```

```
        sx = -1;
    end

    if y1 < y2
        sy = 1;
    else
        sy = -1;
    end

    % Initialize the error term
    err = dx - dy;

    % Traverse the line using Bresenham's algorithm
    while true
        % Add the current point to the return arrays
        rr = [rr; y1];
        cc = [cc; x1];

        % Check if we've reached the end point
        if x1 == x2 && y1 == y2
            break;
        end

        % Update the error term
        e2 = 2*err;
        if e2 > -dy
            err = err - dy;
            x1 = x1 + sx;
        end
        if e2 < dx
            err = err + dx;
            y1 = y1 + sy;
        end
    end
end
```



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```
% =========
% ass3_q2.m
% =========
%
% This assignment will introduce you to the idea of first building an
% occupancy grid then using that grid to estimate a robot's motion using a
% particle filter.
%
% There are three questions to complete (5 marks each):
%
%    Question 1: see ass3_q1.m
%    Question 2: code particle filter to localize from known map
%
% Fill in the required sections of this script with your code, run it to
% generate the requested plot/movie, 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
% and the two resulting AVI files from Questions 1 and 2.
%
% requires: basic Matlab, 'gazebo.mat', 'occmap.mat'
%
% T D Barfoot, January 2016
%
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;

% ================================================
% load the occupancy map from question 1 from file
% ================================================
%  ogres: resolution of occ grid
% ogxmin: minimum x value
% ogxmax: maximum x value
% ogymin: minimum y value
% ogymax: maximum y value
%   ognx: number of cells in x direction
%   ogny: number of cells in y direction
%   oglo: occupancy grid in log-odds format
%    ogp: occupancy grid in probability format
```

```
load occmap.mat;

% =======================================================================
% Question 2: localization from an occupancy grid map using particle filter
% =======================================================================
%
% Write a particle filter localization algorithm to localize from the laser
% rangefinder readings, wheel odometry, and the occupancy grid map you
% built in Question 1.  We will only use two laser scan lines at the
% extreme left and right of the field of view, to demonstrate that the
% algorithm does not need a lot of information to localize fairly well.  To
% make the problem harder, the below lines add noise to the wheel odometry
% and to the laser scans.  You can watch the movie "ass2_q2_soln.mp4" to
% see what the results should look like.  The plot "ass2_q2_soln.png" shows
% the errors in the estimates produced by wheel odometry alone and by the
% particle filter look like as compared to ground truth; we can see that
% the errors are much lower when we use the particle filter.

% interpolate the noise-free ground-truth at the laser timestamps
numodom = size(t_odom,1);
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);

% interpolate the wheel odometry at the laser timestamps and
% add noise to measurements (yes, on purpose to see effect)
v_interp = interp1(t_interp,v_odom,t_laser) + 0.2*randn(size(t_laser,1),1);
omega_interp = interp1(t_interp,omega_odom,t_laser) +
 0.04*randn(size(t_laser,1),1);

% add noise to the laser range measurements (yes, on purpose to see effect)
% and precompute some quantities useful to the laser
y_laser = y_laser + 0.1*randn(size(y_laser));
npoints = size(y_laser,2);
angles = linspace(phi_min_laser, phi_max_laser,npoints);
dx = ogres*cos(angles);
dy = ogres*sin(angles);
y_laser_max = 5;   % don't use laser measurements beyond this distance

% particle filter tuning parameters (yours may be different)
nparticles = 200;       % number of particles
v_noise = 0.2;          % noise on longitudinal speed for propagating particle
u_noise = 0.2;          % noise on lateral speed for propagating particle
omega_noise = 0.04;     % noise on rotational speed for propagating particle
laser_var = 0.5^2;      % variance on laser range distribution
w_gain = 10*sqrt( 2 * pi * laser_var );     % gain on particle weight

% generate an initial cloud of particles
x_particle = x_true(1) + 0.5*randn(nparticles,1);
y_particle = y_true(1) + 0.3*randn(nparticles,1);
theta_particle = theta_true(1) + 0.1*randn(nparticles,1);
```

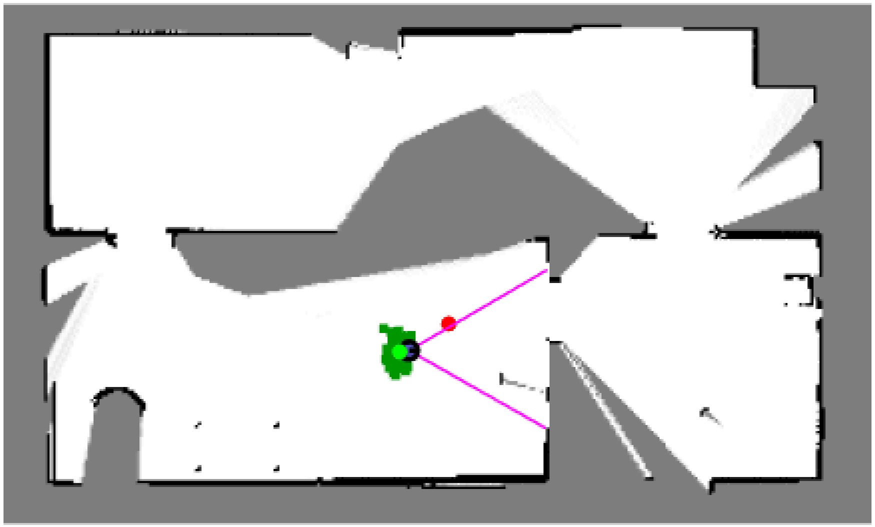
```
% compute a wheel odometry only estimate for comparison to particle
% filter
x_odom_only = x_true(1);
y_odom_only = y_true(1);
theta_odom_only = theta_true(1);

% error variables for final error plots - set the errors to zero at the start
pf_err(1) = 0;
wo_err(1) = 0;

% set up the plotting/movie recording
vid = VideoWriter('ass2_q2.avi');
open(vid);
figure(2);
clf;
hold on;
pcolor(ogp);
set(plot( (x_particle-ogxmin)/ogres, (y_particle-ogymin)/ogres, 'g.'
 ),'MarkerSize',10,'Color',[0 0.6 0]);
set(plot( (x_odom_only-ogxmin)/ogres, (y_odom_only-ogymin)/ogres, 'r.'
 ),'MarkerSize',20);
x = (x_interp(1)-ogxmin)/ogres;
y = (y_interp(1)-ogymin)/ogres;
th = theta_interp(1);
r = 0.15/ogres;
set(rectangle( 'Position', [x-r y-r 2*r 2*r], 'Curvature', [1
 1]),'LineWidth',2,'FaceColor',[0.35 0.35 0.75]);
set(plot([x x+r*cos(th)]', [y y+r*sin(th)]', 'k-'),'LineWidth',2);
set(plot( (mean(x_particle)-ogxmin)/ogres, (mean(y_particle)-ogymin)/
ogres, 'g.' ),'MarkerSize',20);
colormap(1-gray);
shading('flat');
axis equal;
axis off;
M = getframe;
writeVideo(vid,M);

% loop over laser scans
for i=2:size(t_laser,1)

    % update the wheel-odometry-only algorithm
    dt = t_laser(i) - t_laser(i-1);
    v = v_interp(i);
    omega = omega_interp(i);
    x_odom_only = x_odom_only + dt*v*cos( theta_odom_only );
    y_odom_only = y_odom_only + dt*v*sin( theta_odom_only );
    phi = theta_odom_only + dt*omega;
    while phi > pi
        phi = phi - 2*pi;
    end
    while phi < -pi
        phi = phi + 2*pi;
    end
    theta_odom_only = phi;
```

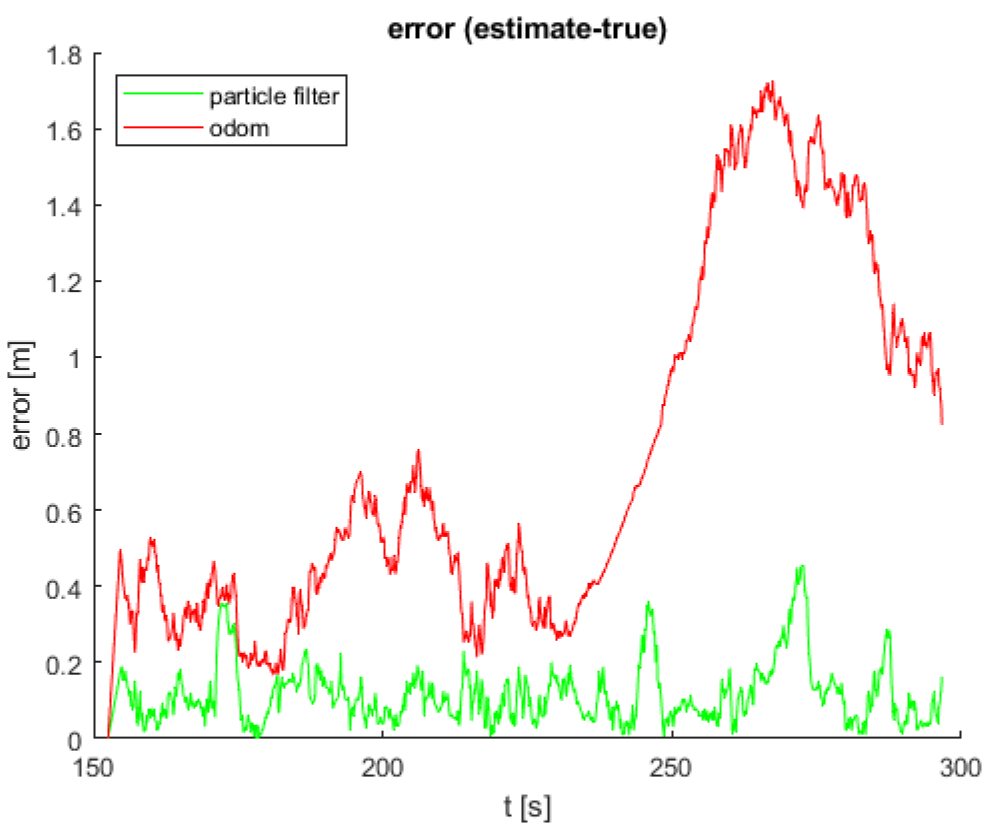
```
    % loop over the particles
    for n=1:nparticles

        % propagate the particle forward in time using wheel odometry
        % (remember to add some unique noise to each particle so they
        % spread out over time)
        v = v_interp(i) + v_noise*randn(1);
        u = u_noise*randn(1);
        omega = omega_interp(i) + omega_noise*randn(1);
        x_particle(n) = x_particle(n) + dt*(v*cos( theta_particle(n) ) -
u*sin( theta_particle(n) ));
        y_particle(n) = y_particle(n) + dt*(v*sin( theta_particle(n) ) +
u*cos( theta_particle(n) ));
        phi = theta_particle(n) + dt*omega;
        while phi > pi
            phi = phi - 2*pi;
        end
        while phi < -pi
            phi = phi + 2*pi;
        end
        theta_particle(n) = phi;

        % pose of particle in initial frame
        T = [cos(theta_particle(n)) -sin(theta_particle(n)) x_particle(n); ...
             sin(theta_particle(n))  cos(theta_particle(n)) y_particle(n); ...
                    0                       0                    1];

        % compute the weight for each particle using only 2 laser rays
        % (right=beam 1 and left=beam 640)
        w_particle(n) = 1.0;
        for beam=1:2

            % we will only use the first and last laser ray for
            % localization
            if beam==1  % rightmost beam
                j = 1;
            elseif beam==2  % leftmost beam
                j = 640;
            end

            % ------insert your particle filter weight calculation here ------

            if ~isnan(y_laser(i,j)) && y_laser(i,j) < y_laser_max

                row_pos = max(1,round((y_particle(n)-ogymin)/ogres));
                col_pos = max(1,round((x_particle(n)-ogxmin)/ogres));
                threshold = 0.5;
                %get predicted range: y_laser_pred
                y_laser_pred = predict_laser_range(row_pos, col_pos, ...
                    theta_particle(n), angles(j), ogp, ogres, threshold);

                % calculate weight using gaussian pdf function
```

```
                w_particle(n) = w_particle(n)*w_gain*normpdf(y_laser(i,
j), ...
                    y_laser_pred, sqrt(laser_var));

            end


            % ------end of your particle filter weight calculation-------
        end

    end

    % resample the particles using Madow systematic resampling
    w_bounds = cumsum(w_particle)/sum(w_particle);
    w_target = rand(1);
    j = 1;
    for n=1:nparticles
       while w_bounds(j) < w_target
           j = mod(j,nparticles) + 1;
       end
       x_particle_new(n) = x_particle(j);
       y_particle_new(n) = y_particle(j);
       theta_particle_new(n) = theta_particle(j);
       w_target = w_target + 1/nparticles;
       if w_target > 1
           w_target = w_target - 1.0;
           j = 1;
       end
    end
    x_particle = x_particle_new;
    y_particle = y_particle_new;
    theta_particle = theta_particle_new;

    % save the translational error for later plotting
    pf_err(i) = sqrt( (mean(x_particle) - x_interp(i))^2 + (mean(y_particle) -
y_interp(i))^2 );
    wo_err(i) = sqrt( (x_odom_only - x_interp(i))^2 + (y_odom_only -
y_interp(i))^2 );

    % plotting
    figure(2);
    clf;
    hold on;
    pcolor(ogp);
    set(plot( (x_particle-ogxmin)/ogres, (y_particle-ogymin)/ogres, 'g.'
),'MarkerSize',10,'Color',[0 0.6 0]);
    set(plot( (x_odom_only-ogxmin)/ogres, (y_odom_only-ogymin)/ogres, 'r.'
),'MarkerSize',20);
    x = (x_interp(i)-ogxmin)/ogres;
    y = (y_interp(i)-ogymin)/ogres;
    th = theta_interp(i);
    if ~isnan(y_laser(i,1)) & y_laser(i,1) <= y_laser_max
       set(plot([x x+y_laser(i,1)/ogres*cos(th+angles(1))]', [y y
+y_laser(i,1)/ogres*sin(th+angles(1))]', 'm-'),'LineWidth',1);
```

```
    end
    if ~isnan(y_laser(i,640)) & y_laser(i,640) <= y_laser_max
       set(plot([x x+y_laser(i,640)/ogres*cos(th+angles(640))]', [y y
+y_laser(i,640)/ogres*sin(th+angles(640))]', 'm-'),'LineWidth',1);
    end
    r = 0.15/ogres;
    set(rectangle( 'Position', [x-r y-r 2*r 2*r], 'Curvature', [1
 1]),'LineWidth',2,'FaceColor',[0.35 0.35 0.75]);
    set(plot([x x+r*cos(th)]', [y y+r*sin(th)]', 'k-'),'LineWidth',2);
    set(plot( (mean(x_particle)-ogxmin)/ogres, (mean(y_particle)-ogymin)/
ogres, 'g.' ),'MarkerSize',20);
    colormap(1-gray);
    shading('flat');
    axis equal;
    axis off;

    % save the video frame
    M = getframe;
    writeVideo(vid,M);

    pause(0.01);

end

close(vid);

% final error plots
figure(3);
clf;
hold on;
plot( t_laser, pf_err, 'g-' );
plot( t_laser, wo_err, 'r-' );
xlabel('t [s]');
ylabel('error [m]');
legend('particle filter', 'odom', 'Location', 'NorthWest');
title('error (estimate-true)');
print -dpng ass2_q2.png

% returns the expected laser measurement given the particle's
% position and map
function y_exp = predict_laser_range(row, col, theta, beam_angle, map, ogres,
 thresh)

    new_angle = atan2(sin(theta+beam_angle), cos(theta+beam_angle));
    incr  = 0;
    r_p = row;
    c_p = col;




    % angle is between -pi/4 and pi/4
    if -pi/4<=new_angle && new_angle<=pi/4
```

```
        c_inc = 1;
        r_inc = tan(new_angle);
        a = cos(new_angle);

    % angle is between -3pi/4 and 3pi/4
    elseif 3*pi/4<=new_angle || new_angle<=-3*pi/4
        c_inc = -1;
        r_inc = -tan(new_angle);
        a = cos(new_angle);

    % angle is between pi/4 and 3pi/4
    elseif pi/4<new_angle && new_angle<3*pi/4
        c_inc = 1/tan(new_angle);
        r_inc = 1;
        a = sin(new_angle);


    % angle is between -pi/4 and -3pi/4
    else
        c_inc = -1/tan(new_angle);
        r_inc = -1;
        a = sin(new_angle);

    end



    [row_bound, col_bound] = size(map);

    while r_p > 0 && c_p>0 && r_p<=row_bound && c_p<=col_bound && map(r_p,
 c_p) < thresh
        incr = incr +1;
        r_p = row + round(incr * r_inc);
        c_p = col + round(incr * c_inc);
    end

    y_exp = abs((incr/a)*ogres);


end
```





error (estimate-true)
particle filter
odom
error [m]
t [s]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
150
200
250
300

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