Mobile robot short Project

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Shared Link with the teacher: https://drive.matlab.com/sharing/bfe7e5c6-3b20-43d3-9f90-27cd7a658e06

Table of Contents

Given the kown workspace: Sensors_Data.mat, Laser_Data_CV__d_b.mat and Enviroment.png

Answer the following question:

Pose estimation (10%)

Before start:

- Open the Simulink model EKF_Pose_estimation.slx and get familiar with: 'Where2Find_Code.pdf'.
- Have a look to section See an animation of the file: 3_MR_SP_support.mlx

Every thing is done, the exercise consist in compile in a mlx file all the concepts.

1.- Implement in this mlx file:

```
clear
close all
load('Sensors_Data.mat')
load('Laser_Data_CV__d_b.mat')
sim("EKF_Pose_estimation_1.slx");
```

a) Pose_theoric, asumme no noise. (review Mobile Robot Kinematics folder)

```
Tf = 60.08;
```

```
Ts = 0.02;
W = 0.52;
Gear_ratio = 100;
r = 0.1;

R_inc = right_angular_speed(:, 2) / Gear_ratio * r * Ts;
L_inc = left_angular_speed(:, 2) / Gear_ratio * r * Ts;
R_acu = [right_angular_speed(:, 1), cumsum(R_inc)];
L_acu = [left_angular_speed(:, 1), cumsum(L_inc)];

t=linspace(0,Tf,length(R_acu(:,2)))';
delta_d=(R_inc+L_inc)/2;
delta_t=(R_inc-L_inc)/W;

Initial_pose=transl(8.95,17.2,0)*trotz(-pi/2);
Initial_position=transl(Initial_pose);
Initial_orientation=-pi/2;

% Pose theoric
x(1) = Initial_position(1);
y(1) = Initial_position(2);
o(1) = Initial_orientation;
```

b) Pose_estimation by adding noise in odometry. review Pose uncertanty folder)

```
% Pose estimation
V = [3.61e-4 0; 0 9e-6];                    % Noise
noise_d = V(1, 1);
noise_t = V(2, 2);
x_est(1) = Initial_position(1);
y_est(1) = Initial_position(2);
o_est(1) = Initial_orientation;
for i=1:(length(t)-1)

    x(i+1) = x(i) + delta_d(i) * cos(o(i));
    y(i+1) = y(i) + delta_d(i) * sin(o(i));
    o(i+1) = o(i) + delta_t(i);

    x_est(i+1) = x_est(i) + (delta_d(i) + randn*sqrt(noise_d)) * cos(o(i) + randn*sqrt(noise_t
    y_est(i+1) = y_est(i) + (delta_d(i) + randn*sqrt(noise_d)) * sin(o(i) + randn*sqrt(noise_t
    o_est(i+1) = o(i) + delta_t(i) + randn*sqrt(noise_t);
end

Pose_theoric = [x; y; o];
% Here we use the data provided by the slx in order to have the same Pose_estimation
% than the teacher (the random numbers were generating a different path for
% us and it is preferable to have the same)
Pose_estimation = [Pose_est.Data(:,1)';Pose_est.Data(:,2)';Pose_est.Data(:,3)']
```

```
Pose_estimation = 3×3001
    8.9501    8.9500    8.9501    8.9500    8.9503    8.9504    8.9504    8.9504 ···
```

```
   17.1652   17.1488   17.1736   17.1671   17.1145   17.0568   17.0580   17.0619
    4.7140    4.7072    4.7082    4.7069    4.7176    4.7136    4.7157    4.7179
```

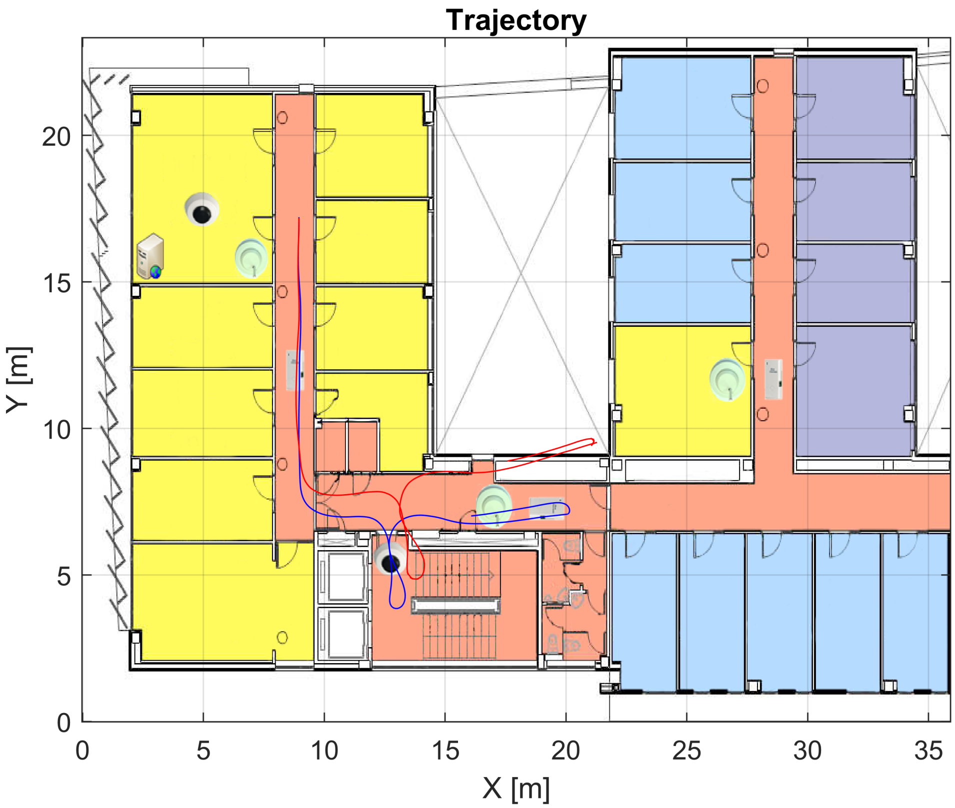
c) Ricatti equation for estimating the covariance matrix representing the uncertanty in the robot pose.

```
% Calcultaing the Jacobians

F_x = zeros([3,3,3004]);
F_x(1,1,:) = 1; F_x(2,2,:) = 1; F_x(3,3,:) = 1;
F_x(1,3,:) = -delta_d .* sin(o(:));
F_x(2,3,:) =  delta_d .* cos(o(:));

F_v = zeros([3 2 3004]);
F_v(3,2,:) = 1;
F_v(1,1,:) = cos(o(:));
F_v(2,1,:) = sin(o(:));

Pk = zeros([3 3 3004]);
Pk(:,:,1) = eye(3) * 0.0001;

for i=2:3004
    Pk(:,:,i) = F_x(:,:,i)*Pk(:,:,i-1)*F_x(:,:,i)' + F_v(:,:,i)*V*F_v(:,:,i)';
end
```

2.- Display in a figure:

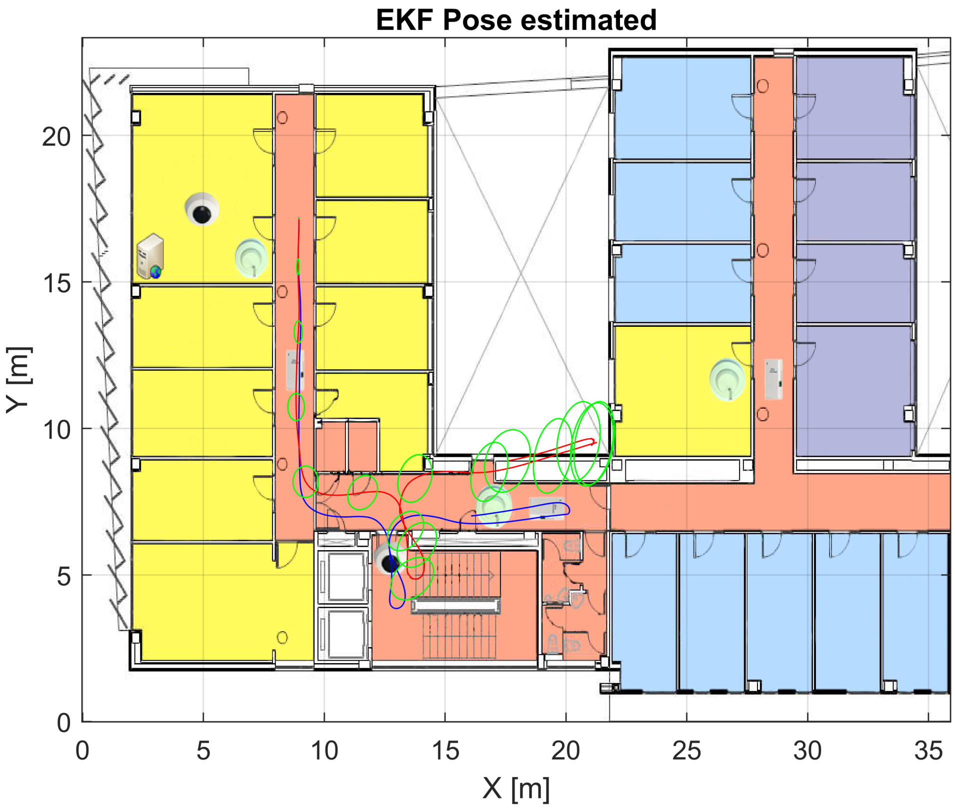
a) x,y poses for both trajectories: theoric and estimated

```
figure
I=imread('Enviroment.png');                  % Read environment
x_ima=[0 35.9];
y_ima=[23.31 0];
image(I,'XData',x_ima,'YData',y_ima);
axis xy
grid on
title('Trajectory')
xlabel ('X [m]')
ylabel ('Y [m]')
hold on

plot(Pose_theoric(1,:), Pose_theoric(2,:), 'b')         % Display a) Pose_theoric
plot(Pose_estimation(1,:), Pose_estimation(2,:), 'r')     % Display b) Pose_estimation
hold off
```



b) ellipses representing x,y uncertanty. Do it every 15-20 poses.

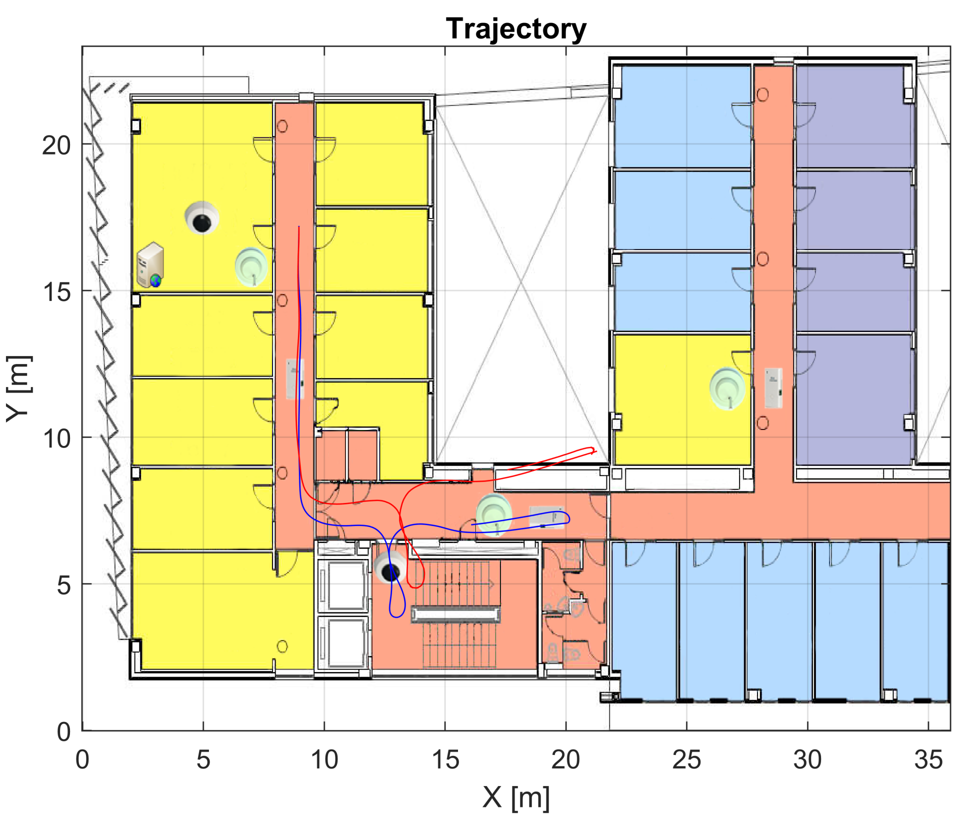
```
figure
image(I,'XData',x_ima,'YData',y_ima);
title('Trajectory')
axis xy
grid on
xlabel ('X [m]')
ylabel ('Y [m]')
hold on
plot(Pose_theoric(1,:), Pose_theoric(2,:), 'b')         % Display a) Pose_theoric
plot(Pose_estimation(1,:), Pose_estimation(2,:), 'r')     % Display b) Pose_estimation

for i=1:round(length(Pose_t.Data)/15):length(Pose_t.Data)

    plot_ellipse(Pk(1:2,1:2,i),[Pose_estimation(1,i), Pose_estimation(2,i)],'g');
    title('EKF Pose estimated');
end

hold off
```



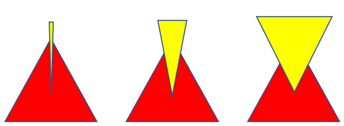
c) represent uncertanty in orientation by adding a isosceles triange in front of the robot the base

```
video = VideoWriter('uncertanty_theoric.avi');
video.FrameRate = 10;
video.Quality = 100;
open(video);
Robot = [0 -0.2 0 1;0.4 0 0 1;0 0.2 0 1];
Triangle = [0 -0.2 0 1;0.4 0 0 1;0 0.2 0 1];
for i=1:20:(length(t)-1)
    clf
    image(I,'XData',x_ima,'YData',y_ima);       % Display environment
    axis xy
    grid on
    title('Trajectory')
    xlabel ('X [m]')
    ylabel ('Y [m]')
    hold on
    plot(Pose_theoric(1,:), Pose_theoric(2,:), 'b')         % Display a) Pose_theoric
    plot(Pose_estimation(1,:), Pose_estimation(2,:), 'r')     % Display b) Pose_estimation

    Triangle_uncertanty = Triangle;
    e = Pk(:, :, i);
    aux1 = Triangle_uncertanty(3, 2) * sqrt(det(e(1:2, 1:2)));
    aux2 = Triangle_uncertanty(1, 2) * sqrt(det(e(1:2, 1:2)));
    Triangle_uncertanty(3, 2) = aux1;
```

```
    Triangle_uncertanty(1, 2) = aux2;

    Robot_pose = transl(x(i), y(i), 0) * trotz(o(i));
    Robot_final = Robot_pose * Robot';
    Triangle_final = Robot_pose * transl(0.5, 0, 0) * trotz(pi) * Triangle_uncertanty';

    rob = patch(Robot_final(1, :), Robot_final(2, :), 'r');
    tri = patch(Triangle_final(1, :), Triangle_final(2, :), 'yellow');

    pause(0.2);

    frame = getframe(gcf);
    writeVideo(video, frame);
    delete(rob);
    delete(tri);
end
```




```
close(video)
```



The robot will be represented by a triangle: Robot= [0 -0.2 0 1;0.4 0 0 1;0 0.2 0 1]

Record a movie of the robot moving along the corridor displaying both trajectories.

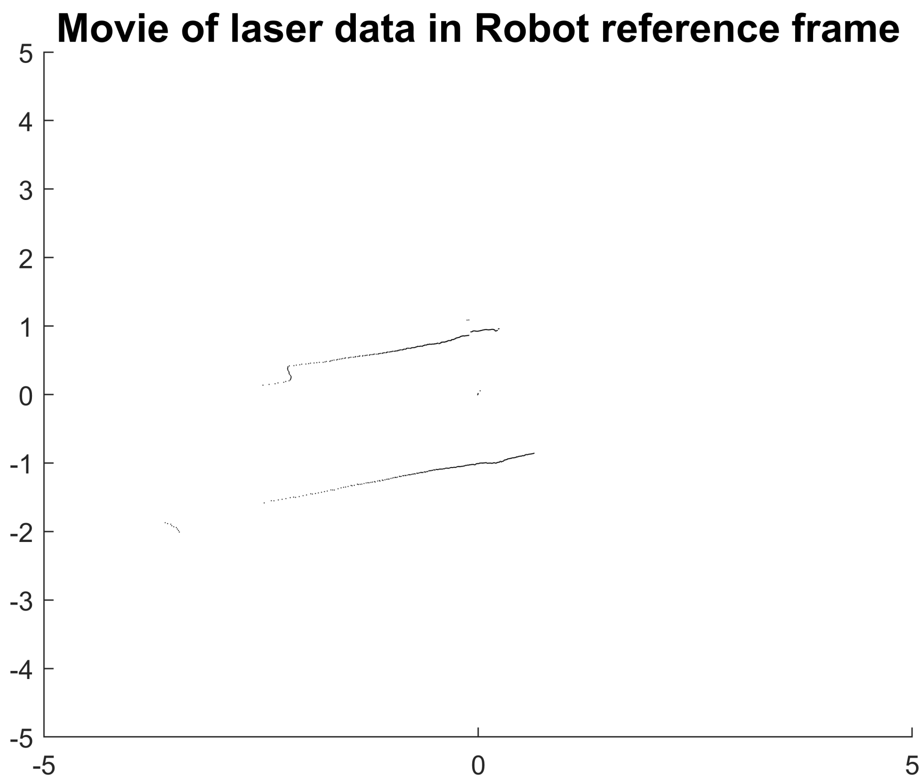
See: help VideoWriter to get familiar with the matlab functions

Laser data (10%)

Make a movie of laser data in Robot reference frame.

copy here the code of the last TODO Lab about laser data. See the video of ATENEA: Movie of the Laser Data seen in Robot Reference FrameURL

```
video = VideoWriter('mapping.avi');
video.FrameRate = 20;
video.Quality = 100;
open(video);
Robot = [0 -0.2 0 1;0.4 0 0 1;0 0.2 0 1];

for k=1:6:(length(t)-1)
    clf
    Robot_pose = transl(x(k), y(k), 0) * trotz(o(k));
    Robot_final = Robot_pose * Robot';

    if (mod(k, 6) == 1)
        clear x2 y2
        count = 1;
        m = size(polar_laser_data);
        i = ceil(k/20.1611);
        for j=1:(m(2)-1)
            if polar_laser_data(i, j) / 1000 > 0
                alpha = (j-1) * 0.3515;
                alpha = o(20 * (i-1) + 1) - 120 * pi/180 + alpha * pi/180;
                x2(count) = (polar_laser_data(i, j) / 1000) * cos(alpha);
                y2(count) = (polar_laser_data(i, j) / 1000) * sin(alpha);
                count = count + 1;
            end
        end
    end

    scatter(x2, y2, 1, '.', 'black');
    axis([-5 5 -5 5]);
    title("Movie of laser data in Robot reference frame", 'FontSize',15);
    pause(0.2)

    frame = getframe(gcf);
    writeVideo(video, frame);
end
```




```
close(video)
```

Localization (40%)

Localize the Robot by using the Similarity Transform.

There are two asummtions :

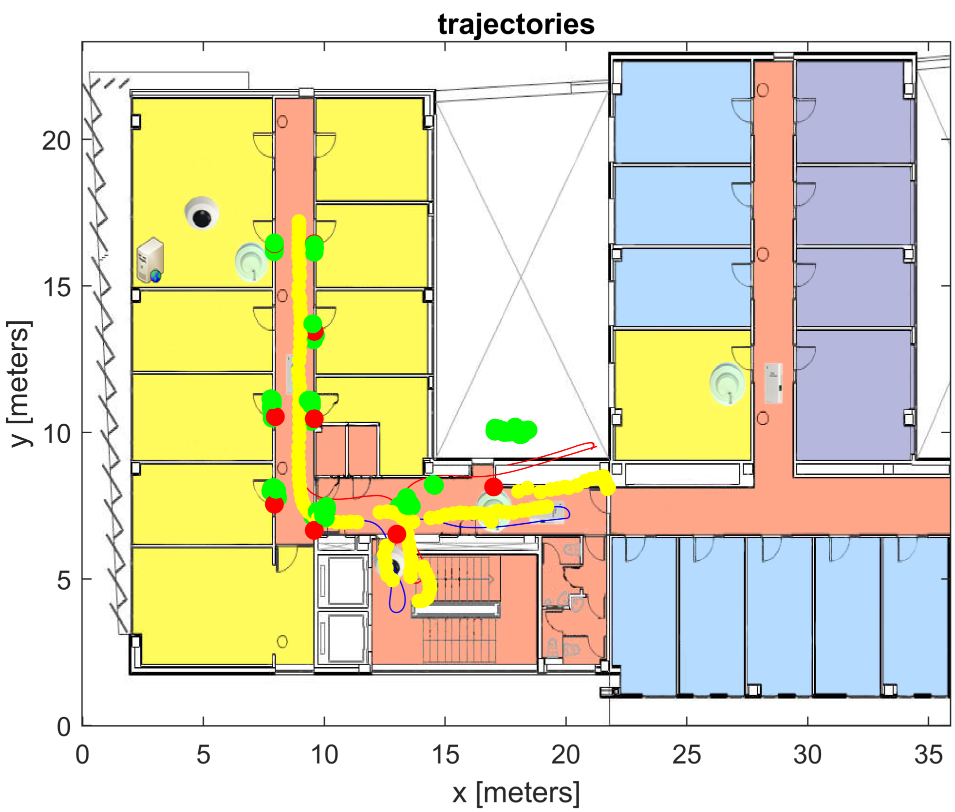
No correction of the trajectory is done.

1.- Make a 'log' with the following columns: time stamp, estimated noisy pose, number of Land-marks seen and the errors. **The log that we have made is named Log_without_correction**

```
landmarks = [...
      7.934 16.431 0 1;...
      9.583 16.431 0 1;...
      9.584 13.444 0 1;...
      9.584 10.461 0 1;...
      7.973 10.534 0 1;...
      7.934  7.547 0 1;...
      9.584  6.654 0 1;...
     13.001  6.525 0 1;...
     17.007  8.136 0 1 ...
]';

Detected_landmarks = [];
Reference_landmarks = [];
```

```
Log_without_correction = [];

image(I,'XData',x_ima,'YData',y_ima);
axis xy
hold on

    plot(Pose_theoric(1,:), Pose_theoric(2,:), 'b')          % Display Pose_theoric
    plot(Pose_estimation(1,:), Pose_estimation(2,:), 'r')     % Display Pose_estimation
    title('trajectories');
    xlabel ('x [meters]');
    ylabel ('y [meters]');

    for time=3:length(l_s_b(:,1))

        Robot_pose = transl(Pose_estimation(1,time),Pose_estimation(2,time),0)*trotz(Pose_estin

        for landmark_index=1:length(landmarks(1,:))
            if l_s_b(time,landmark_index) ~= 0

                d=l_s_d(time,landmark_index);
                b=l_s_b(time,landmark_index);

                [X,Y]=pol2cart(b(1,1),d(1,1));

                L_w=Robot_pose*[X Y 0 1]';

                Detected_landmarks  = [Detected_landmarks L_w];
                Reference_landmarks = [Reference_landmarks landmarks(1:2,landmark_index)];
            end
        end

        if ~isempty(Detected_landmarks)

            scatter(Reference_landmarks(1,:),Reference_landmarks(2,:), 50, 'r','filled');
            scatter(Detected_landmarks(1,:),Detected_landmarks(2,:), 50, 'g','filled');

            A = [];
            for i=1:size(Reference_landmarks, 2)
                A = [A;[Reference_landmarks(1,i),Reference_landmarks(2,i),1,0]];
                A = [A;[Reference_landmarks(2,i),-Reference_landmarks(1,i),0,1]];
            end

            B = [];
            for i=1:size(Detected_landmarks, 2)
                B = [B; Detected_landmarks(1,i); Detected_landmarks(2,i)];
            end

            Similarity_transform = linsolve(A,B);
            tx_ST = Similarity_transform(3);
            ty_ST = Similarity_transform(4);
```

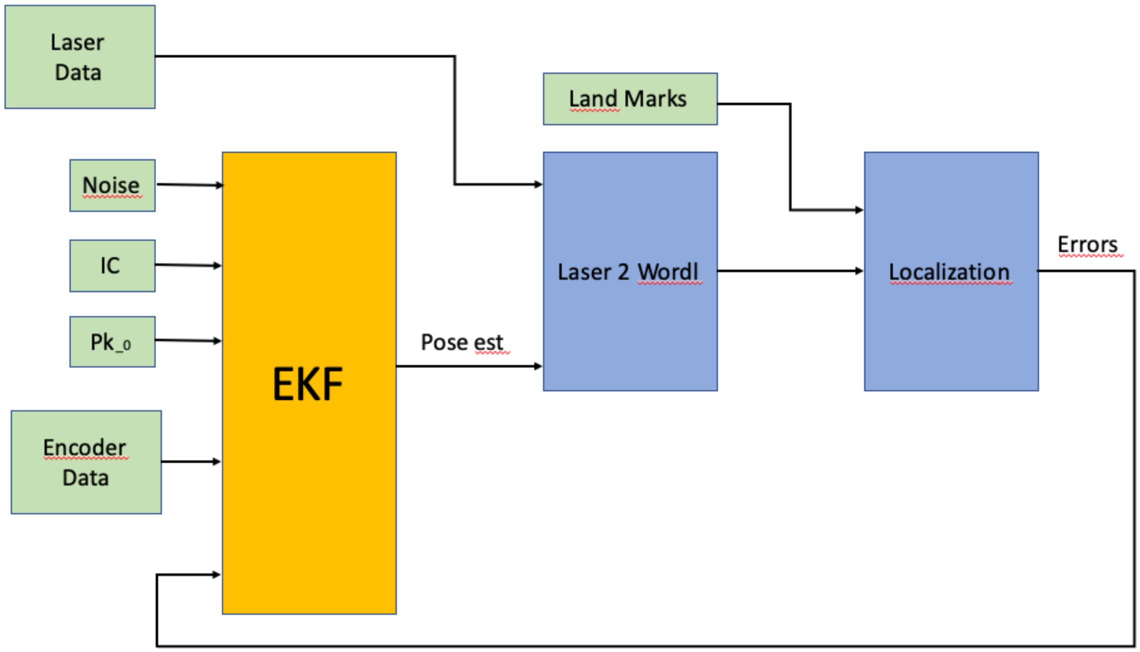
```
            alpha_ST = atan2(Similarity_transform(2),Similarity_transform(1));

            Error = transl(-tx_ST,-ty_ST,0)*trotz(alpha_ST);
            Corrected_robot =  Error * [transl(Robot_pose); 1];
            scatter(Corrected_robot(1),Corrected_robot(2), 30, 'yellow','filled');

            % time stamp, estimated noisy pose, corrected position, number of Land-marks, and t
            Single_log.Time_stamp = time;                                    % timestamp is
            Single_log.Robot_pose = Robot_pose;                              % estimated noi
            Single_log.Corrected_robot = Corrected_robot;                    % corrected pos
            Single_log.Number_of_landmarks = length(Detected_landmarks(1,:));  % number of lan
            Single_log.Error = Error;                                        % errors

            Log_without_correction = [Log_without_correction Single_log];
        end

        Detected_landmarks = [];
        Reference_landmarks = [];
    end
hold off
```



Correct the noisy trajectory.

To get an inspiration get familiar MR_SP_support.mlx

Pay attention to the relationship of the variables



Update the estimated covarianze matrix by the sensor, knowing that the Laser scanner has and acuracy 4 mm with a standard deviation of 0.2 mm.

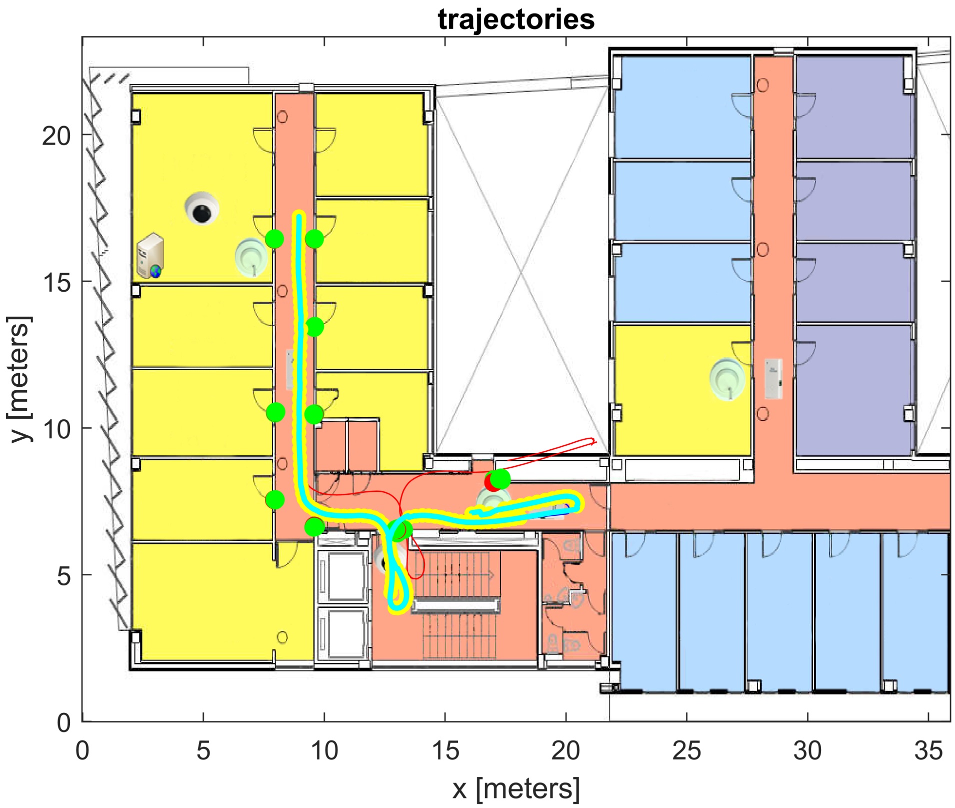
1.- Display in a figure: the map, theoric trajectory (no noise) the noisy trajectory and the corrected trajectory.

2.- Make a 'log' with the following columns: time stamp, estimated noisy pose, corrected position, number of Land-marks, and the errors. **The log that we have done is named Log_with_correction**

```
Detected_landmarks = [];
Reference_landmarks = [];
Log_with_correction = [];

Position_with_correction(:,1) = zeros(size(Pose_theoric(:,1)));
Position_with_correction(:,2) = Pose_theoric(:,2);

Orientation_with_correction = zeros(3004,1);
Orientation_with_correction(2) = Pose_theoric(3,2);
mu_noise = 0;
mu_laser = 0;
mu_fused = 0;

image(I,'XData',x_ima,'YData',y_ima);
axis xy
hold on

    plot(Pose_theoric(1,:), Pose_theoric(2,:), 'b')          % Display Pose_theoric
    plot(Pose_estimation(1,:), Pose_estimation(2,:), 'r')     % Display Pose_estimation
    title('trajectories'); xlabel ('x [meters]'); ylabel ('y [meters]')

    for time=3:length(l_s_b(:,1))
```

```
        Position_with_correction(1,time)  = Position_with_correction(1,time-1) + (delta_d(time
        Position_with_correction(2,time)  = Position_with_correction(2,time-1) + (delta_d(time
        Orientation_with_correction(time) = mod(Orientation_with_correction(time-1) + delta_t(t

        Robot_pose = transl(Position_with_correction(1,time),Position_with_correction(2,time),0

        for landmark_index=1:length(landmarks(1,:))
            if l_s_b(time,landmark_index) > 0

                d=l_s_d(time,landmark_index);
                b=l_s_b(time,landmark_index);

                [X,Y]=pol2cart(b(1,1),d(1,1));

                L_w=Robot_pose*[X Y 0 1]';

                Detected_landmarks  = [Detected_landmarks L_w];
                Reference_landmarks = [Reference_landmarks landmarks(1:2,landmark_index)];
            end
        end

        if ~isempty(Detected_landmarks)

            scatter(Reference_landmarks(1,:),Reference_landmarks(2,:), 50, 'r','filled');
            scatter(Detected_landmarks(1,:),Detected_landmarks(2,:), 50, 'g','filled');

            A = [];
            for i=1:size(Reference_landmarks, 2)
                A = [A;[Reference_landmarks(1,i),Reference_landmarks(2,i),1,0]];
                A = [A;[Reference_landmarks(2,i),-Reference_landmarks(1,i),0,1]];
            end

            B = [];
            for i=1:size(Detected_landmarks, 2)
                B = [B; Detected_landmarks(1,i); Detected_landmarks(2,i)];
            end

            Similarity_transform = linsolve(A,B);
            tx_ST = Similarity_transform(3);
            ty_ST = Similarity_transform(4);
            alpha_ST = atan2(Similarity_transform(2),Similarity_transform(1));

            Error = transl(-tx_ST,-ty_ST,0)*trotz(alpha_ST);
            Corrected_robot =  Error * [transl(Robot_pose); 1];
            scatter(Corrected_robot(1),Corrected_robot(2), 30, 'yellow','filled');
            Position_with_correction(1,time) = Corrected_robot(1);
            Position_with_correction(2,time) = Corrected_robot(2);

            %time stamp, estimated noisy pose, corrected position, number of Land-marks, and th
```

```
            Single_log.Time_stamp = time;                                    % timestamp is
            Single_log.Robot_pose = Robot_pose;                              % estimated noi
            Single_log.Corrected_robot = Corrected_robot;                    % corrected pos
            Single_log.Number_of_landmarks = length(Detected_landmarks(1,:)); % number of lar
            Single_log.Error = Error;                                        % errors

            Log_with_correction = [Log_with_correction Single_log];
        end

        Detected_landmarks = [];
        Reference_landmarks = [];
    end

    plot(Position_with_correction(1,2:end), Position_with_correction(2,2:end),'k','Color','c','

hold off
```



Mapping (40%)

This is part of the last TODO.

Walls

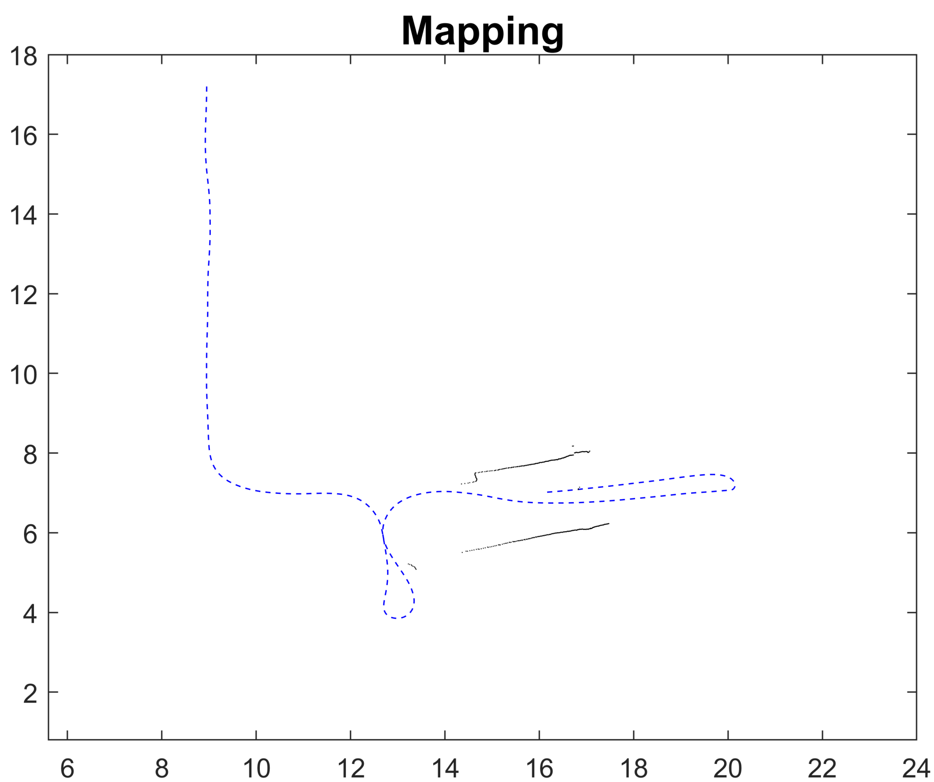
Draw the *'walls/obstacles'* *seeing by* the laser data. Do it only when Land Marks are avalaible and the trajectory have been corrected.

Make a movie erasing the previous walls after 200ms for better understanding.

See the video: '3_mapping.mp4' for inspiration

```
close all

video = VideoWriter('mapping2.avi');
video.FrameRate = 20;
video.Quality = 100;
open(video);
Robot = [0 -0.2 0 1;0.4 0 0 1;0 0.2 0 1];
visible = 0;
for k=1:3:(length(t)-1)
    clf
    plot(Pose_theoric(1,:), Pose_theoric(2,:), 'b--');
    xlim([5.6 24.0])
    ylim([0.8 18.0])
    hold on

    Robot_pose = transl(x(k), y(k), 0) * trotz(o(k));
    Robot_final = Robot_pose * Robot';

    rob = patch(Robot_final(1, :), Robot_final(2, :), 'r');

    if (mod(k, 6) == 1)
          clear x2 y2
        count = 1;
        m = size(polar_laser_data);
        i = ceil(k/20.1611);
        for j=1:(m(2)-1)
            if polar_laser_data(i, j) / 1000 > 0
                alpha = (j-1) * 0.3515;
                alpha = o(20 * (i-1) + 1) - 120 * pi/180 + alpha * pi/180;
                x2(count) = x(20 * (i-1) + 1) + (polar_laser_data(i, j) / 1000) * cos(alpha);
                y2(count) = y(20 * (i-1) + 1) + (polar_laser_data(i, j) / 1000) * sin(alpha);
                count = count + 1;
            end
        end
    end

    if mod(k, 20) == 0
        visible = 0;
        for i = 1:width(l_s_b)
            if visible == 0 && l_s_b(k, i) ~= 0
                P = landmarks(:, i);
                dist = sqrt( (x(k) - P(1))^2 + (y(k) - P(2))^2 );
                if dist <= 4
                    visible = 1;
                end
            end
```

```
        end
    end

    if visible
        scatter(x2, y2, 1, '.', 'black');
    end
    title("Mapping", 'FontSize',15);
    pause(0.2)
    frame = getframe(gcf);
    writeVideo(video, frame);
    delete(rob);
end
```




```
close(video)
```

Occupancy grid

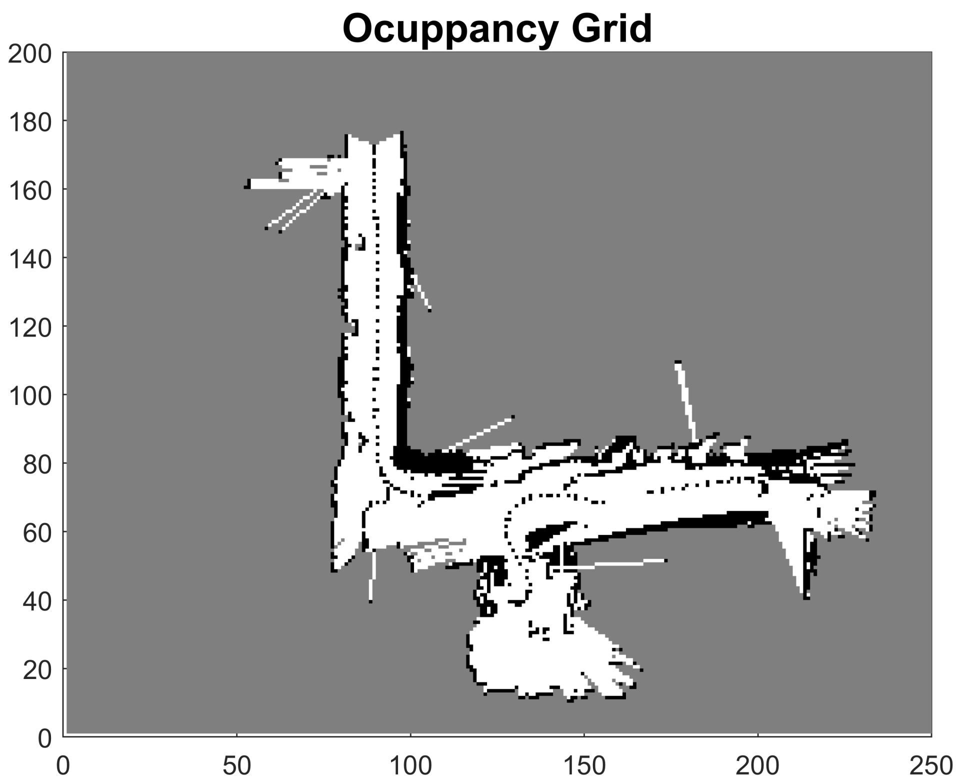
Use Breshehan algorithm to build the map. Do it only when Land Marks are avalaible and the trajectory have been corrected.

Use the idea behind the line tracing: Visit: https://es.wikipedia.org/wiki/Algoritmo_de_Bresenham

See: Mapping.mlx and '4_occupancy.mp4' for inspiration

```
video = VideoWriter('Occupancy.avi');
video.FrameRate = 5;
video.Quality = 100;
```

```
open(video);

resolution = 10;
A = ones(20*resolution, 25*resolution);
for p=20:20:(length(t)-1)
    clear x2 y2 o2
    i = ceil(p/20.1611);
    count = 1;
    m = size(polar_laser_data);
    for j=1:(m(2)-1)
        if polar_laser_data(i, j) / 1000 > 0
            alpha = (j-1) * 0.3515;
            alpha = o(20 * (i-1) + 1) - 120 * pi/180 + alpha * pi/180;
            x2(count) = x(20 * (i-1) + 1) + (polar_laser_data(i, j) / 1000) * cos(alpha);
            y2(count) = y(20 * (i-1) + 1) + (polar_laser_data(i, j) / 1000) * sin(alpha);
            o2(count) = alpha;
            count = count + 1;
        end
    end

    for j = 1:(count-1)
        P_w = transl(0, 0, 0) * trotz(0) * [x2(j) y2(j) 0 1]';
        [X Y] = bresenham(x(p)*resolution, y(p)*resolution, P_w(1)*resolution, P_w(2)*resolutio
        l_xy = [X Y];
        L=height(l_xy);
        for k=1:L
            if l_xy(k, 1) > 0 && l_xy(k, 2) > 0
                if k == L
                    A(l_xy(k, 2),l_xy(k, 1)) = 0;
                else
                    A(l_xy(k, 2),l_xy(k, 1)) = 2;
                end
            end
        end
    end
    h = pcolor(A);
    h.EdgeColor = 'none';
    axis xy
    ylim([0 20*resolution]);
    xlim([0 25*resolution]);
    title("Ocuppancy Grid", 'FontSize',15);
    colormap(gray(3))
    pause(0.2)

    frame = getframe(gcf);
    writeVideo(video, frame);
end
```


Ocuppancy Grid
200
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250

```
close(video);
```