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Concordia University

MECH6631 Project Report

Qiaomeng Qin(40207375)

Design and implement an Image Processing algorithm to locate and identify all objects in the map. Design and implement an Hiding Strategy to find the closest safe point.

Xiaobo Wu(40216033)

Design and implement a path planning algorithm (ASIA) by myself to find a collision-free sequence of motions (path point) between an initial(current) position and a final(expected) position and complete this part report. Design a hiding of robot algorithm with Qiaomeng Qin and write the report of this part.

Mario Araujo(40059376)

Design and implement a controller to move the robot to any desired location. Also, implement a strategy for the attack task.

Yuelong Wu(xxxxxx)

2022.04.01

Contents

Chapter 1

Introduction

As shown in Figure 1.1, two robots perform a competition in this project. Two robots chase each other and try to hit the opponent with laser, which are controlled via intelligent algorithms. This report mainly introduces the algorithms for image processing and robot control.

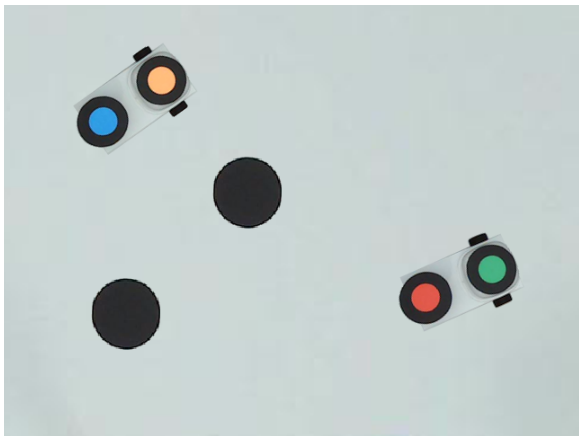


Figure 1.1: Overview of the project.

We assume that there is no wheel slipping,

$$v_r = \omega_r R$$

Where v_r is the linear velocity, R is the radius of wheel, and ω_r is the angular velocity.

x_c and y_c is the coordinate of the vehicle centre. θ is the direction of vehicle. D is the distance bewteen two wheels. The geometry model of this vehicle is shown below:

$$v_c = (v_r + v_l)/2$$

$$\omega_c = (v_r - v_l)/D$$

$$\dot{\theta}_c = \omega_c = (v_r - v_l)/D$$

Chapter 2

Image Processing

2.1 Locating Objects

The flowchart of whole image processing algorithm is shown in figure 2.1.

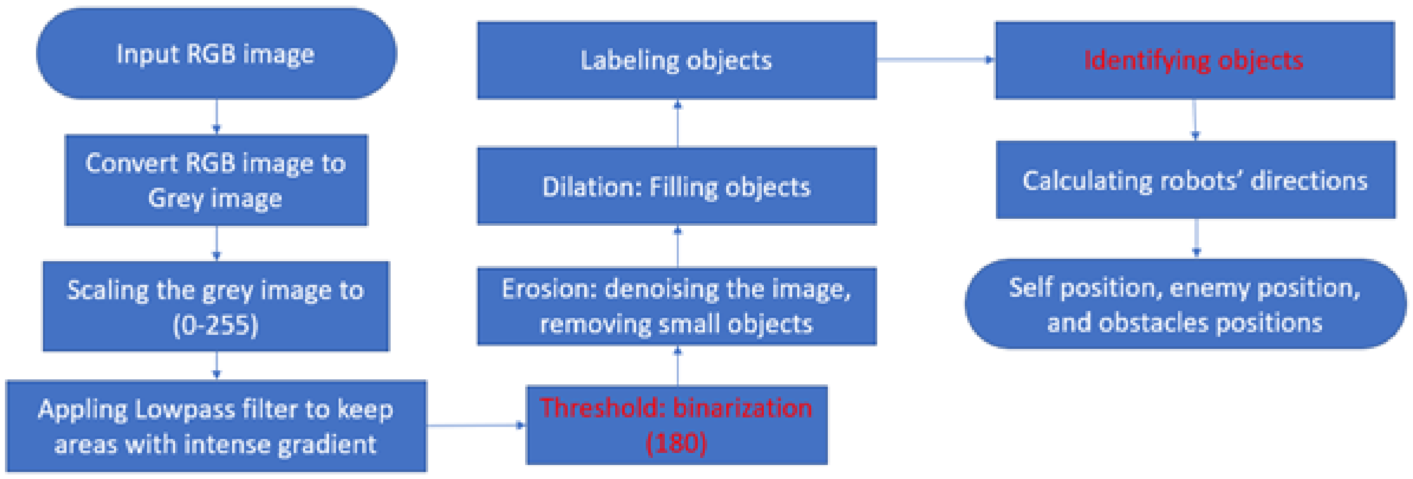

Input RGB image
Convert RGB image to Grey image
Scaling the grey image to (0-255)
Appling Lowpass filter to keep areas with intense gradient
Threshold: binarization (180)
Erosion: denoising the image, removing small objects
Dilation: Filling objects
Labeling objects
Identifying objects
Calculating robots' directions
Self position, enemy position, and obstacles positions

Figure 2.1: Image processing flowchart.

While testing the code, we found that if color of obstacle is changed to blue, the threshold of binarization, with original value of 80, would be not suitable anymore. After testing, the threshold is determined as 180, which is suitable for all colors of obstacles. The comparison of different thresholds is shown in figure 2.2.

2.2 Identifying Objects

Identifying objects is the core part of it, the flowchart is shown in figure 2.3 (assume that self-robot is robot A, red and green)

To differentiate self and enemy, we analyzed the RGB values of four different colors as shown in table **??**

The final result of image processing is shown in figure 2.4 and 2.5.

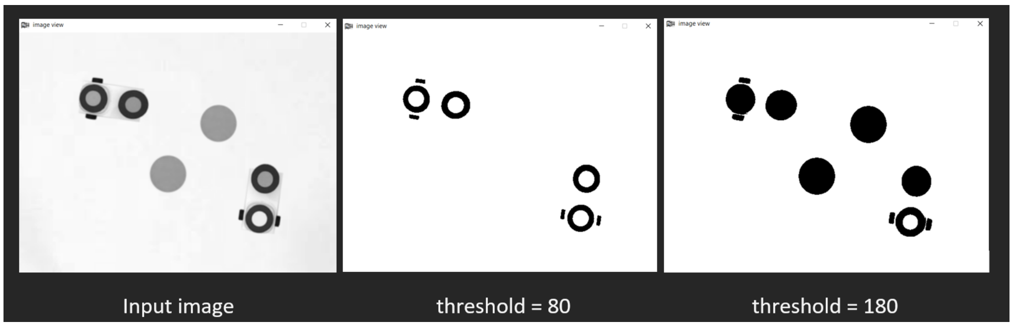


Figure 2.2: Different thresholds in binarization.

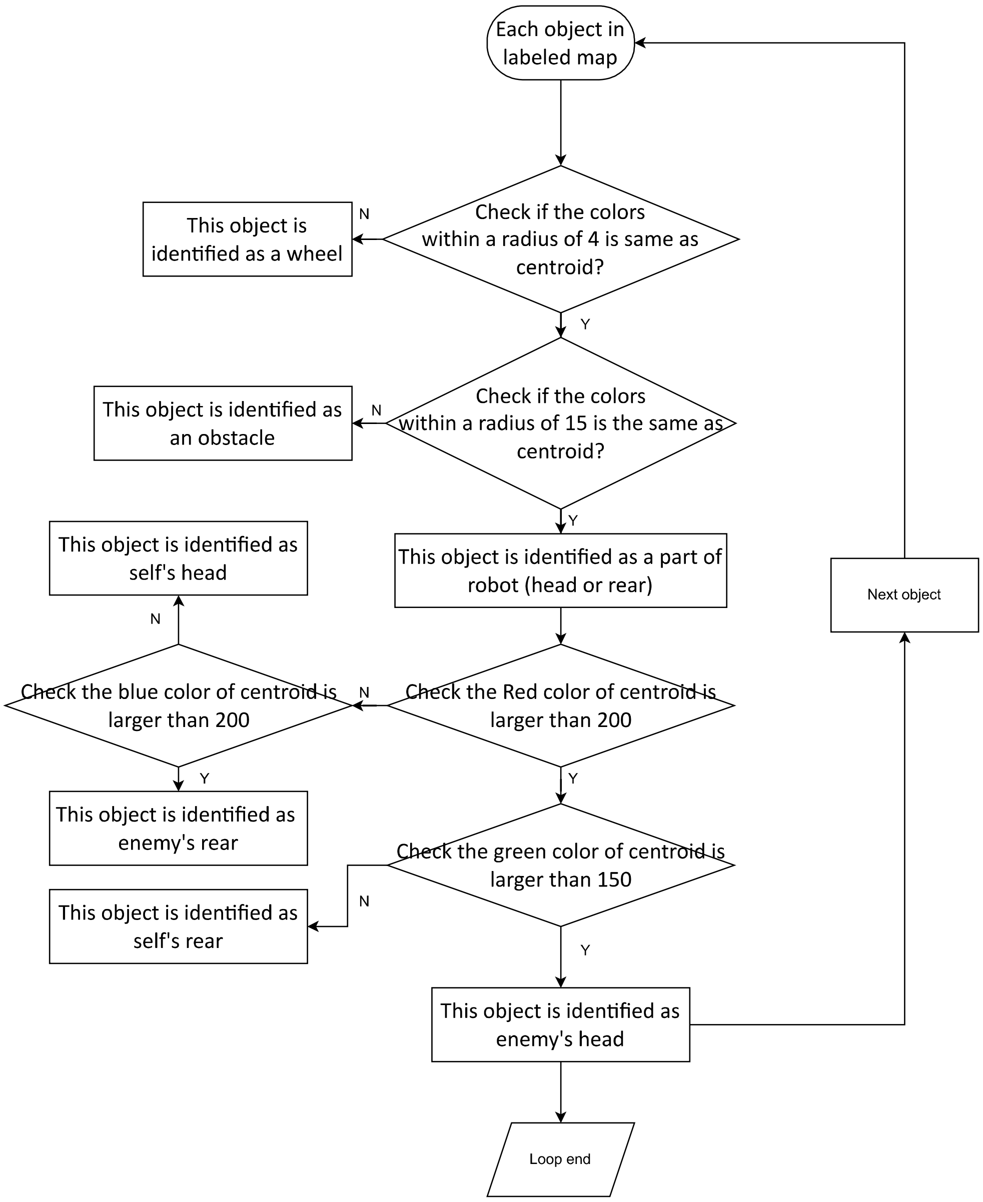

Each object in labeled map
Check if the colors within a radius of 4 is same as centroid?
N
This object is identified as a wheel
Y
Check if the colors within a radius of 15 is the same as centroid?
N
This object is identified as an obstacle
Y
This object is identified as a part of robot (head or rear)
Check the Red color of centroid is larger than 200
N
Check the blue color of centroid is larger than 200
N
This object is identified as self's head
Y
This object is identified as enemy's rear
Y
Check the green color of centroid is larger than 150
N
This object is identified as self's rear
Y
This object is identified as enemy's head
Next object
Loop end

Figure 2.3: Identifying flowchart.

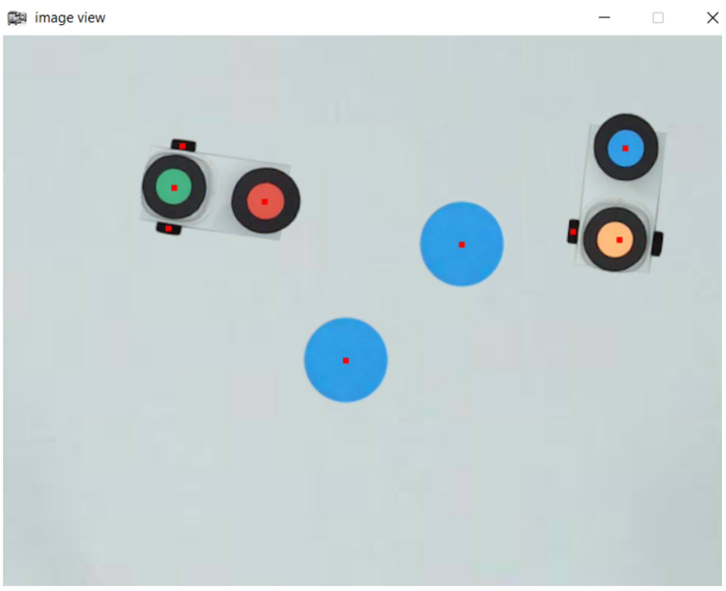
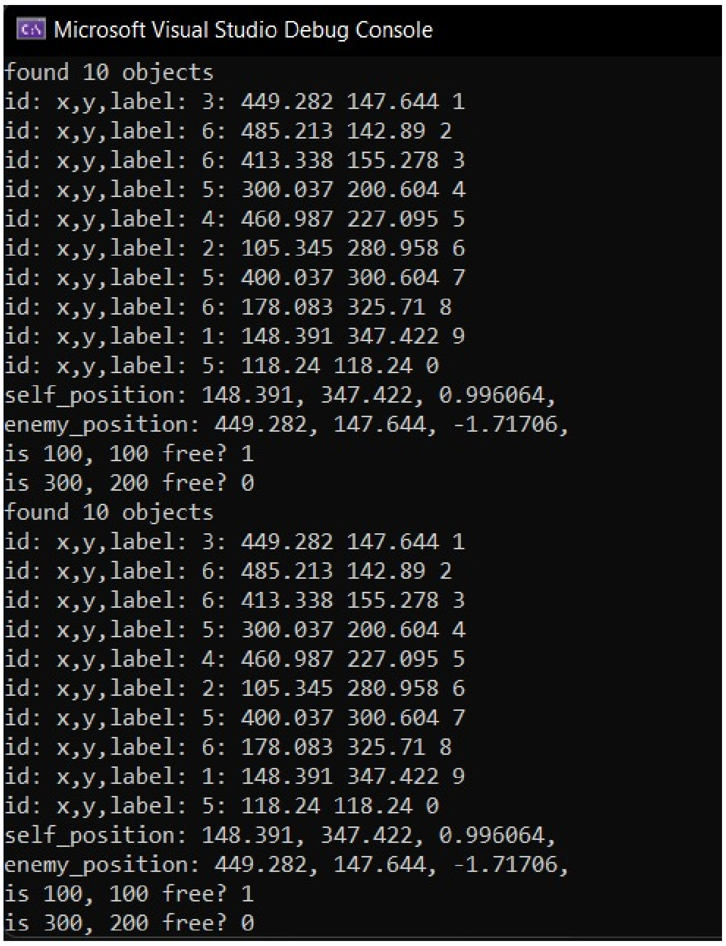


Figure 2.4: Locating all objects.



Microsoft Visual Studio Debug Console

```
found 10 objects
id: x,y,label: 3: 449.282 147.644 1
id: x,y,label: 6: 485.213 142.89 2
id: x,y,label: 6: 413.338 155.278 3
id: x,y,label: 5: 300.037 200.604 4
id: x,y,label: 4: 460.987 227.095 5
id: x,y,label: 2: 105.345 280.958 6
id: x,y,label: 5: 400.037 300.604 7
id: x,y,label: 6: 178.083 325.71 8
id: x,y,label: 1: 148.391 347.422 9
id: x,y,label: 5: 118.24 118.24 0
self_position: 148.391, 347.422, 0.996064,
enemy_position: 449.282, 147.644, -1.71706,
is 100, 100 free? 1
is 300, 200 free? 0
found 10 objects
id: x,y,label: 3: 449.282 147.644 1
id: x,y,label: 6: 485.213 142.89 2
id: x,y,label: 6: 413.338 155.278 3
id: x,y,label: 5: 300.037 200.604 4
id: x,y,label: 4: 460.987 227.095 5
id: x,y,label: 2: 105.345 280.958 6
id: x,y,label: 5: 400.037 300.604 7
id: x,y,label: 6: 178.083 325.71 8
id: x,y,label: 1: 148.391 347.422 9
id: x,y,label: 5: 118.24 118.24 0
self_position: 148.391, 347.422, 0.996064,
enemy_position: 449.282, 147.644, -1.71706,
is 100, 100 free? 1
is 300, 200 free? 0
```

Figure 2.5: Locating all objects.

Chapter 3

Path planning

After we get the position information of car, obstacles, and boundary by image processing, if we want to hide and attack using laser, we really need to control car move from current position to expected position in a special space seeing Figure 3.1, For example, when we want to attack the opponent car behind the obstacles ,we need to catch up opponent car as soon as possible on the one hand, and on the another hand we should avoid the obstacles and boundary. But how to move car effectively in a special space is hard question. Robot path planning is used to find a collision-free sequence of motions (way point) between and an initial(current) position and a final(expected) position within a specified environment.

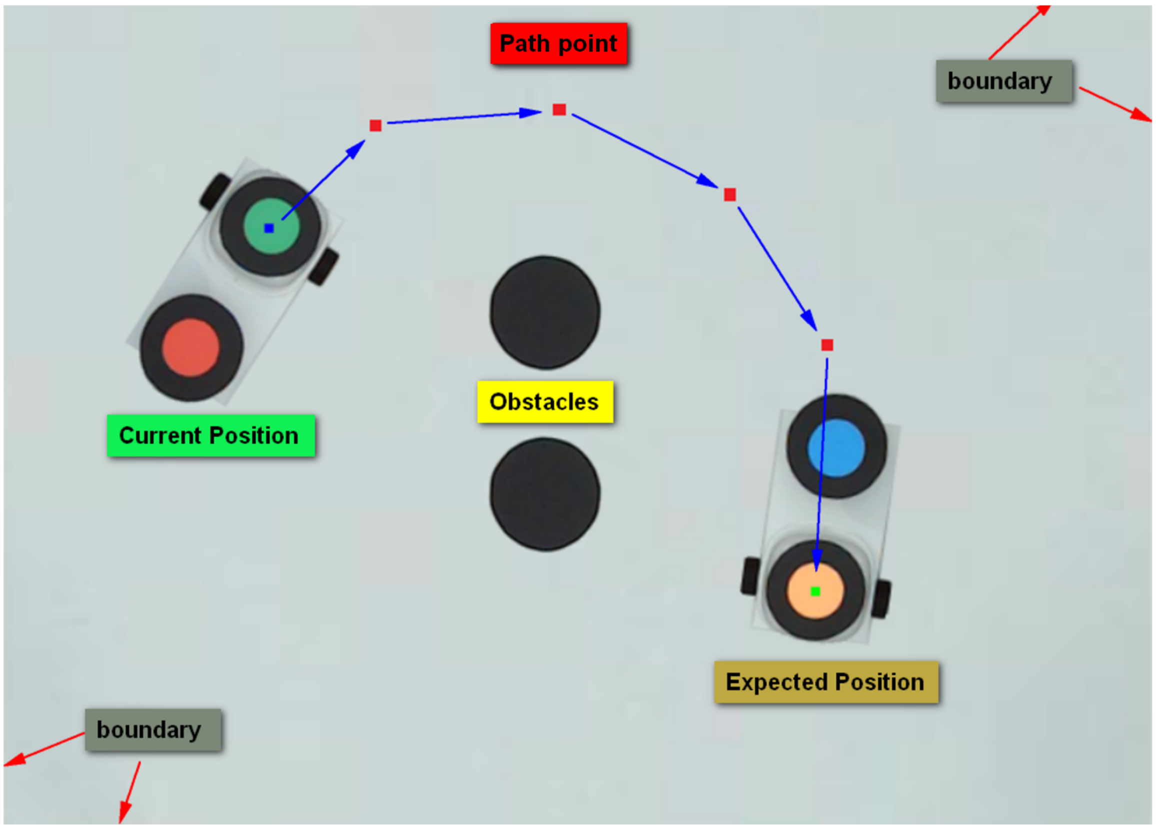


Figure 3.1: How to find the path point.

According to the special tasks and requirements of this project of MECH 6631 and after reading all kinds of path planning algorithms, a novel sampling and iterative based path planning algorithm (called Arc Sampling and Iterative Algorithm(ASIA)) is designed to used in this project.

3.1 The principle and process of ASIA

ASIA uses four steps to find and renew a new path point from current position to expected position.

1. **Step 1: Get sampling points**
   As shown in Figure 3.2, First, we need to build a body coordinate system. The body coordinate origin is current position , and axis X points the the expected position, and axis Y and axis X intersect at right angles. Second, initialize the value of sampling distance, sampling radian interval and total sampling radian. And get sampling sequence around current position.

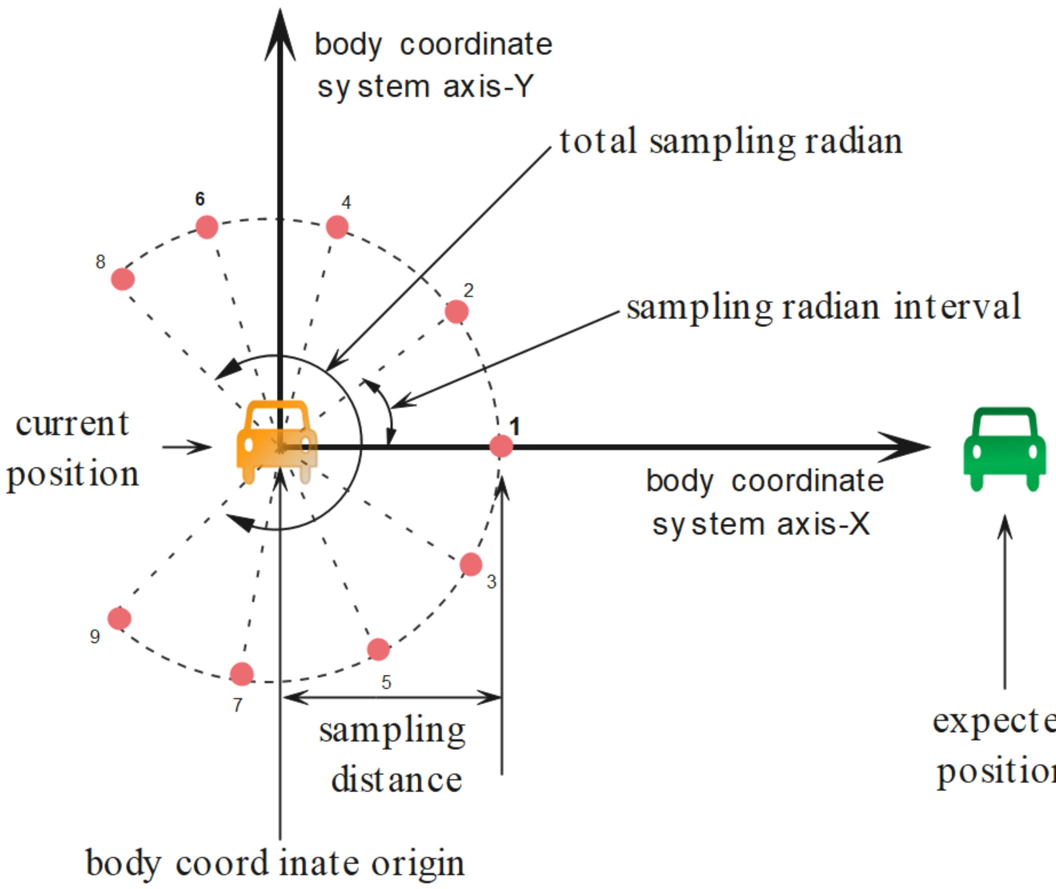


Figure 3.2: How to get sampling points.

2. **Step 2: Coordinate transformation**
   As seen in Figure 3.3,We need to translate sampling points from body coordinate system to image coordinate system using rotation matrix after getting sampling points because we need to create path point sequence in image coordinate system.

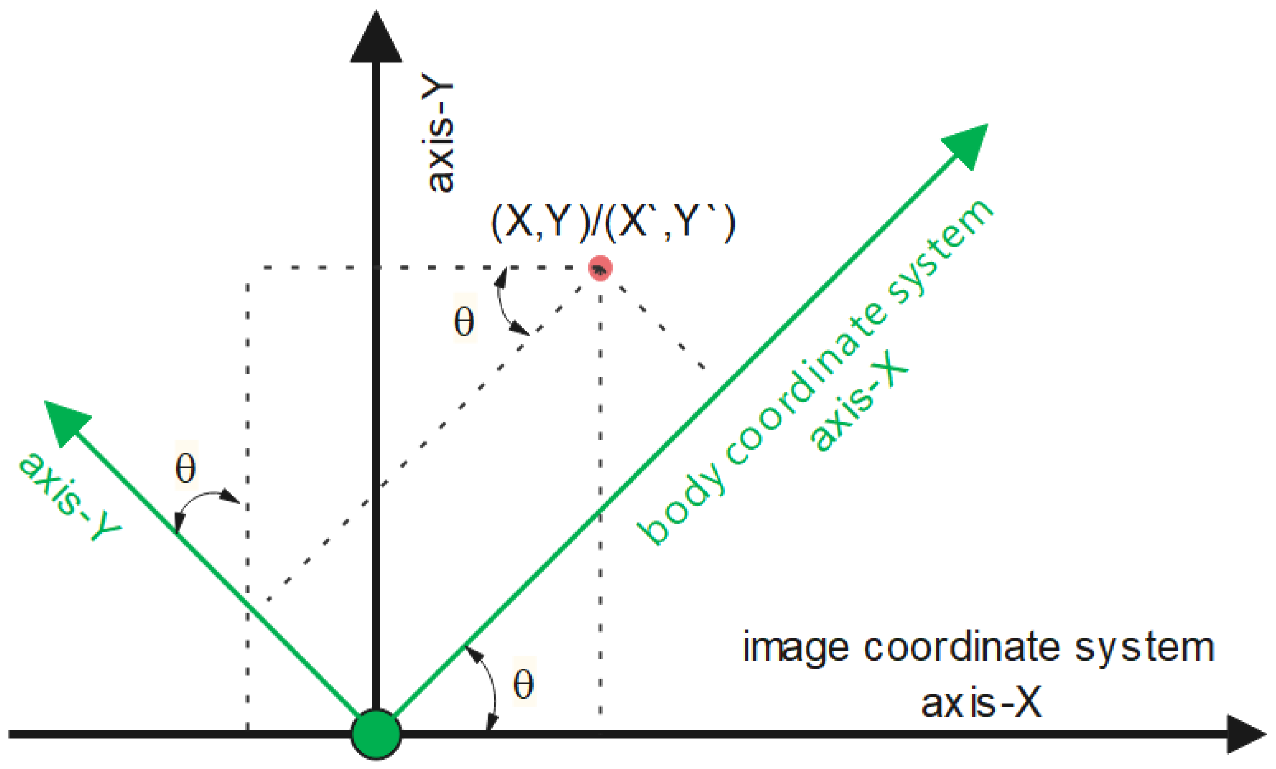


Figure 3.3: coordinate transformation.

According to the simple geometric knowledge in figure 3.3, we will get the transformation equation

$$\begin{cases} X = X' * cos\theta - Y' * sin\theta \\ Y = X' * sin\theta + Y' * cos\theta \end{cases} \tag{3.1}$$

If the origin between body coordinate system and image coordinate system is not in the same position——in other words the origin position of body coordinate system is (X_0, Y_0) in the mage coordinate system, a translation transform need to be added.

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} X' \\ Y' \end{bmatrix} + \begin{bmatrix} X_0 \\ Y_0 \end{bmatrix} \tag{3.2}$$

3. **Step 3: Get path point**
   As seen in Figure 3.4,Judging if the sampling points(here it is represented by sampling points 1 9) is located in the free space sequentially (not coincide with the obstacle and is located within the image boundary). Once the conditions are met , the sampling point will be taken as the path point and renew current position, at the same time stop the judgement.

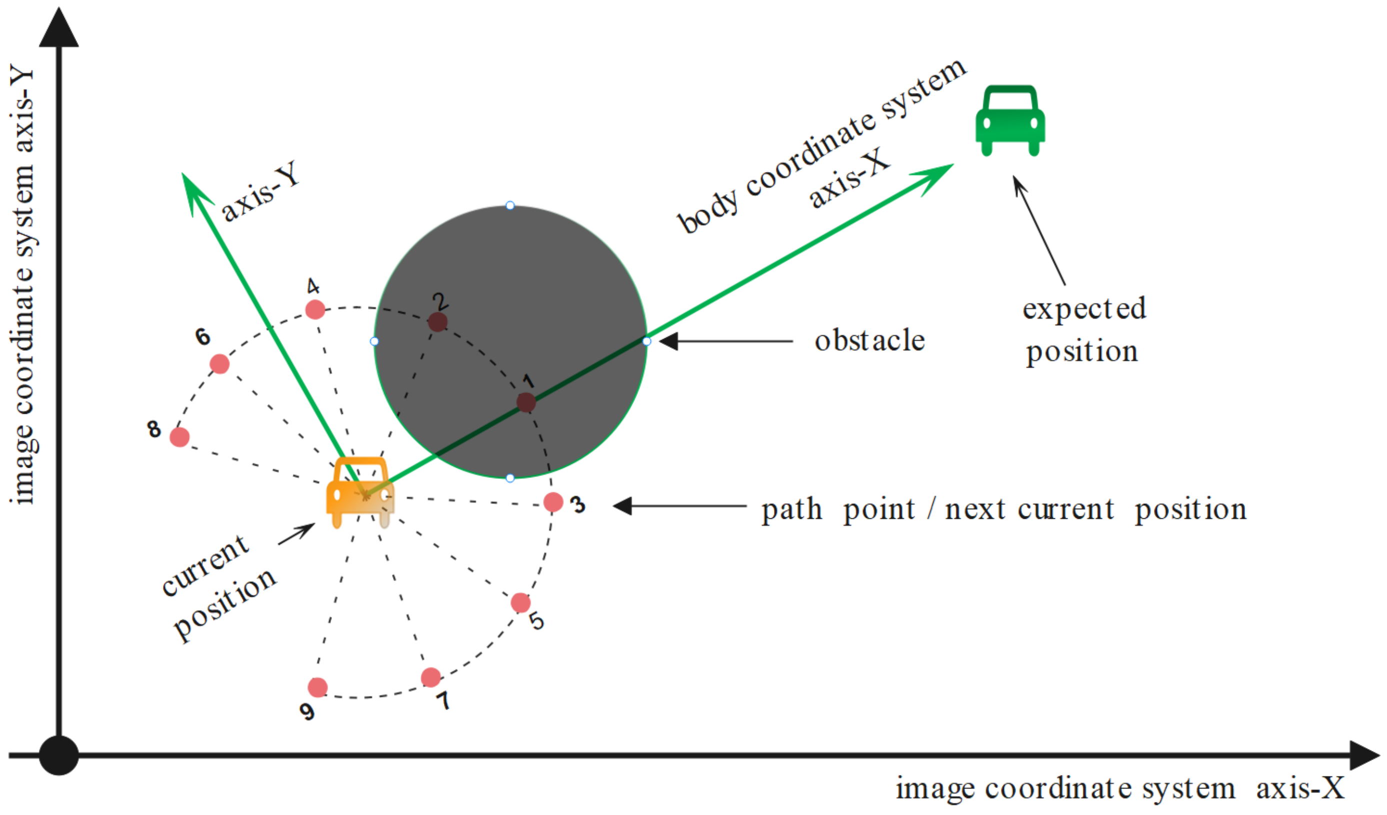


image coordinate system axis-Y
axis-Y
body coordinate system
axis-X
expected
position
obstacle
4
2
6
1
8
3
path point / next current position
current
position
5
9
7
image coordinate system axis-X

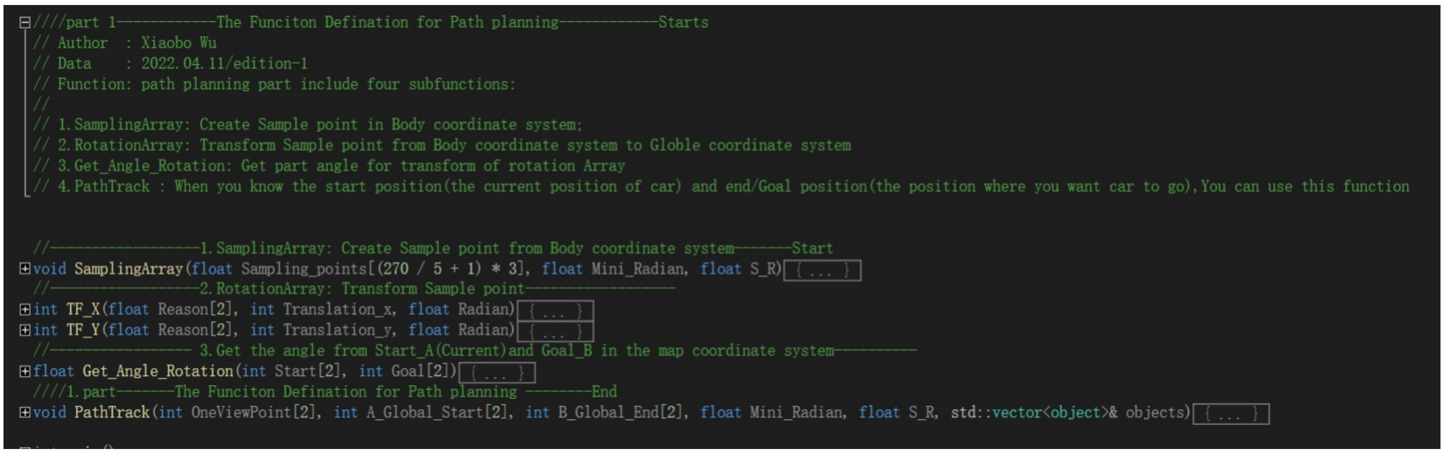
Figure 3.4: how to get path point and renew current position.

4. **Step 4: Iterate to get all of the path point**
   Iterate steps 1 3, until the distance between the current position and the expected position is less the the sampling distance. Up to now , we get all of the path point of path planing.

3.2 The implement of ASIA

There are two parts codes to implement the ASIA. As seen in Figure 3.5, there are four Sub functions Sampling _ Array, Rotation _ Array(including TF _ X and TF _ Y), Get _ Angle _ Rotation and PathTrack to support ASIA.

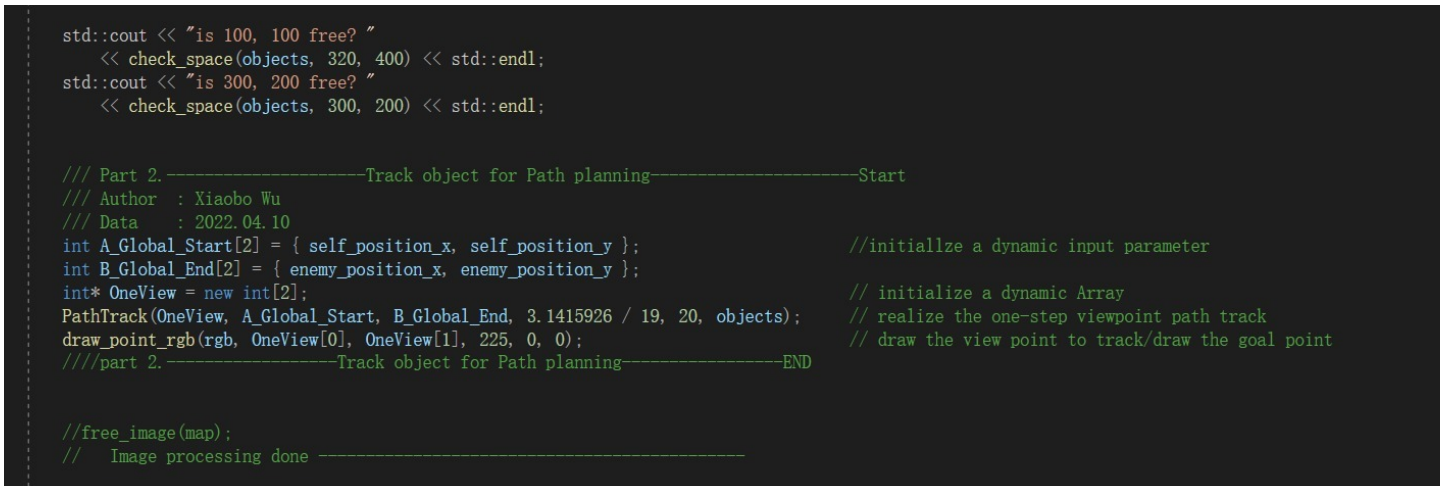
As seen in Figure 3.6, Call the path planning / PathTrack, sub function in the main function.



```
////part 1------------The Funciton Defination for Path planning------------Starts
// Author  : Xiaobo Wu
// Data    : 2022.04.11/edition-1
// Function: path planning part include four subfunctions:
//
// 1.SamplingArray: Create Sample point in Body coordinate system;
// 2.RotationArray: Transform Sample point from Body coordinate system to Globle coordinate system
// 3.Get_Angle_Rotation: Get part angle for transform of rotation Array
// 4.PathTrack : When you know the start position(the current position of car) and end/Goal position(the position where you want car to go),You can use this function


//------------------1.SamplingArray: Create Sample point from Body coordinate system-------Start
void SamplingArray(float Sampling_points[(270 / 5 + 1) * 3], float Mini_Radian, float S_R){ ... }
//------------------2.RotationArray: Transform Sample point------------------
int TF_X(float Reason[2], int Translation_x, float Radian){ ... }
int TF_Y(float Reason[2], int Translation_y, float Radian){ ... }
//----------------- 3.Get the angle from Start_A(Current)and Goal_B in the map coordinate system----------
float Get_Angle_Rotation(int Start[2], int Goal[2]){ ... }
////1.part-------The Funciton Defination for Path planning --------End
void PathTrack(int OneViewPoint[2], int A_Global_Start[2], int B_Global_End[2], float Mini_Radian, float S_R, std::vector<object>& objects){ ... }
```

Figure 3.5: implement of ASIA Using four sub functions.



```
    std::cout << "is 100, 100 free? "
        << check_space(objects, 320, 400) << std::endl;
    std::cout << "is 300, 200 free? "
        << check_space(objects, 300, 200) << std::endl;


    /// Part 2.---------------------Track object for Path planning----------------------Start
    /// Author  : Xiaobo Wu
    /// Data    : 2022.04.10
    int A_Global_Start[2] = { self_position_x, self_position_y };          //initiallze a dynamic input parameter
    int B_Global_End[2] = { enemy_position_x, enemy_position_y };
    int* OneView = new int[2];                                              // initialize a dynamic Array
    PathTrack(OneView, A_Global_Start, B_Global_End, 3.1415926 / 19, 20, objects);     // realize the one-step viewpoint path track
    draw_point_rgb(rgb, OneView[0], OneView[1], 225, 0, 0);                // draw the view point to track/draw the goal point
    ////part 2.------------------Track object for Path planning-----------------END


    //free_image(map);
    //   Image processing done ---------------------------------------------
```

Figure 3.6: Call the path planning algorithm.

Chapter 4

Robot Control

The robot is required to move to any point inside the image frame by controlling the wheels speed. This goal can be achieved by designing a controller to correct for position errors sensed by the camera. To design the controller, the knowledge of the robot's motion is extremely important. The kinematics model of the robot was discussed in section **??** as it is used in this section.
In literature, the commands for the system (controller output) are usually the linear velocity v_c and the angular velocity ω_c. First, a relationship between the controller output and the wheels' motor angular velocity is needed. Solving for the motors' angular velocities gives the following:

$$\omega_r = \frac{1}{R_w}(v_c + \frac{D}{2}\omega_c) \tag{4.1}$$

$$\omega_l = \frac{1}{R_w}(v_c - \frac{D}{2}\omega_c) \tag{4.2}$$

Where R_w is the wheel radius. These are called the inverse kinematic equations.
The trajectory is described by a path planning algorithm. This trajectory is broken down into single points (x and y coordinates) to be followed by the robot. Therefore, the controller must bring the robot to these points that are calculated in real time. The design of this controller is described by the block diagram in Figure 4.1.

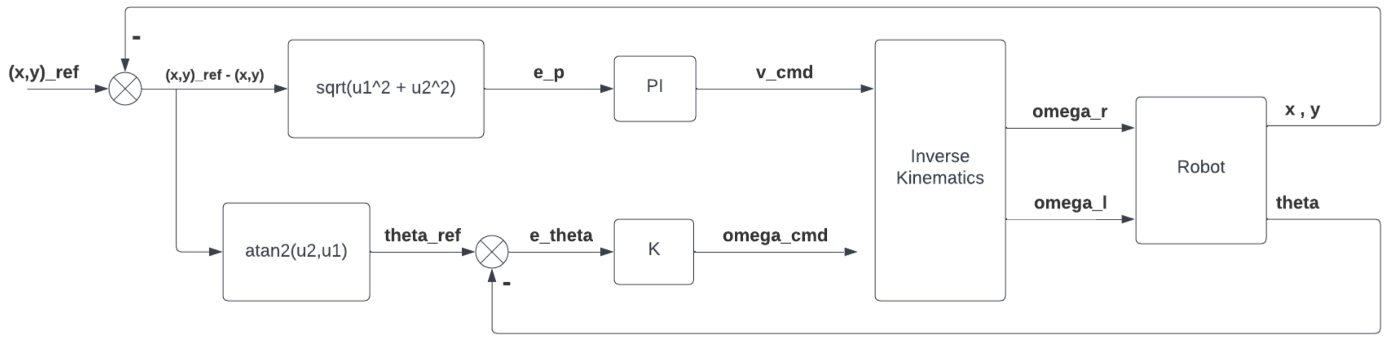


Figure 4.1: Controller block diagram

The reference (x,y) coordinates are given by the path planning algorithm. These coordinates are compared to the position measured by the image processing algorithm to compute an error. The errors are described as:

$$e_p = \sqrt{(x_{ref} - x)^2 + (y_{ref} - y)^2} \tag{4.3}$$

$$e_\theta = \theta_{ref} - \theta \tag{4.4}$$

$$\theta_{ref} = atan2\left(\frac{y_{ref} - y}{x_{ref} - x}\right) \tag{4.5}$$

There is an error of the distance between the desired point and our measured point, and there is another error that calculates the difference between the robot's orientation and the angle between the robot's x-axis and the distance vector. The first error helps the robot to approach the desired coordinate as best as possible and the second error orients the robot towards the desired coordinates. The position error is fed to a PI controller and the orientation error is fed to a proportional controller to generate the following commands:

$$v_{cmd} = k_p e_p + k_i \int e_p dt \tag{4.6}$$

$$\omega_{cmd} = k_p e_\theta \tag{4.7}$$

The controller gains were tuned for best performance. The robot was tested with multiple reference locations to measure the step response. Some of these results are shown in Figure 4.2. Large distances were input to the robot model to check if there was still a fast response. Most of the time the robot operates with the maximum speed which ensures that the robot moves as fast as possible. It is expected to have a similar speed response for shorter distances.

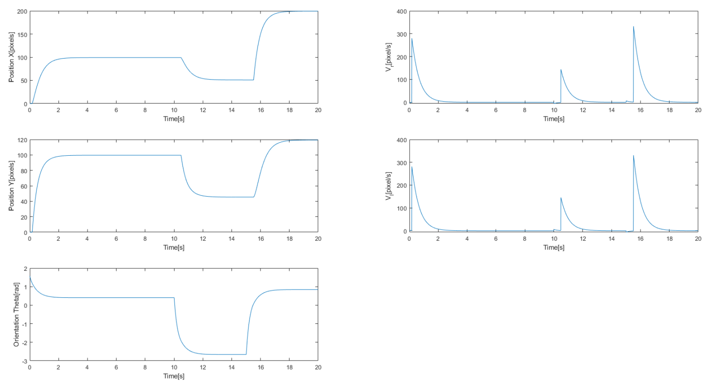


Figure 4.2: Robot response to multiple reference positions

Chapter 5

Hiding and Attacking Strategies

As we all know , there are two tasks everyone robot / program should be able to complete on the vision simulator. First, Your robot chases the opponent robot and tries to hit it with the laser while the other robot tries to avoid getting hit. Second, The opponent robot chases your robot and tries to hit it with the laser while your robot tries to avoid getting hit. We find that obstacles are considered to block the laser so we give the following hiding and attacking strategies.

5.1 Hiding

Always goushi hide self robot behind a obstacle and keep two robots and obstacle at a straight line, as shown in figure 5.1:

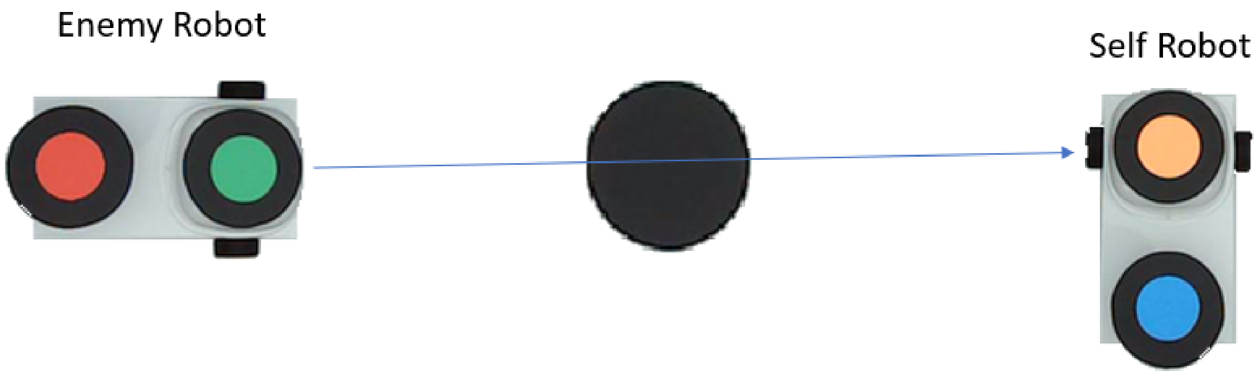


Figure 5.1: an example of positions that satisfies the hiding strategy.

5.2 The tactics of hiding

In order to implement the strategies above, detail tactics will be introduced. As we can see in the figure 5.2. Here we assume that there are three obstacles (1 3 obstacles in the environment randomly placed in the central part of the environment) in workspace. The red points are the centre of obstacles and robot,

O point is the centre of opponent robot and P point is the centre of my robot. In hiding model, my robot need to move to hiding point behind the obstacles quickly. But how to pick the specific hiding point is a difficult problem to be solved. There is a feasible solution to be introduced. Three straight lines (auxiliary lines) pass through the center of the opponent robot and the center of the obstacle, they are line OD, line OE and line OF. The vertical feet are point A, point B and point C, when make vertical lines from point P to these three lines— line OD, line OE, line OF. My robot will regard C point as the best hiding point. Compared with other hiding points (A position and B position) C is the nearest point where to the current my robot position. According to the position of obstacles and robot (my robot and opponent robot), the algorithm of hiding model will update the dynamic hiding point to avoid the hit and attack from opponent robot.

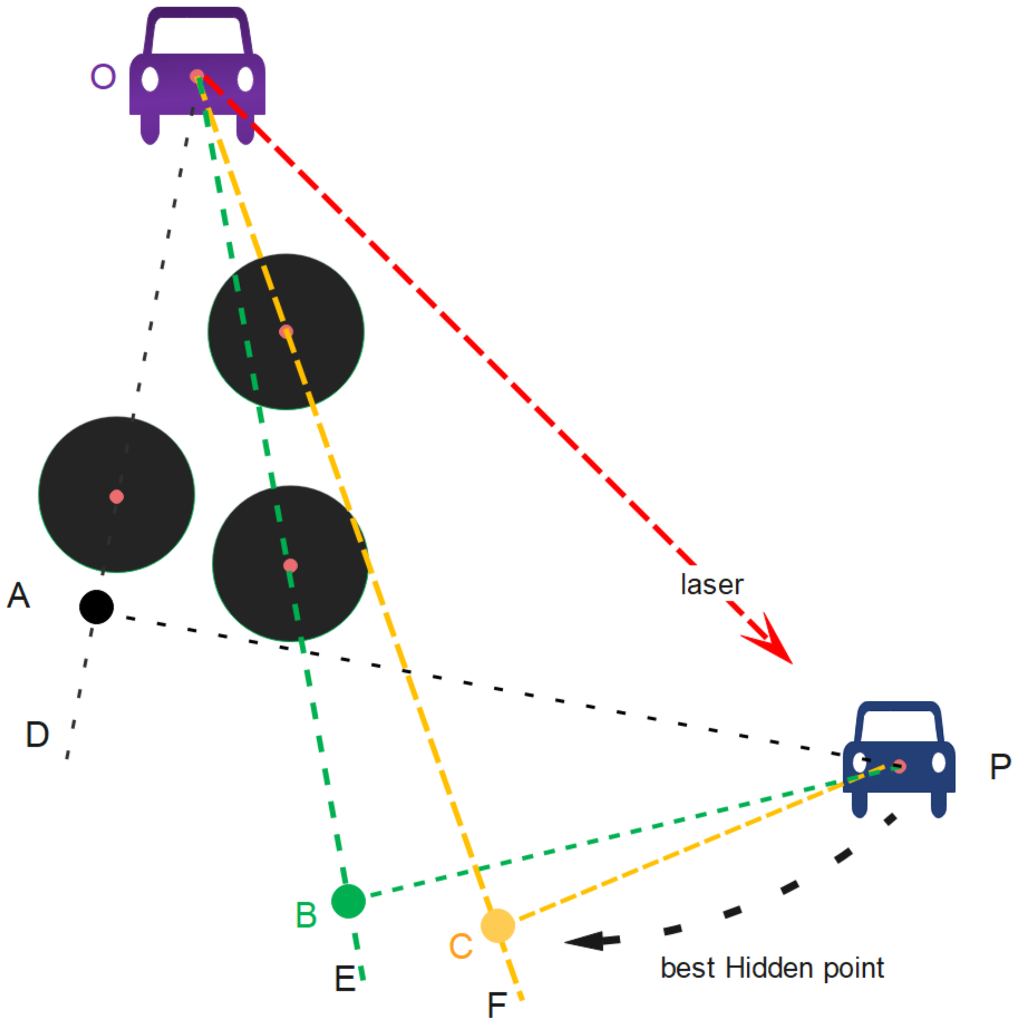


Figure 5.2: tactics for hiding strategy.

5.3 The implementation of hiding

In order to find the nearest point that satisfies the condition, an obstacle between the self and enemy, the foot of perpendicular from current position to the straight-line connecting enemy and obstacles, as shown in figure 5.3

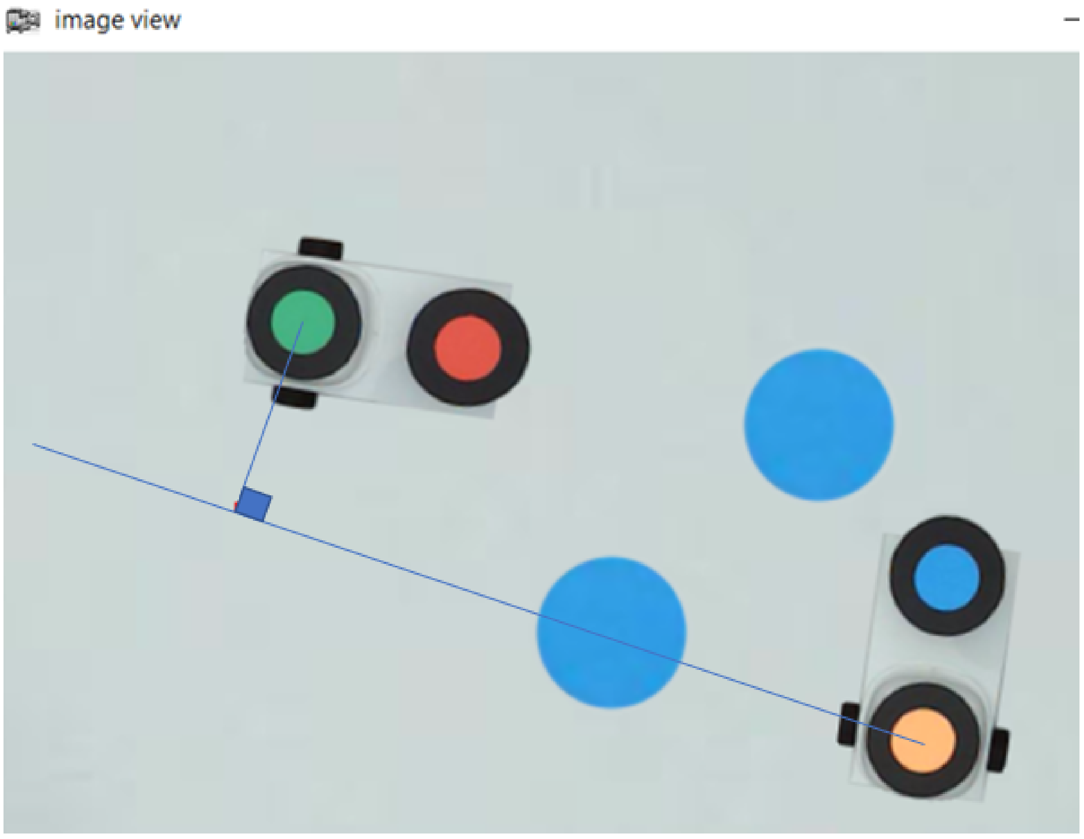


Figure 5.3: the foot of perpendicular from current position to the straight-line connecting enemy and obstacles.

The calculation of the foot of the perpendicular is as follows: We assume that $A = (x_a, y_a)$, $B = (x_b, y_b)$ are position of enemy and obstacle as shown in figure 5.4. $C = (x_c, y_c)$ is the position of self-robot, $O = (x_o, y_o)$ is the foot of perpendicular from point C to line AB.

Since $\overrightarrow{AB} \perp \overrightarrow{CO}$, we have:

$$(x_b - x_a)(x_o - x_c) + (y_b - y_a)(y_o - y_c) = 0 \tag{5.1}$$

Since $\overrightarrow{AB}$ and $\overrightarrow{AO}$ has same direction, we have:

$$\begin{cases} x_o = k(x_b - x_a) + x_a \\ y_o = k(y_b - y_a) + y_a \end{cases} \tag{5.2}$$

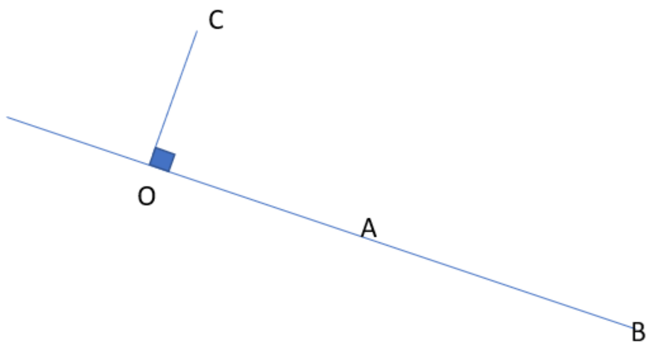


Figure 5.4: The foot of perpendicular.

Substitute x_o and y_o in the second equation to find out k. Then substitute k in the third equation to find out x_o and y_o.

$$k = -\frac{(x_a - x_c)(x_b - x_a) + (y_a - y_c)(y_b - y_a)}{(x_b - x_a)^2 + (x_b - x_a)^2} \tag{5.3}$$

Once we have arrived at the expected position, direction of the self-robot is also important. As shown in figure 5.5 a, if the direction of self-robot is not opposed to the enemy-robot, to run away from the enemy, the self-robot should rotate first, and then move around the obstacle. However, if we keep the direction of self-robot as opposed to the enemy, as shown in figure 5.5 b, we do not need to rotate robot first, we can move robot around the obstacle directly instead.

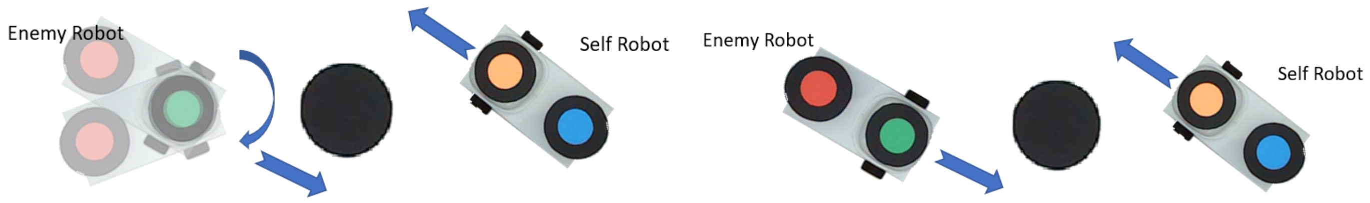


Figure 5.5: The importance of self-robot direction

Therefore, to keep the direction as opposed to the enemy, the expected position also requests a specific theta. For the convenience of calculation, we should stipulate that the theta of robot is between pi and -pi as shown in figure 5.6.

5.4 Attacking

Since there is only one chance to fire the laser, it should fire until there is no obstacle between two robots. To do so, the attacking robot should chase the other robot. We defined the criteria to fire the laser when:

- The laser is pointing to one of the enemy robot's centroids
- There is a free path (no obstacles) between the laser position and the enemy robot.

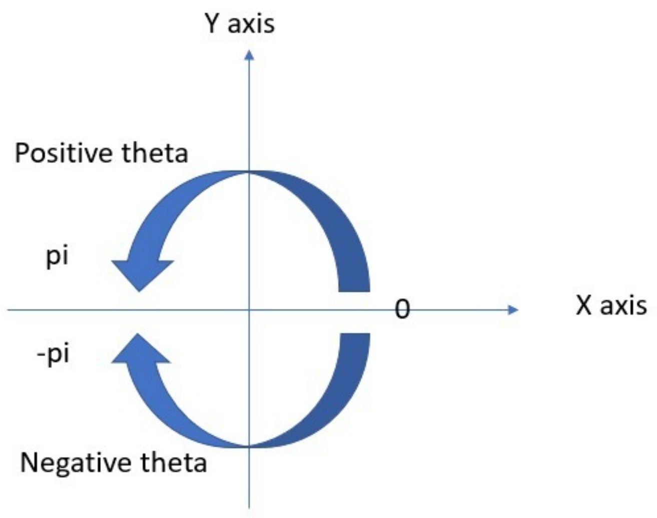


Figure 5.6: The representation of theta.

Inside the while loop, a series of conditions are programmed to check if the robot can fire the laser. For the first condition, the laser will be tracking the nearest enemy's centroid. Figure 5.7 shows the distances measured by the program. These distances are compared and the smallest one is provided to the laser track algorithm. This function is just a simple adjustment to the laser's servo motor according to the error angle between the laser and the centroid location measured in the image frame. The function will output the error angle for the first condition to be met.

The second condition is met when there is no obstacles in the laser's path. Once the nearest centroid is chosen, the freepath() function will check if the laser is passing through an obstacle or not. This function keeps track of the pixels that are in between the laser and the enemy's chosen centroid. Then, the function checkspace() will tell if the pixel is an obstacle or not.
When condition one and condition two are met, the robot will laser the fire to the oponent.

To meet these conditions, the robot has to find a proper location with respect to the enemy. The strategy consists on chasing the enemy's closest centroid. This is done by using the mentioned path planning algorithm which finds the best trajectory while avoiding obstacles. When the described conditions are met, the robot will be able to fire the laser to the enemy.

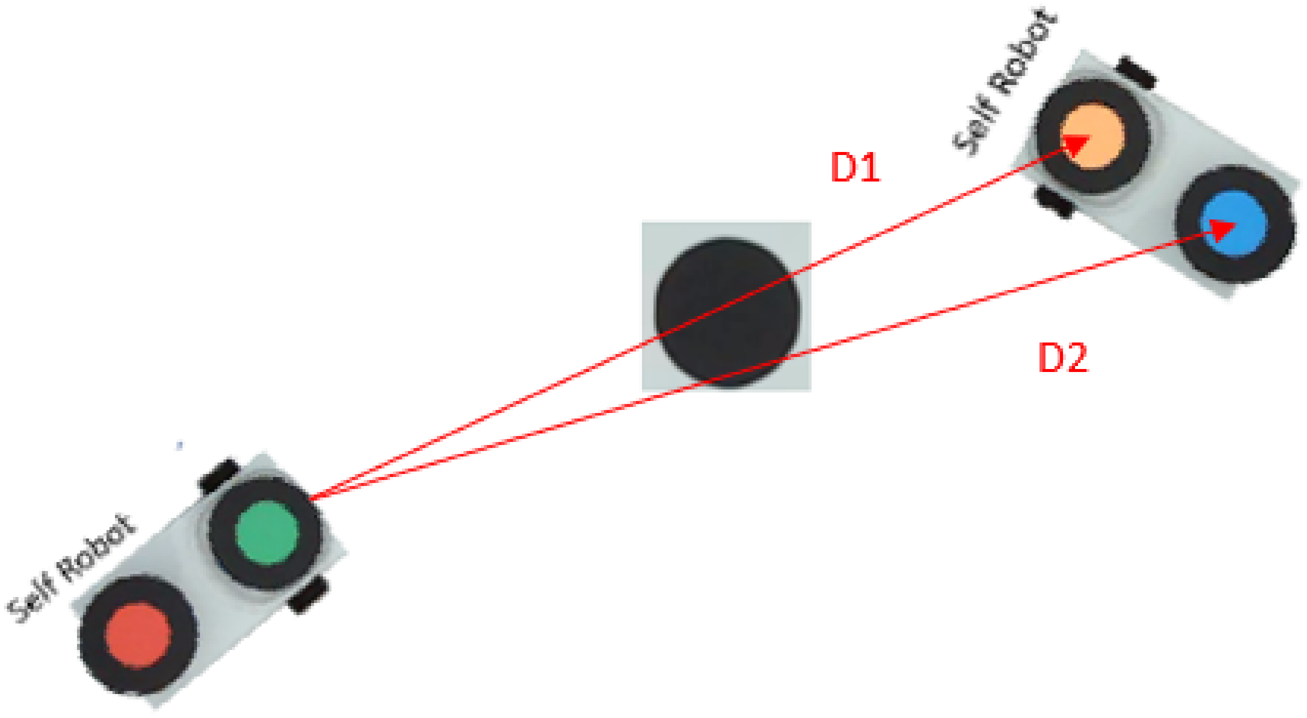


Figure 5.7: Laser tracks the smallest distance to the robot's enemy