基于遗传算法和贝塞尔曲线方法实现的拖拉机避障

1.贝塞尔曲线原理

三阶贝塞尔曲线定义如下：

$$[x\ y] = \left[t^3\ t^2\ t\ 1\right] GP, t \in [0,1] \tag{1}$$

where t indicates the normalized time variable; $(p_{0,x}, p_{0,y})$, $(p_{1,x}, p_{1,y})$, $(p_{2,x}, p_{2,y})$, and $(p_{3,x}, p_{3,y})$ are coordinates of control points P_0, P_1, P_2, and P_3, respectively.

$$G = \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 3 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix},$$

$$P = \begin{bmatrix} P_{0,x} & P_{0,y} \\ P_{1,x} & P_{1,y} \\ P_{2,x} & P_{2,y} \\ P_{3,x} & P_{3,y} \end{bmatrix}$$

The first derivative and second derivative of the third-order Bezier curve are expressed as in Equation (2).

$$\begin{cases} [\dot{x}\ \dot{y}] = [3t^2\ 2t\ 1\ 0]GP \\ [\ddot{x}\ \ddot{y}] = [6t\ 2\ 0\ 0]GP \end{cases} \tag{2}$$

where $\dot{x}$, $\dot{y}$, $\ddot{x}$, and $\ddot{y}$ are the components of first and second derivatives of the point (x(t),y(t)) for the X and Y coordinates, respectively.

The curvature of the third-order Bezier curve is expressed as follows:

$$k(t) = \frac{\dot{x}\ddot{y} - \ddot{x}\dot{y}}{\left(\dot{x}^2 + \dot{y}^2\right)^{\frac{3}{2}}} \tag{3}$$

where k(t) represents the radius of curvature.

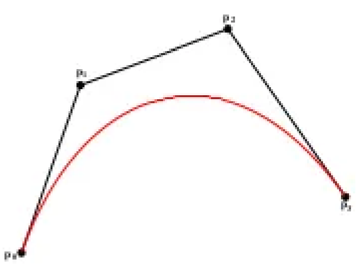


Figure 1. Third-order Bezier curve.

贝塞尔曲线公式推导

The obstacle avoidance path was planned in the world standard latitude and longitude coordinate system (WGS84 coordinate system), and the navigation path L is a sequence of path discrete points {k0, k1, k2, . . . , ki . . . }, where ki = (loni,lati). As shown in Figure 2, the obstacle avoidance path contains two third-order Bezier curves. The shapes of third-order Bezier curves are determined based on the coordinates of control points, and the first curve is connected to the second curve through $P_{1,3} = P_{2,0}$. Therefore, the problem of obstacle avoidance path planning is transformed into the acquisition of coordinates of optimized control points [19].

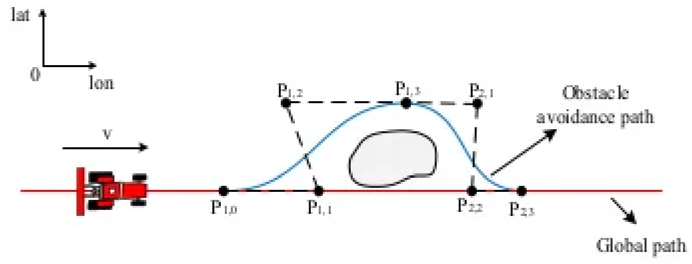
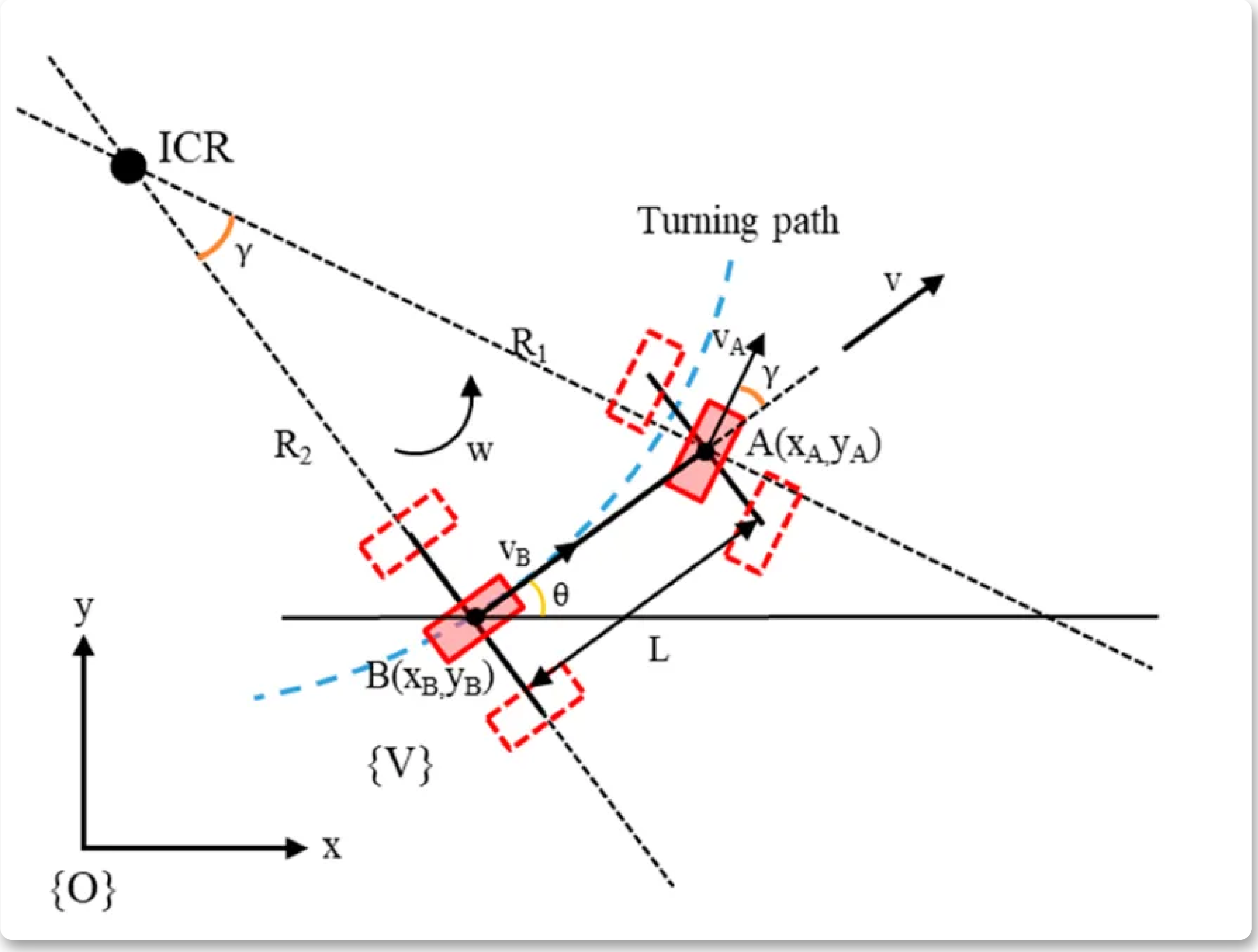


Figure 2. Obstacle avoidance path model.

分为段贝塞尔曲线来处理

2.拖拉机动力学模型

- 拖拉机做出的模型假设
  - 假设拖拉机是刚体
  - 假设拖拉机前轮转角左右轮的角度是相等的
  - 假设滚转角和俯仰角是被忽略的
  - 假设无横向侧滑



拖拉机动力学模型

Figure 3. Tractor model. Note: The shape of the four-wheeled tractor is shown as a red dashed area and the approximate two-wheeled tractor is shown as a red straight area. γ indicates the steering angle of the steering wheel (front wheel deflection) and the velocity of the rear wheel in the x-axis direction is v. The front and rear wheel axes are shown as black dashed lines, the intersection of which is the instantaneous center of rotation (ICR); the blue dashed lines indicate the steering trajectory; the distances from the front and rear wheels to the instantaneous center are R_1 and R_2, respectively. L is the length of the tractor or wheel base. A (x_A, y_A) are the rear axle coordinates, B(x_B, y_B) are the front axle coordinates, θ is the traverse angle (heading angle) of the tractor, w is the traverse angular velocity of the tractor, v_A is the front axle center velocity, and v_B is the rear axle center velocity of the tractor.

参数指示

Figure 4 illustrates the tractor path tracking model. With the goal of minimizing the heading angle of the tractor, preview point C can be determined by searching for the points in the planned path, and the preview point satisfies the requirement that the distance to point C_s is less than d_1. The tractor reaches preview point C by the desired path.

Based on Figure 4, the following results can be calculated:

$$\frac{L_d}{\sin 2\alpha} = \frac{R}{\cos \alpha} \tag{12}$$

The kinematic model of automatic tractor navigation can be obtained by combining Equations (12) and (13):

$$\theta = \arctan\left(\frac{2L\sin\alpha}{L_d}\right) \tag{13}$$

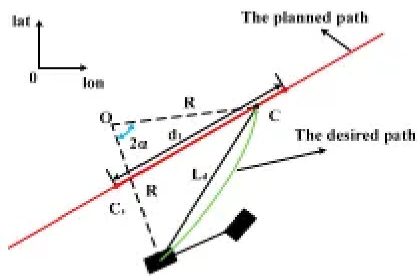
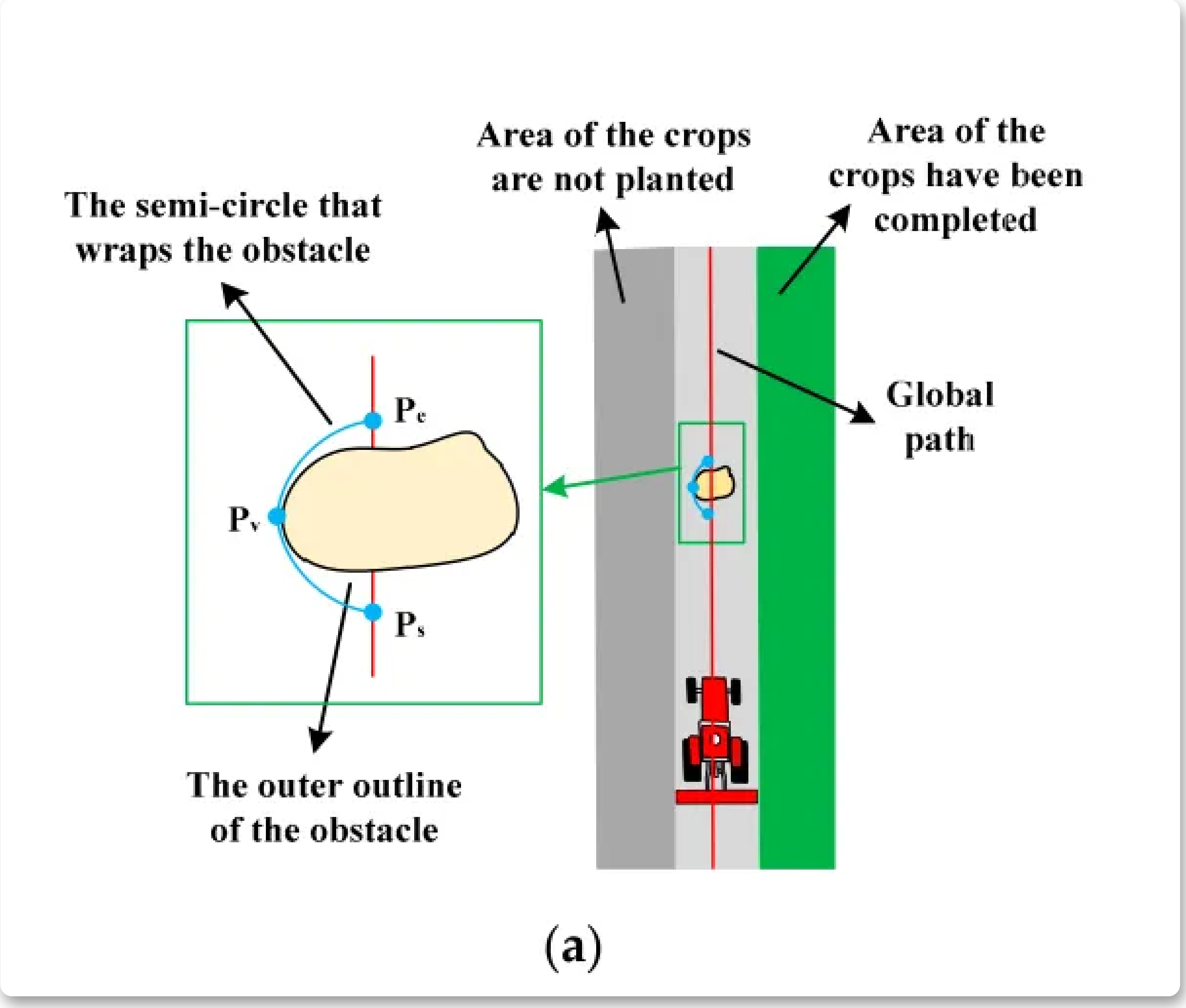


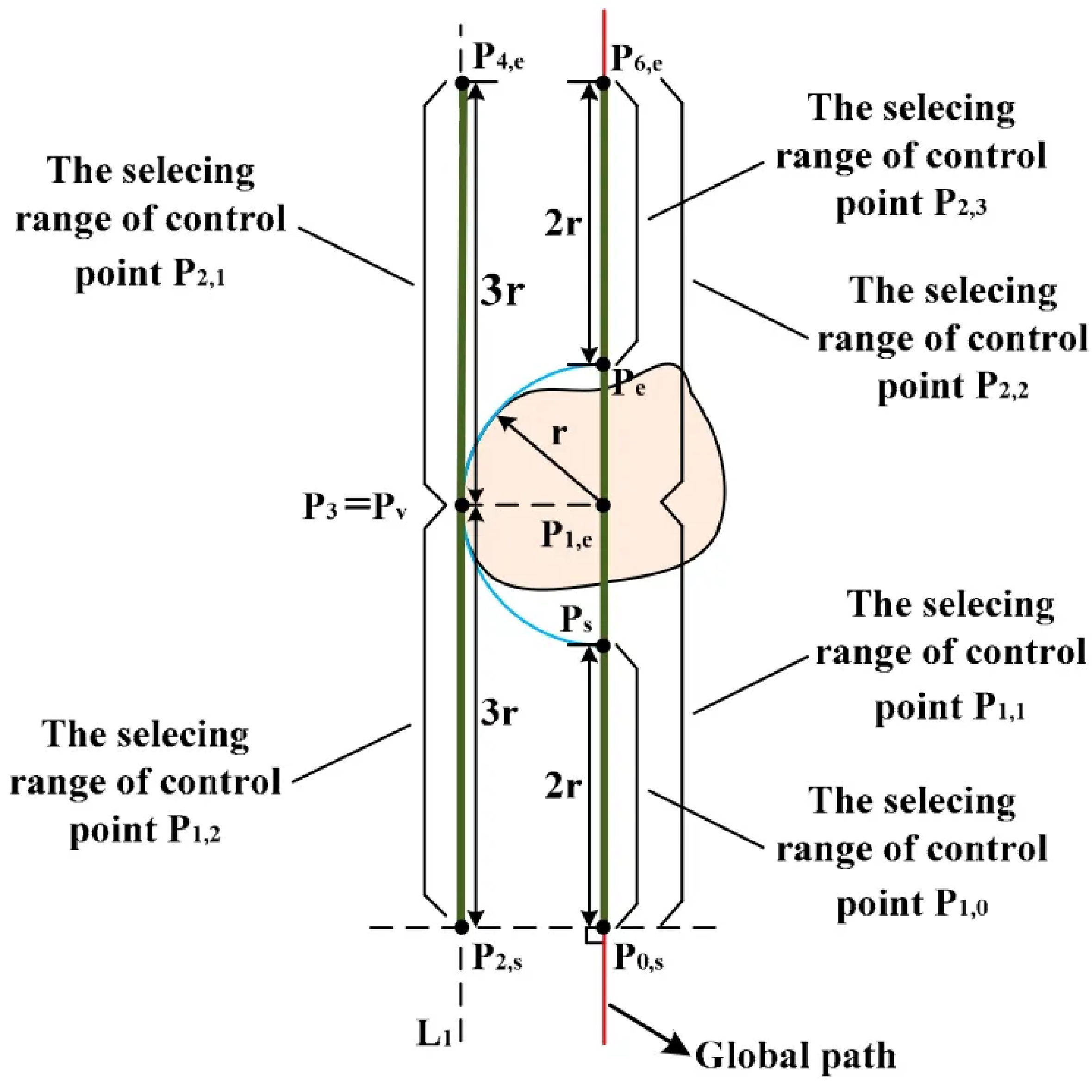
Figure 4. Tractor path tracking model. Note: C is a preview point on the planned path. L_d is the distance between the tractor rear axle and preview point C. 2α is the angular deviation of the tractor with respect to the preview point C. C_s is the point on the planned path with the least distance from the tractor.

拖拉机最大航向角确定

3.必要的关键思路


Area of the crops are not planted
Area of the crops have been completed
The semi-circle that wraps the obstacle
Pe
Pv
Ps
Global path
The outer outline of the obstacle
(a)

拖拉机避障关键点



拖拉机关键点选择的范围确定

The selection range of all control points is shown in Equation (23):

$$\begin{cases}
\min\{2x_s - x_e, x_s\} \le x_{1,0} \le \max\{2x_s - x_e, x_s\} \\
\min\{2x_s - x_e, \frac{x_s+x_e}{2}\} \le x_{1,1} \le \max\{2x_s - x_e, \frac{x_s+x_e}{2}\} \\
\min\{x_v + x_s - x_e, x_v\} \le x_{1,2} \le \max\{x_v + x_s - x_e, x_v\} \\
\min\{x_v - x_s + x_e, x_v\} \le x_{2,1} \le \max\{x_v - x_s + x_e, x_v\} \\
\min\{2x_e - x_s, \frac{x_s+x_e}{2}\} \le x_{2,2} \le \max\{2x_e - x_s, \frac{x_s+x_e}{2}\} \\
\min\{2x_e - x_s, x_e\} \le x_{2,3} \le \max\{2x_e - x_s, x_e\} \\
\begin{bmatrix} y_{1,0} & y_{62,3} \\ y_{1,1} & y_{52,2} \\ y_{1,2} & y_{42,1} \end{bmatrix} = \frac{1}{x_e - x_s}\left[(y_e - y_s)T_1 + T_2 T_3\right] \\
\begin{bmatrix} x_{1,3} & y_{1,3} \end{bmatrix} = \begin{bmatrix} x_v & y_v \end{bmatrix}
\end{cases} \tag{23}$$

where T_1, T_2, and T_3 are defined as follows:

$$T_1 = \begin{bmatrix} x_{1,0} & x_{62,3} \\ x_{1,1} & x_{52,2} \\ x_{1,2} & x_{42,1} \end{bmatrix}, T_2 = \begin{bmatrix} y_s & -y_e & 0 & 0 \\ y_s & -y_e & 0 & 0 \\ y_v & -y_e & y_v & -y_v \end{bmatrix}, T_3 = \begin{bmatrix} x_e & x_e \\ x_s & x_s \\ x_v & x_v \\ x_s & x_s \end{bmatrix}$$

直角坐标系下确定的各个关键点的范围公式

$$k(t)=\frac{\dot{x}\ddot{y}-\ddot{x}\dot{y}}{\left(\dot{x}^2+\dot{y}^2\right)^{\frac{3}{2}}}\leq\frac{1}{R_{min}}$$

曲率约束

$$\sqrt{\left(x(t)-\frac{x_s+x_e}{2}\right)^2+\left(y(t)-\frac{y_s+y_e}{2}\right)^2}\geq\frac{1}{2}\sqrt{(x_s-x_e)^2+(y_s-y_e)^2} \qquad (25)$$

避障约束

$$\theta=\arctan\left(\frac{2L\sin\alpha}{L_d}\right)<\theta_{max}$$

航向角约束

$$\begin{cases} m=w_1 d_{max}+w_2\frac{4s'}{\pi\left[(x_s-x_e)^2+(y_s-y_e)^2\right]} \\ w1+w2=1,(0<w1<1,0<w2<1)\end{cases} \qquad (28)$$

vhere m is the objective function value, (xs,ys) is the coordinate of key point Ps, (xe,ye) s the coordinate of key point Pe, and d_{max} and s′ are defined as Equations (29) and (30), espectively.

$$d_{max}=\max\left\{d'_0,d'_1,\ldots,d'_i,\ldots\right\} \qquad (29)$$

vhere d′i is the error value of the ith tractor path tracking simulation and d′i is the naximum error value in this tractor path tracking simulation.

$$\begin{aligned} s'&=S_{w1}+S_{w2} \\ &=w\left(\sqrt{(x_s-x_0)^2+(y_s-y_0)^2}+\sqrt{(x_e-x_6)^2+(y_e-y_6)^2}\right)\end{aligned} \qquad (30)$$

目标函数

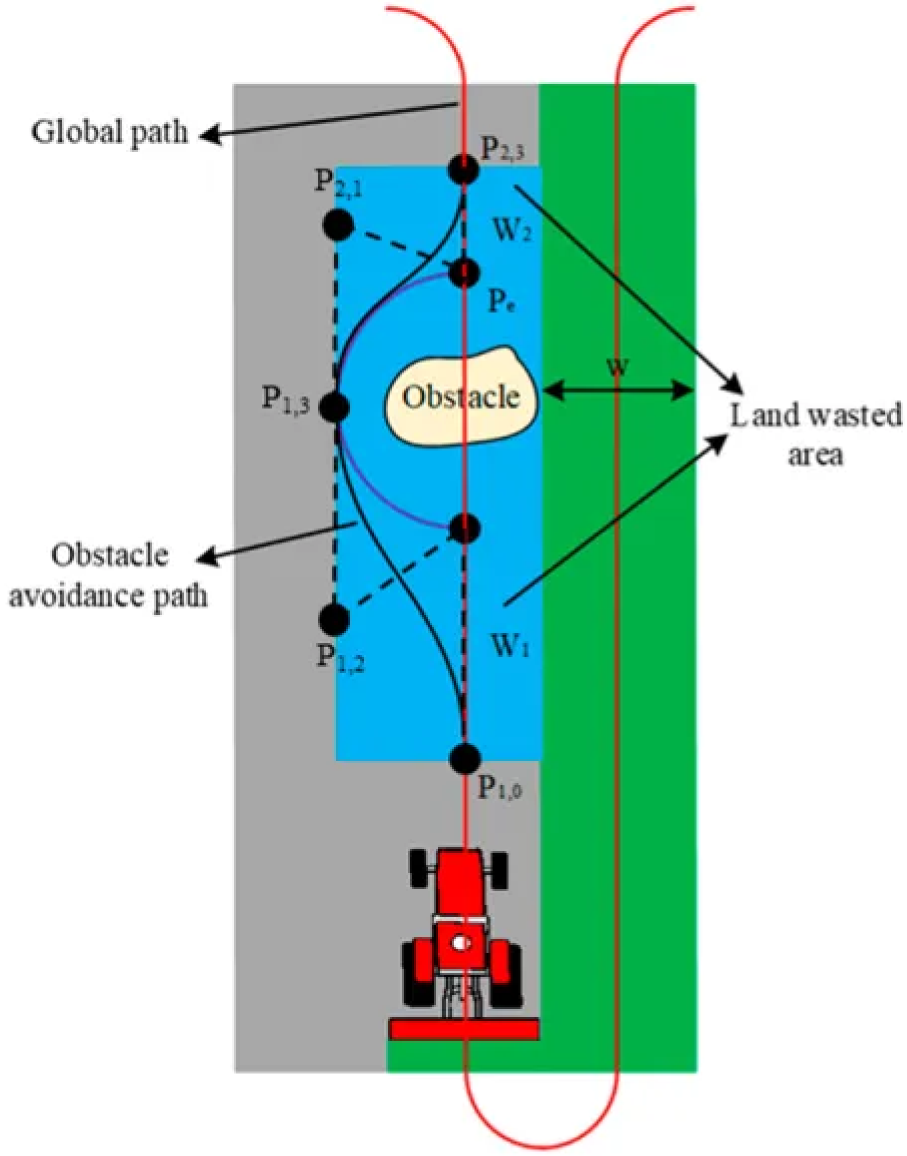


Figure 6. An example of wasteful land.

实际避障时的demo

The fitness function is established according to the objective function shown in Equation (25) and constraint functions shown in Equation (33).

$$f = \frac{X}{m} = \frac{X}{\left(d_{max} + \frac{4s'}{\pi\left[(x_s - x_e)^2 + (y_s - y_e)^2\right]}\right)} \tag{33}$$

where f is the fitness function value and X is defined as follows:

$$x = \begin{cases} 1 \text{ if obstacle avoidance path satisfy the Equation (24)} \\ 0 \text{ else} \end{cases} \tag{34}$$

遗传算法的适应度函数

参考文献[1]

Reference

[1] 天大出品: research_on_tractor_optimal_obstacle_avoidance_path_planning_for_improving_navigation_accuracy_and_avoiding_land_waste