STUDY OF THE PARAMETERS NECESSARY TO DEFINE THE VEHICLE MANUFACTURING ENVELOPE

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ABSTRACT

This document provides a method for modeling a maneuverability envelope of a vehicle in a parking lot of any size. The method uses the turning radius, the vehicle size and the type of parking to be used to determine the parking trajectory. Parking space management requires knowledge of the minimum space occupied by a vehicle; therefore, it is important to define the width and length occupied by a vehicle. To do this, we must consider the size of the desired location, as well as that of the circular road. In this paper, we have to studies about parallel parking, perpendicular parking and angle parking.

Keyword: *parallel parking, perpendicular parking, vertical parking, angle parking, oblique parking, maneuverability, turning radius*

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1. INTRODUCTION

Nowadays, with the fast development of science and technology and increase of people's living standard, the number of cars is increasing very fast. The space of car parking significantly reduced, and traffic accidents are particularly prone to happen when backing the car for these drivers who have less experience. Thus, the automatic parking problem has become a hot research topic but for this paper, the research is based on "How to define the maneuverability envelope of a vehicle in a parking lot?"

Parking types include parallel parking, vertical parking, and oblique parking, as shown in Figure 1. Parallel parking is most common in our daily life, so the parallel automatic parking system has become a hot spot of current research. The perpendicular or vertical parking is the most efficient and economical since it accommodates the most vehicles per linear meter and is especially effective in long term parking areas. As for oblique parking, this is the same of a perpendicular parking, but the only difference is the value of the angle inclination. So, in this paper, we have to studies especially about parallel and vertical parking.

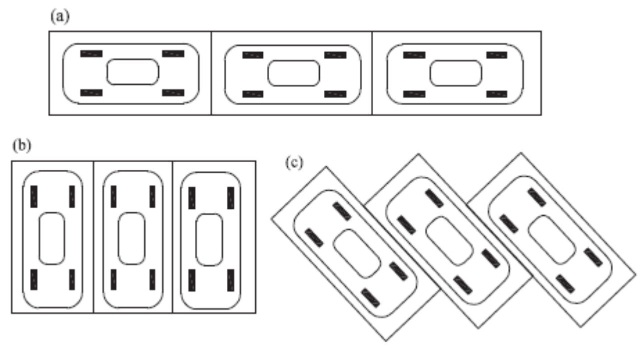


Fig -1: Classification of parking: (a) parallel parking, (b) vertical parking, and oblique parking.

2. PARKING STRATEGY FOR PARALLEL PARKING ROUTE

This part of article proposes an optimized route scheme for roadside parking, while considering the surrounding environment and the positioning of vehicles. The obstacles can be presented like a vehicle or other things. In general, the body of the vehicle is square-shaped, with four wheels and two variations limiting the motion: linear (forward and backward) and turning variation (change of direction). When the turning angle is limited, it also limits the curvature of the route, leading to the change of tangent direction of the vehicle. Previous studies have provided designs and research rules for the parking route planning and orbit. For instance, the triangular function design has been used for tracking and controlling the orbit to follow the reference of the orbit route by the feedback linearity of the input status; which controls the steering angle and forward position through the motion formula of the vehicle, allowing the car driver to complete the parking action within the shortest route. Another work studies the curvature radius for the parallel parking of vehicles on the roadside.

2.1 Geometrics and mathematics methods

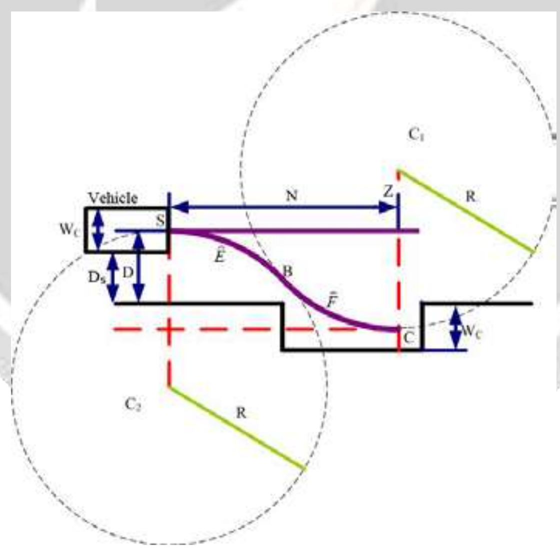


Fig -2: Parking orbit

As indicated in Figure 2[1], the parking orbit proposed in this article has four steps with which the parking process can be completed. Before the basic vehicle dynamic analysis, there are three assumptions, first of which is that the vehicle must be driven by the front wheels, and the rear wheels must be paralleled; and the second is that there is no gliding between tires and ground, while the third, the angle of the two front wheels must be the same as the turning angle; the last, the center of the rear bumper is the main reference point. Hence, the vehicle dynamic analysis will be processed through the statements above. The first step measures the side distance D_s ; while the second step determines the distance N from the start point Z to point S by the known distance D_s, which requires entering the vehicle back-up mode; and the third step determines the arc distance E from start point S to point B from the known distance D_s. When the vehicle moves from point S to the turning point B, it will enter the final phase. Given that the rotating distance for the two sections is the same, the vehicle back-up distance needed from points B to C can be determined to complete the action of parking. The method proposed in this article uses the maximum steering angle of the vehicle since the demand for the steering angle of the parking action can create two circles, namely, C_1 and C_2 (using the minimum rotating radius of the vehicle R). When the center point of the circle C_1 is fixed, and the two circles C_1 and C_2 create a tangent line (point B), the starting point of the reverse steering angle of the vehicle can be determined. This means that the parking action can be easily completed if the starting point of the vehicle parking and the vehicle reverse steering angle are known. The change of back-up starting point as indicated in Figure 3 will create different back-up starting points (S_1, S_2 to S_n) with the change of distance between the center of the rear bumper and the site D (D_1, $D_2 \ldots D_n$). Moreover, the moving distance M from the original point Z to the starting point will also change (M_1, $M_2 \ldots M_n$).

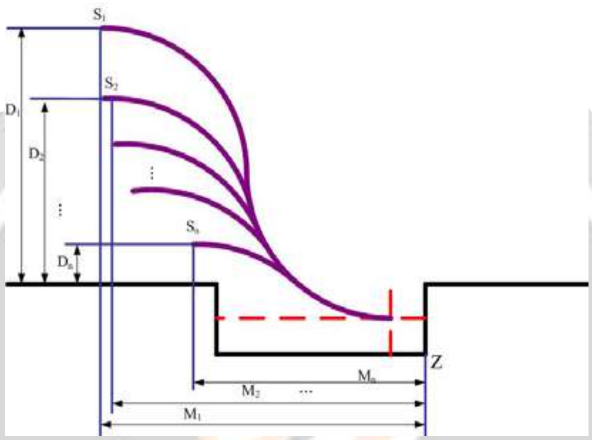


Fig -3: Change of back-up start point

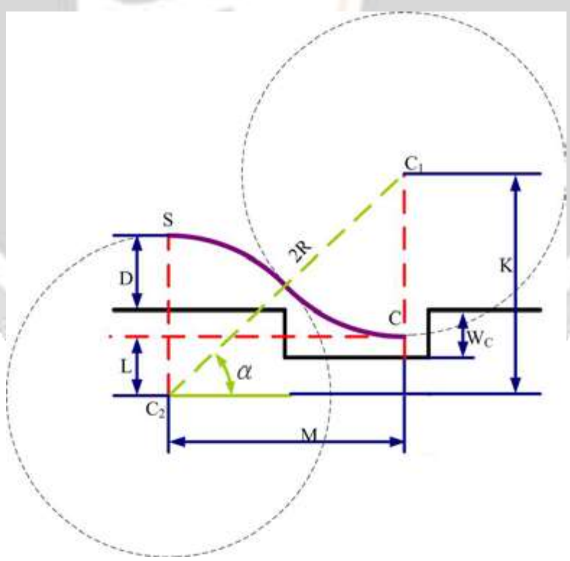


Fig -4: Relationship of the vehicle back-up starting point

The decision determining the vehicle back-up starting point must first be discussed. As indicated in Figure 4, the vehicle back-up starting point S to the vehicle back-up end point C can form a group of back-up routes (represented by purple arc lines). The center points of C_1 and C_2 can form a right triangle wherein 2R is the hypotenuse and a is the included angle. The relationship among a, D, and N can thus be determined using the trigonometric function theory:

$$\alpha = \sin^{-1}\left(\frac{2R-(W_c/2)-D}{2R}\right) \tag{1}$$

$$D = D_s + \frac{1}{2}W_c \tag{2}$$

and

$$N = 2R\cos\left[\ \sin^{-1}\left(\frac{2R-(W_c/2)-D}{2R}\right)\right] \tag{3}$$

$$M = N + P_d \tag{4}$$

Where D_s is the distance measured by distance infrared sensor, W_c is the car width. P_d is the safe marginal distance of the reversed vehicle ; M is the required distance from the starting point Z to the vehicle back-up starting point, W_c is the width distance of the vehicle, and R is the minimum rotating radius of the vehicle. The data presented above can be obtained in advance.

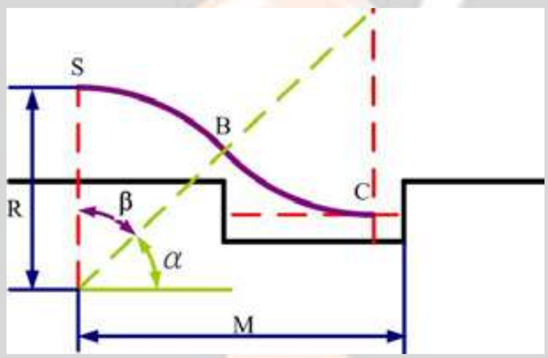


Fig -5: Relationship between β and α

When the starting point S is determined, it will determine the position of the tangent point B from the relationship between α and β. In the figure 6, the relationship between α and β can be observed as indicated in Equation (5):

$$\beta = 90 - \alpha \tag{5}$$

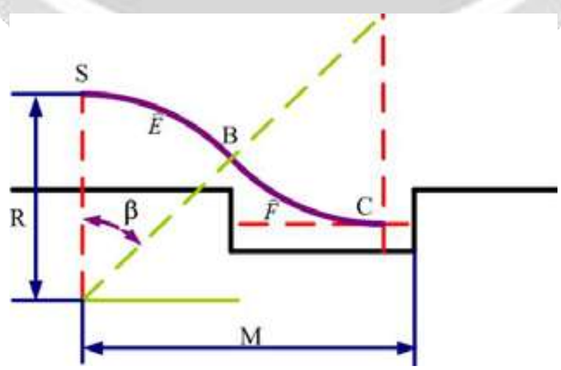


Fig -6: Relationship between β and arc length

Finally, the position of point B can be determined from the relationship between β and α. The arc length is indicated in Figure 7. $\hat{E}$ equal to $\hat{F}$ is an arc that takes the minimum rotating radius R as the radius. Therefore, $\hat{E}$ can be obtained if β is known, as indicated in Equation (6):

$$\hat{E} = 2\pi R\left(\frac{\beta}{360}\right) \tag{6}$$

Where β can be determined from Equation (5), and the distance from points S to B can be determined by substituting it with Equation (6). Therefore, the position of point B can be determined.

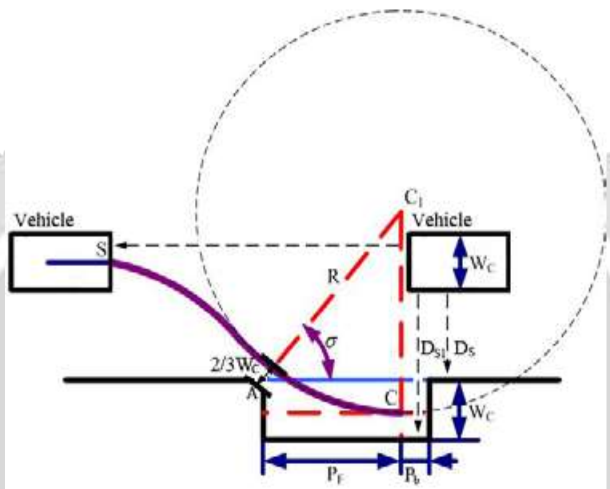


Fig -7: Illustration of parking space

After the parking path is determined, the parking space should be estimated whether it is larger enough to accomplish parking behavior. Figure 6 shows the size of the parking space. When the vehicle moves forward, the sided ultrasonic radar of the vehicle can measure the distance of D_S and D_{S1}. Therefore, the width of the parking space can be calculated, and it's the actual size of can be estimated by forward distance. The following content will mention about the calculation of size for a parking space. Referred to Figure 7, the minimum width of the parking space is equal to the width of the vehicle (W_c). To avoid the front edge of the vehicle crashing point A of the parking space, the minimum distance from the front edge of the parking space to the circle center, C_1, should plus a rotating radius, R, for safety distance margin that should be larger two third than the original width of the vehicle; hence, the crashing situations can be avoided. σ can be obtained by using trigonometric function theorem. As shown in Equation (7):

$$\sigma = \sin^{-1}\left(\frac{R-(2W_C/3)}{R+(2W_C/3)}\right) \tag{7}$$

The equation of σ and P_F can be expressed in Equation (8):

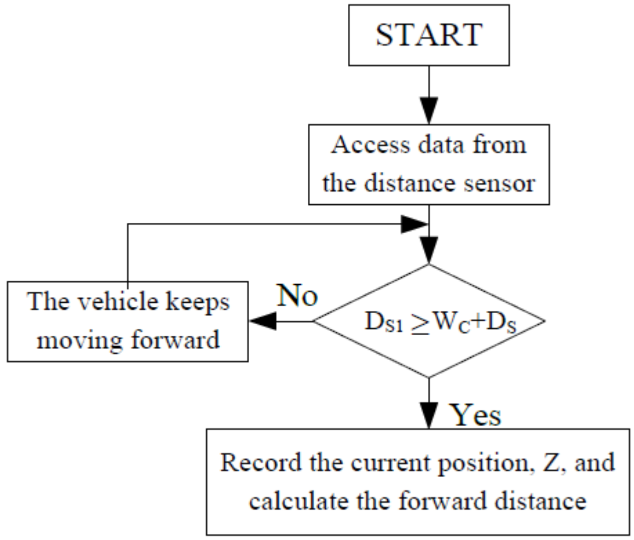
$$\cos\sigma = \frac{P_F}{R+(2W_C/3)} \tag{8}$$

At last, Equation (7) is substituted into Eq.(8), and the minimum length of the parking space can be determined.

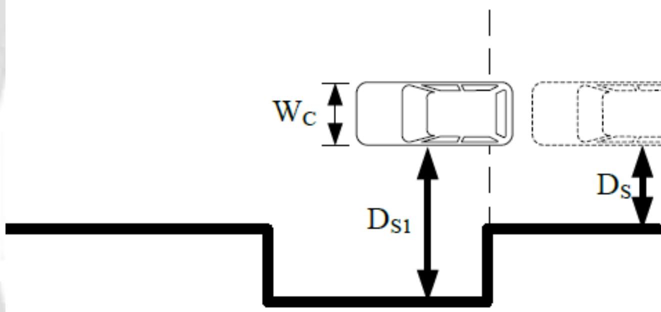
$$P_{F(min)} = \left(R+(2W_C/3)\right)\ \cos\left(\sin^{-1}\left(\frac{R-(2W_C/3)}{R+(2W_C/3)}\right)\right) \tag{9}$$

Known from Equation (9), the size of parking space is relative to the minimum rotating radius of the vehicle. If the rotating radius is smaller, the parking space can also be smaller.

2.2 Algorithm



(a)



(b)

Fig -8: Flow chart of the 1st movement (b) illustration of parking behavior

As following, the flow chart and the parking illustration will explain the principle of the entire auto parking behavior. At first, we must calculate the distance (D_S) between the vehicle and the edge of the parking space. Also, Equation (3) and Equation (4) can calculate the forward distance(M) of the vehicle. Later, the car driver starts to move and detect the distance of the edge for the parking space to meet $D_{S1} \geq W_C+D_S$. Once the equation is established, it means that the correct position, Z, is reached. On the other hand, the vehicle keeps moving and detecting the distance D_{S1} again, as shown in Figure 8 (a) (b).

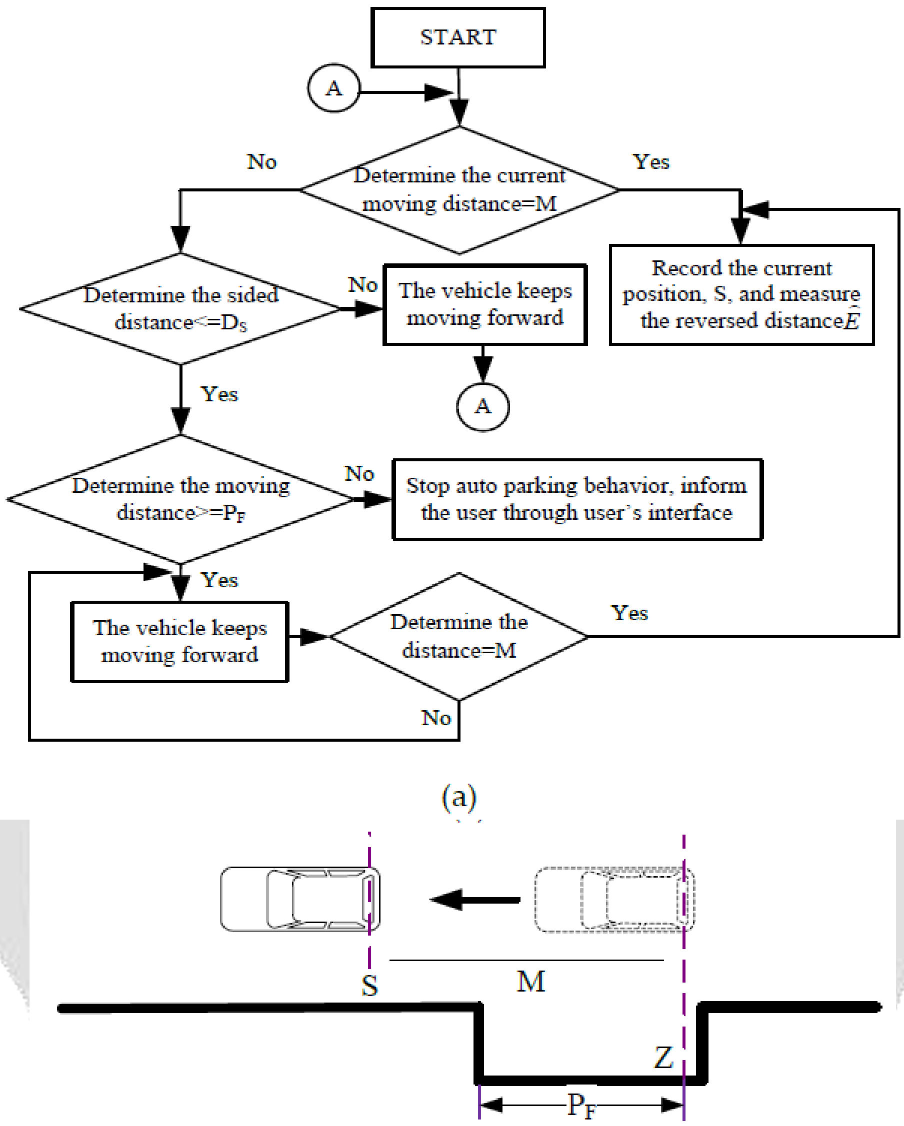


Fig -9: Flow chart of the 2nd movement (b) illustration of parking behavior

Next, when the vehicle moves back to reach to position, Z, the forward distance for the vehicle starts to be calculated. To compare with the moving distance and M obtained from the path formula, it helps to judge the forward distance on whether it reaches S or not. Once the forward distance and M are equal, it shows that the vehicle arrives to the destination exactly. If not, the vehicle keeps detecting until the forward distance and M are the same, as shown in Figure 9(a) (b). When the vehicle reaches S, we must start to calculate the reversed distance to make sure that $\hat{E} = \hat{F}$. Besides, the vehicle can determine the parking space which is larger enough or not.

Finally, step 3 and 4 will be the accomplished parking behavior in the end. When the vehicle enters starting point, S, the steering wheel will be turned to left to the end. Thus, the vehicle switches to reversed parking mode. In the meantime, using algorithm the MCU will also calculate the distance until the vehicle reaches the reversing point, B. If the vehicle reaches B, the MCU will command the vehicle to turn right of the steering wheel to the end. Then, the vehicle starts to be reversed to move into the parking space. The whole parking behavior is accomplished. Therefore, due to the importance of the reversing point, as shown in Figure 10(a) (b), the flow chart is about how to find a reversing point.

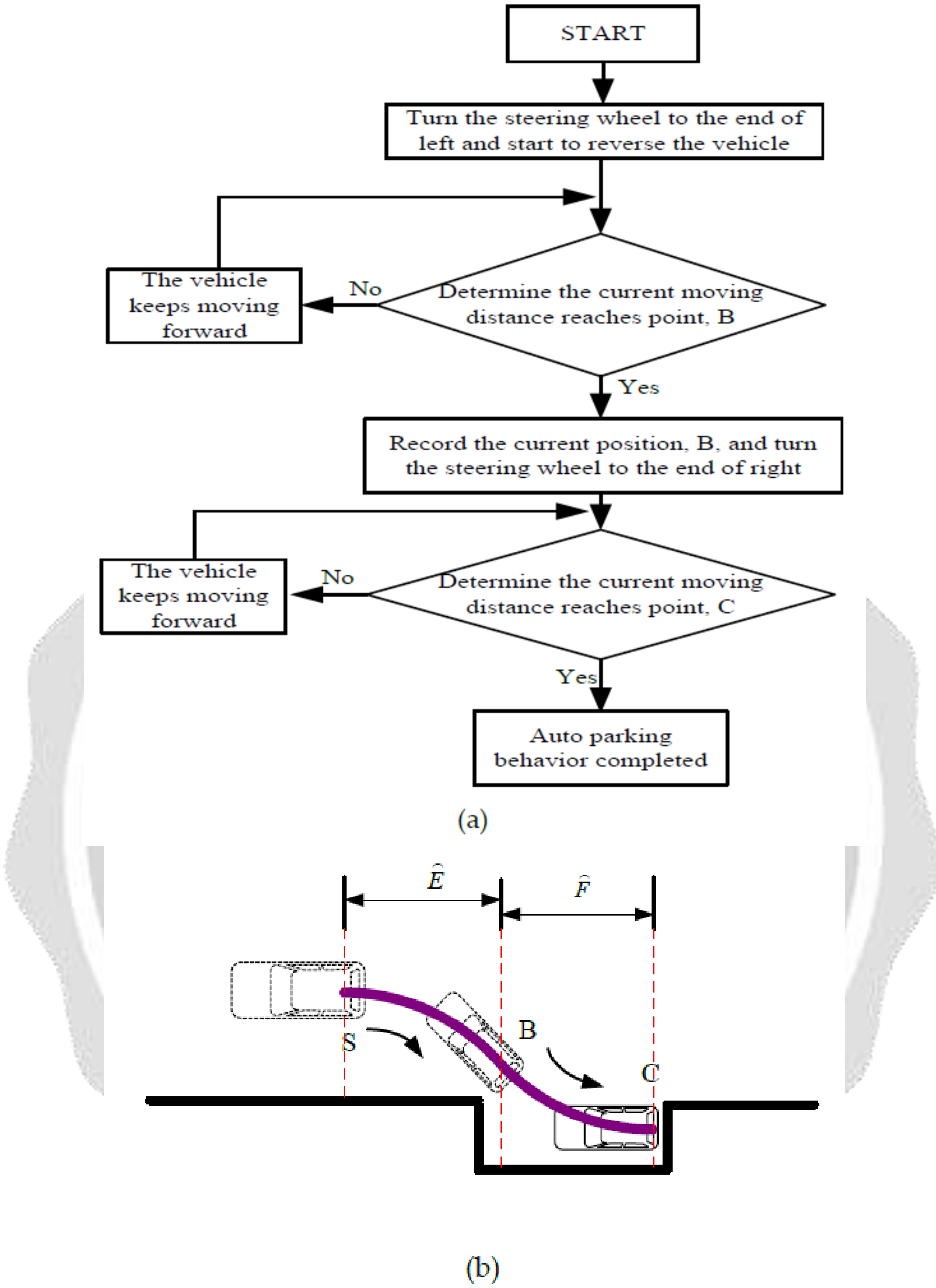


Fig -10: (a) flow chart of the 3rd and 4th movement (b) illustration of reversed parking behavior

Through the description above, the proposed parking strategy can help to park the vehicle into the parking space accurately with only two times rotating behavior.

3. PARKING STRATEGY FOR PERPENDICULAR PARKING ROUTE

The perpendicular parking is the most efficient and economical since it accommodates the most vehicles per linear meter [2] and is especially effective in long term parking areas. Due to the special constraint environments, much attention and driving experience is needed to control the vehicle, and this parking maneuver may be a difficult task. For this reason, automated operation attracts significant attention from research view point, as well, and from the automobile industry. One of the difficulties in achieving automatic parking is the narrow operating place for collision-free motion of the vehicle during the parking maneuver and planning of optimal trajectories is often used in the applications. In [3], an optimal stopping algorithm was designed for parking using an approach combining an occupancy grid with planning optimal trajectories for collision avoidance. The geometry of the perfect parallel parking maneuver is presented in [4]. In [5], a practical reverse parking maneuver planner is given. A trajectory planning method based on forward path generation and backward tracking algorithm, especially suitable for backward parking situations is reported in [6]. A car parking control using trajectory tracking controller is presented in [7]. In [8], a saturated feedback control for an automated parallel parking assist system is reported. In recent years, automatic parking systems have been also developed by several automobile manufacturers.

In this paper, we focus on geometric collision-free path planning, and feedback steering control for perpendicular reverse parking in one maneuver. Geometric path planning based on admissible circular arcs within the available parking spot is presented to steer the vehicle in the direction of the parking place in one maneuver. Two steering controllers (bang-bang and saturated tanh-type) for path tracking are proposed and evaluated.

3.1 Geometrics and mathematics methods

In this paper, a rectangular model of a front-wheel passenger vehicle is assumed. The vehicle parameters which affect the parking maneuver, as well as the parameter values used in the simulations, are presented in Table 1.

Table -1: Vehicle parameters

Vehicle parameters	Notation	Value
Longitudinal vehicle base	l	2.6m
Wheel base	b	1.8m
Distance between the front axle and the front bumper	l1	0.94m
Distance between the rear axle and the rear bumper	l2	0.74m
Maximum steering angle	α_{max}	π/6rad

The geometry of the reverse perpendicular parking in one collision–free maneuver is shown in Fig. 1. In the perpendicular parking scenario considered in this paper, the vehicle starts to move backward from an initial position 1 in the parking aisle, with constant steering angle αc, which may be smaller than the maximum steering angle (|αc| ≤ |αmax|), and has to enter in the parking place (position 2) without colliding with the boundary c1 of parking lot L1 and boundaries c2, and c3 of parking lot L2. In position 2 the orientation of the vehicle is parallel with respect to the parking place. After that, the vehicle continues to move backward in a straight line into the parking place until it reaches the final position 3 (Fig. 1). Assuming a circular motion of the vehicle (with turning radius ρ_c), with center O (Fig. 1). The radius ρc is calculated from the formula:

$$\rho_c = \frac{1}{\tan \alpha_c} \qquad (10)$$

The boundaries of the turning path during the perpendicular parking are determined by the dimensions of the traces (circular arcs) formed by the left corner of the front bumper B2 with radius rB2, the left corner of the rear bumper B4 with radius rB4, and the end of the rear wheel axle C1, respectively, as shown in Fig.1. Since the vehicle executes a plane rotation, the trajectories of these points form arcs of concentric circles.

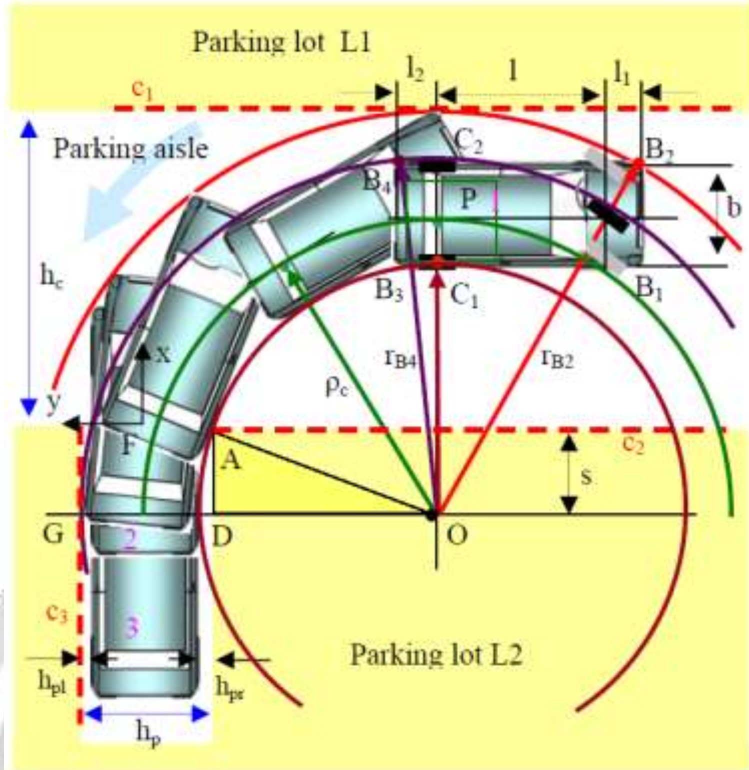


Fig -11: Geometry of the collision-free perpendicular parking maneuver

From the ΔOC_2B_2, applying the Pythagorean Theorem, we obtain an expression for the radius r_{B2} of the circular arc traced by the left corner of the front bumper B_2 in terms of the vehicle parameters l, l_1, b , and the turning radius ρ_c, as follows

$$r_{B2} = OB_2 = \sqrt{(l + l_1)^2 + \left(\rho_c + \frac{b}{2}\right)^2} \tag{11}$$

From the ΔOC2B4, we determine the radius rB4, of the circular arc traced by the left corner of the rear bumper B4

$$r_{B4} = OB_4 = \sqrt{{l_2}^2 + \left(\rho_c + \frac{b}{2}\right)^2} \tag{12}$$

We assign an inertial frame F_{xy} attached to the parking place, where the center F is placed in the middle between the borders of the parking place, which has its y-axis aligned with the boundary c2 of parking lot L2, as shown in Fig. 1. Let O denotes the center of rotation of the vehicle (the Instantaneous Center of Rotation (ICR)) when it starts the parking maneuver with constant steering angle αc. Depending on the sign of x-coordinate of ICR (point O) with respect to the F_{xy} frame, i.e., the offset s (Figure 11), different formulas can be derived in order to determine the required width hp of the parking place and the width of the parking aisle (the corridor) h_c as functions of s in order to ensure collision-free perpendicular parking in one maneuver. We consider right turning of the car in the following two cases:

- The ICR O belongs to the interval: $s \in \left[-\left(\rho_c - \frac{b}{2}\right), 0\right]$

The lower value of the interval corresponds to the case when the right side of the vehicle B1B3 (Figure 11) lies on the boundary line c2 of parking lot L2.

In order to avoid collision between the left corner B2 of the front bumper with the boundary c1 of L1 (Figure 11), using (11), we obtain an expression for the width of the parking aisle h_c, as follows

$$h_c = r_{B2} - |s| = \sqrt{(l + l_1)^2 + \left(\rho_c + \frac{b}{2}\right)^2} - |s| \qquad (13)$$

The function $h_c = f(s)$ defined by (13) is linear in s, positive and monotonically increasing in the above-mentioned closed interval for s. Therefore, it takes its minimum and maximum values at the ends of this interval.
To avoid a collision between the right point C1 of the rear axle with the vertex A of obstacle L2, from the ΔOAD, applying the Pythagorean Theorem, the distance OD (Figure 11) is calculated as follows

$$OD = \sqrt{\left(\rho_c - \frac{b}{2}\right)^2 - s^2} \qquad (14)$$

To avoid a collision between the left corner B4 of the rear bumper with the edge c3 of the parking place, using (12) and (14), the following expression for the width hp of the parking space is obtained

$$h_p = r_{B4} - OD = \sqrt{{l_2}^2 + \left(\rho_c + \frac{b}{2}\right)^2} - \sqrt{\left(\rho_c - \frac{b}{2}\right)^2 - s^2} \qquad (15)$$

The function $h_p = f(s)$ defined by (15) is continuous on the closed interval of s mentioned above. This function is differentiable on the open interval $s \in \left[-\left(\rho_c - \frac{b}{2}\right), 0\right]$, and its derivative is given by

$$\frac{\partial h_p}{\partial s} = \frac{s}{\sqrt{\left(\rho_c - \frac{b}{2}\right)^2 - s^2}} < 0 \qquad (16)$$

Therefore, the function $h_p = f(s)$ is strictly decreasing on the closed interval $\left[-\left(\rho_c - \frac{b}{2}\right), 0\right]$. The maximum and minimum values of h_p can be found by replacing in (15) the boundary values of the interval: $s = -\left(\rho_c - \frac{b}{2}\right)$ and s = 0.

- The ICR O belongs to the interval: $s \in [0, l_2]$

The upper bound l_2 corresponds to the case when the rear bumper lies on the Fy-axis at the instant when the orientation of the vehicle is parallel to the parking place.
In order to avoid a collision between the left corner B2 of the front bumper with the boundary c1 of L1, using (11), we obtain an expression for the width of the parking aisle h_c

$$h_c = r_{B2} + s = \sqrt{(l + l_1)^2 + \left(\rho_c + \frac{b}{2}\right)^2} + s \qquad (17)$$

Again, the function $h_c = f(s)$ defined by (17) is linear in *s*, positive and monotonically increasing in the above-mentioned close interval of *s*. Therefore, it takes its minimum and maximum values at the ends of this interval.

To avoid a collision between the left corner *B4* of the rear bumper with the edge C_3 of the parking place, and between the right point C_1 of the rear vehicle axle with the vertex *A* of obstacle L2, we obtain the following expression for h_p

$$h_p = \sqrt{{l_2}^2 + \left(\rho_c + \frac{b}{2}\right)^2 - s^2} - \left(\rho_c - \frac{b}{2}\right) \qquad (18)$$

The function $h_p = f(s)$ defined by (18), is continuous on the closed interval of. This function is differentiable on the open interval $s \in [0, l_2]$ and the derivative is

$$\frac{\partial h_p}{\partial s} = \frac{s}{\sqrt{l_2^2 + \left(\rho_c + \frac{b}{2}\right)^2 - s^2}} < 0 \qquad (19)$$

Therefore, the function is strictly decreasing on the closed interval s ∈ [2,0l]. The maximum and minimum values of hp can be found by replacing the limit values s = 0 and s = l2 of the interval, respectively, in the expression (19). It should be noted that for s = 0, the two functions defined by (15) and (18) take the same maximum value. For $s = l_2$, the function $h_p = f(s)$ takes minimum value, which is exactly the width b of the vehicle.

From a practical point of view, it is important to determine the starting positions of the vehicle for parking without collision in one maneuver in the case when the widths h_c and h_p of the parking aisle and the parking space, respectively, are specified in advanced. Suppose that the widths of the parking aisle and the parking place are set as $h_p = h_{cd}$ and $h_p = h_{pd}$, respectively, and that $h_{cd} < r_{B2}$. In this case, from (11) and (13), it follows that

$$-|s|_{max} = h_{cd} - r_{B2} \qquad (20)$$

From (12) and (15), we obtain a formula for the minimum value of s as follows

$$-|s|_{max} = -\sqrt{\left(\rho_c - \frac{b}{2}\right)^2 - \left(r_{B4} + h_{pd}\right)^2} \qquad (21)$$

Simulation results were performed to illustrate the relationships between the widths h_c and h_p of the parking aisle and the parking space, respectively, as functions of the offset s in the interval [-(ρ – b/2), 0] by using parameters of the test vehicle (Table I) with $\alpha_c = \alpha_{max}$, ($\rho_c = \rho_{min}$). The values of h_c and h_p, (h_{cd} and h_{pd}), were chosen as follows: $h_{cd} = 6m$ and $h_{pd} = 2.5m$.

As seen from Figure 13, the function $h_p = f(s)$ (the solid blue line) decreases in the interval and converges to b=1.8m (the red dotted line), which is exactly the length of the wheel base of the vehicle. Meanwhile, the graph intersects the horizontal line for the assigned value of $h_{pd} = 2.4m$ (the blue dotted line) at $s = -|s|_{min} = -1.91$m, which is the minimum value of s obtained from (17) for collision-free parking. To park the vehicle in one maneuver for $s = -|s|_{min} = -1.91$m, from (13), the required minimum width h_c of the parking aisle is obtained to be h_c = 4.55m which is less than the specified value of $h_{cd} = 6m$.

The function $h_c = f(s)$ (the green solid line) increases linearly in the interval and the graph intersects the horizontal line for the assigned value of $h_{cd} = 6m$ (the green dotted line) at $s = -|s|_{max} = -0.46$m, which is the maximum value of s, obtained from (16). For $s = -|s|_{max} = -0.46$m, from (14), the required minimum width hp of the parking place must be hp = 1.88m, which is less than the assigned value of h_{pd} = 2.4m.

Therefore, given specified values $h_c = h_{cd}$ = 6m and $h_p = h_{pd}$ = 2.4m for the parking aisle and the parking space, respectively, for collision-free parking, the offset s can take values in the interval $-|s|_{max}[-|s|_{min}, -|s|_{max}]$ = [-1.91m, -0.46m], where the boundary values are determined by (15) and (14), respectively.

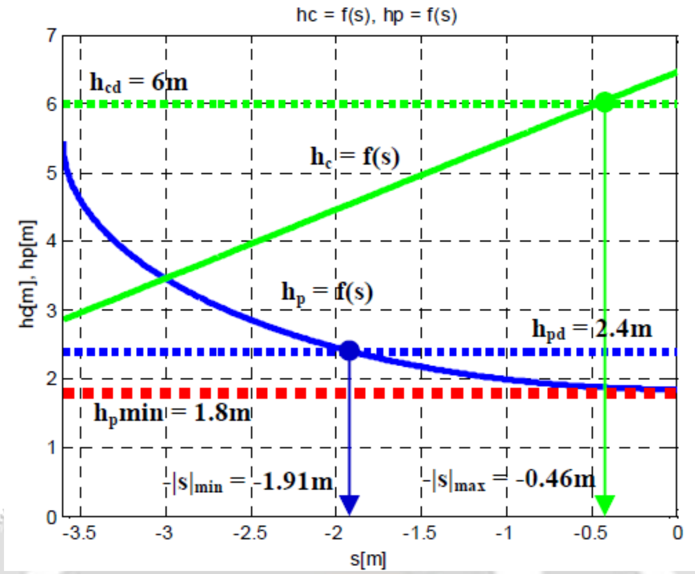


Fig -13: Collision-free interval for s

The distances between the car and the boundaries of the parking space h_{pl} and h_{pr} (Figure 12), when the vehicle is parallel to the parking space, are determined as follows

$$h_{pr} = \left(\rho_c - \frac{b}{2}\right) - \sqrt{\left(\rho_c - \frac{b}{2}\right)^2 - s^2} \quad (22)$$

$$h_{pr} = h_{pd} - b - h_{pd} \quad (23)$$

From the simulations, for $s = -|s|_{min} = -1.91$m, the obtained values of h_{pr} and h_{pl} are h_{pr} = 0.55m and h_{pl} = 0.05m.

From a practical view point, it is better to park the car symmetrically with respect to the boundaries of the parking place, since it is not very wide. For this end, we calculate the minimum value of the offset $s = s_m$, to park the vehicle symmetrically in the center of the parking space (Figure 13). We set:

$$h_{ps} := h_{pr} = h_{pl} = \frac{h_{pd} - b}{2} \quad (24)$$

From the ΔOAD (Figure 14), the distance OD is determined as:

$$OD = \sqrt{\left(\rho_c - \frac{b}{2}\right)^2 - s_m^2} \quad (25)$$

Since the turning radius can be expressed as

$$\rho = \frac{b}{2} + h_{pr} + OD \quad (26)$$

and substituting h_{pr} from (13) and OD from (25) into (26), we arrive to an expression for s_m, as follows:

$$-|s|_{max} = -\sqrt{\left(\rho_c - \frac{b}{2}\right)^2 - \left(\rho_c - \frac{h_{pd}}{2}\right)^2} \qquad (27)$$

The new offset $-|s_m|$ is bigger than those given by (12) $(-|s|_m > -|s|_{min})$. In the simulation results, $-|s|_m$= -1.44m > -1.91m. In general, it must be checked whether the new offset $-|s|_m$ is smaller than -|s|max given by (11). If it is the case, the car can park symmetrically without collision in reverse when s is at least $s = -|s|_m$. In this case, however, the boundary c_3 of the parking place will not be tangent to the arc of circle traced by point B4 of the left corner of the rear bumper; nevertheless, point A (vertex A of obstacle L2) will lie again on the arc of circle traced by point C1 of the rear vehicle axle. Therefore, given specified dimensions of the parking aisle and parking place $h_c = h_{cd}$ and $h_p = h_{pd}$, respectively, the offset s can take values in the closed interval $-|s| \in [-|s|_m, -|s|_{max}]$, where $-|s|_m$ and $-|s|_{max}$ are determined from formulas (18) and (11), respectively, (Figure 13).

Hence, in order to perform reverse perpendicular parking in one maneuver and to place the vehicle symmetrically in the parking place, the starting position, i.e., the reference point P of the vehicle has to be on any one of the arcs of circles with radius ρ of center *O*(x_O, y_O), where $x_O \in [-|s|_m, -|s|_{max}]$ and $y_O = -\rho_C$, with respect to an inertial frame *Fxy* attached to the parking place. The initial orientation must be tangent to the arc (Figure 14). The reference path of the parking maneuver consists of two parts. The first one is a circular arc with center *O* connecting the staring position of the vehicle and the tangent point *T* between the arc and the x-axis of *Fxy*. At that point, the car will be parallel to the parking place. The second part of the reference path is a straight line along the y-axis of the coordinate frame *Fxy* between point *T* and the goal position *G* of the parking place, where point *G* lies on the *x-axis* of *Fxy*, (Figure 13).

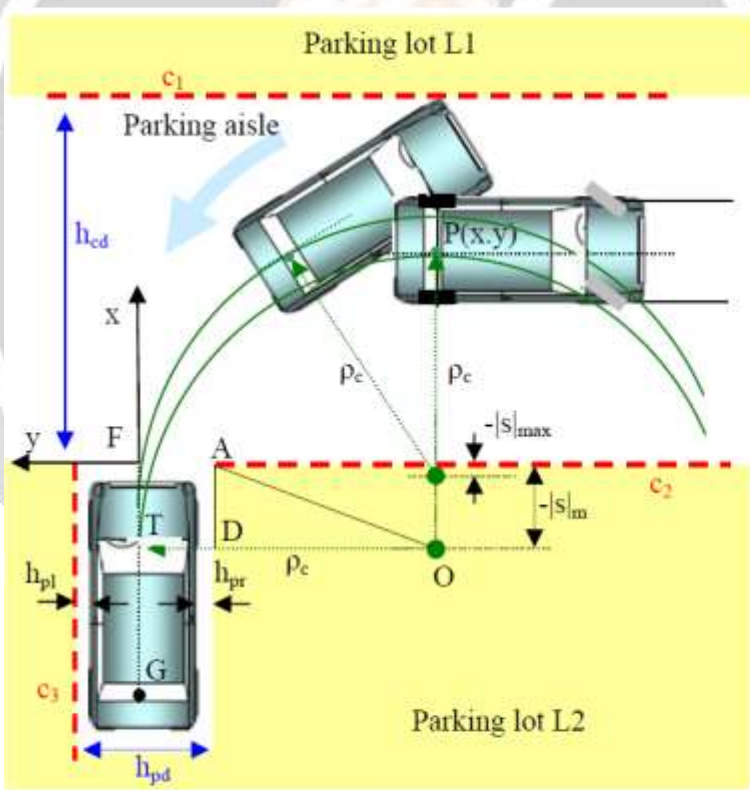
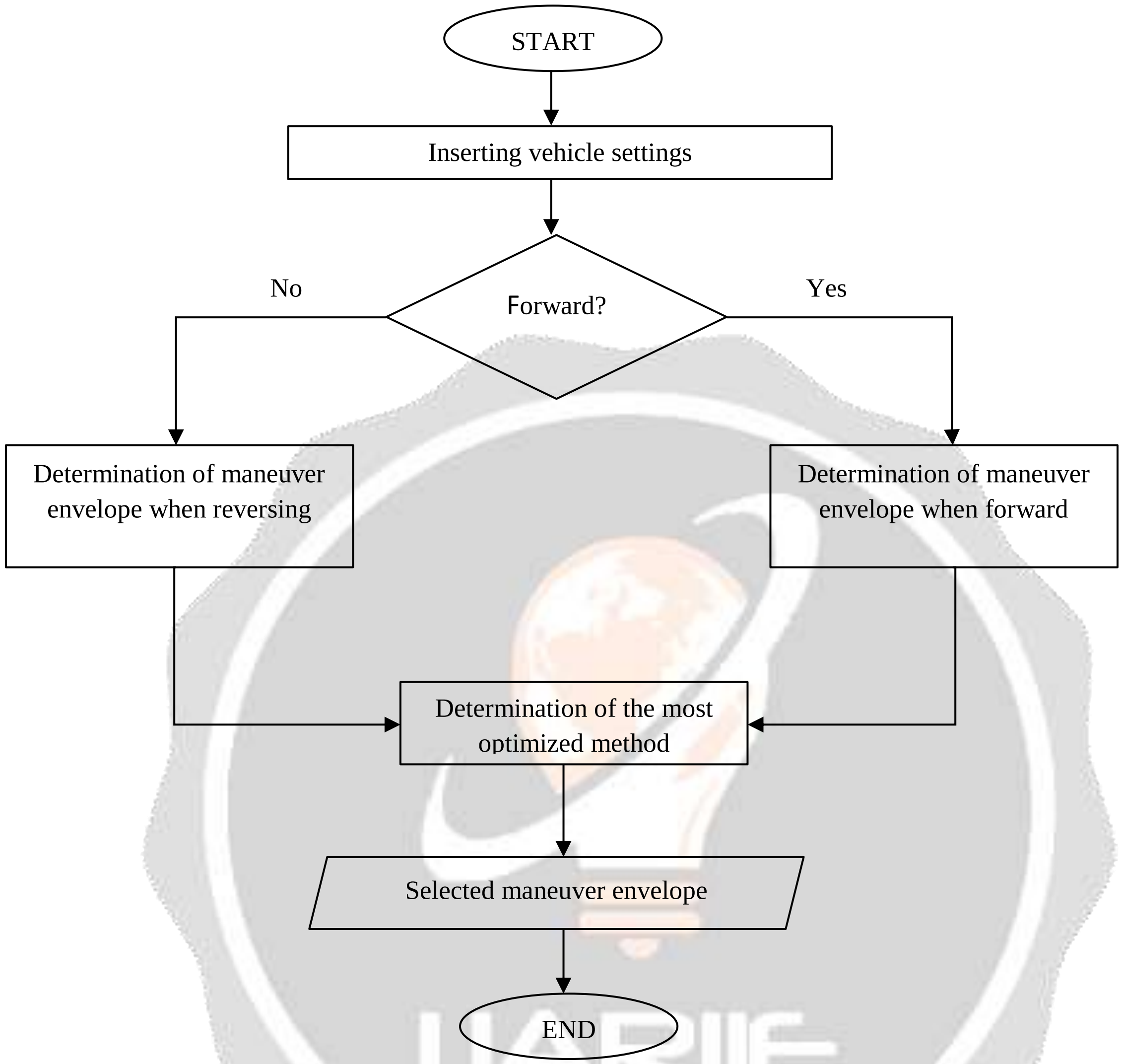


Fig -14: Geometry of collision-free perpendicular parking

3.2 Algorithm



4. CONCLUSIONS

The paper offers a simple auto parking strategy. Auto parking behavior can be achieved easily. The distance between the vehicle and boundary of parking space be detected, referring to the minimum rotating radius. In addition, auto parking behavior will be accomplished without any control of extra rotating angle. An experimental vehicle with auto parking function has been developed. According to the experimental results, APS is satisfactory and available.

In this paper, the problem of perpendicular reverse parking of front wheel steering vehicles was considered. Geometric considerations for collision-free perpendicular parking in one reverse maneuver were first presented, where the shape of the vehicle and the parking environment were expressed as polygons. Relationships between the widths of the parking aisle and parking place, as well as the parameters and the initial position of the vehicle have been given, to plan a collision-free maneuver, in the case, when the car must be symmetrically positioned into the parking place. Two types of steering controllers (bang-bang and saturated controllers) for straight-line tracking have been proposed and evaluated. It was demonstrated that, the saturated tanh-type controller, which is continuous, was able to achieve also quick steering avoiding chattering and can be successfully used in solving parking problems. Simulation results and the first experiments with a test vehicle confirm the effectiveness of the proposed control scheme.

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