

Influencing Factors Research on Vehicle Path Planning Based on Elastic Bands for Collision Avoidance

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ABSTRACT

This paper presents the different influence factors to vehicle's path planning, including the guide-potential shape and its parameters, the guide-potential influence scale factor, the stiffness of the elastic bands and the speed of the host vehicle. The assessment of emergency path is based on the dynamic performance of the host vehicle, the lateral acceleration and yaw rate, and its mean-square values accesses the stability of the host vehicle when following the path. In order to take evasion maneuvers more steadily, a guide-potential affecting the moving vehicles behind the obstacle is built, which encourages the host vehicle to change lane appropriately. Three different shape guide-potential models, namely half-circle-like, half-ellipse-like and parabola-like, are proposed and compared in this paper. Meanwhile, hazard map of the road environment which includes the lanes, borders and obstacles is generated. Trajectory of low hazard level is generated based on virtual elastic bands which are composed with a number of nodes. Thus, the forces acting on the corresponding nodes of an elastic band are calculated by the directional derivate of those potentials. The sum of the forces acting on each node of the elastic bands should be zero due to equilibrium condition. The simulation results show that the stiffness of the elastic bands and the speed of the host vehicle have the most significance influence to the emergency path generating, the guide-potential influence scale factor and the parameters of the guide-potential follow the second, while the shape of the guide-potential has the least influence.

CITATION: Song, X., Cao, H. and Huang, J., "Influencing Factors Research on Vehicle Path Planning Based on Elastic Bands for Collision Avoidance," *SAE Int. J. Passeng. Cars - Electron. Electr. Syst.* 5(2):2012, doi:10.4271/2012-01-2015.

INTRODUCTION

Vehicle collision avoidance and driver assistance systems are active safety field of research. Statics show that over 60,000 people died because of traffic accident in 2011 in China. The casualty is huge, while active driver assistance systems that support in guiding and stabilizing the vehicle is very promising approach which will hope to avoid traffic accidents. For vehicle emergency path planning, a method based on artificially potential field, originally motivated by works in the field of robotics (Quinlan and Khatib[1] [2]) is modified for the problem of automotive guidance and extended compared to related methods (Gehrig and Stein[3], 2001; Higert et al.[4], 2003). And an important contribution of the predictive motion planning approach is the incorporation with the moving objects. This method has some advantages compared to geometric path planning, as proposed in Sattel and Brandt [5] (2004). Brandt and Sattel's work [5, 6, and 8] focuses on lateral guidance strategies and environment inception with GPS and sensor data. An extension of the elastic bands path-planning method incorporating with vehicle dynamics is proposed in Hesse and

Sattel [6][7] (2007). And a further research on path planning with potential field based and elastic bands (Sattel and Brandt [8] (2008)), gives a more specific and systematic approach.

The artificial potential method is used more and more widely in vehicle lane-keeping and lane-changing[9]; the dynamics of the vehicle are coupled with the environment, which ensures the system exhibits safe motion in the absence of the driver inputs[10][11]. It is also used on collision avoidance on high-way [12]. There are some other approaches for path planning in emergency situation, for example, with a propagation method, possible and unavoidable collisions are identified to derive evasive trajectories in scenarios with multiple objects [13]. Beyond that, a tree search algorithm and mixed-integer linear programming for multiple objects could be used [14].

Our previous work is based on Sattel and Brandt's, but we found that the vehicle took emergency evasion maneuver only the time closing to the obstacle, which means the vehicle might become unstable with a high speed in that situation. Thus, the obstacle vehicle model with a guide potential is proposed, the simulation results show that when the obstacle

with a guide-potential, the host vehicle following the trajectory gets a lower lateral acceleration. That implies the host vehicle could be safer and stabler, especially with a scenario in high speed. Meanwhile simulations show that a variety factors affecting the path generation such as the guide-potential influence scale factor, the shape of guide-potential and its parameters, the stiffness of the elastic band and the speed of the host vehicle and so on. Therefore, typical factors are discussed in the paper. The scenarios are simulated in Carsim and the better path is obtained according to the dynamic performance of the host vehicle following the trajectory.

HAZARD MAP GENERATION

REFERENCE FRAME

For the path planning, the reference frames are depicted in Fig. 1, including road fixed reference frame, road-fixed reference frame moving tangentially along with the road, host vehicle fixed reference frame and obstacle fixed reference frame. At the initial planning instant t_0 , the origin of the road-fixed reference frame is placed laterally from the vehicle center gravity point.

Sensor information about the obstacle's position $\vec{r}_o$, the velocity $\vec{v}_o$, the acceleration $\vec{a}_o$, the orientation ψ_o and the geometry of the obstacle L, W are assumed to be available at the planning instant t_0 . The rotational transformation between the road-fixed reference and the obstacle-fixed reference frame is given by

$$\begin{bmatrix} \vec{e}_{ox} \\ \vec{e}_{oy} \end{bmatrix} = \begin{bmatrix} \cos \psi_o & \sin \psi_o \\ -\sin \psi_o & \cos \psi_o \end{bmatrix} \begin{bmatrix} \vec{e}_x \\ \vec{e}_y \end{bmatrix} \quad (1)$$

It is similar to the host vehicle, with the orientation ψ_v of the host vehicle, the rotational transformation between the road-fixed reference and the host-vehicle-fixed reference frame is given by

$$\begin{bmatrix} \vec{e}_{vx} \\ \vec{e}_{vy} \end{bmatrix} = \begin{bmatrix} \cos \psi_v & \sin \psi_v \\ -\sin \psi_v & \cos \psi_v \end{bmatrix} \begin{bmatrix} \vec{e}_x \\ \vec{e}_y \end{bmatrix} \quad (2)$$

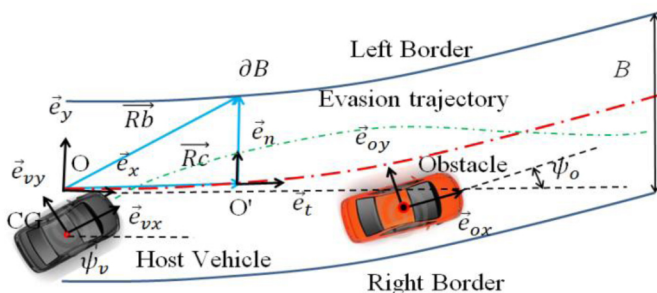


Figure 1. The reference frame and road geometry

ROAD GEOMETRY IMPLEMENTATION

The environment sensors could detect the main course of the road. The width of the road B is identified as well. The road centerline is constructed by a clothoid with a constant curvature change. For a clothoid segment, its curvature c starts at c_0 and varies linearly with arc length l . At a certain point of the clothoid after length l the curvature is:

$$c(l) = c_0 + c_1 l \quad (3)$$

Where the parameters are the initial curvature c_0 , the curvature change c_1 , and the length of the segment l . Since clothoid cannot be evaluated in closed form, clothoid segments are often approximated by the following polynomial in road fixed frame.

$$yc(x) = y_0 + \tau_0 x + \frac{1}{2} c_0 x^2 + \frac{1}{6} c_1 x^3 \quad (4)$$

The initial lateral offset and heading direction are denoted as y_0 and τ_0 respectively. The polynomial model is sufficiently precise as long as the change in heading direction, the heading direction τ of the clothoid segment is less than 15 degrees. As illustrated in Figure 2, the position vector $\vec{Rc}$ of the road centerline in Cartesian coordinates is given by

$$\vec{Rc} = x\vec{e}_x + yc\vec{e}_y \quad (5)$$

Obviously, with the boundary conditions, $yc(0) = 0$, $yc'(0) = 0$ the lateral offset y_0 and tangent the beginning heading direction τ_0 vanish. In normal-tangential coordinates along the road centerline the unit vectors are:

$$\vec{e}_t = \frac{\vec{Rc}'}{\|\vec{Rc}'\|} = \frac{\vec{e}_x + yc'\vec{e}_y}{\sqrt{1 + yc'^2}}, \vec{e}_n = \frac{\vec{Rc}'}{\|\vec{Rc}'\|} = \frac{-yc'\vec{e}_x + \vec{e}_y}{\sqrt{1 + yc'^2}} \quad (6)$$

Thus, the corresponding points at the borders of the road are given by

$$\vec{Rb} = \vec{Rc} \pm \frac{B}{2} \vec{e}_n \quad (7)$$

As for the points on the road, the position vector is

$$\vec{R} = x\vec{e}_x + y\vec{e}_y \quad (8)$$

Considered that the angle of the clothoid segment of the road is small, with a small curvature assumption, the position

vector of the points on the road could approximately express as

$$\vec{R} \approx \vec{Rc} + (y - y_c)\vec{e}_n \quad (9)$$

INTERNAL POTENTIAL IN ELASTIC BAND

We assume that the collision free path is controlled by an elastic band [6] as illustrated in Figure 3; the elastic band is composed with N nodes. Each node P_i of the elastic band is represented by its position vector $\vec{r}_i$ with respect to the center of the vehicle reference frame at the planning instant t_0 . The position vector of each node is denoted by

$$\vec{r}_i = x_i\vec{e}_{vx} + y_i\vec{e}_{vy} \quad (10)$$

The node P_0 is fixed on the vehicle and the ending node P_N is also fixed ahead far away from the vehicle. Thus, the boundary condition of the elastic band is given by,

$$\vec{r}_0 = \begin{bmatrix} x_0 \\ y_0 \end{bmatrix} \quad \vec{r}_N = \begin{bmatrix} x_N \\ y_N \end{bmatrix}$$

Assuming the transitional springs to be linear, each node is immersed in a quadratic internal potential field and it is affected by its neighboring nodes.

$$U_{int,i} = \frac{1}{2} (k_{i-1}(\|\vec{r}_i - \vec{r}_{i-1}\| - l_{i-1})^2 + k_i(\|\vec{r}_{i+1} - \vec{r}_i\| - l_i)^2) \quad (11)$$

With $i = 1, 2, 3, \dots, N-1$ and k_i, l_i represents the spring constant and un-stretched length of the spring respectively. The Euclidean norm is defined as

$$\|\vec{r}_i - \vec{r}_{i-1}\| = \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \quad (12)$$

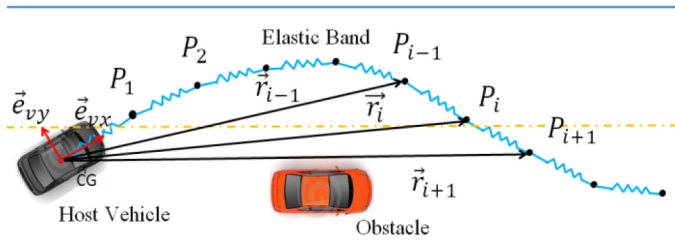


Figure 2. The elastic bands

ROAD POTENTIALS

One of the key parts is creating an appropriate potential function $U(r)$ to constraint the motion and the position of the vehicle. According to the application in the robotic field, the configuration space should have the characters listed below [11]:

1. The vehicle should have a preference to stay in the well-defined lanes and further to stay in the middle of a lane. Furthermore, the direction of travel is limited on the high way.

2. Lateral velocity due to lane change is generally small comparing with longitudinal velocity. Accordingly, acceptable tolerances for obstacle proximity vary by direction; that is, being one meter to the side of another car is more acceptable than following one meter behind.

Thus, we present a potential function for high way driving that encodes avoiding obstacles and road edges while preferring travel in a lane center, which describes detailed in following section.

Lane Potentials

The lane potential creates a barrier to lane changing and keeping the vehicle staying in its lane, but it also should be small enough so that the vehicle could change the lane when necessary for collision avoidance. We choose a Gaussian-like function as the lane potential which list below.

$$U_{lane} = A_{lane} e^{-\frac{(\|\vec{R} - \vec{Rc}\|)^2}{2\sigma^2}} \quad (13)$$

Where A_{lane} is the maximum amplitude of the lane potential and σ determines how quickly the potential rise or fall and is proportional to the lane width. Figure 3(A) shows the cross-section of lane potential.

Road Border Potentials

The road border potential prevents the vehicle leaving the high way. When the vehicle comes close to the edge of the roads, the value of the potential should be become infinite. Thus, we employ a repulsive potential.

$$U_{border,q} = \frac{\eta}{2} \left(\frac{1}{\|\vec{R} - \vec{Rb}_q\|} \right)^2 \quad (14)$$

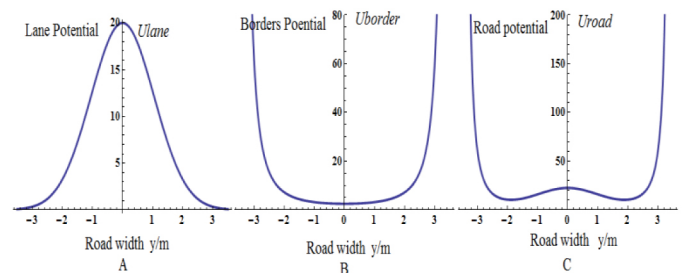


Figure 3. Cross-section of lane (A), borders (B) and road potentials (C)

Where η is a scaling factor and $q \in [1, r]$, which denotes the position of left border or right border.

Figure 3(B) shows the plot and Figure 3(C) shows the roadway cross-section with the cumulative effect of lane, borders and road potentials.

EXTERNAL POTENTIALS OF OBSTACLES

The obstacle vehicle potential aims to keep the host vehicle a safe distance away from itself by building a potential that rises to infinite strength approaching any part of the vehicle. Additionally, the potential must be shaped such a lane change is encouraged if the host vehicle is rapidly approaching from behind. The vehicle should be forced away rather than stop. We choose a logarithmic potential [4] as the obstacle vehicle potential listed below

$$U_{car} = -k_{obst} \cdot \ln \left(\left\| \vec{r} - \vec{r}_o^{(m)} \right\| - r_{safe} \right) \quad (15)$$

Where $\left\| \vec{r} - \vec{r}_o^{(m)} \right\|$ denotes a distance measurement to the m^{th} obstacle, k_{obst} is the scaling factor of the obstacle vehicle. We also introduce the safety circle detailed in [4] for simplicity, r_{safe} is the radius of the safety circle, depicted in the Figure 4.

In order to guide the vehicle avoid the collision each other, particular when a following vehicle behind the obstacle, the potential function influence should occur a larger distance. Thus, an extra guide-potential is added, as shown in Figure 4, a half circle parameterized by τ is appended behind the vehicle. Set (x_o^*, y_o^*) as the middle point of the left border of the obstacle vehicle, so the τ is the distance between the border of the guide-potential and the middle point, depicted in Figure 4.

$$U^{(m)}_{guide} = \begin{cases} -k_{obst} \cdot \ln \left(\left\| \vec{r} - \vec{r}_o^{(m)} \right\| - \tau \right), & x \leq x_o^* \\ 0, & \text{otherwise} \end{cases} \quad (16)$$

This area is also impossible to enter, actually it acts as an additionally safety area behind the obstacle vehicle. However, in order to shrink the effective distance as motivated above, another modification of the model to the $\left\| \vec{r} - \vec{r}_o^{(m)} \right\|$ in the region behind the vehicle is applied. For different guide-potential shape, the calculation of the τ is also different.

Before determine the Euclidean distance to the closest distance on the half-circle, the $\vec{e}_{ox}$ direction relative to the half-circle is scaled by a factor ξ to scale down in $\vec{e}_{ox}$ coordinates (in obstacle reference frame). On a straight road, the transform relation in road fixed reference frame can be easily obtained by

$$\begin{cases} x^* = \xi_m (x - x_o^*) \\ y^* = y - y_o^* \end{cases} \quad (17)$$

That means the current position to half-circle is actually much closer than it really is. In order to ξ is dependent on vehicle speed. For m^{th} obstacle, define

$$\xi_m = \xi_0 e^{-\gamma(v-v_m)} \quad (18)$$

Where v denotes the speed of the host vehicle and v_m is the speed of the obstacle vehicle; x_0 denotes x-coordinates of the center of the half-circle. The exponential factor therefore depend on relative speed, scaled by γ , formulated in (21), set $\beta = -\gamma(v - v_m)$. it is called the guide-potential influence scale factor. ξ_0 represents the scale factor when the vehicles are travelling the same speed and depend on the vehicle's absolute speed. To set ξ_0 we get a "three second rule" which means a following vehicle should allow a distance to the leading vehicle equal to the time travelled in three seconds.

$$\xi_0 = \begin{cases} \frac{d_0}{T_f v} & v \geq \frac{d_0}{T_f} \\ 1 & \text{otherwise} \end{cases} \quad (19)$$

Where T_f (for example 3 seconds) is the desired following time (for example, three seconds) and d_0 is essentially the maximum distance at which the potential exerts an influence, d_1 is the desired distance which the potential actually affect. Finally, for M obstacles, the potential of the vehicle obstacle is given by

$$U_{obst} = \sum_{j=1}^M (U_{car} + U_{guide})^{(j)} \quad (20)$$

DIFFERENT GUIDE-POTENTIAL SHAPE

One key part of the guide potential is the calculation of the τ in (16). The τ denotes the distance between the points on the road and the middle points of the left border of one rectangle obstacle, depicted in Fig 4, it is different as well for various shape guide-potential. Three kinds of guide-potential shape, namely half-circle, half-ellipse and triangle, are discussed in this paper. Thus the way of calculation of the τ for each guide-potential shape is list as follow. The calculation of the τ is derived in the reference frame which the origin is set on (x_o^*, y_o^*) . With different guide-potential, the meaning of a is also various.

Half-circle Shape

The half circle is the simplest case which τ equals the radius r of the half-circle, as shown in Figure 4 (A).

Half-ellipse Shape

As depicted in Figure 4(B), the intersection of an ellipse centered at the origin (x_o^*, y_o^*) which semi-axes are a and b