Collision Avoidance Trajectory Design

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Abstract: *The task of the ACC autonomous vehicle – mobile robot – is to follow a trajectory which is defined of line. During this task, initial unknown obstacles must be avoided. This manoeuvre generates the following problems: designing the avoidance trajectory and controlling the mobile robot on this trajectory. Present work focuses on the first problem: designing the avoidance trajectory. After an introduction in which are discussed the know solutions of this problem, we propose our solution based on the road potential concept. In the end we simulate this solution.*

Keywords: *Mobile Robot, Autonomous Car, Collision avoidance, Trajectory, Potential field of the road*

I INTRODUCTION

The Automotive Competence Centre (ACC) is a main project of Applied Sciences University of Heilbronn, Germany. The aim of this project is to develop a new Competence Centre in the Automotive Industry. The project is divided into several subprojects: Haptics; FEM Optimizations; Dynamic Elastomer Assay; Optical measuring procedures in the car industry etc. One of these subprojects is the ACC project 'Fahrautomat', which has the goal to improve knowledge in the field of car locomotion control engineering. More precisely, we intend to develop (design, simulate and implement), control algorithms that can be used to control an entirely autonomous car. In fact, an autonomous car is a mobile robot. To achieve our purpose, we have transformed a car into a mobile robot and implement several tasks [1]. The 'trajectory following' task demands several actions: defining the trajectory (knowing the map of the road, the trajectory is defined a priory); controlling the car on the trajectory; avoiding possible obstacles which interfere with the car (because there are a priori unknown obstacles the initial defined trajectory must be corrected on line); etc.

After we have solved the trajectory definition and control problems [2] we are confronted with the avoiding obstacle problem. In [3] and [4] two solutions are presented: the first is based on the mathematical theory of differential games, and the second, which is called 'the elastic bands', was developed by Quinlan and Khatib for mobile robots path planning. In [3] the two methods are compared and it is proved that the 'elastic band' method is more suitable for path planning. This method is based on repulsive potential field generation. More precisely the road (the right and left kerb) and the obstacles are modelled by an elastic network which is composed by several nodes linked by springs. The nodes are disposed on the right and left kerbs. The spring's stiffness is related to the desired trajectory which is the equilibrium position of the network in the absence of the obstacle. The presence of the obstacle (a new point and new springs) will perturb the initial position of the network and will generate a new equilibrium position. Using this equilibrium position a smooth avoiding trajectory is designed.

From our point of view this method has the following inconvenient: first, because of the nonlinear stiffness definition, the equilibrium position computation is a time consuming process, and second, in practice, the shape and the dimensions of the obstacle are discovered during the avoiding manoeuvre.

II MINIMUM POTENTIAL FIELD CONCEPT

a) The Definition of the Problem

Before introducing our solution we must define the task that we intend to accomplish.

The car is following a trajectory and in a certain moment, discovers an obstacle which makes the initial trajectory impossible to pursuit. The car control system must react and perform the following on line tasks: discover the shape and dimensions of the obstacle; compute the avoiding trajectory; control the robot on the trajectory and, in the end, return to the initial trajectory. Some comments are necessary: because the obstacle is discovered on line, during the avoiding manoeuvre, the avoiding trajectory will be composed by several parts; this means that, on line, the control system must perform a loop which is composed by: discovering the obstacle and the road (the universe), designing a part of the avoiding trajectory and controlling the robot (car) on this trajectory part.

Because this is an on line process we must avoid time consuming computation. For this reason we must link together, from mathematical point of view, the universe knowledge with the trajectory generation. This means that it is important to consider the sensors behaviour when we design the avoiding trajectory.

b) The Potential Field

In fact, if we analyze the '*elastic bands'* solution we can see that the escaping trajectory is the static deformation of a hypothetically elastic network associated with the car, road and obstacle. It is also know that the equilibrium of these kinds of structures can be obtained by imposing a minimum potential energy condition. Our idea starts from this point: it is not necessary to construct such a complicated potential field and to compute the nonlinear solution of equilibrium; it is more suitable to construct a simple potential field which can be used very quickly.

The construction of the potential field is related on finding a mathematical function which has the following properties: in absence of the obstacle, the minimum of this function is the initial trajectory; the presence of the obstacle will generate a new minimum which will avoid the obstacle; the computation of minimum must be a non time consuming process; the function definition can be linked to the relative speed between the obstacle and the car; the function can be easily constructed, based on the data sensors.

In order to present our potential field concept, we will start with the potential of the road. In Figure 1 is presented the graphically representation of this function, there are two maximums which are linked to the road margins and a minimum linked with the desired trajectory of the car (there are not obstacles yet).

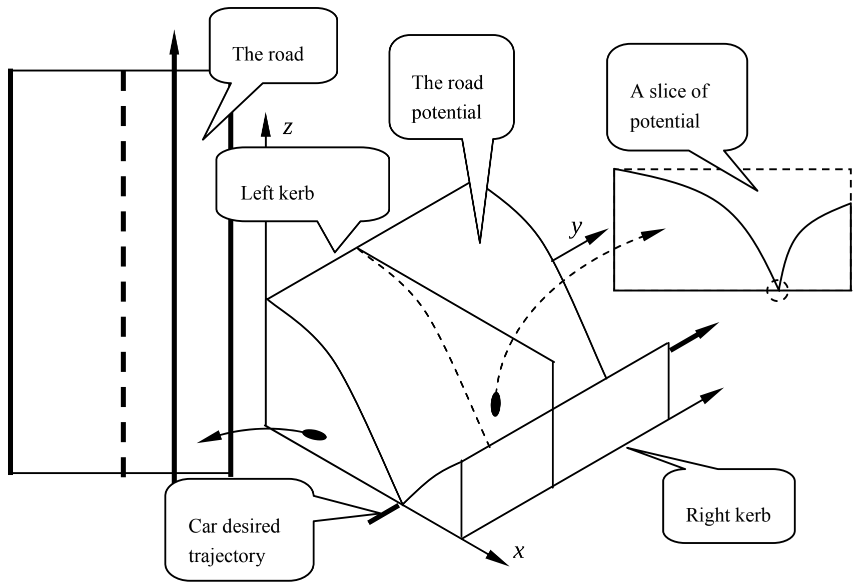


Figure 1
The road potential field

In order to compute easily the minimum of this function: $z_R = z(x, y)$ previously we define a mesh grid$(x_{1...n}, y_{1...m})$. The potential function minimum is a collection of m points. Each point is the minimum of a function slice (see Figure 1) $z_R = z(x_{1...n}, y_i)$ where $i \in (1, m)$. Because the obstacles are discovered in the car referential system, this function must be defined also in this referential system. In Figure 2 is illustrated the link between the road and car referential systems.

The mathematical expression of this function (in the car referential system) is:

$$z_R = \frac{1}{2}\left(m_2\left(sign\left(y - e_y\right) + 1\right) - m_1\left(sign\left(y - e_y\right) - 1\right)\right) \cdot abs\left(y - e_y\right), \quad (1)$$

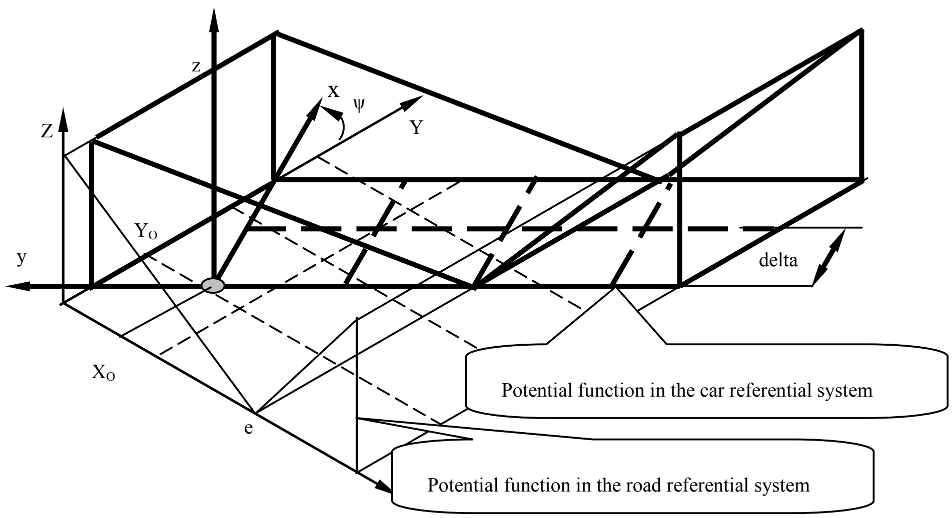


Figure 2
The potential function in the road and car referential systems

where: $e_y = \dfrac{X_O - e}{\cos(\psi)} - x\tan(\psi)$

e is the desired position of the car in the road referential frame; X_O, Y_O is the car position on the road referential frame; ψ is the car orientation $m_1 = \dfrac{1}{L-e}$; $m_2 = \dfrac{1}{e}$; L is the wide of the road

Because we intend to use a laser scanner the obstacle(s) is a collection of scanned points. The idea is to generate a potential function for each point, so in the end the obstacle potential function will be a sum. In Figure 3 is presented the shape of the potential function for one scanned point (no road potential is considered).

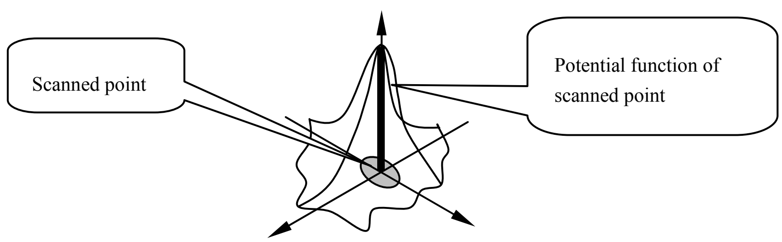


Figure 3
The potential function in the road and car referential systems

For the obstacle we have imagined the following mathematical function:

$$z_O = \sum_{i=1}^{n} e^{-\frac{c_1(y-y_i)^2 + c_2(x-x_i)^2}{2\sigma^2}} \qquad (2)$$

where: c_1, c_2 and σ are parameters linked to the steering motor performance and the relative speed between the car and the obstacle;
x_i, y_i is the position of the scanned point i ($i \in (1,n)$);

To obtain the minimum points we must solve the equation:

$$\begin{Bmatrix} x_i \\ y_i \end{Bmatrix} = \begin{Bmatrix} \min(z_R + z_O) \\ y_i \end{Bmatrix} \Bigg|_{y_i \in (y_{i-1} - I,\, y_{i+1} + I)} \qquad (3)$$

where x_i=0:delta:Lr; Lr is the road length in the xoyz referential frame and I is a parameter. We restrict the search area to $y_i \in (y_{i-1} - I, y_{i-1} + I)$ to avoid shaded minimum points (see the simulations results).

III THE AVOIDING TRAJECTORY

With (3) we have obtained a collection of minimum potential points. Using this result we must design a smooth curve which will be the avoiding trajectory of the mobile robot. Before defining the trajectory some comments are necessary: the smooth trajectory is a C_2 class curve; because the obstacle is discovered during the avoiding manoeuvre we will use only a part of these points. More precisely, the avoiding trajectory will be composed by several parts, for each part definition we imagine a strategy composed by two steps: first, recognize the environment obtain the minimum potential points, use the first *k* points and define the trajectory, and second, control the car (robot) on this trajectory. In Figure 4 we illustrate this idea.

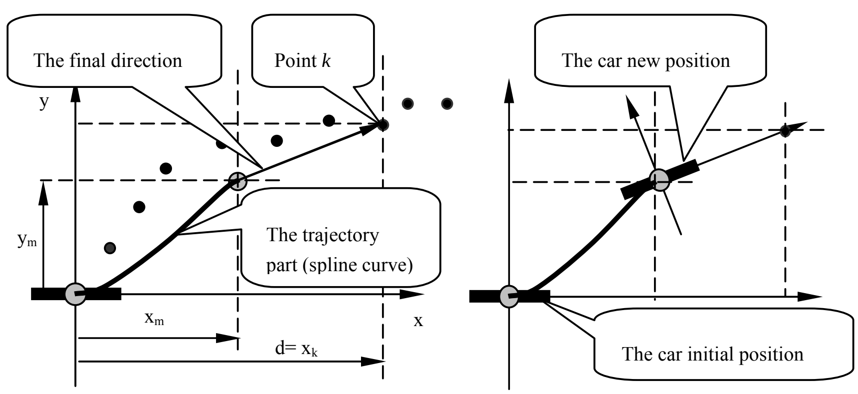


Figure 4
Defining one part of the trajectory

In order to define a part of the trajectory the following steps are necessary:

1. from the minimum points, select the first *k* and compute the middle point x_m, y_m;
2. using the middle point and point *k* define the direction *t*;
3. corroborate the initial position, direction (tangent to Ox) and curvature (0) with the final position (x_m, y_m), direction (*t*), curvature (0) and define a spline trajectory

In the end, for each part, we will obtain a polynomial function:

$$y(x) = a_5 x^5 + a_4 x^4 + \ldots + a_0 \qquad (4)$$

Some comments are necessary:

- The number of points (*k*) is related with a certain length *d* (see Figure 4). Because we have used the mesh grid for the potential function definition we have assumed that the distance between two points is *delta* (see Figure 2); Choosing the first *k* points means that we trust in our prediction enough that we will follow the trajectory upon the distance x_m. To implement this idea we must design an algorithms which will establish the *k* value;
- The final trajectory is composed by several parts. Because each part is a C_2 curve and because of the boundary condition the final trajectory will be also a C_2 curve.

IV SIMULATION RESULTS

In order to avoid obstacle we have proposed a strategy based on the potential field concept. To simulate this strategy we have designed in Matlab a program structure able to reproduce the car behaviour during the avoiding manoeuvre.

More precisely we have:

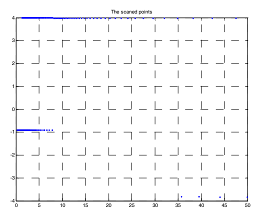
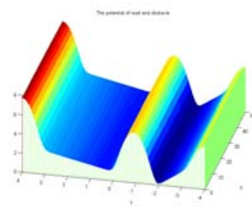
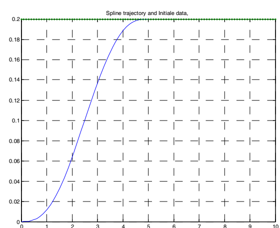
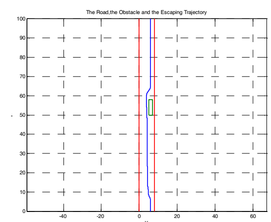
1. Defined the universe: the road left and right kerbs and the obstacles positions;
2. Defined the desired trajectory of the robot (car) which ignore the obstacle;
3. Designed a program which simulates the scanner behaviour;
4. Designed a program which performs the loop: uses the scanner to discover the obstacle, generates the potential function of the universe (road + obstacle) computes the minimum potential points, designs a part of the avoiding trajectory, and assumes that the robot is controlled on this trajectory.

In the simulation we have considered the following initial data: the road width is 8 m, the desired position of the car, measured from the left kerb is 6m, the obstacle position is (6 m, 50 m). The results of simulation are presented in Table 1.

Conclusions

Present work is a part of the ACC Fahrautomat project. The aim of the project is to construct an autonomous car (mobile robot). In order to follow a trajectory we have imagined a control strategy which must include obstacle avoiding algorithms. Avoiding obstacle means first of all, to design a trajectory and after this to control the car on the trajectory.

Table 1

The simulation results (loop number 10)	
 Scanned points	 The potential field
 The avoiding trajectory: part 10	 The final result

This paper focuses on the trajectory design problem, where a new concept: the potential field of the road is proposed. The designing of this trajectory is an, on line process, because the obstacles forms and dimensions are discovered during the avoiding manoeuvre.

Using the concept of the potential field we have integrated the sensors output in a mathematical function. The minimum of this function, which is the avoiding trajectory, can be easily computed.

Even the simulation results confirm our idea to obtain all the parameters of the function, needs experimental tries. In order to pursuit these try we must design the controller which allows following the designed trajectory.

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