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# Modeling the Turning Speed and Car Following Behaviors of Autonomous Vehicles in a Virtual World

## *Modelado de la velocidad en curvas y el comportamiento en seguimiento de coche de vehículos autónomos en un mundo virtual*

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**Abstract**

This article deals with mathematical models for controlling vehicles behavior in a virtual world, where two behaviors are considered: 1) curve turning and 2) car following situations, in this last is essential to provide a safety distance between the leader and the follower and at the same time keep the follower not delayed with respect to the leader, and in a curve turning the complexity is to provide a safety speed inside the curve and keep the car inside the lane. Using basic information as vehicles position, mathematical models can be developed for explaining the heading angle and the autonomous vehicles speed on curves, i.e. the controlled by the models. A model that predicts the autonomous vehicle speed on curves is developed considering previous data in other curves. Two models that control the acceleration/deceleration behavior of autonomous vehicles in a car following situation are proposed. In the first model, the parameters are calibrated with a proposed algorithm which enables accuracy in order to imitate the human behavior for accelerating and braking, and the second model provides a safety distance between the follower and the leader at sudden stops of the latter and employs the acceleration/deceleration top capabilities to follow the leader car similar to the human behavior.

**Keywords:**

- mathematical model
- car following
- curve turning
- autonomous behavior
- simulation

**Resumen**

*Este artículo introduce modelos matemáticos para controlar el comportamiento de vehículos en un mundo virtual; estos comportamientos consideran dos situaciones: 1) en toma de curvas, donde la complejidad es resultado de mantener al vehículo a una velocidad segura durante la toma de la curva y dentro del carril y 2) de seguimiento vehicular, donde es esencial mantener una distancia segura entre los vehículos, así como evitar que el vehículo seguidor quede rezagado con respecto al líder. Usando información básica sobre la posición de los vehículos se desarrollan modelos matemáticos que explican el ángulo de dirección y la velocidad en curvas de vehículos autónomos. Se desarrolla un modelo para predecir la velocidad del vehículo autónomo en curvas considerando datos previos en otras curvas. Se proponen dos modelos para controlar el comportamiento para acelerar y desacelerar de los vehículos autónomos en situaciones de seguimiento de coche, el primer modelo se calibra con un algoritmo propuesto y asemeja el comportamiento humano para acelerar y frenar, el segundo proporciona una distancia segura para evitar colisiones cuando el líder frena repentinamente, además emplea la máxima capacidad para acelerar y desacelerar del vehículo autónomo y asemeja el comportamiento humano.*

***Descriptores:***

- *modelo matemático*
- *seguimiento de coche*
- *tomando curvas*
- *comportamiento autónomo*
- *simulación*

## Introduction

The car following situations had been studied over the years because its importance in understanding and predicting the human behavior to accelerate and brake. A historical review of the models that describe this phenomenon is presented in Brackstone & McDonald (1999), where it can be seen the car following model proposed by Gazis *et al*. (1961), called GHR, with formula $a_f(t) = cv_f^m(t)\Delta v(t-T)/\Delta x^l(t-T)$ where $a_f$ is the car following acceleration, $v_f^m$ is the car following speed, $\Delta v$ and $\Delta x$ are the relative speed and distance between the leader and the follower, *c, m* and *l* are the model parameters. Ceder & May (1976) found the parameters values for congested and uncongested traffic using a larger set of data and concluding that the data is fitted better using two regimens. Treiterer & Myers (1974) split the GHR model in two phases, when the vehicle accelerates or decelerates. Recently in Ma & Andréasson (2006), the reaction time, i.e. the time required by the driver to respond, is estimated and used in the nonlinear General Motor model. The reaction time is calculated analyzing data in the frequency domain through Fourier transform and spectrum analysis, then with the estimated reaction time the parameters of the model are calibrated, the data used for calibration is taken from the stable following regime. In Ranjitkar *et al*. (2005) an optimization considering a genetic algorithm is implemented in order to calibrate car following models, some of these are the Chandler, Gipps, and Leutbach models, the results of their work are the mean and standard deviation of the models parameters optimum values.

In relation with the vehicle speed on curves, it becomes important to consider the curve design and the vehicle behavior in order to implement speed predictions. In Zhang *et al*. (2013) an algorithm based on a recursive least square method with a forgetting factor is employed to calibrate their model, employing as independent variables the vehicle velocity at the entrance of the curve, the road curvature and two regression coefficients, these variables are adjusted for representing a particular user driver behavior. In Wolfermann *et al*. (2011) a model that describes the vehicle speed at intersections is presented, including vehicle turning to right and left, where it was observed that when a vehicle is turning decelerates until a minimum speed is reached, after this accelerates to the desired speed. The profile is explained by the model in two parts, the inflow and outflow, separated by the point when the minimum speed is reached. The model is presented as a polynomial of third degree where the dependent variable is the turning speed and the independent variable is the time, the coefficients are calibrated for the inflow and outflow cases. Considering the speed that a vehicle will maintain on a curve, in Abbas *et al*. (2011) an equation for predicting the 85th percentile operating speed on horizontal curves through multiple linear regression analysis is presented, where the inverse square root of the radius curve and the 85th percentile speed at approach tangent result as significant variables to explain that 85th speed.

Two mathematical models are proposed in this article to control the autonomous vehicles in car following situations. The models simulate the behavior of a vehicle that is following another vehicle in the next