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Predicting Optimal Trajectory of Left-Turning Vehicle at Signalized Intersection

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Abstract

Microscopic simulation is used for safety evaluation of the interactions between turning vehicles and pedestrians/cyclists at signalized intersections. For reliability, the employed models should realistically capture the vehicle turning trajectory. Previous studies considered the vehicle path and speed using different models. However, this may not guarantee consistency of the physical relationship between the location and speed. We propose a minimum jerk theory-based method for modelling the trajectory of a left-turning vehicle at a signalized intersection. The method enables simultaneous determination of the vehicle path and speed and was verified by comparing its results with several empirical trajectories.

Keywords: Left-turning trajectories; Safety simulation; Signalized intersections; Pedestrian safety

1. Introduction

Microscopic simulation models are emerging as useful tools for performance and safety assessments of signalized intersections. The reliability of such tools largely depends on their ability to realistically reproduce the trajectory of a vehicle at the intersection. This requires the accurate capture of the vehicle movement with respect to the path, speed, and acceleration profiles

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Such reliable microscopic simulation tools enable the evaluation of conflicts among turning vehicles and pedestrians/cyclists—considered to constitute a major safety issue at signalized intersections[1][2].

Historical crash statistics-based methods are traditionally, and perhaps most famously, used for the safety assessments of signalized and non-signalized intersections [3][4]. Various crash factors were considered in the foregoing studies to statistically model the relationship between crash occurrence and the contributing factors, which basically comprise the characteristics of drivers and the geometric features of intersections. Traffic conflict analysis methods [5], which utilize empirical data, are also popular. However, due to the difficulties of collecting and processing historical crash data, alternative methods such as traffic simulation-based surrogate safety methods have been more recently employed [6][7]. Unfortunately, most of the microscopic simulation software that are currently used for surrogate safety evaluations utilize simplified vehicle maneuvers (e.g., turning maneuvers) at intersections. Consequently, the properties of the vehicle trajectory, especially the speed variation, at an intersection may not be accurately captured. The application of such tools to surrogate safety assessments is thus questionable. To address these issues, specialized simulation methods for evaluating the safety of signalized intersections have been recently developed, such as that of Tan et al. [8]. However, these methods separately consider the vehicle path and speed profile using different models. For example, Tan et al. [8] integrated the stochastic path model developed by Asano et al. [1] and the speed profile models developed by Wolfermann et al. [9] in a microscopic simulation model for the safety and conflict assessment of signalized intersections. However, such combination of different models does not guarantee consistency of the physical relationship between the location and speed of a turning vehicle. Moreover, it should be borne in mind that not only the path and speed profiles, but additional information such as the properties of the jerk profiles are also required for accurate identification of critical traffic conflicts [10]. It is thus extremely important to precisely represent such kinematic information about a turning vehicle in a microscopic simulation model for safety evaluation.

In view of the above-highlighted gaps in current technology, this paper proposes a novel method for modelling the trajectory of a turning vehicle at a signalized intersection. The proposed method is based on the minimum jerk theory, which has been used to describe the skillful movement of the human arm during writing, reaching, and catching tasks. A vehicle turning maneuver performed by a driver was also considered as a skilled task in this study, and could therefore be described by the minimum jerk theory. Using trajectory data collected from several signalized intersections, we demonstrated that the proposed modelling method enabled reasonably accurate generation of the trajectories of turning vehicles at intersections with different geometries with respect to the turning radii and intersection angles.

The rest of this paper is structured as follows. The next section briefly discusses the minimum jerk theory and the geometric characteristics of the intersections from which the data utilized in this study were collected. This is followed by a comprehensive description of the proposed modelling method. Trajectories generated using the proposed method are also compared with empirical trajectories. Lastly, the conclusions of the study and associated recommendations are presented.

2. Minimum Jerk Theory

As demonstrated by Flash and Hogan [11], the smoothness of a skilled human planar arm movement during tasks such as reaching, writing, and drawing can be evaluated in terms of the jerk, which is defined as the time derivative of the acceleration. They noted that the objective function that should be minimized to obtain the smoothest trajectory of the hand from an initial position to a final position in a given time t_f is the time integral of the square of the jerk, expressed as follows:

$$\mathrm{J} = \frac{1}{2}\int_0^{t} f\left(\left(\frac{d^3x}{dt^3}\right)^2 + \left(\frac{d^3y}{dt^3}\right)^2\right)dt \tag{1}$$

Pham et al. [12] experimentally demonstrated that the movement of the entire human body, such as during walking, had some common features with that of the hand and could therefore be analyzed using the minimum jerk theory. The minimum jerk approach has also been used to investigate more complex scenarios such as the movement of a