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Application of social force model to pedestrian behavior analysis at signalized crosswalk

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ABSTRACT

Limited pedestrian behavior models shed light on the case at signalized crosswalk, where pedestrian behavior is characterized by group or individual evasion with surrounding pedestrians, collision avoidance with conflicting vehicles, and response to signal control and crosswalk boundary. This study fills this gap by developing a microscopic simulation model for pedestrian behavior analysis at signalized intersection. The social force theory has been employed and adjusted for this purpose. The parameters, including measurable and non-measurable ones, are either directly estimated based on observed dataset or indirectly derived by maximum likelihood estimation. Last, the model performance was confirmed in light of individual trajectory comparison between estimation and observation, passing position distribution at several cross-sections, collision avoidance behavior with conflicting vehicles, and lane-formation phenomenon. The simulation results also concluded that the model enables to visually represent pedestrian crossing behavior as in the real world.

1. Introduction

The importance of modeling pedestrian behavior has been well recognized in both fields of safety and capacity assessment of road facilities (Papadimitriou et al., 2009). In this regard, simulation can be a powerful tool for pedestrian behavior reproduction. It has been successfully applied to human navigation analysis (Usher and Strawderman, 2010; Kneidl et al., 2013), pedestrian facility assessment (Zhang et al., 2008; Maria et al., 2013) and crowd dynamic analysis (Hoogendoorn and Daamen, 2005; Helbing et al., 2005). The simulation technology offers a flexible approach for detailed analysis of pedestrian behavior that may result in safety or efficiency problem at road facilities.

This study is part of intensive efforts to develop a microscopic simulation model for safety assessment at signalized intersection. Although signalized crosswalks are operated to give pedestrians prioritized right of way, more than 30% of the total traffic accident fatalities in Japan are pedestrians at crosswalks (National Police Agency of Japan, 2013) whereas 15% in Germany (German Institute for Economic Research, 2010). Many reasons exist behind such statistics, such as risk-taking behavior, intersection geometry, and traffic signal control. Among these factors, stochastic pedestrian behavior is deemed

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as a critical factor that may result in safety problems. In order to develop such a simulation model, pedestrian behavior must be reasonably represented.

To date, pedestrian behavior modeling has attracted considerable attention. With comparison to macroscopic models, microscopic models provide a more detailed description of pedestrian behavior. Generally, existing microscopic models can be classified into two categories: discrete and continuum models.

The family of discrete models essentially includes discrete choice model (Antonini et al., 2006; Robin et al., 2009; Guo and Huang, 2012), lattice gas model (Helbing et al., 2003; Guo and Huang, 2008) and cellular automaton model (Burstedde et al., 2001; Kirchner and Schadschneider, 2002), in which space is discretized to approximate real pedestrian movement. It is convenient to set various rules in a discrete model, such as direction keeping, destination orientation, free-flow acceleration, leader–follower maneuver, and collision avoidance. However, only limited choices for speed and direction in a discrete choice model and limited cellular alternatives in a cellular automaton model are provided, which is difficult to represent the flexible pedestrian behavior, especially for the interactive case in the real world.

Continuum models use differential equations to describe the dynamic movement in space. At the early stage, a magnetic-force model was developed by borrowing a motion equation used for magnetic fields (Okazaki, 1979). Based on this concept, a more robust physical force based model, i.e., social force model, was applied to evacuation analysis (Helbing and Molnar, 1995). A comparison overview of crowd motion simulation models shows that the force based model has many advantages (Duives et al., 2013). Firstly, it enables to describe the dynamic movement of pedestrian in space and time. Secondly, each equation and parameter can be easily explained from the viewpoint of kinematics. Thirdly, it allows reproducing the typical features of pedestrian flow, such as lane formation and oscillation, due to the interaction with other pedestrians (Helbing et al., 2000, 2001). Although numerous studies based on social force model focused on the general mechanism of pedestrian behavior, few of them shed light on the application of social force model to pedestrian behavior at signalized crosswalk. Teknomo (2006) developed a social force based model and analyzed the pedestrian behavior of one-way and two-way pedestrian flow at crosswalk. It was found that two-way traffic performance reduces significantly as the number of pedestrians increase. Li et al. (2012) modified the social force model by considering the required space and the critical gaps with turning vehicles, which makes it possible to describe the stop/go decision to the conflicting vehicles. However, these models, neither fully developed nor calibrated based on real trajectory data, failed to illustrate the crucial pedestrian behavior at crosswalk.

To fill the gap, the special characteristics of pedestrian behavior at signalized crosswalk are considered in this study. It takes into account the crossing behaviors such as group evasive and individual evasive behavior with surrounding pedestrians, collision avoidance with turning vehicles, reaction to crosswalk boundary, and response to signal control, which are all important to evaluate the safety performance of signalized intersections. Then, a statistical method is applied to parameter calibration. In this study, the parameters are separated into two groups, measurable and non-measurable ones. The measurable parameters are directly estimated from the observed trajectory dataset, and the non-measurable parameters are derived by using maximum likelihood estimation (MLE). Last, the results of simulation scenarios conclude that the model enables to represent the typical characteristics of pedestrian behavior at signalized crosswalk such as lane-formation phenomenon, collision avoidance with conflicting vehicles and surrounding pedestrians.

2. Model framework

As shown in Fig. 1, the general structure of the model is based on the decision making level of psychological process. The first level is strategic level, at which pedestrians make a decision of the intended direction. The second level is operational level, which is the second step for pedestrians to adjust their walking behavior at the crosswalk. Note that after reacting to the pedestrian signal phase and deciding to enter the crosswalk, pedestrians will adjust their speeds and directions dynamically when interacting with other road users and crosswalk facilities.

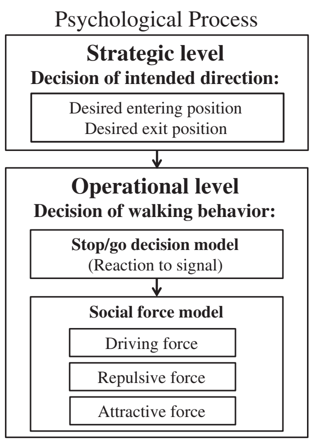

Fig. 1. Psychological process of pedestrian behavior.