Simulating Realistic Pedestrian Behaviors in the Context of Autonomous Vehicles in Shared Spaces

Doctoral Consortium

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ABSTRACT

In this PhD thesis, we investigate how pedestrians will behave in a shared space with an autonomous vehicle, by modeling and simulating realistic pedestrians' behavior. Our approach integrates agent-based social simulation with standard robotic tools. We proposed an agent-based model through extensions of the Social Force Model. We implemented this model as an open source tool to simulate the interactions between pedestrians and an autonomous vehicle in shared spaces. Simulation results, when compared with available data, show that combining an agent-based model and robotics is promising for handling real-world scenarios. The proposed model and simulator are used: 1) to simulate various shared space scenarios with heterogeneous and realistic pedestrians' behaviors; 2) to provide a simulated environment to test autonomous vehicle navigation strategies; 3) to reproduce real-world scenes and predict pedestrians trajectories around the autonomous car in real time.

KEYWORDS

Agent-based modeling and simulation; Crowd simulation; Social force model

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1 INTRODUCTION

In the near future, autonomous vehicles (AVs) will navigate in complex, human-populated urban environments, i.e. shared spaces. A shared space is a place where segregation between pedestrians and vehicles is minimized, by removing road markings, traffic lights, traffic signs and curbs [12]. This quite new urban design approach can be applied to a pedestrian zone, a parking area or a public square in a city center. In shared spaces, pedestrians and vehicles have to negotiate their trajectories without explicit traffic rules [12]. In order to provide AVs with a safe and socially-compliant navigation in shared spaces, we need to anticipate pedestrians' behavior.

In this thesis, we address the following question: how will pedestrians behave in a shared space with an AV? Our work contributes to give the AV knowledge of its current and future social environment by modeling and simulating pedestrians' behaviors. The proposed model and simulations must meet three objectives: 1) to reproduce human navigation to better understand how pedestrians move in crowds, and what social norms they follow; 2) to provide a simulated environment to test AV navigation algorithms in near-real life conditions; and 3) to help predict pedestrians trajectories so that the AV can anticipate and adapt its navigation.

Microscopic approaches like Social Force Models (SFM) [7, 13, 14], models based on Reciprocal Velocity Obstacles (RVO) [9, 26], and data-driven models [2, 10] have been widely used to model pedestrian movements. Pedestrians adapt their behavior to the context and these models have been recently adapted to simulate pedestrians in shared spaces with vehicles [1, 3, 4, 11, 22, 27].

In order to meet our objectives, the model needs to reproduce accurate trajectories, with diverse and realistic pedestrians' behaviors, and simulations must be executed faster than real time. However, the existing models have limitations; they are difficult to generalize to various situations, they lack diversity in pedestrians' behavior and sometimes consider that pedestrians have a perfect behavior, they do not consider the social aspect of crowd navigation, or they need a lot of data to learn a model. Moreover, there is no model of shared space that integrates both advanced pedestrians' behavior and robotic functionalities for the AV's behavior.

2 CONTRIBUTIONS

2.1 Methodology

We proposed an agent-based model (ABM), where each pedestrian is represented by an agent with individual behaviors. A crowd of pedestrians is a set of heterogeneous agents, which move in their environment, perceive other agents and collaborate to avoid collisions. The ABM approach has the ability to reproduce specific individual behaviors, and to allow the model to be refined iteratively.

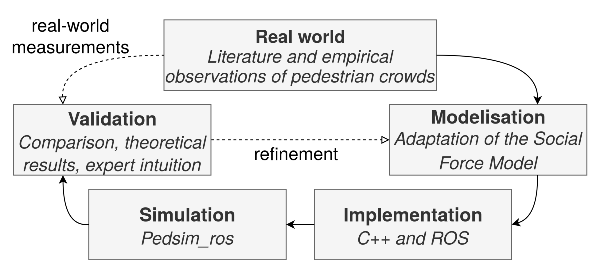

Figure 1: Proposed approach

Figure 1 presents the followed methodology. In the absence of a lot of empirical data, our model is based on video observations, and

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results from literature and social sciences. We proposed extensions to one of the most famous crowd simulation models: the SFM [7]. The SFM uses physical forces to represent the internal motivations of pedestrians to move and avoid collisions. This model does not require large amounts of data and is computationally fast. After implementation, complex scenarios were simulated. The model and the simulations were validated by comparison with real-world measurements and theoretical results.

2.2 Model

In an open environment like a shared space, pedestrian's behavior is governed by social norms, e.g. keep a minimum distance, and pedestrians adapt their behavior according to the crowd density [6]. We proposed an adaptation of the SFM to simulate sparse crowds in shared spaces [17]. The proposed model considers the visual perception and attention of pedestrians, and the adaptations of their personal space depending on the crowd density around them. The SFM of Moussaïd [13] and the refined model were compared through simulations of several crowd scenarios. The results show that the proposed model produces less dense crowds of more dynamic pedestrians with less collisions, which better fits the empirical observations for a sparse crowd. Moreover, the proposed model runs faster and provides a simple way to vary individual characteristics among agents.

Social groups, such as friends, couples, coworkers and families, represent a significant part of most urban crowds [14]. In order to simulate crowds in several contexts of shared space, e.g. a campus, a shopping street or a business area, we need to represent groups with various relationships. We proposed an extension of the SFM of [14], based on empirical observations from literature [18]. Four types of groups are modeled according to social relations: couples, friends, families and coworkers, and forces are customized according to the type of group. We also implemented and compared two approaches from the literature to simulate group avoidance behavior [18]. Intra-group distances and angles, as well as collision avoidance maneuvers in the simulation are compared with the SFM of [14] and with ground truth. The results show that the SFM is very sensitive to intra-group distances, which is of major importance in avoidance behavior of groups. Putting simulated groups members at realistic distances can reproduce realistic group avoidance behaviors. By simply adjusting the distribution of each social relationship in the crowd, the model can simulate many scenarios.

In order to be able to model pedestrians' reactions to an AV, we extended our model with an AV agent, which integrates the AV's characteristics, and kinematic and dynamic constraints in the SFM and generates realistic movements. Pedestrians act with AVs as they do with conventional vehicles [5, 16, 24], and models of pedestrian interactions with conventional vehicles already exist [1, 4, 8, 11, 23, 25, 27]. However, they fail to accurately predict the individual trajectories in real time, and they do not deal with the diversity of pedestrian-AV interactions in a shared space. We proposed a hybrid model of pedestrians' reactions that integrates the different observed pedestrians' behaviors when they encounter a car in shared spaces, i.e. running to cross, stopping to let the car pass, turning, stepping back, as well as groups' behaviors [19]. The proposed model combines the SFM, and a new decision model for conflicting interactions. The model was validated through qualitative and quantitative comparisons with ground truth trajectories, and the predictive capabilities of the model were compared to the SFM. The results show that the model can reproduce the various pedestrian behaviors that occur in shared spaces, and outperforms the SFM at predicting pedestrians trajectories on the used dataset.

2.3 Simulation

The proposed model was implemented in C++ with Pedsim_ros, and is open source and available [20]. Pedsim_ros [15] is an open source crowd simulator that integrates ROS [21], a set of software libraries and tools to develop robot applications . Pedsim_ros can be coupled very easily with robotic tools and developments by robotics specialists. In particular, the AV movements in the simulation can be controlled with ROS commands from an external algorithm, and simulated pedestrians dynamically react to the AV.

Figure 2: Snapshot of a shared space simulation

We designed and implemented scenarios for 3 shared spaces environments and 8 crowd configurations, which gradually go from a simple interaction to very complex interactions with a big crowd, as illustrated by Figure 2. Simulations of other shared space scenarios can be easily designed and executed, by tuning the characteristics of the environment, of the crowd, of the pedestrians, and of the AV.

3 CONCLUSIONS AND FUTURE WORK

This PhD thesis investigates how pedestrians will behave in a shared space with an AV. We model and simulate pedestrians' behaviors, by adapting an ABM to the context of shared spaces with an AV. The proposed model does not require large data sets and was validated by comparison with real-world measurements. Using the proposed model, we provided an agent-based simulator to help the robotics community to develop AV's navigation among humans. The model and simulator can be used to simulate shared space scenarios with heterogeneous pedestrians' behaviors. The simulator offers an environment to test AV navigation algorithms in near-real life conditions and in complete safety. The model can reproduce real-world scenes and can run faster than real time to predict pedestrian trajectories. The simulation can thus be used by a real AV to predict pedestrians' trajectories around it and to adapt its navigation dynamically. The current work is being pursued by testing navigation algorithms on simulated shared space scenarios, and by identifying situations where interactions may be problematic.

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