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Validating social force based models with comprehensive real world motion data

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Abstract

Over the last years multiple variations of the Social Force model have been proposed. While most of the available force-based models are calibrated on observed human movement data, validation for investigating the model characteristics, e.g. variance in parameter values, is still sparse. We present a novel methodology for validating Social Force based models which investigates the reproducibility of human movement behavior on the individual trajectory level with real-world movement data. Our approach estimates model parameter values and their distribution with non-linear regression on observed trajectory data, where the resulting variances of the parameter values represent the model's validity. We demonstrate our approach on a comprehensive (235 pedestrians) and highly accurate (within a few centimeters) set of human movement trajectories obtained from real-world pedestrian traffic with bidirectional flow using an automatic people tracking approach based on Kinect sensors. We validate the Social Force model of Helbing and Molnár (1995), Helbing and Johansson (2009) and Rudloff et al. (2011).

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1. Introduction

Nowadays, pedestrian simulation is used in many different applications and has proven to be a valuable tool to support the design and evaluation of architectural plans, to estimate traffic needs and capacities, to increase safety, efficiency and comfort in crowded areas and to analyze different scenarios for emergency evacuations. Microscopic models, in particular, allow to simulate very detailed human movement interactions on the individual level and thus can reveal a multitude of useful information for designers and planners of infrastructures and urban places. As computational power increases, and becomes more affordable, these microscopic models are also more frequently used for highly complex environments which comprise crowd flows of several 10,000 individuals such as airports, public transit hubs and mass events.

Human movement involves different behavioral processes which according to Hoogendoorn and Bovy (2004) can be roughly grouped into a *strategic* (choice of general behavior, e.g. destinations, and activity area), a *tactical* (activity scheduling and route choice) and an *operational* (short range behavior and instantaneous decisions) level. This paper

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focuses on the microscopic modeling of pedestrian movement on the operational level where a model generally has to take care of the following two tasks: 1) each pedestrian wants to walk with an individual desired speed while 2) keeps a certain distance from other pedestrians and static obstacles.

Various academic tools, e.g. NOMAD (Hoogendoorn (2003)), Hermes (Holl et al. (2014)), and commercial software, e.g. SimWalk (Savannah Simulations), PedGo (TraffGo), VisWalk (PTV), MassMotion (Oasys Software), Cast (ARC), exist. On the operational level, many of them are based or are closely related to the Social Force approach which was first described in Helbing and Molnár (1995). Inspired by the principles of the Social Force model different variations have been proposed in the scientific literature such as in Lakoba et al. (2005), Parisi et al. (2009), Seyfried et al. (2006).

In order to develop a model that is able to represent realistic movement behavior one has to perform model calibration and a validation of the results. Therefore, observations of real pedestrians are needed which can be obtained from (controlled) experiments (Daamen and Hoogendoorn (2012)) or from real-world measurements. Quantitative data from human movement observations can comprise, for instance, travel times, flow rates, speed-density fundamental relation or even trajectories of individual pedestrians. The process of collecting individual trajectories to calibrate microscopic models is cumbersome since robust (including all individuals being in a scene at the same time), accurate (within a few centimeters) and comprehensive (minimum of several 100 individuals) trajectories from various scenarios (e.g. different pedestrian densities) are needed. To meet these high standards, typically video footage of pedestrian movement is recorded and annotated either manually or semi-automatically (Boltes et al. (2010)). Recently, an approach using the Microsoft Kinect as a low cost sensor for obtaining highly accurate people trajectories (Seer et al. (2012)) was shown to be a valuable tool for developers of microscopic models in the calibration and validation process. In this paper we also rely on the data set collected in the work of Seer et al. (2012).

Several calibration procedures were suggested in the literature where in particular two distinct approaches are predominant: the first is model estimation by maximum likelihood or nonlinear least square methods (e.g. Hoogendoorn et al. (2007) or Ko et al. (2013)). However, as shown in Rudloff et al. (2014) this approach suffers strongly from errors in variables due to the large measurement errors from data collection using pure video data. The second approach involves the comparison of real and simulated trajectories (e.g. Moussaïd et al. (2009), Rudloff et al. (2011)) and hence is time consuming as a complete simulation run is needed during each optimization step.

Since the quality of the trajectories from Seer et al. (2012) is significantly higher compared with those automatically extracted from video footage, it needs to be determined if the added data quality makes a nonlinear least square estimation feasible. Many of the available force-based models are calibrated on observed human movement data (e.g. Campanella et al. (2014)) However, validation for investigating the model characteristics, e.g. variance in parameter values, is still sparse. It needs to be determined if the estimated parameters can explain the diverse behavior of pedestrians or if parameters need to be more flexible and differ for different pedestrians. This would suggest that a Social Force model with a single parameter set might not be able to explain pedestrian behavior in different situations for example with respect to different densities.

The contribution of this work is to present a methodology for validating Social Force based models which investigates the reproducibility of human movement behavior on the individual trajectory level for different settings with real-world movement data. Our approach estimates model parameter values and their distribution with non-linear regression on observed trajectory data, where the resulting variances of the parameter values represent the model's validity. We demonstrate our approach on a comprehensive (235 pedestrians) and highly accurate (within a few centimeters) set of human movement trajectories obtained from real-world pedestrian traffic with bidirectional flow using an automatic people tracking approach based on Kinect sensors (Seer et al. (2012)). We validate the Social Force model of Helbing and Molnár (1995), Helbing and Johansson (2009) and Rudloff et al. (2011).

The remainder of this paper is structured as follows. Section 2 describes the variants of the Social Force model that are used in this work. In Section 3, we describe the data set originating from real-world observations and the preprocessing of the trajectories. Section 4 presents our methods of model calibration and validation also including the results. Section 5 concludes the main findings and discusses future research directions.

2. Variants of the Social Force model

In the scientific literature, different variants of the Social Force approach have been described. All of them are based on the principle of modeling behavioral changes guided by so-called *social forces*. Given that the movement of