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Handling obstacles in pedestrian simulations: Models and optimization

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ABSTRACT

In this paper we are concerned with the simulation of crowds in built environments, where obstacles play a role in the dynamics and in the interactions among pedestrians. First of all, we review the state-of-the-art of the techniques for handling obstacles in numerical simulations. Then, we introduce a new modeling technique which guarantees both impermeability and opacity of the obstacles, and does not require ad hoc runtime interventions to avoid collisions. Most important, we solve a complex optimization problem by means of the Particle Swarm Optimization method in order to exploit the so-called Braess's paradox. More precisely, we reduce the evacuation time from a room by adding in the walking area multiple obstacles optimally placed and shaped.

1. Introduction

In this paper we are concerned with the simulation of crowds in built environments, where obstacles play a role in the dynamics and in the interactions among pedestrians. Although obstacles are commonly included in numerical simulations, in many cases no special attention is given to the (numerous) related issues. Usually the method used to handle obstacles is poorly or not at all described, sometimes obstacles are processed as normal boundary conditions or even as frozen pedestrians. We think instead that this matter deserves more attention, especially considering its importance and impact in the simulations. In particular, we refer to simulations which investigate the well-known Braess's paradox [1,2], which states that an additional obstacle or constraint can improve global dynamics. Note that in the case of crowds, placing an additional obstacle may be intuitively seen as a bad idea. However, a well-placed obstacle can decrease the internal pressure among pedestrians and break symmetries in front of an exit, resulting in a faster outflow, see, e.g., [3, Section 6.3]. The obstacles can also facilitate the evacuation ensuring that all the available exits are equally used, see, e.g., [4]. It is then crucial that interactions between crowd and obstacles are correctly handled.

As an introduction to the field of pedestrian modeling, we refer the reader to the survey papers [5–7] and the books [8,9]. Here we consider a macroscopic description of the crowd based on a two-dimensional first-order nonlocal conservation law already considered in [4,8,10–13]. The peculiarity of this formulation is that no fundamental diagram is involved. Moreover, it is proven to be able to catch several self-organizing phenomena actually observed in crowds (see [8, Section 1.1.2] for some examples). However, the model is not naturally endowed with the capability of handling obstacles, which must be added as an independent feature.

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To begin with, we review all the existing (in the knowledge of the authors) techniques employed to handle obstacles in pedestrian simulations, pointing to the main related references. Advantages and drawbacks of each method are discussed. This section can be useful to researchers who are entering the field.

Secondly, we introduce a new modeling technique to handle obstacles which is both simple to implement and effective for realistic simulations, thus giving a valid alternative to the existing techniques. The new method enforces that *obstacles are impermeable* (regardless of the model parameters) and *collisions are avoided* without ad hoc runtime interventions. Pedestrians bypass the obstacle smoothly, are not trapped in bays, and, importantly, they do not see through the obstacles, which are assumed to be *opaque*. This avoids unrealistic effects around thin walls.

Thirdly, we tackle a challenging problem which consists in finding the optimal position and shape of some obstacles so that the global dynamics of pedestrians are improved (e.g., by a reduction of the evacuation time from a room). Several papers investigate numerically the effectiveness of the Braess's paradox by means of both microscopic models (e.g., Helbing's social force model) and macroscopic models, reporting the effect of additional obstacles manually placed in the walking area. See, among others, [14–19]. In this paper, instead, we follow the lines of [4,20–23], where an optimization algorithm is used. The main novelty here is that we consider *multiple free-shaped* obstacles, optimally placed and shaped by means of a modified Particle Swarm Optimization (PSO) method. The PSO is expected to give better results than genetic algorithms [20–22], differential evolution [23], or random compass search [4].

Finally, let us stress the importance of pedestrians guidance in the context of emergency situations. Such a circumstances – although rarely characterized by an actual state of *panic* (intended as irrational, competitive, and non-altruistic behavior) [24,25] – involve fast decision process which can lead to non-optimal route choice. For example, it is known that heading toward the nearest exit is not always the best evacuation strategy [26]. Moreover, people could be influenced by others (social influence or herding effect) and tend to follow people who show definiteness [3,27]. This urges us to design environments where *natural* (intended as actually observed) behavior ideally coincides with the *optimal* (with respect to some criterion to be defined) behavior. This can be achieved by means of suitably placed obstacles, as already investigated in [4].

Paper organization. In Section 2 we review the existing techniques used to handle obstacles in numerical simulations. In Section 3 we present the new method to include obstacles and a first numerical test to show its main features. In Section 4 an outline of the optimization algorithm, together with the description of the techniques for obstacle parameterization and management, is presented. In Section 5 some preliminary tests put some light on the convergence properties and the numerical accuracy of the model. Section 6 contains the results of the optimization of a simple environment.

2. A brief review of obstacles' handling techniques

In this section we briefly review the most common techniques used to deal with obstacles in the literature about pedestrian modeling. A general-purpose survey of pedestrian models can be found in [8]. Here we just recall the two main ingredients of pedestrian models: (i) a *desired velocity* which steer pedestrians toward a (common) target, for example an exit door. This is the velocity field people would follow if they were alone in the walking area; (ii) a *repulsion (social) force* exerted by pedestrians themselves, which accounts for the tendency of people to stay away from crowded regions and avoid collisions.

- *Repulsive obstacles.* One of the most common methods used to manage obstacles is obtained assuming that they generate a repulsive (social) force, exactly as pedestrians themselves do. In other words, obstacles are treated as frozen pedestrians. In this way one can use a repulsion function of the same kind to model both the interactions with group mates and with obstacles. This method is extensively used in microscopic models, see, e.g., [15,28–33] and also in macroscopic and multiscale models, see, e.g., [12,34–36], with or without the pre-evaluation of the distance-to-obstacle function. The main drawback of this approach is that it is quite difficult to tune the strength of the repulsion force in such a way that the resulting behavior is both admissible and realistic. Indeed, if the force is too small there is the risk that pedestrians enter the obstacles, while if it is too large pedestrians bypass the obstacles excessively far away. The paper [34] proposes a method to tune automatically the strength of the repulsion. From the computational point of view, it is useful to note that interactions with obstacles must be computed continuously during the simulation.
- *Cut off of the velocity field.* Another easy method to deal with obstacles is obtained by computing the velocity field first neglecting the presence of the obstacles, then nullifying the component of the velocity vector which points inside the obstacle. This method is used in, e.g., [3,4,11]. Again, handling obstacles in this way is expensive from the computational point of view, since interactions with obstacles must be checked continuously during the computation. Moreover, one must be sure that pedestrians do not stop walking completely because both components of the velocity vector vanish. This can happen around corners, stair-shaped obstacles and when obstacles are very close to each other (i.e. the distance is comparable with the spatial resolution of the numerical grid).
- *Rational turnaround.* In more sophisticated models which take into account the rationality and predictive ability of pedestrians, obstacles can be managed including them into the decision-making process. For example, in the Hughes's model [17] the pedestrians move, at each given time, along the fastest path toward the target, taking into account that the walking speed is reduced in crowded regions. In this framework, obstacles are easily included assuming that inside them the speed is null, so that the computation of the fastest path will circumvent them automatically. In [37] it is assumed that obstacles have a "zone of influence". This is translated by the fact that the admissible maximum speed is reduced as