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Forecasting pedestrian evacuation times by using swarm intelligence

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ABSTRACT

Many models have been developed to provide designers with methods for forecasting the time required for evacuation from various places under a variety of conditions. Particularly for high traffic buildings or buildings of cultural, governmental, or industrial importance, it is of paramount importance to properly evaluate and plan for the necessary evacuation time. To address this need, a number of models for pedestrian simulation, either considering the system as a whole or studying the behavior and decisions of individual pedestrians and their interactions with other pedestrians, have been developed over the years. In this work, a model for evacuation simulation and for estimating evacuation times is proposed. It is inspired by the so-called Particle Swarm Optimization (PSO). The multi-agent-based simulation characteristics of PSO and the way this technique combines individual and collective intelligence make it suitable for this problem. The PSO-based model presented here allows for assessment of the behavioral patterns followed by individuals during a rapid evacuation event. Evaluation of these behaviors can address a variety of public safety concerns, such as architectural design, evacuation protocol definition, and regulation of public space.

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1. Introduction

During the past several decades, many researchers and authorities have shown great interest in traffic problems, especially under critical circumstances [1–4]. For example, researchers have considered safe evacuation of vehicles from parking lots or from wider structures like road networks or even whole cities under extreme conditions, including earthquakes, fires and terrorist attacks, evacuation of people from ocean-going ships [5], and pedestrian evacuation, particularly from high traffic buildings or buildings of cultural, governmental, or industrial importance.

Pedestrian modeling is one of the most appealing fields in traffic science and engineering. Understanding pedestrian flow is very important in designing or improving public places. Nevertheless, pedestrian evacuation is much more difficult to capture than normal pedestrian flow due to particular human behaviors, such as different perception of danger, panic caused by incidents, etc. In addition, real-life experiments on evacuation are almost impossible. This fact has encouraged researchers to simulate evacuation behavior using various modeling approaches.

Different methods from a variety of disciplines (computer graphics, robotics, evacuation dynamics, etc.) have been successfully used to study the problem. A few of these, among others, are the Lattice Gas Model [6,7], Social Force Model [8], Cellular automata [9,10], Discrete Choice Model [3] and Ant Trail Model [11].

In this paper, we present a multi-agent simulation approach implementing a set of rules defining individual and social behaviors borrowed from the field of Particle Swarm Optimization, which the authors have used with success in other fields [12–16]. It must be said from the outset that this problem cannot be viewed as a typical optimization problem due to different reasons. The solution for the evacuation problem is the situation for which all the pedestrians are out of the venue. As a consequence, the solution is known beforehand and what is of interest here is the optimization process itself.

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The fitness function is the sum of the distances between each pedestrian (still in the evacuation area) and the set of exits. The minimization of such a function is achieved by minimizing each individual's distance to the set of exits. Thus, the decision variables are the coordinates of the position of each particle. Consequently, the dimensionality of the problem varies from number_of_individuals × number_of_coordinates (when evacuation starts) to number_of_co-ordinates (for the last pedestrian to evacuate). Of course, the minimum cannot be obtained in one step due to the sundry constraints conditioning pedestrians' movements. These constraints are posed by those elements that prevent an individual from occupying certain positions and by natural speed bounds. Some of these constraints are static, such as those imposed by walls and fixed obstacles in the area. On the other hand, other constraints are dynamic, like the ones imposed by the own pedestrians that prevent other pedestrians from running into them.

The complexity of the problem is addressed through the multi-agent approach considered here borrowed from PSO. Broadly speaking an agent is an identifiable unit which is autonomous and goal-directed. Autonomous because an agent is capable of effective independent action and goal-directed because its autonomous actions are directed towards the achievement of defined tasks. In addition, agents may possess other capabilities, such as intelligence and adaptability. These properties are essential to distinguish agents from ordinary software objects. All in all, agents are a kind of software object, and the use of object-oriented programming techniques greatly facilitates agent-based modeling.

The PSO-based model presented here allows for assessment of the behavioral patterns followed by individuals during a rapid evacuation event and for forecasting the time required for evacuation under different conditions. Classical approaches rely on rough estimates of people flows and velocities and aim to determine evacuation times [17]. By using these evacuation times, allocation of people to different exits, design of evacuation routes and other aspects are fulfilled. However, a number of simplifying hypotheses are used in order to get those evacuation times; these taken most commonly as linear functions, which do not correspond to reality. On the other hand, the conventional Lattice Gas Model, based on a similarity between the dynamics of a crowd and that of a fluid or gas, cannot be used to accurately compute the (average) evacuation time for pedestrians due to the use of regular lattices. In reality, especially in the case of emergency evacuation, there exist interactions between pedestrians and between pedestrians and the building walls, obstacles and doors. So, an approach considering continuous (as opposed to discrete) movement must be considered. Also, the use of complicated formulae to calculate the probabilities for a pedestrian to move to any of the neighbor cells and the use of factors like repulsion, friction, etc., as used, for example in the Social Force Model, which introduces physical forces among pedestrians abiding the laws of Newtonian Mechanics, impose heavy computational burden. In addition, those probabilities are calculated in a deterministic way, and no room for randomness is provided. However, it is a fact that pedestrians' movements have clear random character components. As a consequence, a stochastic technique seems to be more appropriate.

The PSO-based approach we propose here:

- considers continuous movement instead of grid movement, which is more realistic;
- considers not only the individual behavior, but also some social interaction, which is what constitutes the essentials of PSO;
- takes into account randomness, inherent to evacuation processes;
- imposes much less computational burden than other models;
- exhibits great flexibility in order to include other behavioral components;
- provides useful information and gives accurate evacuation times, even with this great flexibility.

In passing, we note that simulations indicate that our model captures the basic characteristics of pedestrian evacuation, revealed by the Social Force Model and the Lattice Gas Model, such as arching and clogging behaviors.

The paper is organized as follows. First, a description of the PSO algorithm is presented, and its different elements are identified in relation to the problem under consideration. Then, the distinctive behavioral rules for the problem and the algorithm used are presented. Next, some practical examples are considered, which take into account location, dimensions, and number of exits. Results of an application to the evacuation of people from a simple area are also presented. Finally, we summarize the paper with our conclusions.

2. Description of PSO

Particle Swarm Optimization is an evolutionary computation technique that was first developed by Kennedy and Eberhart [18]. Their original idea was to simulate the social behavior of a flock of birds trying to reach an unknown destination (fitness function), e.g., the location of food resources when flying through the field (search space). For the problem considered here, the destination would represent any of the exits from the confined spaced under study. In PSO, each problem solution is a bird in the flock and is referred to as a "particle", which, for the purposes of the present study, also refers to each person fleeing from a public space. Initially, a number of particles are generated and distributed randomly around the study area. Different kinds of particles or agents can be generated, exhibiting different physical and/or psychological attributes. Then, particles evolve in terms of their individual and social behaviors and mutually coordinate their movement towards their destination [19].

The ith particle, an element of the aforementioned problem, is represented by its location in an N-dimensional space, where N corresponds to the number of variables of the problem. Naturally, we consider here only 2D or 3D problems, but the algorithm can be extended in a straightforward manner to any dimension. In general optimization problems, any set of values of the N variables determining the particle locations represents a candidate solution for the optimization problem.

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