Commun. Comput. Phys.
doi: 10.4208/cicp.200513.290114a

Vol. **16**, No. 1, pp. 264-286
July 2014

Efficient Dynamic Floor Field Methods for Microscopic Pedestrian Crowd Simulations

Dirk Hartmann[1,*] and Peter Hasel[1]

[1] *Siemens AG, Corporate Technology, 80200 Munich, Germany.*

Received 20 May 2013; Accepted (in revised version) 29 January 2014

Communicated by Chi-Wang Shu

Available online 16 April 2014

Abstract. Floor field methods are one of the most popular medium-scale navigation concepts in microscopic pedestrian simulators. Recently introduced dynamic floor field methods have significantly increased the realism of such simulations, i.e. agreement of spatio-temporal patterns of pedestrian densities in simulations with real world observations. These methods update floor fields continuously taking other pedestrians into account. This implies that computational times are mainly determined by the calculation of floor fields. In this work, we propose a new computational approach for the construction of dynamic floor fields. The approach is based on the one hand on adaptive grid concepts and on the other hand on a directed calculation of floor fields, i.e. the calculation is restricted to the domain of interest. Combining both techniques the computational complexity can be reduced by a factor of 10 as demonstrated by several realistic scenarios. Thus on-line simulations, a requirement of many applications, are possible for moderate realistic scenarios.

AMS subject classifications: 52B10, 65D18, 68U05, 68U07

Key words: Pedestrian dynamics, cellular automata, adaptive grids, floor field methods, fast marching method, navigation.

1 Introduction

The study of pedestrian crowd dynamics is an emerging field in complexity science [18, 35, 36, 42, 52]. Theoretical insights into crowd behaviour are valuable sources for improving such diverse fields as the operation of large buildings and infrastructures, the optimization of passenger exchange times, or the optimization of egress strategies [52].

*Corresponding author. *Email addresses:* `hartmann.dirk@siemens.com` (D. Hartmann), `peter.hasel@googlemail.com` (P. Hasel)

With respect to these applications the realism of the underlying models is of crucial importance, since it ultimately determines the utility and reliability of computational predictions [44]. For a broad overview on the topic of pedestrian crowd simulations we refer e.g. to [2, 3, 23, 30, 46, 52].

Theoretical approaches to pedestrian crowds either adopt a density based description (e.g. [7, 10, 12, 13, 22, 25, 27–30, 58, 59]), i.e. adopt a continuum macroscopic point of view, or explicitly resolve the behaviours of single pedestrians (e.g. [24, 34]), i.e. adopt an individual point of view. Within this work we will restrict ourselves to individual-based models, often referred as microscopic models. Very recently also a hybrid multi-scale approach combining the two modelling concepts has been proposed [10].

The most popular microscopic approaches are continuum social force field models going back to [24], e.g. [8, 9, 37, 41, 45, 63], and discrete cellular automata models, e.g. [4, 5, 16, 21, 26, 32, 34, 43, 52, 56, 60]. One of the central (computational) challenges of microscopic approaches is the navigation of single pedestrians through complex topologies (for a review of navigation strategies in microscopic pedestrian crowd models we refer e.g. to [32, 46, 52]). Navigation of pedestrians typically addresses different spatial scales: long range, medium range and small range aspects. Long range navigation considers more strategic aspects, e.g. navigation using maps, floor plans or signage rather than direct visual information, and can be modelled quite well by a sequence of intermediate destinations. The typical scale is $10 \sim 200$m. Usually graph based approaches are used to model long range navigation decisions [33] (and references therein) or even to optimize long range routing [17, 19]. Medium scale navigation addresses the navigation from one intermediate destination to the next along the shortest or fastest path, e.g. from one graph node to the next. Thus medium scale navigation is based mostly on visibility, i.e. typical scales are $5 \sim 50$m. The most popular approach for medium scale navigation is floor field based navigation. Floor fields are scalar continuum fields, usually of a static nature, and are defined independently of pedestrians present in the scenario, e.g. [4, 5, 32, 34, 52, 56, 60]. Interactions of pedestrian is typically modelled via dynamic short range repulsion (focusing on distances up to $1 \sim 10$m). In contrast to the long range part, this short range interaction is highly dynamic. It is typically modelled using social force models (or corresponding potentials in cellular automaton models)

A common criticism [36] is that these classical navigation strategies do not mimic natural movement behaviour of humans. Most humans take other pedestrians into account once they are visible (independently how far these are away) and not only once they are close enough, i.e. in the short range of $1 \sim 10$m. That is, other pedestrians are included on short as well as medium scale navigation decisions rather than only in short scale navigation decision. This difference typically leads to artefacts in microscopic simulations based on short range interactions of pedestrians (cf. Fig. 1(a)).

Recently, [21] and [36] have proposed independently a dynamic medium range navigation strategy in the context of floor field methods in cellular automata based simulations. (A generalization of these methods to other microscopic pedestrian simulations is possible.) Both works are inspired by concepts for pedestrian navigation originally intro-