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A cognitive pedestrian behavior model for exploratory navigation: Visibility graph based heuristics approach

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ABSTRACT

Navigation is a complex issue in simulating pedestrian dynamics. Many existing studies have investigated how pedestrians navigate from an origin to a specific destination, i.e., traveling to familiar or novel destinations. However, pedestrians' navigation through built environment without specific destinations still remains as an open issue. This exploratory navigation usually involves more spatial cognitive behaviors and perceptual considerations. To represent realistic route choice and natural movement of theses pedestrians, this paper presents a cognitive pedestrian behavior model with a focus on the space visibility and individual characteristics. Then the sensitivity of model parameters is analyzed, indicating that regional target, memory of visiting records and individual crowd tendency can have varied influences on pedestrians' navigation decisions and movement patterns. As a case study, the proposed model is implemented using the pedestrian movement data collected from an observational study of Tate Gallery Museum. The simulation results show good consistency with the actual data at the aggregate level and those obtained individually, indicating that our proposed model is credible and can benefit real applications such as master planning of a museum.

1. Introduction

Pedestrian movement is one of the most basic mobility modes, explorations on which never stop. To predict pedestrian's movement at different simulation environments using current pedestrian models, the origin and destination are usually defined before the moving process is calculated [1]. However, some individuals actually do not have a specific destination at all, for instance, when they are walking around in a museum or in a shopping mall. They would wander and dynamically alter their targets based on their perceptions of the environmental conditions. During the movement process, pedestrians tend to orient themselves by reference to what they can see and where they can go. There is a complementary relationship between visual perception and movement [2]. Thus agents' general movements are directed along their lines of sight, and the location where more lines of sight meeting at would more likely to be chosen by individuals. In other words, visibility graph (VG)—the graph of inter-visible locations in a spatial layout, can be adopted to determine walking potential at different points within the space and facilitate prediction of realistic pedestrian movement [3].

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Most researchers advance the exploration towards the understanding of how pedestrians navigate from an origin to a specific destination, mostly with complete knowledge of the environment. We note there is a research gap in pedestrian navigation literature, i.e., a comprehensive theory and proper simulation models reflecting pedestrians' navigation behavior without specific destinations needs to be developed. This motivates us to investigate into the probable route of a pedestrian who navigates through the environment without a specific destination, i.e., exploratory navigation. The space visibility conditions are incorporated into newly proposed section-and-portal graph to represent walking potential and topological relationship of space. By considering a number of factors affecting pedestrian routing behavior in exploratory navigation, we develop a cognitive pedestrian behavior model with a focus on the realistic navigation strategy and natural movements using simple heuristics. The potential factors that may significantly influence exploratory navigation of pedestrians are discussed, and their influences on pedestrian navigation results and moving performances are analyzed.

The rest of the article is organized as follows. In Section 2, we briefly review the related work in the field of pedestrians' navigation behavior. In Section 3, the proposed model is presented, which includes space representation and algorithms on pedestrians' exploratory navigation. In Section 4, we conduct sensitivity analyses on potential factors influencing exploratory navigation. People movements in a museum is applied as a case study to prove the simulation performance of the prosed model in Section 5. The conclusions are drawn in the final section.

2. Literature review

One of the key challenges of microscopic pedestrian simulation models is the navigation behavior of an individual through complex built environment. According to varied familiarity level to environment and trip purposes, pedestrian navigation behavior can be differentiated into three modes: travel to familiar destination, travel to novel destinations, and exploratory navigation [4]. Commuting between home and work place is a typical example of travel to familiar destinations; wayfinding guided by maps or other devices to unknown places is a typical example of travel to novel destinations; and traveling in a new museum and exploring the surroundings is a typical example of exploratory navigation.

Most existing research work focus on navigation behavior with specific destinations [5–7]. According to different spatial scales involved in interacting with the space layout and other pedestrians, pedestrian navigation approaches can typically be divided into three categories: graph based approaches for long range navigation, floor field based approaches for medium range navigation, and dynamic potential based approach for short range interactions of pedestrians [8]. By means of "nodes" and "edges", graph based approaches can capture many structural properties as well as topological relationships of spatial arrangement. Thus the problem of navigation is simplified to moving from origin to destination through a sequence of intermediate targets as given by the nodes and edges. In this category, the most widely used ones include the Cell and Portal Graph (CPG) [9], Roadmaps [10], and Navigation meshes [11,12]. In terms of the floor field based approaches usually for pedestrian navigation between intermediate targets, highly detailed configurations are needed to represent the environment at a finer scale, such as the Floor Field approach [8,13]. Typically the static floor fields are considered, in which the gradient of each grid corresponds to the repulsive potential at the presence of obstacles and attractive potential generated by the goal [14]. As lacking of representations on presence of dynamic pedestrians, a common criticism for these approaches is that they cannot reveal natural movement behavior of humans, e.g., unrealistic congestion could emerge in "least cost" routes while other routes are seldom used [1]. Therefore recent studies pay more attention on employing dynamic floor fields in medium range navigation decisions [8,15–17]. However, to enable a wide range of applications, the dynamic floor field approach need to largely reduce the computational complexity without losing natural representation of pedestrian behavior [8,18]. The dynamic potential based approach deals with pedestrians' interaction with environment boundary and others at the locomotion level, in which force-based [19,20], rule-based [21], velocity-based [22,23], vision-based [24] and etc. models are usually used to calculate movement potentials in terms of collision avoidance and target approaching. Furthermore, to improve the navigation performance, some hybrid model linking navigation methods among different ranges occur recently [1].

Exploratory navigation within built environment usually involves more spatial cognitive behaviors and perceptual considerations, which has seldom been investigated. The exploration usually depends on directly perceived structure of the environment, i.e., visualization ability, involving a series of comprehensive assessments of the information available [25–27]. Turner et al. [28] proposed Visibility Graphs Analysis (VGA) as those reflecting mutually visible locations in a spatial environment. It is computed by overlaying a two-dimensional grid (at uniform resolution) over a spatial layout, calculating and storing which points within the grid can see other points. As a promising way to reveal individuals' perception on the environment by considering both local and global spatial properties, the visibility graph can predict pedestrians' spatial behavior and affective qualities of indoor spaces [29]. Turner and Penn developed and updated their space syntax based agent model, in which agents randomly select a destination point from their view fields with reassessment of destination point every few steps [29,30]. Although agents correlate with human movement on aggregate, individuals in the models move more erratically than people do in actual environments, involving much backtracking and almost constant turning around [29,31]. It might be due to the frequent change of temporary targets and lack of memory of previous targets. Similarly, as indicated in another research employing random walking process to imitate pedestrian visual search in an urban environment, random walks can not describe the actual pedestrian movement in the strict sense, but concerns topological and geometric properties of the environment [25].