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Prediction of pedestrians routes within a built environment in normal conditions

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ABSTRACT

Modelling and prediction of pedestrian routing behaviours within known built environments has recently attracted the attention of researchers across multiple disciplines, owing to the growing demand on urban resources and requirements for efficient use of public facilities. This study presents an investigation into pedestrians' routing behaviours within an indoor environment under normal, non-panic situations. A network-based method using constrained Delaunay triangulation is adopted, and a utility-based model employing dynamic programming is developed. The main contribution of this study is the formulation of an appropriate utility function that allows an effective application of dynamic programming to predict a series of consecutive waypoints within a built environment. The aim is to generate accurate sequence waypoints for the pedestrian walking path using only structural definitions of the environment as defined in a standard CAD format. The simulation results are benchmarked against those from the A* algorithm, and the outcome positively indicates the usefulness of the proposed method in predicting pedestrians' route selection activities.

1. Introduction

Steering and navigation tasks through an environment constitute an essential activity in our daily lives. Investigations towards establishing an appropriate engineering-based framework that has the potential to predict pedestrians' steering behaviours and developing a synthetic method are the dominant motivations underpinning this study. Indeed, a concrete and accurate model pertaining to pedestrians' steering behaviours is of significance because it has a high practical value in a variety of domains, such as public area design, architectural wayfinding, geo-positioning and navigation, as well as urban planning and environmental design.

Many investigations have been undertaken to improve our understanding of the pedestrian route selection activity. The main research focus is on empirical studies of crowd evacuation behaviours under stressful and panic conditions (Holscher, Brosamle, & Vrachliotis, 2012). However, pedestrians' routing and steering objectives in a normal condition are different from that in a panic situation. In safety critical situations, the pedestrian's primary goal is saving life; therefore the corresponding behaviour, which can sometimes be irrational, is dictated by this goal.

There are two categories of modelling and simulation in pedestrian behaviour research, i.e., microscopic and macroscopic scales (Helbing, 1992). The microscopic scale of modelling typically considers each pedestrian as an active particle that has its attributes and intentions, and interacts with other pedestrians. A microscopic model normally engages the local emergent behaviours and phenomena such as crowd evacuation, lane formation, etc. (Helbing, 2001). On the other hand, the macroscopic scale of modelling considers an overall situation of the problem without taking into account local interactions (AlGadhi & Mahmassani, 1991; Maldonado, Wachowicz, & Vazquez-Hoehne, 2011). Therefore, the rules that govern the pedestrian flow have fluid-like properties. As an example, agent-based models of pedestrian behaviours belong to the microscopic scale, while network-based models of pedestrian behaviours belong to the macroscopic scale, respectively.

Researchers have considered pedestrians' flow from different points of view. In regards to the continuous and deterministic methods, the Helbing social force model (Helbing & Molnair, 1995) is popular. On the other hand, the cellular automata model

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proposed by Blue and Adler (2001) is useful for describing pedestrians' flow in a discrete stochastic framework. An event-based queuing method to model pedestrians' traffic flow has been proposed in Løvas, 1994. In addition, many utility-based approaches, such as decision field theory (Busemeyer & Townsend, 1993) and discrete choice models (Antonini, Bierlaire, & Weber, 2006), have been adopted to construct different models for decision making under uncertainty. Recently, an agent-based paradigm (Zheng, Zhong, & Liu, 2009) has been used to simulate heterogeneous characteristics of pedestrians. Under normal circumstances, different effective properties, such as personal factors, trip characteristics, route characteristics, and socio-economic factors can be considered. As an example, it has been stated (Bitgood, Davey, Huang, & Fung, 2012) that choosing a path with fewer steps constitutes an effective way to navigate within shopping mall intersections in United States and China.

In regards to the modelling approaches identified above, pedestrian movements are described from different perspectives, and are application-dependent. Researches in the field of pedestrian wayfinding have been focused on trajectory predictions, in order to provide rich and useful contextual information (Liu & Karimi, 2006) and location-based information services to complete path finding activities for mobile devices including personal digital assistants (PDA) or mobile phones (Li, 2006). Another application is indoor routing and navigation for pedestrians with disabilities or elderly who have special preferences (Karimi & Ghafourian, 2010). Karimi and Ghafourian (2010) proposed two algorithms, namely ONALIN-FN and ONALIN-PR, to compute a feasible network and a preferred route, which are accessible for visually and mobility impaired. Yet another application is focused on pedestrian safety systems such as driver assistant systems or intelligent vehicles to enable safe interactions with pedestrians.

There are reports relating to routing strategies through the public buildings from various perspectives. For instance, Hill (1982) comprehensively investigated cognitive aspects of pedestrians and routing strategies through observations, Raubal and Worboys (1999) proposed a wayfinding model founded on a framework using image schemata and affordance of the objects in built environment. A case study of an individual finding way within an airport was represented. Holscher, Meilinger, Vrachliotis, Brösamle, and Knauff (2005) focused on the human cognitive processes through wayfinding task within public buildings. They conducted controlled experiments for test participants to investigate the navigation performance within a complex building. Kneidl, Hartmann, and Borrmann (2013) developed a multi-scale model to simulate both small-scale and large-scale wayfinding decisions by determining the fastest path. Those researches advance the exploration towards a comprehensive understanding of how pedestrians navigate through a built environment. However, we note that there exists a gap in the pedestrian routing and wayfinding literature whereby a comprehensive theory that specifies how pedestrians choose a route within a built environment during normal conditions is yet to be established. This leads us to investigate into pedestrian routing behaviour under normal conditions. We consider a number of aspects in movement behaviours, and devise a model that can produce a reliable and meaningful prediction pertaining to pedestrians' routing patterns. In short, the focus of this study is on predicting and generating the probable route of a pedestrian from an origin to a destination in a large built environment under a normal condition using behavioural theories in modelling and simulation. Our aim is to approach the problem from different perspective and investigate towards developing an appropriate engineering framework that has the potential to provide a macroscopic (global) outlook.

The main contribution of this study is a new macroscopic model of pedestrian navigation behaviours that is able to generate a list of consecutive waypoints for prediction of pedestrians' steering paths within a built environment. In the proposed model, the environment is first discretised by using the constrained Delaunay triangulation (CDT) method in order to develop a network, and dynamic programming (DP) is then utilised to generate an itinerary list according to a new stochastic utility function formulated in this study. The proposed model generates a global list of intermediate waypoints, which acts as an itinerary list of consecutive waypoints from the origin to the destination to be followed by a pedestrian within a built environment. The key novelty is development of the optimum waypoints for trajectory prediction in a macroscopic scale by employing DP with only structural definitions of the environment, as defined in a standard AutoCAD format. To gain an in-depth understanding of the usefulness of the proposed model, the popular A* search algorithm (Hart, Nilsson, & Raphael, 1968) for path finding is implemented for performance comparison purposes. The results show that the proposed algorithm outperforms the A* algorithm, but with the expense of a longer computational time.

The rest of this paper is structured as follows. In Section 2, an overview of pedestrians' routing behaviours, which includes effective factors and environmental design values in modelling, is discussed. In Section 3, two path-finding algorithms, i.e., A* search and Dijkstra, are described. A discussion pertaining to the theoretical basis of the proposed method is presented in Section 4. In Section 5, the model structure, assumptions, and model components are explained. Sections 6 and 7 address the travel plan algorithm and simulation results. Finally, conclusions and suggestions for future research are presented.

2. Overview of pedestrians' routing behaviours

2.1. Indoor versus outdoor environments

Many differences exist between indoor and outdoor wayfindings. In Karimi (2011), the major characteristics of indoor versus outdoor environments were categorised. Outdoor areas comprise road and sidewalk networks with different modes of travel, such as driving, biking, and walking. Subsequently, the routing criteria extend from the shortest to the quickest, have fewer intersections, and are more comfortable, or more scenic. The problem space is large; therefore leading to a high complexity in computation. Besides that, unavoidable factors such as weather (deMontigny, Ling, & Zacharias, 2012), street configuration and proximity (Koohsari, Karakiewicz, & Kaczynski, 2012) can impact the walking behaviours.

On the other hand, an indoor space is normally represented by hallway networks. Generally, the main travel mode is walking, and the points of interest (POI) in indoor environments are room, exit, and restroom. The routing criteria are based on the shortest path and accessibility. Moreover, the problem space is defined by small networks with a low computation complexity.

2.2. Pedestrians' routing and navigation behaviours

Pedestrian routing can be divided into two main categories based on spatial and implicit behaviours. Spatial behaviours relate to the physical movement of pedestrians through the environment. They can be represented by equations of velocity, flow, and density (Kuligowski & Gwynne, 2008). On the other hand, implicit behaviours relate to actions that are not performed by pedestrians physically. Delay time, waiting time to start an action, and reaction towards other pedestrians are examples of some implicit actions. They represent thinking and decision making during navigation activities.