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A genetic fuzzy system to model pedestrian walking path in a built environment

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ABSTRACT

A study on the pedestrian's steering behaviour through a built environment in normal circumstances is presented in this paper. The study focuses on the relationship between the environment and the pedestrian's walking trajectory. Owing to the ambiguity and vagueness of the relationship between the pedestrians and the surrounding environment, a genetic fuzzy system is proposed for modelling and simulation of the pedestrian's walking trajectory confronting the environmental stimuli. We apply the genetic algorithm to search for the optimum membership function parameters of the fuzzy model. The proposed system receives the pedestrian's perceived stimuli from the environment as the inputs, and provides the angular change of direction in each step as the output. The environmental stimuli are quantified using the Helbing social force model. Attractive and repulsive forces within the environment represent various environmental stimuli that influence the pedestrian's walking trajectory at each point of the space. To evaluate the effectiveness of the proposed model, three experiments are conducted. The first experimental results are validated against real walking trajectories of participants within a corridor. The second and third experimental results are validated against simulated walking trajectories collected from the AnyLogic® software. Analysis and statistical measurement of the results indicate that the genetic fuzzy system with optimised membership functions produces more accurate and stable prediction of heterogeneous pedestrians' walking trajectories than those from the original fuzzy model.

1. Introduction

The field of pedestrian behaviour modelling and simulation has attracted researchers' attention from multiple disciplines owing to its application in a vast spectrum of domains, including computer graphics, architecture, psychology, urban planning, and robotics [1,2]. The floor layout is one of the key factors that play an important role in a built environment. In terms of designing the indoor areas, operating efficiency of public facilities is a matter of concern that needs to be addressed. Prediction of pedestrians' walking trajectories is an important requirement for efficient design of urban public areas like

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shopping malls and terminals. Nevertheless, the inter-relationship between a pedestrian's walking trajectory and the pedestrian's perception towards the environmental design is often neglected in this area of research. As such, the impetus underlying the current study is to develop a useful model that is able to capture the relationship between the environmental design and the pedestrian's perception, and subsequently to predict the pedestrian's walking trajectory under normal conditions in a built environment. Moreover, a dominant requirement of the model is its ability to provide natural-looking results for the predicted walking trajectories. To meet these requirements, we treat the pedestrian's steering behaviours as a complex model that comprises human perception towards the surrounding environment and the possible reactions towards the environmental stimuli. In this regards, a pedestrian's perception of the surroundings is inherently vague, and is subjective to an individual's characteristics and intention. To deal with the uncertainty and vagueness issues in pedestrian perception–action modelling, we employ a fuzzy logic approach in this study. Fuzzy logic serves as an appropriate framework to incorporate imprecision and subjective features of the environmental perception into the perceptual-action model. In problems that involve human behaviour modelling, fuzzy logic also has certain advantages over other methods, such as the ability to imitate human thought processes [3].

However, the primary challenge in applying a fuzzy-based approach is the manual and time consuming procedure for rule generation and membership parameter tuning [4]. In this study, the fuzzy rule-based model needs to provide outputs with smooth transitions, rather than sudden changes between states, of the walking trajectory. Moreover, the diverse nature of heterogeneous pedestrians with varying speeds and step-lengths of their walking behaviours requires the model parameters to suit each pedestrian's characteristics. As such, there is an obvious need to develop a generic and robust model that covers the walking behaviours of heterogeneous pedestrians.

The novelty of this study is the integration of the concepts of environmental stimuli, pedestrians' subjective and vague perceptions towards the environmental stimuli, and socio-psychological steering forces, to model heterogeneous pedestrians' walking trajectories. The main contributions are twofold: (i) a representation of diverse and imprecise characteristics of pedestrians' perceptions towards the surrounding environment by using a fuzzy-based system; and (ii) inclusion of the environmental design and the corresponding socio-psychological stimuli into the proposed fuzzy-based system by employing the Helbing social force model. Specifically, a genetic fuzzy system (GFS) is proposed, whereby the genetic algorithm (GA) is employed to optimise the associated membership function parameters of the fuzzy model. To the best of the authors' knowledge, this study also constitutes a new application of the GFS in the domain of modelling and prediction of heterogeneous pedestrians' steering behaviours under normal conditions in built environments.

1.1. Background of pedestrian behaviour models

Over the years, researchers have proposed various approaches to model pedestrian behaviours in either individual or crowd situations. Pedestrian behaviours have been considered from different viewpoints. Amongst them, route (itinerary) choice, steering (navigation), wayfinding (path finding), and crossing intersections [5] are the most dominant behaviours [6]. Moreover, the focus of many investigations is on modelling and simulation of behaviours under panic situations such as crowd evacuation due to fire, natural disasters, or terrorism attacks [7–9]). Hamacher et al. [9] employed a dynamic network flow model in a macroscopic scale and a cellular automaton simulation model in a microscopic scale to study the time bound of evacuation. Manley and Kim [8] addressed emergency evacuation from built environments by employing internal forces to follow the shortest path. In a comprehensive study by Zheng et al. [7], seven methods were presented, which were further categorised with six specific features. The features highlighted a number of important aspects pertaining to modelling of pedestrian behaviours, which include heterogeneity, scale of modelling, condition, space, and time steps.

In this paper, we focus on the interaction of individual pedestrians with the surroundings under normal and non-panic situations. The problem is investigated using a microscopic approach. In this aspect, there are three main microscopic approaches, i.e., the social force model (SFM) [10], Cellular Automata (CA) [11], and agent-based model (ABM) [8,12]. The details are as follows.

The Helbing SFM describes a pedestrian's with a mathematical model of attractive and repulsive effects from the surrounding environment with respect to the speed and movement direction [10,13,14]. Contradictory socio-psychological forces within the environment motivate the entity to move towards a desired destination, with an ideal speed. The SFM describes the pedestrian's behaviour in a microscopic level with a continuous deterministic approach. However, capturing complex behavioural rules and behavioural heterogeneity is difficult. Moreover, it is a myopic technique that does not include the vision ability of the pedestrian.

In the second approach, CA expresses the pedestrian flow by a discrete arrangement of the floor into grids of equal cells. According to the CA principles, a pedestrian dynamic model provides a transition matrix that indicates the preferences to move from one cell to the neighbouring cells [11,15]. This method expresses the pedestrian flow in a discrete stochastic framework. Therefore, time and space are discrete elements. This is a drawback for steering behaviour modelling. Another downside of this approach is the weakness in exact calculation of the travel time and distance. Moreover, a cell-based model discretises the floor into cells, which is a limitation for some of the applications that need to consider the topological characteristics of the route.

The recent approach of ABM replicates the pedestrian's behaviour using an agent with different levels of intelligence, or a set of if-then rules for steering behaviour modelling. The key feature of ABM is the capability of representing heterogeneity in a pedestrian's behaviour. During the last two decades, ABM has become an increasingly important approach for modelling