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Inclusion of environmental effects in steering behaviour modelling using fuzzy logic

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ABSTRACT

This paper investigates the effectiveness of a fuzzy logic-based approach to modelling of pedestrian steering behaviours through built environments under normal, non-panic conditions. The proposed approach considers the effects of surrounding objects on a pedestrian's walking path. The developed model associates vague and fuzzy characteristics of a pedestrian's environmental perceptions with his/her steering behaviours. This is a challenging problem, as a pedestrian's perceptions in a specific environment vary from one individual to another, and are subjective in nature. To formulate a realistic model with a high degree of fidelity, a number of factors that include variable pedestrian speeds and step-lengths are incorporated. To validate the proposed fuzzy logic model, a hallway in an indoor environment is used as a case study. A dynamic contour map that represents the effects of physical perceptible objects within the pedestrian's field of view is established, and the proposed model is deployed to yield the predicted walking path of a pedestrian through a corridor. The environmental stimuli are modelled as attractive or repulsive socio-psychological forces that affect the pedestrian's decision in choosing the next step position of the walking trajectory. A data set containing real walking trajectories is collected using appropriate motion tracking devices for evaluation of the proposed model. Four different scenarios are used for evaluation. The predicted walking paths from the fuzzy logic model and the real ones (collected from real experiments) are analysed and compared. The results in terms of statistical error measurements show improved performance in the scenario with variable speeds and step-lengths. The outcomes positively demonstrate the usefulness of the proposed approach in modelling pedestrian steering behaviours.

1. Introduction

Local path determination, known as steering, is a spatial behaviour that is based upon the cognitive process for choosing the next step location (Gibson, 2009). This spatial cognition is important, as it enables an individual to perform activities in relation to the environment, especially in steering and navigation tasks. The cognitive process involved includes obtaining sensory information from the surroundings, and interpreting the obtained information to understand the environment in order to implement the next course of action. Psychologists have named the outcome of this cognitive process 'environmental perception' (Downs & Stea, 2005). Researchers in various disciplines, such as architecture (Hidayetoglu, Yildirim, & Akalin, 2012), environmental design (Samarasekara, Fukahori, & Kubota, 2011), and computer science (Raubal & Worboys, 1999), have developed a range of frameworks with respect to environmental perception. The process by which the energy from physical objects received by a pedestrian which is then converted into perceptions of physical items such as desks, couches, walls, and buildings, is an open question. This paper provides a method to estimate the environmental effects on the steering behaviours of a pedestrian from the engineering perspective.

Garling and Evans (1991) believed that visual perception is necessary to relate the physical environment with spatial actions. They argued that an individual's perception from the physical surroundings directs his/her spatial actions. Lynch (1960) showed that pedestrians obtain and perceive information from the immediate environment to implement locomotion. Interaction with the surrounding environment and physical stimuli from objects within the built environment provides an internal motivation for pedestrians to choose the next step position. In a recent study by Lee, Yang, and Lin (2012), the authors pointed out that social, psychological, and physical stimuli are the internal motivational parameters for

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various movements by pedestrians. In their study, this motivation was represented by a measurement analogue to the Newtonian force.

Gwynne, Galea, Owen, Lawrence, and Filippidis (1999) conducted an extensive research related to different modelling approaches to emergency actions within a built environment. They highlighted four major interacting modelling factors, viz., environment, environmental configuration, behaviour, and procedures. Padgitt and Hund (2012) examined the relationship between the sense of direction and wayfinding efficiency in a complex built environment. In the study of Fajen and Warren (2003), how information exchange with the surrounding environment controls a pedestrian's locomotion tasks was described. The locomotion task is an action that originates from an imperfect observation of the surrounding space, and it leads to imprecise and vague knowledge of the environment (Raubal & Worboys, 1999). Lynch (1960), a pioneer in path-finding research, described a pedestrian's uncertain knowledge of the surroundings in his/her mental image of the environment with fuzzy logic-based features.

According to recent studies by Ma, Song, Fang, Lo, and Liao (2010) and Hidayetoglu et al. (2012), environmental design is one of the indoor environmental factors that directly affects a pedestrian's spatial perception and orientation. These authors identified that further research is required to understand how, and to what extent, environmental design influences the spatial orientation. In this paper, our study concentrates on the prediction of the next step location, whereby influences from the environmental objects are taken into account. A specific gap in research related to walking path prediction is how a pedestrian chooses his/her next step position and speed when he/she is exposed to environmental stimuli during a normal and non-panic situation. As a result, the main objective of this paper is to introduce a modelling approach that considers diverse and subjective nature of the environmental perception by different pedestrians while moving through indoor areas. The following section discusses the related work and justifies the application of fuzzy logic models for pedestrian walking path prediction.

1.1. Related research on fuzzy logic-based concepts

Understanding a pedestrian's perception of the physical environment is largely based upon empirical studies that postulate how different features of the environment, such as landmarks, routes, and configuration, are integrated to build the environmental knowledge and influence the pedestrian's perception towards the environment (Golledge, Ruggles, Pellegrino, & Gale, 1993; Hidayetoglu et al., 2012). Golledge et al. (1993) observed that information acquired from the surroundings is fuzzy, and is subject to a variety of variables. The relationship between a pedestrian's perception and his/her displacement was studied by Wineman and Peponis (2010), with the aim to forecast the pedestrian's movement. In another study, dynamic interactions between a pedestrian and the environment, which incorporate mobile devices to assist in urban wayfinding, was suggested (Li, 2006). Similar to the pedestrian's steering behaviour, a driver's steering model was developed using a fuzzy preference relation method (Ridwan, 2004). In another related work, a fuzzy type II model that addresses the driver's behaviour in high speed signalised intersections was proposed (Hurwitz, Wang, Knodler, Ni, & Moore, 2012).

In a study on crowd simulation (Li, Li, & Liang, 2012), a new approach integrating fuzzy logic with a data-driven method was introduced. The Modified Learning From Example (MLFE) method is applied to extract behavioural rules from state-action data samples extracted from video footage. Tome, Bonzon, Merminod, and Aminian (2008) introduced a fuzzy classifier for Pedestrian Dead Reckoning (PDR) navigation. The classifier combines biomechanical principles with fuzzy logic for recognising a pedestrian's walking behaviour with 3D replacement. In the proposed method, the stride length was calculated by using a simple inverse pendulum model, and a fuzzy logic classifier was proposed to classify the walking behaviour in the broader range of 3D displacement. In the field of pedestrian evacuation, a Takagi–Sugeno type of fuzzy model was used to represent pedestrian dynamics in crowd evacuation behaviours (Zhu, Liu, & Tang, 2008). The main idea is to convert the observed behaviours of the crowd during evacuation to mathematical models based on fuzzy logic approaches.

On the other hand, fuzzy rule-based modelling has been implemented successfully in robot path planning and navigation problems. In this context, a fuzzy rule-based model for robot path planning around a terrain was developed (Seraji & Howard, 2002). Three navigation behaviours, i.e., seek-goal, obstacle avoidance, and traverse terrain, were defined using a fuzzy logic approach. Similar to the robot path planning approach, in the domain of science, such as psychology, social science and biology, the behaviours of complex systems have been observed by a human expert, which were transformed into a linguistic description of the phenomenon. Tron and Margaliot (2004) addressed the application of a fuzzy logic approach to building a mathematical model based on the linguistic description of the observer.

The aforementioned studies advocate that fuzzy logic is an appropriate and reliable approach to explore and represent the heterogeneous nature of a pedestrian's perception–reaction during the steering process. Recent research from different fields, such as robotic, artificial intelligence, geospatial, and navigation, put emphasis on trajectory prediction and utilise this information in various applications, which include providing rich context information (Liu & Karimi, 2006) and location-based information services to complete path finding activities for mobile devices (Li, 2006). In this study, our aim is to consider the use of fuzzy logic for prediction of a pedestrian's walking path within a built environment. More specifically, the proposed model connects spatial configuration to navigation performance, and associates the impacts of the surrounding environment with the walking path. The next section provides an overview of the proposed approach.

1.2. Overview of the paper

In this paper, a fuzzy logic-based approach is proposed to model a pedestrian's steering behaviours in an indoor environment. We postulate that, during pedestrian–environment interaction, one's perception is an imprecise and fuzzy concept. As such, the proposed fuzzy logic model accepts as its input the level of stimulation in three future positions within the pedestrian's field of view. In addition, speed and step-length are two important input variables of the model. The input variables are subject to six membership functions, namely low, medium, and high in both attractive and repulsive forces. The fuzzy inference engine evaluates the inputs and makes a predicted output according to a rule matrix of 216 if–then rules. The output represents the turning angle (in degrees) for the next walking step. To verify and validate the model, an experimental study employing a motion tracking system for real data collection was conducted. The experiment was carried out on a physical layout, and data samples pertaining to the walking trajectories were collected. Then, the fuzzy logic model was used to predict the pedestrians' walking paths under four different scenarios consisting of constant or variable speeds and step-lengths from heterogeneous pedestrians. Statistical error measurements were used to quantify the performances.

The key contributions of this study are: (1) employing the social force method to quantify the attractive or repulsive environmental stimulation as the steering force; (2) using a fuzzy logic approach to handle vagueness and uncertain information of pedestrians'