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Fuzzy Simulation of Pedestrian Walking Path Considering Local Environmental Stimuli

Mojdeh Nasir, Saeid Nahavandi, Douglas Creighton
Centre for Intelligent Systems Research
Deakin University
Victoria, Australia
mnas@deakin.edu.au

Abstract—*Pedestrian steering activity is a perception-based decision making process that involves interaction with the surrounding environment and insight into environmental stimuli. There are many stimuli within the environment that influence pedestrian wayfinding behaviour during walking activities. However, compelling factors such as individual physical and psychological characteristics and trip intention cause the behaviour become a very fuzzy concept. In this paper pedestrian steering behaviour is modelled using a fuzzy logic approach. The objective of this research is to simulate pedestrian walking paths in indoor public environments during normal and non-panic situations. The proposed algorithm introduces a fuzzy logic framework to predict the impact of perceived attractive and repulsive stimuli, within the pedestrian's field of view, on movement direction. Environmental stimuli are quantified using the social force method. The algorithm is implemented in a simulated area of an office corridor consist of a printer and exit door. Stochastic simulation using the proposed fuzzy algorithm generated realistic walking trajectories, contour map of dynamic change of environmental effects in each step of movement and high flow areas in the corridor.*

Keywords-pedestrian walking path; pedestrian-environmen interaction; steering behaviour; environmental stimuli; fuzzy logic

I. *Introduction*

Wayfinding behavioural studies have revealed that the spatial ability of pedestrians allows them to find a path from the current location to a destination [1]. In fact, wayfinding involves a combination of abilities known as environmental perception, internal interpretation of surroundings, decision making and execution of the chosen countermeasure. All of these variables are intangible and hardly measurable quantities.

During wayfinding activities pedestrians are confront with environmental stimulations that change dynamically after each step. Interaction with environmental stimulations such as fixed obstacles, goal and moving elements have important influence on visually directed walking tasks. However, variable factors like trip intention and pedestrian's personal attributes are pivotal elements that make the prediction of pedestrian–environment interactions an imprecise and fuzzy problem.

Dynamical changes of environmental stimulations constantly update the pedestrians' world view of their surroundings and affect their perception. Understanding a pedestrian's perception of environmental stimuli is necessary to accurately estimate the pedestrian movement [2]. It is believed that information exchange within a dynamic environment contributes to the control of human locomotion tasks [3]. In a study of urban pedestrian wayfinding by Li [4], a dynamic interaction model of pedestrian, environment and mobile devices as an information communication tool has been proposed. Golledge, Ruggles, Pellegrino, and Gale [5] elevated the question of information integration of the route attributes. They highlighted that orientation and movement direction are more fuzzy and related to a wide range of elements. Ridwan [6] modelled driver route choice behaviour in a fuzzy preference relation approach. The main portion of the method is FiPv (fuzzy traveler preferences) that is a fuzzy choice function.

Recently, fuzzy rule-based systems have also been successfully applied in the field of robot navigation and path planning. Seraji and Howard [7] developed a robot navigation strategy applying fuzzy logic rules. In this paper, two control variables of motion are defined by linguistic fuzzy sets. Three navigation behaviours of robot, which are seek-goal; traverse-terrain and avoid-obstacle are represented by a set of fuzzy logic rules. All of those behaviours are integrated by applying weighting factors and centroid defuzzification method.

Fuzzy logic has the capability to model the imprecise and diverse nature of pedestrian perception and reaction towards the environmental impacts.

This study addresses two challenging issues: firstly, it investigates how to quantify the environmental effects, and secondly, how the environmental stimuli influence the spatial behaviour. In this context, we have proposed a fuzzy logic approach to model local navigation behaviour. Pedestrian in each step perceive the level of attractive and repulsive impact of surrounding environment in next three future travel points. The summation of attractive and repulsive stimulation builds basic information to infer the movement direction for the next step. The aim is providing an agent with real-time assessment of the environment and inclusion of this information in the wayfinding strategy. The strategy of selecting next step direction is a perception-based fuzzy logic framework.

II. PEDESTRIAN-ENVIRONMENT INTERACTION

It is discussed by Zacharias, Bernhardt, and de Montigny [8] that pedestrians who are familiar with a shopping environment have a global perception of whole the area to define itinerary plan for moving through the shopping centre. Subsequently, local factors such as fixed obstacles, shop windows and final goal have preponderant effects on orientation and route selection. In fact, local stimuli cause the agent to modify the travel plan [8]. To model local environmental stimuli that cause by pedestrian-environment interaction, Helbing social force model has been applied [9]. In this context, we have proposed a fuzzy approach to simulate the impact of local stimulus on navigaton behaviour. Following sections illustrate the concept of proposed model.

A. Environment Discretisation Based on Field of View

Any path finding problem deals with an important element, namely environment discretisation. In previous research, a static representation of the environment is used most often, although in some cases, a dynamic spatial discretisation is preferred [10]. Grid-based methods can be classified in the static category. These methods apply a discrete arrangement of space to simplify the environment by dividing the floor to geometrical shapes. In contrast, dynamic representation is an individual-based method, which is time dependent and varies by different agents. Following each step, the physical space representation alters according to the agent behaviour. Radial decomposition of terrain [11] is a dynamic and individual-based representation of physical space that employs the concept of *Field of View* (*FOV*) to capture visually directed walking tasks. There is a large volume of published studies describing the role of *FOV* in spatial activities such as steering, navigation, walking and route-choice [12]. In this study, the traversable terrain in the area of *FOV* is divided into two sectors, which provide three points of interest with the radius 2 meters (approximately 5 steps ahead). These three points of interest are feasible future positions collected in A= {Front Position (FP), Right Position (RP), Left Position (LP)}. This region is the range of perception-reaction of the environmental stimuli [13].

B. Psycho-Sociological interactions in the environment

Contradictory psycho-sociological interactions in the environment motivate the agent to move towards a desired destination. The Helbing social force model is one of the more practical and reliable methods describing the behaviour of pedestrians, which considers the effects of attractive and repulsive interactions [14]. Helbing, Farkas, and Vicsek [14] in their major study, assumed socio-psychological forces during the environment influence the behaviour in life threatening situation. They interpreted the pedestrian psychological motivation to move towards or stay away from an object by an interaction force. Also, they consider two other forces, which are body force and sliding friction force to represent the entire behaviour in panic conditions. In another study, self-organisation phenomena results from collective interaction between pedestrians are also described by social force model [15]. Position of pedestrian is changed over time by a cumulative of several interactions that simultaneously act on the pedestrian. We have adopted this approach for this investigation.

$$F_{ij}^{I}(t) = A_i \exp\left[\left(r_{ij} - d_{ij}\right)/B_i\right] n_{ij}, \qquad (1)$$

Where $F_{ij}^{I}(t)$ reflects social interaction force between object i and j at time t. Parameter A_i represents strength of interaction and parameter B_i indicate range of interaction.

$$n_{ij} = \left(n_{ij}^1, n_{ij}^2\right) = \left(r_i - r_j\right)/d_{ij} \qquad (2)$$

$r_{ij} = r_i + r_j$ denote sum of two objects radii and $d_{ij} = \|x_i + x_j\|$ shows distance between two objects' center. n_{ij} is normalised vector from object j to object i.

Dynamic environmental stimulations inspire the pedestrians to choose a path during the environment. A contour map of stimulations is able to represent environmental effects by using a value in each grid of terrain. Maury and Venel [16] in their simulation of spontaneous velocity of crowd have considered a contour level to show the geodesic distance from exit node of a room. This value should be calculated in each point of grid. In this work, contour map of attractive, repulsive and total amount of environmental effects is depicted, while attractive influences have negative value versus positive values for repulsive impacts.

III. FUZZY LOGIC SIMULATION OF WALKING PATH

Two distinguished variables in route-choice activity are speed and direction. The assumption is that the agents characterised with constant speed and variable movement direction. Therefore, the direction of movement can be manipulated by the local environmental factors.

The fuzzy system comprises of three inputs, one output and 216 rules as illustrated in Figure 1. Inputs are total psycho-sociological interactions with surrounding environment that is perceived by the agent in three possible future travel points, which are {Front Position, Right Position, Left Position}. The summation of attractive and repulsive stimulation is measured for each future position. This perceived information is then recognised as {High attractive, Medium attractive, Low attractive, Low repulsive, Medium repulsive, High repulsive} to express level of perception. Therefore, each input consists of six membership functions and change of movement direction can be inferred by the output of fuzzy system.

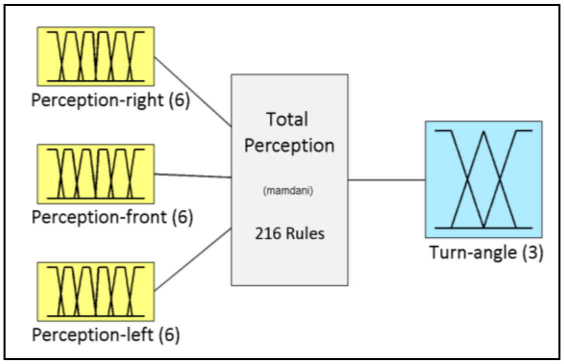


Figure 1. Structure of proposed fuzzy steering simulation model, with 3 inputs, 1 output and 216 rules.

A. Model Assumptions

To succinctly express pedestrian behaviour, we have made the following assumptions.

- Pedestrians' foot steps are presented by a small circle in a two-dimension simulated environment.
- Pedestrian's speed for normal movement is 5 km/h equal to 1.39 m/s [17].
- Goal location is defined in itinerary plan by user at the start of simulation; hence we call it a goal-directed movement.
- All the objects induce attractive or repulsive effects to the surrounding environment, and the cumulative sum of attractive and repulsive stimulations is computed for each point in the terrain surface.
- The level of stimulation at the front, right and left hand side of the agent are inputs of the fuzzy system.
- In each step along the walking path three alternatives exist, which known as move forward, change direction to the right or to the left.
- The agent is able to change the direction in a continuous range from, -12 to +12 degrees, in subsequent steps.
- The angular change of direction is the final command for movement driven from fuzzy rules.
- Tendency to keep the direction and move ahead is more than changing the direction to either right or left side. Therefore, if the attractive and repulsive effects of surrounding in three alternatives have equal strength, the agent would rather to move forward to minimise angular displacement [13].

The three fundamental elements of the model investigated are total psycho-sociological motivations during the environment, dynamic environmental information that is provided by objects located in field of view to reflect local awareness, and the movement direction of agent that is the output of the model.

B. Indicating pedestrian perception by fuzzy input sets

Local awareness is a level of information that is provided by vision ability. Obtaining the information and perceiving surrounding environment enable the agent to navigate and choose a direction. The problem highlighted in this section is to describe the impact of local stimulus on the walking path by means of fuzzy input sets. Fuzzy sets imply the degree that a feeling belongs to a set.

Psycho-sociological interactions with objects within field of view lead to a level of perception with attractive and repulsive effects. In present work, fuzzy input sets are the agent's perception in three feasible future positions, known as {Front Position (FP), Right Position (RP), Left Position (LP)}.

In each current position of the agent, the level of total attractive and repulsive psycho-sociological interactions in three feasible future positions are measured by applying social force model. This perceived information is then recognised as {High attractive, Medium attractive, Low attractive, Low repulsive, Medium repulsive, High repulsive} to express level of perception. Therefore, each input consists of six membership functions and change of movement direction can be inferred by the output of fuzzy system. Figure 2 depicts membership functions for level of perception in front location. Perception in the right and left hand side apply the same membership functions as well.

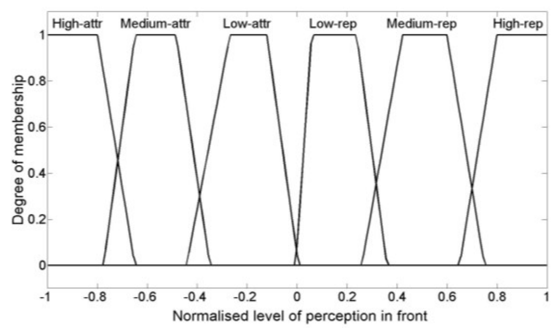


Figure 2. Membership function for perception in front of the agent.

C. Change of Direction by Applying Fuzzy Logic System

Observations show that pedestrian during walking task perform gradual change of heading direction over subsequent steps instead of sudden switch of direction in the next step [18]. Rate of turning angle is determined with respect to the influence of attractive and repulsive stimuli located/inhabited within *FOV*. Assessments of the environmental stimuli in three positions provide enough information for the agent to select next step direction. Employing the fuzzy rules will empower the agent to find the angular change of direction for the next step. Figure 3 shows the output membership function that is defined in a continuous range from -12 to +12 degree [18]. As it was mentioned before, current movement direction of the agent is a variable that is manipulated by the output of fuzzy system from zero to -12 degree to the left or zero to +12 degrees to the right. It is a fuzzy perceived base route choice between three alternatives, but the output is not just evaluating the utility of each alternative and selecting the alternative with maximum utility. The output is a continuous range of changing direction (turn angle, β) of -12 to +12 degrees for the next step.

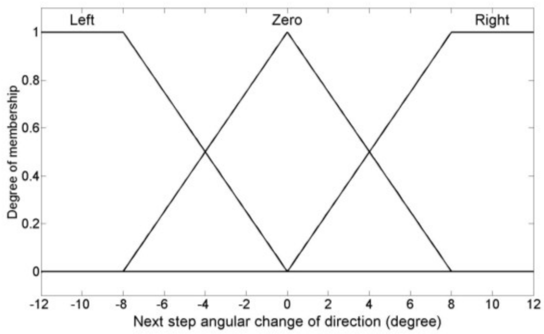


Figure 3. Next step angular change of direction membership function.

D. Fuzzy Rules for Motion Command Strategy

Decision making rules, guiding the agent local behavior, are subject to following strategy which is developed according to human expert's heuristic knowledge.

Strategy: total attractive and repulsive effects of surrounding environment in the three positions are assessed. Dealing with two indicators in three levels for three positions lead to 6x6x6=216 rules. The agent deduces the amount of turning degree for the next step according to the level of total perception in each point. Should perception in one of the alternatives is attractive and in the others are repulsive; the agent would rather to move towards the attractive point and vice versa. Conditions could happen when all of three positions containing the same level of attractive or repulsive effects. In this case, the alternatives are indifferent to the agent. We have established 216 linguistic rules using the following intuitive.

IF LP is high-attractive AND FP is low-attractive AND RP is medium-repulsive THEN β is go to the left,

Where LP is left position, FP is front position, RP is right position and β is angle of changing the direction for the next step.

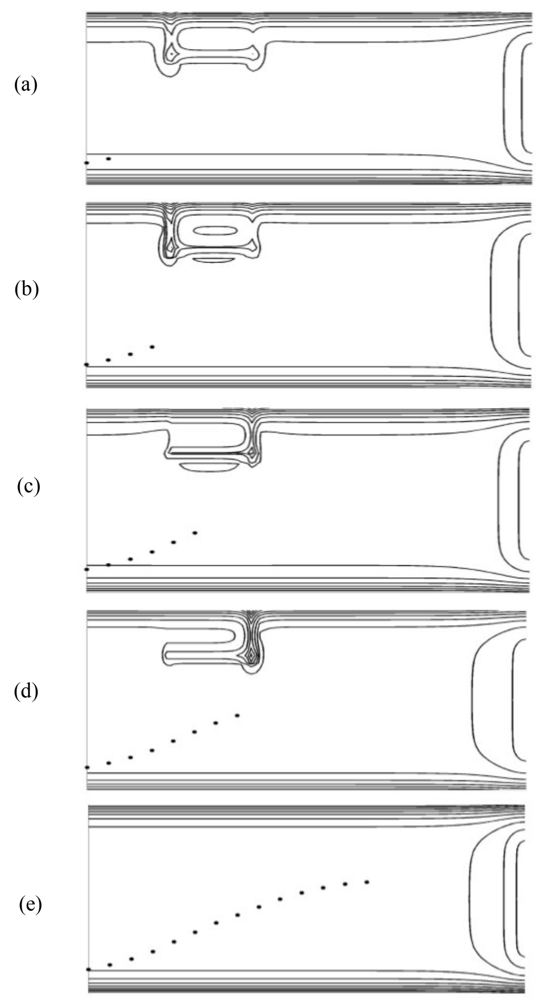
IV. Simulation Results

A two dimensional space with walls, printer, entrance and exit, which depicts a corridor in an office area, was studied. Definition of the environment in CAD format and stochastic introduction of the agents to this environment provides the opportunity to simulate a realistic pedestrian walking behaviour and understand the algorithm implementation. Figure 4 shows the simulated corridor.

Figure 4. A two-dimension simulated environment(corridor).

The agent moves through the area using the information from the environment within its *FOV*. The perceived information pass to the fuzzy logic system and lead to manipulate the movement direction that is the number of degrees needs to change for the next step.

Attractive, repulsive and total stimulation in that area due to the printer and the exit door are the inputs of fuzzy system, which is changing at each step of movement. It is assumed that the printer has both attractive and repulsive effects, while the exit door provides an attractive influence. Presumably, walls provide repulsive impacts on the agent. After taking each step, the agent confronted with varying level of attractive and repulsive stimuli within the vision field. The dynamical changes of environmental stimuli that are perceived by the agent direct the agent towards next position. Figure 5 is the summation of attractive and repulsive influences that reflects total stimulation in the environment after taking each step. The impact of dynamic changes of environmental stimuli is presented in walking trajectory. Figure 6 depicts the trace of walking path of 20 agents in the simulated corridor. All the agents have different origin and destination modelled stochastically.



(f)

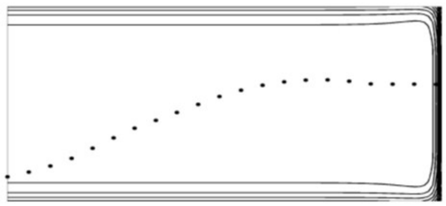


Figure 5. Contour map of dynamic change of total environmental stimuli after taking, (a) Second step, (b) Four steps, (c) Six steps, (d) Eight steps, (e) Fourteen steps, (f) Twenty one steps.

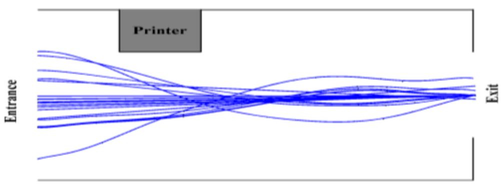


Figure 6. Simulated trajectories of 20 pedestrians.

V. CONCLUSIONS

The simulation results indicate that the proposed fuzzy-based approach is a promising method to model the pedestrian walking path under normal conditions. In this methodology, the individual-based representation of terrain employs the concept of *field of view* to capture visual stimuli that impact walking direction and acquire dynamic environmental information, which is a necessary characteristic for local awareness.

Pedestrian perception and interaction with the local environment is a system inherently inexact and indeterminate. Uncertain characteristic of this problem is due to arbitrary factors in the environment, ambiguous nature of environmental influences on pedestrians and diversity in each individual characteristic.

To verify the concept, a two dimensional space with walls, printer, entrance and exit was studied. As pedestrian interaction with the environment is an important feature of steering behaviour, we assessed the level of induced effects exerted by the environment on the pedestrian using social force model to obtain the turning angle of direction for the next step using fuzzy logic framework. In this regard, fuzzy logic offers a framework to model the problem considering both imprecise nature of environmental effects and diversity in pedestrian perception and decision making.

In artificial intelligence and computer science, it is highly desired to imitate the abilities of human in perception and navigation during the environment for agents. In this regard, fuzzy logic offers a framework to model the problem considering both imprecise nature of environmental effects and variations/diversity in pedestrian perception and decision making.

To gain a deeper insight, it is necessary to investigate the requirements for inclusion of behavioural theories and knowledge from human dynamics, cognitive science and psychology. An improved understanding of pedestrian path finding behaviour, for both spatial and implicit actions, will serve as a blueprint for implementing a model to improve prediction based on these incompletely defined behaviours in the environment. Moreover, it will assist in guiding pedestrians to desired spots in public areas such as shopping, airport or hospital through the improved use of signs and advertisements. According to the results, we are confident that the predicted path by the proposed algorithm is life-like and reliable.

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