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Crowd Modelling Validation for Modified Social Force Model

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Abstract: Crowd modeling is mainly used to observe and analyze the movement pattern of the crowd, including their behavior with the influence of building geometry. It also has been used widely in many application areas such as for transportation services, urban planning and event planning. Representation of crowd dynamics using a simulation tool is useful in various crowd studies, where experiments with humans are too dangerous and not practical to be implemented. As to ensure the validity and accuracy of the developed simulation model, it has to be validated with the real data, in which most of recent crowd modeling works are lacking. Therefore, in this paper, we propose three types of approaches to validate our proposed crowd simulation model, the Magnetic Social Force Model, which are the component testing, qualitative validation and quantitative validation. Real data of crowd movement at concourse area of a train station in Kuala Lumpur has been used for the validation purpose in this work. By comparing the simulation analysis with the real data, results for component testing shows that our proposed crowd model has successfully produced crowd trajectories that are similar to the real crowd data with an accuracy of 90%. Meanwhile, for the qualitative validation, the proposed model is able to produce collective types of self-organized crowd behaviours such as lane formation, counter flow formation and corner hugging formation. Furthermore, the model has also been validated using the fundamental diagram.

Keywords: Crowd modelling validation, component testing, magnetic social force model, qualitative validation, quantitative validation

1. Introduction

Crowd modelling has found its applications in various areas of science including physical science, computer science as well as social and psychological sciences [1]. It is used to observe and analyze crowd behaviours including its interactions with building geometry in a virtual environment. The introduction of crowd modelling as a crowd simulation tool is beneficial in devising better crowd management, control and crowd risk mitigation, where experiments with real humans are too risky to be conducted.

There are two types of modeling approach in crowd dynamics: macroscopic and microscopic approaches. In the macroscopic approach, the state of the system is described by calculating gross quantities, namely the crowd density, linear momentum, and kinetic energy that are regarded as dependent variables of time and space [2]. This is usually used in the study of the movement pattern of the whole crowd and requires less computational and processing demand. In the microscopic approach, each individual in the crowd is integrated with a variety of behavioural factors that take into

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account the characteristics of each individual, such as the position, the speed of motion of an individual and the radial field of view size [3]. This microscopic approach has been widely utilized in this research area because of its ability to produce realistic agent simulation model integrated with agent intelligence [4] and greatly reduces the complexity of the problem and has been used in this paper. This approach can be classified into two main categories, the Cellular Automata (CA) model and the continuous space model [5]. By using CA, runtime performance is represented in discrete-time. Since the environment of this model is segmented into grids, agent movement can hop from one cell to a different cell based on the state of transition probability. Implementation by using this concept is easy and quick but limited agent interaction can be studied as the agent movement appears unsmooth when visualized [4]. For the continuous space model, the social force model is one of the most popular choices to model the dynamical behavior of pedestrians as it produces realistic simulated movements of individuals in crowds [6]. However, many models developed based on the social force model lack a commonly accepted validation method that is an essential step in the acceptance of any model [7].

This paper aims to validate a modified social force model, called the Magnetic Force Model [4]. To validate the model, we compare the simulation output with the trajectories of the real-life crowd to ensure the Magnetic Force Model is able to produce accurate results. In this work, three different crowd model validation aspects have been taken into considerations. They are the component testing, qualitative validation and quantitative validation [8]. An entire validation process was performed according to international guidelines [9].

2. Method

2.1 Magnetic Social Force Model

Magnetic Social Force model is a modified version of the original social force model [10]. The development of the Magnetic Social Force model consists of two stages: the basic agent model and the integration of a path finding feature in the model [4]. The dynamical movement of each individual in the crowd, also known as the 'agent', is modeled using Newton Second Law as shown in Equation (1) and (2).

$$F(t) = m \frac{\mathrm{dv(t)}}{\mathrm{dt}} \tag{1}$$

where,

m = Agent's mass

$\mathrm{v}(\mathrm{t})$ = Velocity in respective time

Also,

$$(t) = F^0(\mathrm{t}) + \sum_{i \neq j} F_{ij}(\mathrm{t}) + \sum_w F_w(t) \tag{2}$$

where,

(t) = Summation of the three main forces

$F°(t)$ = Motivational force to move towards target destination

$F(t)$ = Repulsion force to evade agents

(t) = Repulsion force to evade obstacles

For the motivational force, $F°(t)$, in Equation (2):

$$F^0(t) = \mathrm{m}\frac{v^0(t)e^0(t) - \mathrm{v(t)}}{\mathrm{t}} \tag{3}$$

$v°(t)$ = Agent desired speed

$e°(t)$ = Direction to move towards target destination

(t) = Agent actual speed that adapted in time, t.

The repulsion force between the agent and an obstacle is represented by Equation (4).

$$F_{ij}(t) = k_r \frac{M_i M_j}{x^2} n_{iw} \tag{4}$$

$M_{i,} M_j$ = Agent social mass

k_r = Repulsion constant

x = Distance between agent

$R_{i/j}$ = Body radius agent

The agent distance is calculated based on Equations (5) and (6) below.

$$D_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

$$x = D_{ij} - R_i - R_j \tag{6}$$

The model also represents a collective agent movements including the social interaction tendency to follow others with a variety of agent physical characteristics [4]. By using Equations (5) and (6), the conditions for the agent to repulse in the model i.e. the distance for an agent to repulse, x, will be 7 m. On the other hand, the repulsion force between the agent and the obstacle,, is given by Equations (7) and (8).

$$F_w = \frac{k_w}{x^2{}_w} n_{iw} \tag{7}$$

$$x_w = \sqrt{(x_i - x_w)^2 + (y_i - y_w)^2} \tag{8}$$

k_w= An obstacle repulsion constant
x_w= Distance between agent position and obstacle
n_{iw}= A normalized vector point perpendicular from the obstacle

2.2 Intelligent Path Finding Feature

The intelligent feature has been integrated into the Magnetic Social Force model based on how the agent will navigate the environment and choose the suitable path to move towards their desired destination. It also includes a common social behavior of an agent in a crowd where it has the tendency to follow others in the crowd [4]. Dijkstra algorithm has been used in the path finding feature for the model. It is one of the established algorithms used to find the shortest path, as individuals would normally navigate from their original locations to the destinations, by performing simple nodes calculation in all directions [4]. As depicted in Fig.1, represented the flowchart of the Dijkstra Algorithm integrated with the agent-based model.

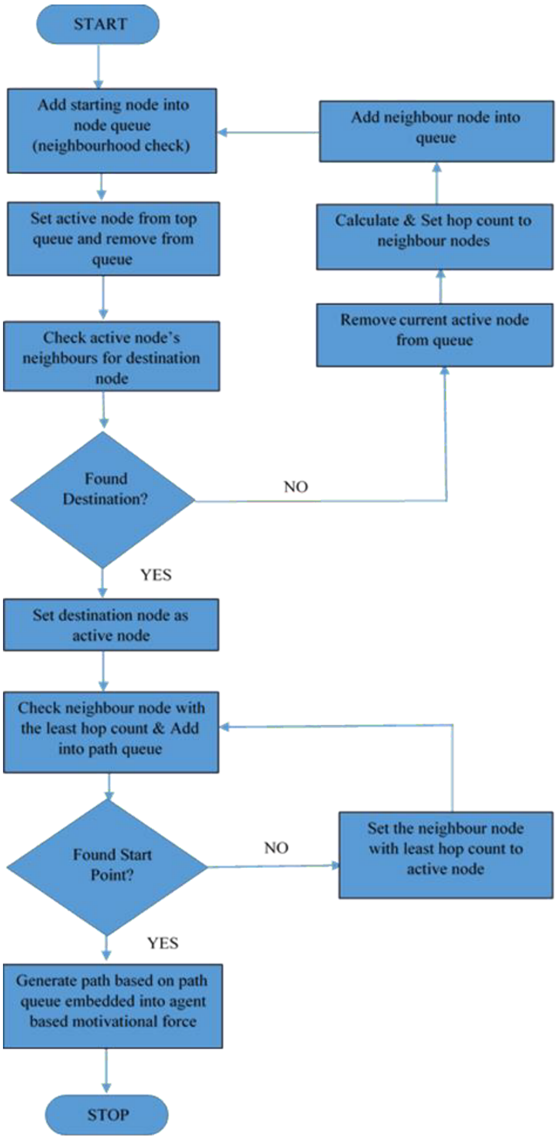

Fig. 1 - Dijkstra Algorithm flowchart [11]

2.3 Video Extraction for Data Collection

Based on suitable video recordings of interactive pedestrian motion, we used recorded crowd videos at the concourse area in KL Sentral train station in Kuala Lumpur, Malaysia during the normal hour and situation to validate our crowd simulation model. The videos are converted into frames of images and several images used for the validation works were selected. This data set contains images for different environments such as corner hugging, lane formation, and counter flow.

2.4 Validation of Magnetic Social Force Model

The Magnetic Social Force model has been used to stimulate agent movements. To prove the effectiveness of the model, component testing, qualitative and quantitative validation was conducted. Below shows the steps taken for validation of magnetic social force model.

2.4.1 Component Testing

Component testing is one part of the development cycle that involves checking if the various components of the software perform as intended [12]. The first step in component testing is to set the agent position. Based on real data from the video recording, we set the agent positions in the simulation according to those in the video, as illustrated in Fig.2 (a).

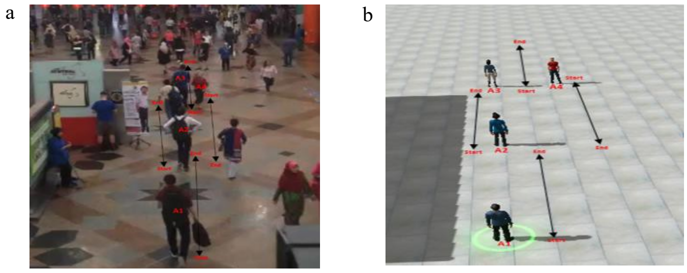

Fig. 2 - (a) Agent selected from real data; (b) Position agent from simulation

Four agents to be tested in the simulation were selected from the video during normal conditions i.e., the agent passes through the simulated environment without many interactions. The selected agents were assigned as agent A1 until agent A4. The starting and ending reference points of each agent were marked. In this paper, only four agents are considered to justify the preliminary analysis for validation of the current software in handling small-scale scenario. Fig. 2(b) shows the four selected agents' representations in the virtual environment i.e. the simulation. The second step in the component testing is to validate the time of arrival of the four agents when moving in specific distances. To do this, a movement area of 4.2m wide and 6 m long was considered (illustrated in Fig.3) and the movement of each agent from one end to another end in the area was simulated using different desired speeds. The range of simulated speeds for the four agents is between 1.2 m/s until 2 m/s.

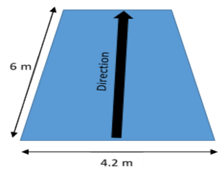

Fig. 3 - Environment of walking time test

2.4.2 Qualitative Validation

Qualitative validation concerns the nature of predicted human behaviour with informed expectations from observed situations [13]. The qualitative tests performed to validate the Modified Social Force Model are the impact of corner hugging, line formation, and counter flow. This test performed according to the environment illustrated in Figure 7, 8 and 9 populated respectively by 13, 24 and 9 individuals in Result Section. As crowd members turn corners, they tend to slow down and move further into them, becoming more densely packed and appearing to 'hug' the corner [14]. This is known as 'corner hugging' as visualized in Fig. 4(a). Lane formation happens when agents move in opposite directions, they self-organize to form a lane for each direction [15] while counter flow situation occurs when there are agents going to different directions and their paths are crossing or opposite to each other [16] as visualized in Fig.4(b) and Fig.4(c).

Fig. 4 - (a) Illustration of corner hugging [17]

Fig. 4 - (b) Illustration of lane formation [18]

Fig. 4 - (c) Illustration of counter flow [19]

2.4.3 Quantitative Validation

In quantitative validation, the use of 'fundamental diagram' that indicates the relationship between crowd density and the flow rate is essential to understand for crowd safety. To assess the efficiency of crowd movement, throughput, and rates of fill for places of public assembly we need to understand the relative risks of moving crowd density [20]. As density increases, flow increases, but when the density increases above the critical density, the crowd flow rate begins to drop. At densities lower than 1 person per square meter the crowd is free-flowing and stable [20] as shown in Fig.5.

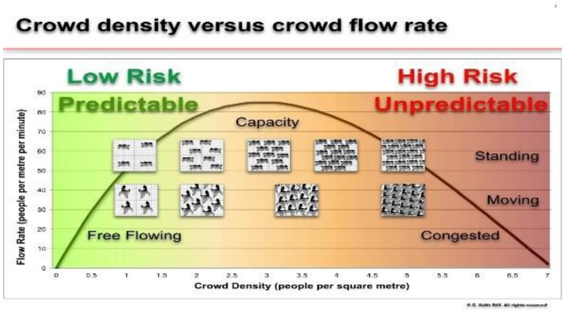

Fig. 5 - Fundamental Diagram [20]

3. Results and Discussion

3.1 Results for Component Testing

Fig. 6(a) and Fig. 6(b) show the trajectories of all the agents from their initial positions towards the target destinations from the video and from the simulation using the Modified Social Force Model respectively. Table 1 shows the details of the movement of each agent.

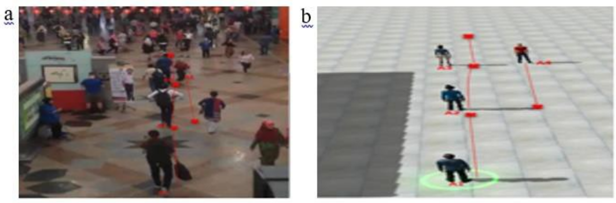

Fig. 6 - (a) Agents trajectory from video; (b) Agents trajectory from simulation

Table 1 - Details on agent movement

Agent	Movement Details			
	Start Point (x,y)	End Point (x,y)	Distance (m)	Desired Speed (m/s)
A1	(20.4,35.2)	(26.3,35.2)	5.9	1.5
A2	(27.5,35.1)	(33.4,34.5)	5.9	1.5
A3	(35.5,35.3)	(41.4,35.3)	5.9	1.2
A4	(35.6,32.7)	(29.7,32.4)	5.9	2.0

By comparing the trajectories of the agents from the video and simulation, the time taken by each agent was estimated (for the video case) and computed (for simulation) and shown in Table 2. Table 2 shows that the time taken to travel the predetermined distance for each agent differs between 0.3s-0.4s only i.e they are approximately 90% similar to the time taken from the video. These comparisons show that the simulation by the Magnetic Social Force model has succeeded in imitating the real agent movement from the video.

3.2 Results for Qualitative Validation

Fig. 7 - (a) Corner Hugging from the video; (b) Corner Hugging from

simulation Table 2 - Time taken to reach the destination

Agent	Simulation time (s)	Estimated Time from the video (s)	Time difference between simulation and video (s)	Percentage Error %
A1	3.63	4.00	0.37	9.25
A2	3.68	4.00	0.32	8.00
A3	4.65	5.00	0.35	7.00
A4	2.74	3.00	0.26	8.67

Fig. 8 - (a) Lane formation from the video; (b) Lane formation from simulation

Fig. 9 - (a) Counter flow from the video; (b) Counter flow from simulation

Figure 7, 8 and 9 shows how the simulation using Magnetic Social Force model is able to demonstrate corner hugging, lane formation, and counter flow phenomena when used in simulation works. The phenomenon of corner hugging, lane formation, and counter flow is a result of the proposed Dijkstra algorithm that includes the force to evade in different direction and repulsion force with another agent.

3.3 Results for Quantitative Validation

In this work, agents have been distributed to each cell and moving at the same speed. When agents reached the final destination, the time taken is recorded. As the number of people per square meter is increased, people cannot take the whole paces forward. The movement starts to contrast and the flow rate drops as shown in Figure 10. When the density increase, the flow rate increases until critical density is reached (2-3 people per square meter). This critical density can be different for different events/crowds.

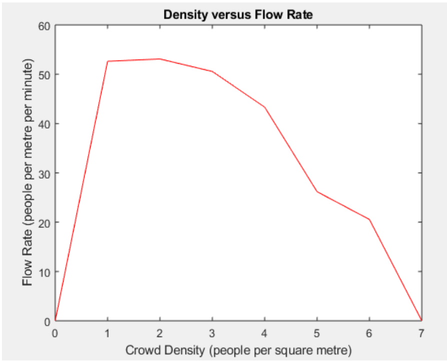

Fig. 10 - (a) Crowd density versus flow rate (1m)

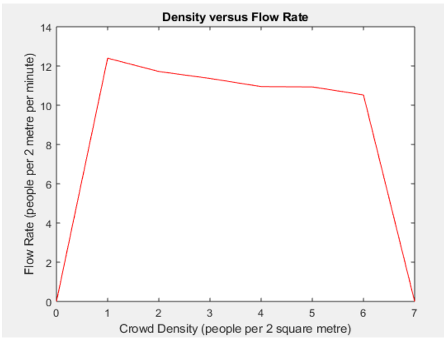

Fig. 10 - (b) Crowd density versus flow rate (2m)

4 Conclusion

The main motivation behind this study was to validate our proposed model which is the Magnetic Social Force Model, through three types of validation analysis which are the component testing, qualitative and quantitative validation. By applying the component testing, it is clearly shown that the proposed model had successfully to produce crowd trajectories similarity with an accuracy of 90% from the real data. Other than that, to highlight the quality of our proposed model based on qualitative validation, our model able to represent collective types of crowd behaviours such as lane formation, counter flow formation, and corner hugging formation. This situation usually occurs when the crowd moves at the high-density level and congested area. Finally, quantitative validation was conducted to show how fundamental analysis of crowd density and flow rate was measured. It is clearly demonstrated that higher density level in the area will cause a higher crowd flow rate with unstable movement. In a conclusion, it is proven that our proposed model achieved to satisfy rules of validation that must adhere to developing a crowd simulation model by validated through the real data. For future studies, we should focus on the more complex environment such as how the location of an obstacle in the simulation environment will affect the model validity and we intend to provide more agent sample with several orientations in the selected area that include medium and large scale during peak hour.

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