Multi-Agent Simulation of Circular Pedestrian Movements Using Cellular Automata

Siamak Sarmady, Fazilah Haron and Abdullah Zawawi Hj. Talib
School of Computer Sciences, Universiti Sains Malaysia
sarmady@cs.usm.my, fazilah@cs.usm.my, azht@cs.usm.my

Abstract

This paper presents a basic multi-layer model of human movement process. A behavior model is used to simulate actions of individual pedestrians while a cellular automata model is used to simulate their small scale movements. A modular platform, which implements the proposed model, is also presented. The platform is being used to simulate different sections of the Muslim holy mosque in Makkah. Preliminary results of the simulation of circular pedestrian movements in a section of the mosque along with the algorithm used are reported.

1. Introduction

Modeling and simulation of crowd behavior has become useful in many different areas. Engineers use crowd simulation tools to investigate behaviors of crowd in buildings and environments to minimize congestion and traffic in public places. Management of evacuation is another application of crowd simulation. Evacuation plans are very important for places like stadiums, large buildings and huge events to avoid catastrophic situations.

More than two million people attend Muslim pilgrimage in the holy mosque in Makkah each year. Thousands of these pilgrims are present in each section of the mosque at any one time. Understanding the behavior and the dynamic of such a huge crowd may help in managing this important event.

Human behavior is complex and this makes it difficult to build an ideal model of the crowd. In addition pedestrians in a crowd are different in specifications and this difference affects the entire crowd. For example, trained and intelligent pedestrians can find their way easier and act better in the case of panic. A crowd with higher percentage of trained and intelligent pedestrians tends to exhibit better way-finding behaviors [1,2]. Adding more details to available models may help us to achieve more realistic simulations. Recently models have been built which consider more extensive parameters such as physiological, psychological and social specifications of pedestrians, group effects, communications between agents and roles of leaders to produce more realistic simulation results [1].

In this paper we extend the work done in our previous papers [18,19] and report the achieved results. Cellular automata model has been used to simulate small-scale microscopic movements and an intentions and actions layer provides the pedestrian behavior simulation.

The organization of the paper is as follows; Section 2 reviews the existing related work. In Section 3 we first introduce our basic layered model of pedestrian movement process and then discuss different layers of the model in our simulation plan. In Sections 4 and 5 we briefly report the methods used and the work done towards development of our simulation platform. In Section 6 we describe the model used for an area of the mosque where Tawaf, an act of moving in a circular manner is performed and in Section 7 we present preliminary simulation results. Finally, the conclusion is given in Section 8.

2. Related Work

Simulation of crowd behavior involves different layers. Microscopic movement behaviors such as collision avoidance inside a room are a very important part of crowd modeling. Macroscopic behaviors on the other hand are considered as navigation between different areas. One should differentiate macroscopic and microscopic behaviors of pedestrians with macroscopic and microscopic categorization of models.

Models reported in the literature can be categorized into two main groups. Macroscopic simulations deal only with general properties of the entire crowd such as flow, density and speed. These models do not consider

978-0-7695-3136-6/08 $25.00 © 2008 IEEE
DOI 10.1109/AMS.2008.104

interactions of individual pedestrians with the environment and other pedestrians and instead use the relation of density to walking speed and flow to calculate overall movements of the crowd.

On the other hand microscopic models simulate the emerging behavior of the crowd by simulating behaviors of individual pedestrians and their interactions. Particle, fluid and gas dynamics methods like social forces model [3-5] and other force based models [10,12] use physics based models to simulate movements of pedestrians. Matrix-based systems like cellular automata approach [6-8, 14] and distance maps [11] on the other hand divide environments into cells and use cellular automata or similar methods to model movements of the pedestrians within cells.

Recently attempts have been made to improve the crowd simulation results by adding a human behavior model on top of the above mentioned models. HiDAC-MACES system created by N. Pelechano uses psychological and geometrical rules on top of the social forces model to simulate hundreds of agents. In this model, braking and repulsion forces have been applied in small distances to simulate pushing effect and collision avoidance [1,13]. Pelechano integrates an additional PMFserv human behavior model unit on top of her MACES crowd simulation system which could influence the decision making of agents at the micro and macro movement levels to allow more individualistic behavior and therefore more realistic crowd simulation [1,15,16].

In our previous paper we have reviewed different microscopic movement models to see which one is more suitable for simulation of a huge and dense crowd such as the crowd in the mosque [18]. In another paper we also reviewed some of the available simulation software by investigating their features and capabilities. We concluded that there is a need in developing specific software which will enable simulation of crowd movements specific to the mosque (like the Tawaf circular movement) since it is not supported by existing simulation software. We would also be able to simulate behaviors of individual pilgrims to achieve more realistic results in this way [19].

3. Pedestrian Movement Process

More complex models of human behaviors (not specifically for crowd simulation) such as the PMFserv by Silverman [15-17] have been built. This system has been able to simulate more than 1000 agents at a time [15]. However we anticipate that it is not suitable for simulating a huge crowd. Hence, in [18] we proposed a simpler human model which provides enough details for our purpose. In this model intentions of pedestrians are mapped into sequences of actions. Actions are mapped into a series of larger scale way finding and navigational movements which in turn are mapped into small scale microscopic movements. Two higher layers model behaviors and two lower layers present physical movements (Figure 1).

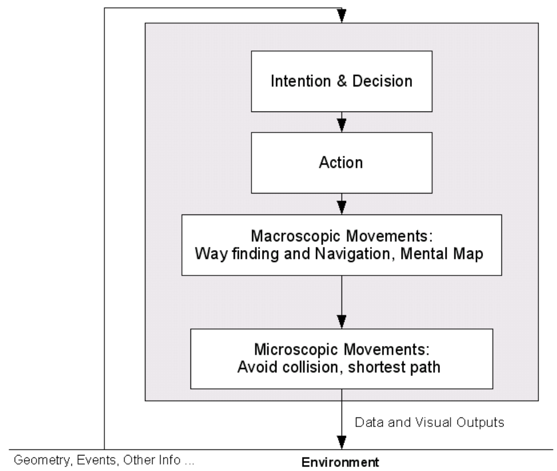

Figure 1. Basic movement process model [18]

This section discusses the details of our human behavior model which will be used on top of the microscopic and macroscopic movement model to simulate the behaviors of individual pedestrians.

3.1. Psychological, Physiological and Social Parameters

A realistic simulation requires additional parameters such as psychological, physiological and social parameters to be taken into account. An impatient pedestrian acts very differently from a relaxed one. People change their behavior when they are in a hurry and in the case of a panic, people may push each other. An old pedestrian walks slower than a young one. Each of the four discussed layers of movement process may become affected by these parameters. We have listed a few example parameters, which may be considered in building a realistic agent model (Table 1).

Table 1. Example parameters

Psychological	Belief, Patience, Tension and Stress, Risk, Time Pressure
Physiological	Intelligence, Physical ability (Age, Health, Energy, Fatigue)
Social	Knowledge (and training level), Communicability, Culture

Some of these parameters are independent. We can directly specify the parameter “Age” for each agent. Some parameters are derived from other parameters – the desired speed of a pedestrian is determined by other parameters such as the physical abilities, stress level, gender and age. Each of the parameters may affect one or all of the layers of the movement process. We can specify independent parameters for each agent separately or prepare agent templates and create crowds by combining agents with attributes copied from those templates. We should also be able to tune and calibrate the crowd model by matching its results to a specific real world observation. Demographic information will help us in this regard.

3.2. Group Effects

In addition to the above mentioned consideration, we may have groups of agents moving together. Members of a family, a group of friends or colleagues are examples of such groups. In a simulation platform, we should be able to assign people to groups. People in a group move and wait for each other. Big groups move slower and may act as obstacles to movement of other pedestrians. They will also communicate and transfer information concerning path and emergency.

4. Simulation Methods

As highlighted earlier the main purpose of this work is to achieve a relatively realistic simulation of the huge and dense crowd in the mosque area. For this reason we have tried to choose a relatively precise microscopic model, which is also capable of modeling big crowds. We have also considered detailed characteristics and behaviors of each individual agent. We plan to calibrate the simulation parameters with the video footages that we have obtained for our case study. In this section, we describe the methods chosen to simulate each layer of the movement process.

4.1. Movements Models

As discussed in our earlier paper [18] the huge number of pedestrians in the mosque area makes it impossible to use social forces model for microscopic movements unless we incorporate parallel programming technique. Because of this, we decided to use a cellular automata model for our initial studies. At a later stage of the work we will decide whether we should move to social forces model.

Simulation of macroscopic navigation behaviors is being done using static path tables. We first specify a number of logical and suitable paths between source and destination rooms and areas. Better routes have lower cost in the path table. Pedestrians will choose one of those routes depending on their knowledge level and other parameters coming from the multi-agent behavior simulation engine.

In the next phase of the work, each agent will have its own mental map of the geometry, which can be different from other agents and may change upon receiving new information during communication with other agents or after visiting a place. Congestions, dangerous events, stress, fatigue and personal status of the agent will affect this mental map.

4.2. The Crowd at the Mosque

The pilgrims perform different actions in the mosque. The most important action in the mosque area is Tawaf (circumambulation) which consists of circling seven times around an 11 meter by 12 meter building in the center of the mosque court called Kaabah in anticlockwise direction. Most of the pilgrims tend to start and end their Tawaf from a line which starts in front of the Hajar Al-Aswad. (Figure 2.)

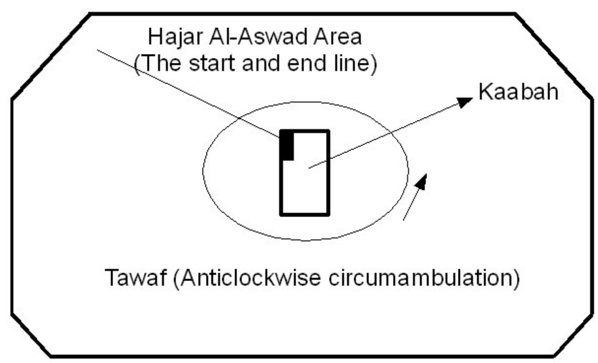

Figure 2. The Tawaf Area

The pilgrims typically move with specific intentions such as “go to pray”, followed by “go to Tawaf” etc. “Going to Tawaf” is considered as an intention according to our movement procedure model. Each intention results in a series of actions. As an example, to perform Tawaf, the person must go to the mosque, perform the Tawaf, and then perhaps pray inside and leave the mosque. We need to map each intention to a series of actions and map each movement action to a series of macroscopic movements – in this case “Going to the Mosque”, “perform Tawaf” and “leave the mosque”. Agents should be able to react to specific events such as danger (which may suddenly appear in a place, e.g. a tear gas). These events may result in new intentions, decisions and actions.

The simulation of the next layer requires us to model the macroscopic movements. To simulate Tawaf motion, we ought to navigate around the Kaabah and maintain an approximate radius around it. To achieve an intention we may have several alternative lists of actions forming an action graph. In a more general scenario, we may want our multi-agent behavior system to determine the intentions, actions etc.

As mentioned earlier, since cellular automata and social forces model focus on the lower-layer microscopic motions so we need other parameters on top of them to build a more realistic simulation. Adding two additional layers on top of the movement process will help us to achieve this objective. These additional layers will simulate behaviors of pedestrians leading to movements in the physical world.

5. Simulation Platform

We are currently developing a simulation platform, which will cover all the layers of our movement process model. We hope that we could use the platform to simulate different sections of the mosque.

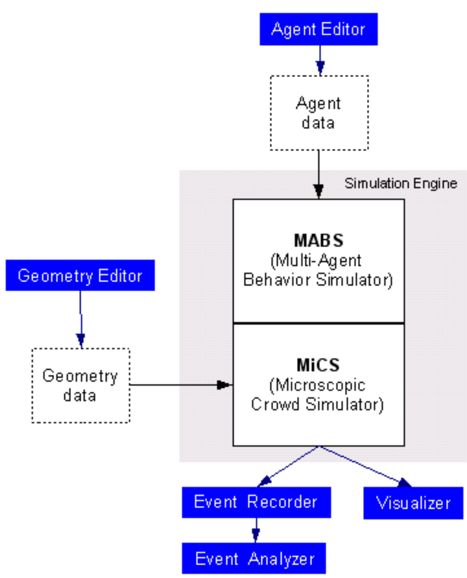

Figure 3. Architecture of the system [18]

The simulation platform consists of a simulation engine which is responsible for the physical movement (MiCS – Micro-macro Crowd Simulator module) and also the behavior (MABS – Multi-Agent Behavior Simulator module) of the pedestrian (Figure 3). MiCS module reads geometry information from the geometry data and receives the information on the subsequent action from multi-agent behavior engine. A navigation path is then selected to achieve the movement action. It then simulates the movement using a cellular automata model and output/results are recorded using event recorder module of the software.

The role of MABS is to generate the crowd behaviors. Though many agents are copied from a single template, each one will act autonomously. Each agent will decide for its next action. Multi-agent behavior module consists of a perception module that can be used to understand the environment and events happening in its surrounding area. This module uses a simple cognition process to determine decisions and actions according to certain rules. For the purpose of this study we chose a relatively simple human behavior model since we anticipate a complex model will consume a lot of computing power.

We use standard Java language and "Repast J" libraries for our current development work. Using existing agent-based simulation libraries and toolkits reduce the development time. This toolkit is an open source library which provides features like object grids, graphical output screens, GIS utilities and basic agent and event scheduling infrastructures.

6. Tawaf Movement Algorithm

Basic assumption in modeling of Tawaf is that pedestrians circling the Kaabah try to maintain a circular path around it. As a result, our cellular automata algorithm will try to maintain this circular macroscopic path while performing collision avoidance and best cell selection. Some of the pedestrians however may try to go nearer to the Kaabah during Tawaf. In each time step pedestrian will select one of the eight possible Moore neighbors to move in. We use an algorithm called "Best Anticlockwise" (Algorithm 1.) to determine which of the eight Moore neighbors will be selected. In the algorithm, we first determine the desire level of each pedestrian to move into each of the 8 possible cells (Figure 4.). Desire level is used as the probability of moving into each cell. If selection of the cell causes the pedestrian to move out from his desired diameter, the cell will get a lower probability. Also if the move helps in finishing Tawaf sooner (i.e. is in anticlockwise side of previous position) a higher probability will be assigned to the cell. If the cell is out of the grid or it is occupied by an object or pedestrian then the desire level will be zero for that cell. To avoid shaking of the pedestrian between the current position and the next position we determine whether the cell is within an anticlockwise direction of the previous position and if the cell is in the wrong direction it will have a very low probability.

```
Point BestAnticlockwise()
{
  for(all 8 neighbors)
  {
  if( PointInGrid )
    if(CellNotOccupied)
      if(CellIsInAntiClockWiseSideOfCurrentPosition)
       {
        ComputeDiameterDifferenceFromDesired()
        MoveToCell=OK
       }
  }

  for(OKCells)
  {
   SelectTheCellWithLeastDifferenceFromDesiredDiameter()
  }

  return Point
}
```

Algorithm 1. Tawaf next cell selection

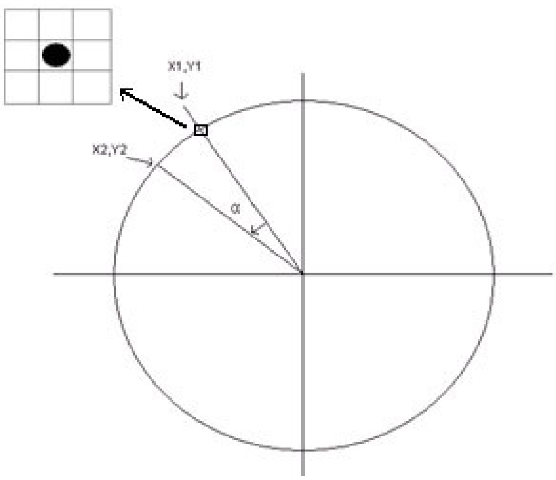

Figure 4. Cellular automata next cell selection

The cell selection algorithm is run for all pedestrians before any movement takes place. After the selection of next cell has been done for all pedestrians the update of the cells will take place.

Burstedde et al. [14], justify that the velocity distribution of pedestrians is sharply peaked and that this fact leads to a model with Vmax = 1 cell in each time step (in discrete space) i.e. only transitions to neighbors are allowed. A greater maximum velocity would be harder to implement in 2 dimensions. The number of possible target cells increases quadratically with the interaction range. In addition we will need to check whether the path is blocked by other pedestrians which will become more ambiguous for diagonal motion and crossing trajectories. We have used the same approach to determine the speed of the pedestrians. All pedestrians will have the same speed of 1.3 m/s in our simulation therefore by assuming the size of each cell to be 40cm, each simulation time step will be equal to 0.3s.

7. Preliminary Results

Initial position of pedestrians and also the initial diameter of circling in our simulation are determined by a random parameter. To simulate the effect of the desire to go nearer to the Kaabah, we use another random process to determine which pedestrians move closer to the Kaabah.

In addition to the above algorithm, we have simulated the effect of a line which results in a denser crowd near Hajar Al-Aswad (see Figure 2. above) that is the start and end of each cycle of Tawaf. To simulate the effect, we have forced most pedestrians to start and end their seven laps within this area and also introduced a small delay (when pedestrian checks to see if he is on the line).

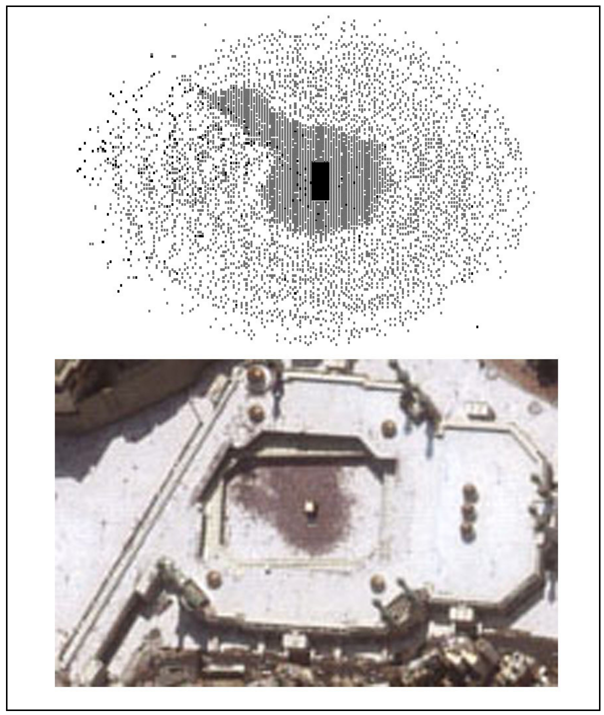

Figure 5. Similar effects for both simulation (top) and satellite (bottom) photos

A quick development of a prototype using the above algorithm on our platform has been able to generate results similar to the effects seen in the satellite photo taken from Tawaf section of the mosque (Figure 5). However more work is needed to calibrate the model to the data gathered from the mosque. GIS data regarding speeds and movement paths in a Koshak's report [9] is also being used for this purpose.

8. Conclusions

In this paper, we have presented our pedestrian movement and behavior models. We have also presented the development of the crowd simulation platform which is based on the model. Our multi-agent system has been able to simulate some of the crowd effects seen in the Tawaf area of the holy mosque. Our future work includes the improvement of the human behavior model which will help us to have a more realistic simulation of the behaviors of pilgrims in the holy mosque area.

9. Acknowledgements

This research was supported by USM-FRGS grant title "Computational Models for Human Movement and Behaviour: A Case study of the Tawaf area".

10. References

[1] N. Pelechano, K. O'Brien, B. Silverman, N. Badler, "Crowd Simulation Incorporating Agent Psychological Models, Roles and Communication", First Int. Workshop on Crowd Simulation, pp 21-30, 2005.

[2] N. Pelechano, N. Badler, "Modeling Crowd and Trained Leader Behavior during Building Evacuation", *IEEE Computer Graphics and Applications*, November /December 2006.

[3] D. Helbing, I. Farakas, T. Vicsek: "Simulating dynamical features of escape panic", *Nature 407*, pp 487-490, 2000.

[4] D. Helbing, P. Molnar, "Social force model for pedestrian dynamics", *Physical Review* E 51, 4282-4286.

[5] D. Helbing, P. Molnar, I.J. Farkas, K. Bolay, "Self-organizing pedestrian movement", *Environment and Planning B: Planning and Design*, volume 28, pages 361 – 383, 2001.

[6] V.J. Blue, J.L. Adler, "Cellular Automata Micro-simulation of Bi-directional pedestrian flows", *Journal of the Transportation Research*, pp.135-141, 2000.

[7] A. Schadschneider, A. Kirchner, K. Nishinari, "CA Approach to Collective Phenomena in Pedestrian Dynamics", *Lecture Notes In Computer Science*; Vol. 2493 archive, Proceedings of the 5th International Conference on Cellular Automata for Research and Industry, 2002.

[8] A. Schadschneider, "Cellular automaton approach to pedestrian dynamics – Theory", *Pedestrian and Evacuation Dynamics*, 75–86, Springer, 2002.

[9] N. Koshak and Arch. A. M. Fouda, "Analyzing Pedestrian Movement in Tawaf Using GPS and GIS", Proc. of Map Asia, Beijing, China, 2004.

[10] S. Okazaki, C. Yamamoto, "A Study of Pedestrian Movement in Architectural Space Part 1-5", *Journal of Architecture, Planning, Environment Engineering*,1981.

[11] P. Thompson, H. Lindstrom, P. Ohlsson, S. Thompson, "Simulex: Analysis and Changes for IMO Compliance", Proceedings of 2nd International Conference: Pedestrian and Evacuation Dynamics, pp. 173-184, 2003.

[12] Laure Heigeas, Annie Luciani, Joelle Thollot, Nicolas Castagné, "A Physically-Based Particle Model of Emergent Crowd Behaviors", In GraphiCon 2003.

[13] N. Pelechano, N. Badler, "Improving the realism of agent movement for high density crowd simulation", University of Pennsylvania, Center for Human Modeling and Simulation, 2006.

[14] C. Burstedde, K. Klauck, A. Schadschneider, and J. Zittartz, "Simulation of pedestrian dynamics using a two dimensional cellular automaton," Physica A, vol.295, pp.507-525, 2001.

[15] B.G. Silverman, M. Johns, J. Cornwell, K. O'Brien, "Human Behavior Models for Agents in Simulators and Games: Part I – Enabling Science with PMFserv", Revision 9/27/2006.

[16] B.G. Silverman, G. Bharathy, K. O'Brien, J. Cornwell, "Human Behavior Models for Agents in Simulators and Games: Part II – Gamebot Engineering with PMFserv", Revision 9/27/2006.

[17] B. G. Silverman, J. B. Cornwell, K. O'Brien, "Progress to Date on the Human Performance Moderator Function Server (PMFserv) for Rapidly Generating Reusable Agents, Forces, and Crowds", University of Pennsylvania, January 2003.

[18] S. Sarmady, F. Haron and A. Z. H. Talib, Agent-based Simulation of Crowd at the Tawaf Area, in proceedings of the "1st National Seminar on Hajj Best Practices Through Advances in Science and Technology", Malaysia, 2007.

[19] S. Sarmady, F. Haron and A. Z. H. Talib, Evaluation of Existing Software for Simulating of Crowd at Masjid Al-Haram, in proceedings of the "1st National Seminar on Hajj Best Practices Through Advances in Science and Technology", Malaysia, 2007.