International Journal of Advances in Computer Science & Its Applications– IJCSIA
Volume 5 : Issue 2 [ISSN : 2250-3765]
Publication Date: 30 October, 2015

Analysis of Crowd Movement in the Prophet (SAW) Mosque in the City of Madinah, Saudi Arabia

Abdullah Alshehri, Muhammad Arif, Marwan Alkhemi, Emad Felemban

Abstract— Number of visitors to Saudi Arabia for performing hajj and umrah from around the world is increasing day by day. Hence the visitors of the Prophet Muhammad (SAW)'s mosque in Madina Munawara, Saudi Arabia are also increasing every year. During Eid days, month of Ramadan and at Friday prayers, thousands of people visits the Prophet's mosque. One of the ritual is to visit the Prophet's grave (Ziara Place). Every visitor want to come to the ziara place and want to spend as much time as they can near the ziara place. This kind of behavior creates bottleneck at the entrance and also at the grave's spot. Analysis and simulation of crowd flow in the mosque is very important for better crowd management, safety and comfort of the visitors. In this paper, we have focused on the ziara place in the mosque where maximum congestion of people occurs. Better crowd management must take into consideration including time response in case of hazardous conditions, waiting time, avoiding barriers, facility management, size, and queuing etc. Crowd simulation and analysis is necessary to avoid the risks of people collisions, and longer waiting time in this area. Visitors (pedestrians) behaviors, crowd densities, and crowd flow in the Prophet's grave is analyzed in this paper for different crowd densities.

Keywords— Crowd Density, Simulation, Optimization

I. Introduction

With the advances in the computational power and availability of huge memory, crowd simulation is not only becoming a tool for creation of virtual environment and rendering the crowd [1] but also to study the behavior of crowd in different scenarios [2]. There are enormous applications in the field of education, training and entertainment [3-6]. Behavior analysis of the crowd has many applications in the area of crowd management (avoiding crowd related disasters), public space design, visual surveillance, virtual and intelligent environments etc [7]. Reasons to develop modeling and simulation systems for crowd behavior include study of the validity of the scientific studies and theories and testing and examining different design strategies.

Abdullah Alshehri, Muhammad Arif , Marwan Alkhemi, Emad Felemban,
Transportation and Crowd Management Center for Research Excellence, Umm Alqura University, Makkah,
Kingdom of Saudi Arabia

Muhammad Arif, Emad Felemban
College of Computer and Information systems
Umm Alqura University, Makkah,
Kingdom of Saudi Arabia

Crowd simulation can be done as goal-driven collision free navigation of group of agents or individual agents. Every agent acts autonomously and perceives its own location in the environment and reacts with the dynamic entities like other agents or moving obstacles in its neighborhood. Collision behavior of agents can also be modeled to incorporate the behavior of agents during collisions. Large environments can be handled by the use of multi-resolution grids in which interaction of pedestrians with the environment is very important to produce realistic animations [8]. Macroscopic approaches tries to model the global behaviors of the crowd based on the environment. Macroscopic models represent the pedestrian movement as continuous fluid and crowd movements depend on the flow, density and speed relationship of the fluid dynamics (Fluid-dynamic model, Regression model, Route choice model, Queuing model). It doesn't include the individual characteristics and also doesn't show the interaction between individuals in the crowd nor their behaviors. Microscopic models represent the behavior of individuals, their decisions and their interaction with each other in the crowd. In 1995, social force model was proposed by Dirk Helbing & Peter Molnar [9] in which behavior of a pedestrian is represented by motion equations. In the social force model, agent behavior is derived from the social force which represents the factors behind the velocity change of individual agents. These factors include desire to reach the destination, repulsive forces with other agents, attractive forces towards other agents and obstacles, and fluctuation effects. In 2000, Dirk Helbing [10] developed an enhanced version of the social force model in order to simulate the crowd in a panic situation by using mathematical formulas. Social force model provides more realistic explanation of the crowd behavior and in the simulation, group of agents are treated homogenously for the ease of simulation.

Velocity fields can be computed using the description or layout of the environment [11, 12]. Velocity fields are used to guide the crowds by particle energy minimization [13]. In this approach local guidance and collision avoidance are integrated into a single optimization framework. Some authors proposed user interaction with the virtual environment and crowd behavior [4, 14]. User specific guidance fields are also used to direct the agents in the simulation [15]. These guidance fields can also be taken from the crowd motion footages. These types of methods are called data driven methods. Data driven approach become challenging in the denser crowds [16, 17]. Many methods are reported in the literature to avoid the collision among agents and agents with the environment. Stochastic cellular automata are used for pedestrian dynamics for the simulation of evacuation processes [18]. Computing collision free path by an agent through velocity obstacles is done to generate simulation of multiple agents in the moving obstacles environment with pre-computed roadmaps [19].

Some collision avoidance techniques consider the agents only in a small neighborhood and ignore the agents which are far away from the neighborhood to reduce the computational cost [20]. Golas et al [21] extended the concept of local collision avoidance to approximate long range collision avoidance. By this method, authors claim that trajectories of the agents become smoother and are calculated at a faster rate. Sakuma et al [22] proposed psychological model to simulate the behavior of the pedestrians in the crowd.

Crowd behavior understanding models are proposed in the literature to understand the behavior of the crowd in various scenarios. These models are used to simulate the behaviors of the agent in the crowd simulation. Temporal information of the crowd like direction of the flow of the crowd, velocities profiles in the crowd and anomalies of the motions can be studied to model the crowd behavior [7]. Unsupervised Bayesian clustering framework is used to detect the individuals in the moving crowds and hence finding the approximate number and location of the individuals in the video sequence of the crowd [23]. Other methods of tracking individuals include parametric models, contour modeling [24] or blob centroids [25, 26]. In highly dense crowds it is difficult to track the spatio-temporal motions of individuals due to inter and intra occlusion of the individuals. Hence dominant motions can be detected in the dense crowds by clustering low level feature tracks [27]. Hu et al [28] proposed a new terminology called super tracks which is collective representation of the motion patterns discovered in the motion field. A good survey of automatic human behavior recognition techniques using image processing methods is given in [25].

Crowd behaviors in the emergency and evacuation scenarios become different from normal behaviors. In these situations, most of the time people lose their logical understanding of the situation and acting [29]. Santos et al [30] presented a critical review of some evacuation simulation models including flow based, cellular automata, agent based and activity based models. Similarly seven methodologies including cellular automata, lattice gas models, social force model, fluid dynamic model, agent based model and game theoretic model are studied and advantages and disadvantages of these models are highlighted in the study of crowd evacuation [31]. Different crowd behaviors in the panic conditions are reported in [32] and empirical results are elaborated for various models.

For the pedestrian crowd behavior, flow and density of the crowd is important. Guy et al [33] introduced an interesting similarity metric to measure the similarity between real world data of the crowd and simulation of aggregate crowd motions for multiple agents. Crowd simulation is evaluated based on quantifying presence in the virtual environment by Pelechano et al [34]. Simulation started with the same initial conditions as the real-world data and then deviation of the desired trajectories are measured to assess the accuracy of simulation [35]. Similarly, Kapadia et al [36] evaluated the simulations based on generated paths or trajectories and considered the trajectory smoothness, number of collisions etc. Musse et al [37] proposed 4-D histogram representing local velocity of each spatial position to compare global flow characteristics of two crowds.

Several simulation tools has been used to simulate Twa'f and path flow such as SimWalk [38] to count the time taken to complete 7 rounds around Ka'aba using Social Force Model. Multi-agent method was utilized to manage the crowd at Twa'f area using Repast [39]. An implemented tool (MAKKSim) [40, 41] was built to simulate and visualize dynamics crowd based on a group of pedestrians. HiDAC [6] was implemented to control high density crowd within individual agents.

II. Methodology

A. *Data Collection from the Prophet's Mosque*

Based on the recorded videos in the Prophet's Mosque during the Hajj period of 2013, sample persons were tracked manually to record their walking speed and total time spent in the corridor of the ziara place. The whole corridor is divided into two regions figure 2. First region is the approaching region which is from the gate of entrance to the ziara place. In this region, people move with their normal speed and try to reach the ziara place as quickly as possible by walking with respect. The second region is in front of ziara place where people slow down and pay salam to Prophet Muhammad (صلى الله عليه وسلم) and the two companions. Our team has tracked 100 persons in different videos to calculate the average speed and standard deviation in both these regions. The walking speed in the approaching region is found to be 1.2 m/s with standard deviation of 0.3 m/s. In the region in front of the ziara place, the walking speed is slowed and found to be 0.42 m/s with standard deviation of 0.2 m/s. These recordings are for normal crowd where people can walk with their own preferred speed. These parameters are used in setting the agents profile in the massmotion in these two regions.

Figure 1. Crowded view of Ziara place

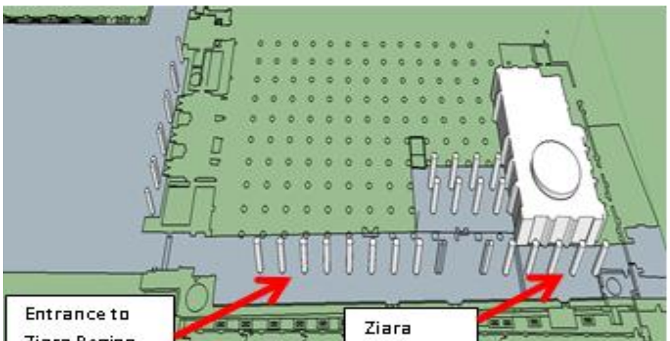

Figure 2. 3D sketch of the concerned area of the Mosque

B. Massmotion: Simulation Software

Mass Motion is a pedestrian simulation toolset for designing and optimizing high occupancy facilities. It is the world's most advanced system of its kind featuring 3D environments, automatic way-finding, discrete event logic and much more. MassMotion is designed for the creation and execution of large scale (1,000,000+ individuals) 3D crowd simulations. The MassMotion toolset has been successfully applied to some of the most demanding pedestrian environments in the world including mass-transit stations, performance venues, airports, and stadiums. MassMotion enables you to make informed decisions about the design and operations of complex facilities.

It is a 3D agent-based simulation tool to simulate the motion behaviors and interactions of thousands of individual agents or group of agents. These autonomous agents are capable of making fuzzy decisions in order to achieve certain tasks. Building structure can be generated inside the software or can be imported from various well known file formats. Properties of individual agents or group of agents can be selected to suit various types of human types or structures (elderly/young people, fat/slim people etc). Agents can react with other agents and structures dynamically to perform the assigned tasks. Decision rules and conditions based on the local information relevant to the agents can be selected. Agents are logically aware of the physical constrains around them, such as walls, and sense of each other in which they are able to see other agents as well. Nevertheless, each individual makes the best guess of the way forward five times per second, as it occurs in reality. Agents are programmed to avoid collision, find open space, and track local goal on the way to their destination. Element of fuzzy logic are adopted probably at about the same rate as in real life.

C. Drawing of the Regions in the Prophet's Mosque

Autocad drawing of the ziara place and the corridor is shown in figure 3. Based on the observations in the videos of real crowd, the whole area is divided into two regions, one region of the approaching region and second region is the delay region where the walking speed is slowed to almost half.

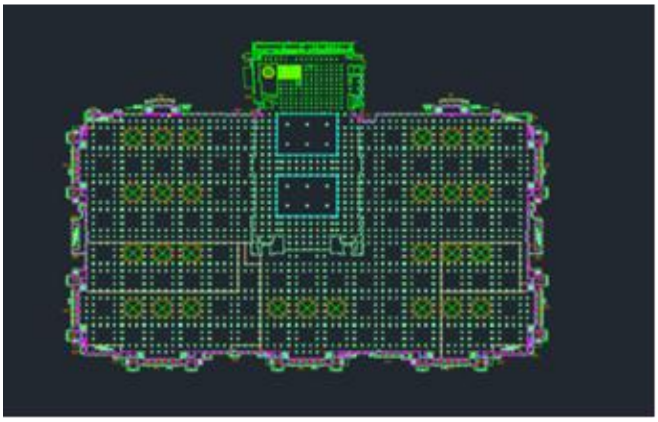

Figure 3. Autocad drawing of Prophet's Mosque

Figure 4 is shown below to show two regions, one is from entrance gate to ziara place and other one is in front of ziara place up to the exit gate. Visitors enter from the enterance gate and rush towards the ziara place where they slow down and say salam to Prophet Muhammad (صلى الله عليه وسلم), Hazrat Abu Bakr RA and Hazrat Umer RA.

Distance from entrance gate to the ziara place is 69.7 meters and from ziara place to the exit door is 22.2 meters. Width of the corridor is 8 meters. Width of the exit door is 3.13 meters. Figure 3 shows the area of concern imported to massmotion defining the boundaries of two regions, pillars and entrance and exit doors.Distance from entrance gate to the ziara place is 69.7 meters and from ziara place to the exit door is 22.2 meters. Width of the corridor is 8 meters. Width of the exit door is 3.13 meters. Figure 3 shows the area of concern imported to massmotion defining the boundaries of two regions, pillars and entrance and exit doors.

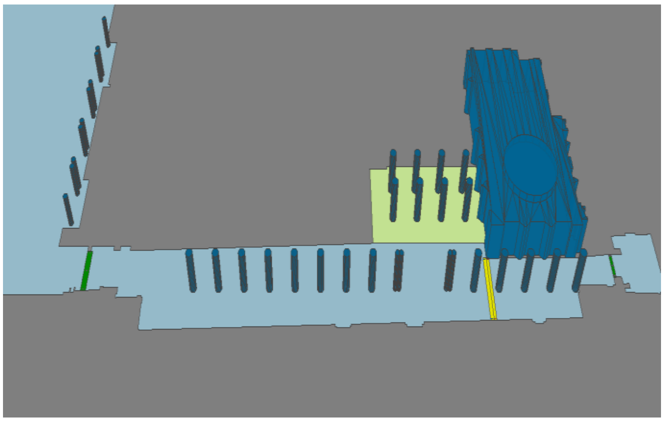

Figure 4. 3D sketch imported in the Massmotion Software

D. Simulation Protocols

We have focused on two protocols for agent simulation. One is Full Crowd Mode and other is Crowd in Batch mode.

- Full Crowd Mode

In this protocol, we have simulated the crowd entering from the entrance gate all in one time. Simulations are done for ten cases, 1000, 2000, 4000, 6000, 8000, 10000, 12000, 14000, 16000, 18000 and 20000 agents.

- Batch Mode

In the batch mode, appropriate number of batches and time between batches are calculated based on the targeted crowd density per square meter. Different settings of batches and the time between batches are simulated.

III. RESULTS AND DISCUSSIONS

In this section, results of simulations are discussed for above mentioned simulation protocols. Detailed results and discussion of the results are given in the succeeding subsections.

In the density maps and agent density graphs, color coding of crowd density as persons per square meter is explained in table1.

TABLE I. TABLE TYPE STYLES

Range	Color
<0.308	
0.308 - 0.431	
0.431 - 0.719	
0.719 - 1.075	
1.075 - 2.174	
2.174 - 3.174	
3.174 - 4.174	
>4.174	

A. *Full Crowd Mode*

In the full crowd mode, simulations are done for ten cases starting from 1000 agents to 20000 agents. In some cases it is done up to 18000 agents. All agents are released from the entrance gate at once and simulation is run until all the agents have left from the exit door. For 1000 agents simulation, figure 5 shows the agents density graph from entrance to ziara region at different times during simulation. As the agents are entering from the entrance gate they are moving towards the ziara place. Crowding of the agents starts building and reach to the peak in about two minutes time. The figure shows that agents experience low crowd density in most of their time during traveling from the entrance to the ziara place.

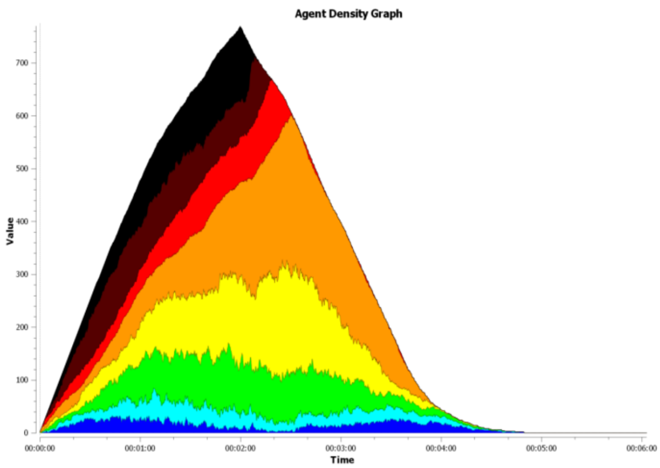

Figure 5. Agent density graph from entrance to ziara place

Figure 6 shows the agent density graph from the start of ziara place to the exit door. In front of ziara place all agents slow down and their walking speed is decreased so density of the agents builds up and at around 3 minutes time, crowd density levels are higher as compared to the density graph shown in figure 4. Most of the time crowd density in front of ziara place remains above two persons per square meter. In some areas it also goes above four persons per square meter.

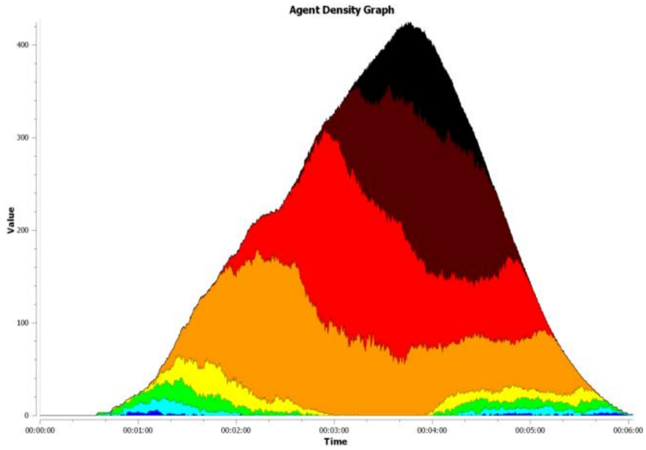

Figure 6. Agent density graph from the start of Ziara place to the Exit door

Average density map for 1000 agents simulation is shown in figure 7. This is calculated as the average of the crowd density at each grid for the whole simulation time. Whole area is shown as blue which means the average crowd density remains below 0.3 persons per square meter.

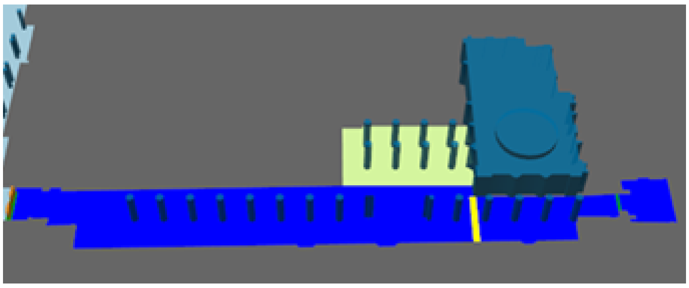

Figure 7. Average density map for 1000 agents simulation

Maximum crowd density map is shown in figure 8. It shows maximum crowd density achieved at different areas in the two regions. It can be observed that maximum density in front of ziara place was more than 2 persons per square meters and the place near to the exit door, maximum crowd density increased above four persons per square meter. It also shows that agents created more crowded regions near the exit door because of it shorter width.

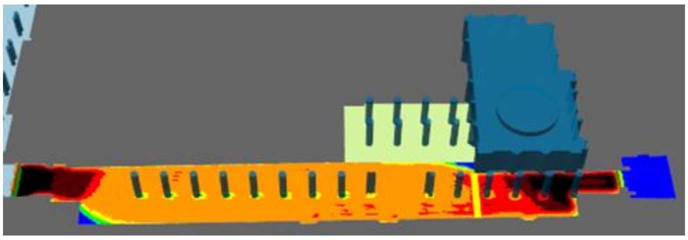

Figure 8. Maximum density map for 1000 agents simulation

Density graphs and density maps for all ten cases are given in the attached CD. As the number of agents are increasing more and more dense crowd behaviors are observed. For the simulation of 10000 agents, agent density graph from entrance to ziara place is shown in the figure 9.

It can be seen from the graph that agent density suddenly increased beyond four agents per square meter and most of the time it remained above four agents per square meter.

Same behavior can be seen in figure 9 which shows the agent density graph in the second region (ziara to exit door). Most of the time agent density remains above four agents per square meter (shown in black color). Average density map and maximum density map are shown in figures 10 and 11 respectively. In figure 10, it can be observed that average agent density remains in the range of approximately two to three agents per square meter (Red color) whereas maximum agent density is above four agents per square meter for the whole region.

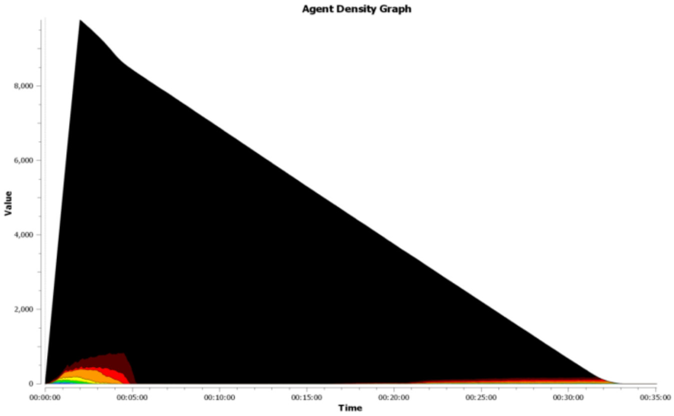

Figure 9. Agent density graph from entrance to Ziara place (10000 agents)

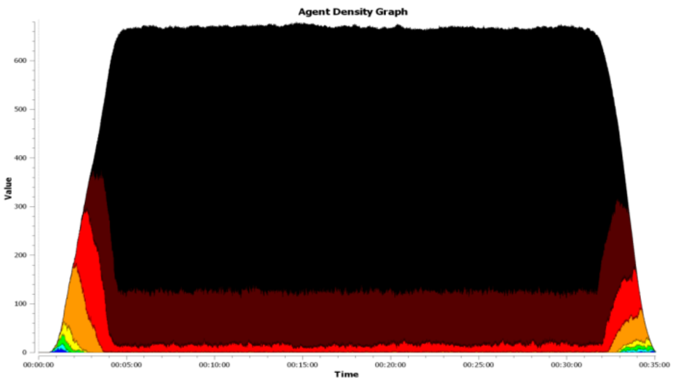

Figure 10. Agent density graph from the start of Ziara place to exit door (10000 agents)

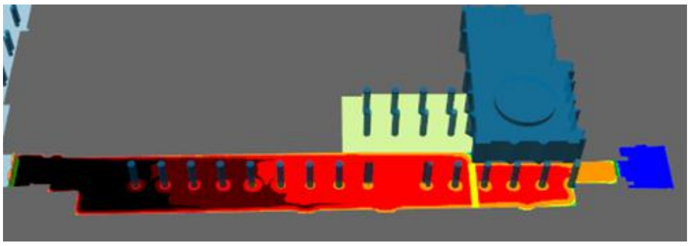

Figure 11. Average density map for 10000 agents

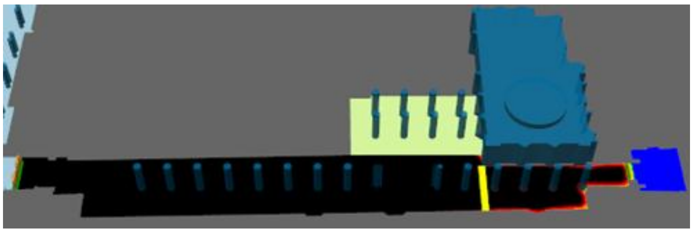

Figure 12. Maximum Density map for 10000 agents

For 16000 agents, the situation of crowd density becomes more worse and most of the time, agent density remains above four agents per square meter in both regions (Figures 13 and 14).

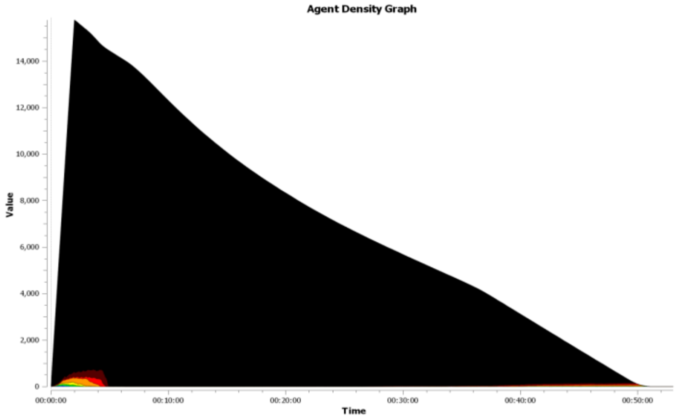

Figure 13. Agent density graph from entrance to Ziara place (16000 agents)

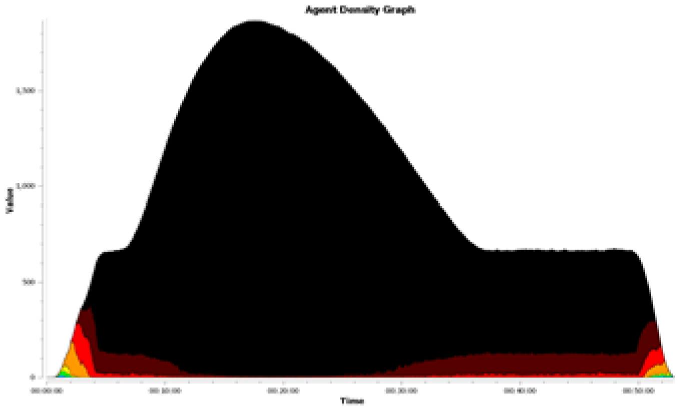

Figure 14. Agent density graph from the start of Ziara place to exit door (16000 agents)

Figure 15 shows average density map which shows black color in all the regions. Average density of the agents also remained above four agents per square meter.

Figure 15. Average density map for 16000 agents

Simulation results are summarized for all the simulations done in the full crowd mode (number of agents from 1000 to 20000) as follows. In table 2, mean and the standard deviation of the time spent by the agents in the two regions (Entrance to start of Ziara En-Z and Start of Ziara to Exit door Z-Ex) is reported for the simulation of different number of agents. Agents entered from the entrance gate to reach to the ziara place and the time spent in the region of En-Z can be considered as the waiting time for the agents trying to reach to the ziara place. It can be seen from the table that as the number of agents are increasing, the time spent in the first region En-Z is also increasing and it reaches up to approximately 25 minutes on average. As the second region is near the exit door, it is easier for the agents to disperse after the exit door. Although time spent in front of ziara place is also increased but this increase is not considerable as compared to the first region.

TABLE II. TIME DURATION SPENT IN TWO REGIONS FOR DIFFERENT NUMBER OF AGENTS

Number of Agents		Mean	Std		Mean	Std
1000	En-Z	1:41	0:28	Z-Ex	1:04	0:18
2000	En-Z	2:48	1:02	Z-Ex	1:34	0:36
4000	En-Z	5:41	3:02	Z-Ex	1:51	0:37
6000	En-Z	8:47	4:58	Z-Ex	1:56	0:38
8000	En-Z	11:53	6:52	Z-Ex	1:59	0:37
10000	En-Z	15:08	8:47	Z-Ex	2:02	0:37
12000	En-Z	18:00	10:40	Z-Ex	2:13	0:45
14000	En-Z	20:29	12:35	Z-Ex	2:45	1:19
16000	En-Z	22:31	14:16	Z-Ex	3:22	1:52
18000	En-Z	23:49	15:24	Z-Ex	3:45	2:06
20000	En-Z	24:39	16:13	Z-Ex	3:58	2:11

Let $d_a(t,k)$ is the number of agents at time t in the agent density slot k (according to table 1). Percentage of the agents experienced kth density slot over all the times is defined as $\mathrm{PDR_k}$ and calculated as below,

$$PDR_k = \frac{\sum_t d_a(t,k)}{\sum_k \sum_t d_a(t,k)} \qquad (1)$$

Values of $\mathrm{PDR_k}$ for simulations of different number agents are summarized in table 3. It can be seen from the table that for 1000 agents, highest percentage is in the density slot of 1.075 to 2.174. Small percentage of the agents (8.5%) experienced the highest density slot. As the number of agents has increased, peak of PDR is moved towards highest density slot (>4.174).

TABLE III. $\mathrm{PDR_k}$ FOR SIMULATION OF DIFFERENT NUMBER OF AGENTS

Agents								
1000	2.69	4.38	10.00	14.58	29.17	16.71	13.94	8.52
2000	0.65	1.10	2.60	4.25	22.78	14.73	13.20	40.70
4000	0.15	0.32	0.66	1.13	5.34	5.67	16.50	70.23
6000	0.07	0.18	0.35	0.52	2.45	2.67	7.57	86.18
8000	0.04	0.10	0.20	0.29	1.33	1.62	4.72	91.70
10000	0.02	0.07	0.12	0.19	0.85	1.07	3.32	94.36
12000	0.02	0.05	0.09	0.14	0.62	0.80	2.50	95.77
14000	0.01	0.04	0.06	0.09	0.45	0.58	1.79	96.97
16000	0.01	0.03	0.05	0.08	0.34	0.44	1.29	97.76
18000	0.01	0.02	0.04	0.07	0.29	0.38	1.04	98.14

In the simulations when number of agents was greater than 8000, PDR value for density slot (>4.174) reached above 90% meaning that most of the agents experienced the highest crowd density are during most of the simulation time. It shows that increasing the number of agents decrease the comfort level of the agents as most of the agents will face high crowd density. This situation is dangerous especially for elderly and sick people. Values of $\mathrm{PDR_k}$ is also plotted in figure 15 for different simulations (number of agents increased from 1000 to 18000). It is evident from the figure 16 that peak of the PDR moves toward the highest crowd density slot and distribution of PDR also shrinks towards the highest crowd density slot.

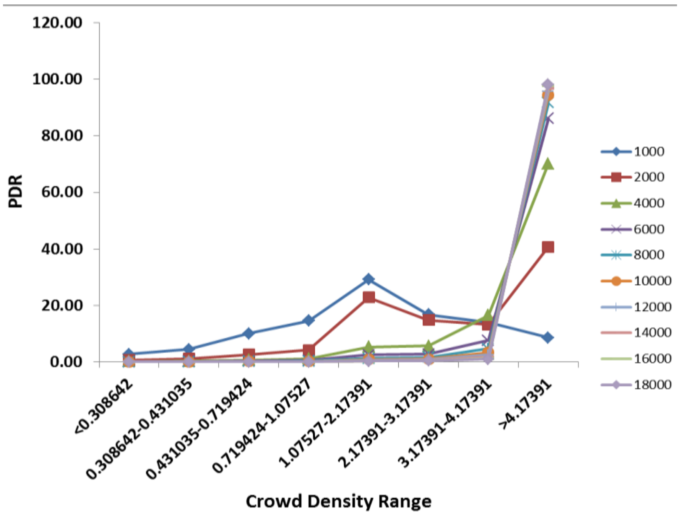

Figure 16. for simulation of different number of agents

Figure 17 shows the time required for all the agents to leave from the exit door. It can be seen from the figure that total time is increased with the number of agents. This increase is not linear which is very obvious as the exit door has limited capacity of throughput.

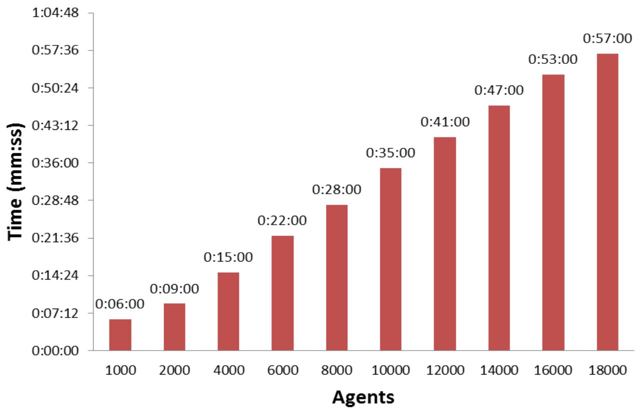

Figure 17. Total Time required for all the agents in one simulation to exit from the exit door.

B. *Batch Crowd Mode*

In this protocol, crowd is divided into batches. Different batch sizes and time duration between batches are used for simulation. Total number of agents is fixed to 16000. Based on the assumption of different crowd densities, initial batch size, batch increment and time between batches are calculated keeping in view the area of both the regions. Table 4 shows six scenarios where different initial batch sizes, batch increments and time between batches are selected.

TABLE IV. BATCH CALCULATION FOR FIXED NUMBER OF AGENTS (16000)

No.	Crowd Density (person/m^2)	Initial Batch Size	Batch increment Size	Time between batches (Seconds)
A1	2	1115	355	113
A2	3	1673	533	170
A3	4	2230	710	227
A4	5	2788	888	284
A5	6	3346	1066	340
A6	7	3903	1243	397

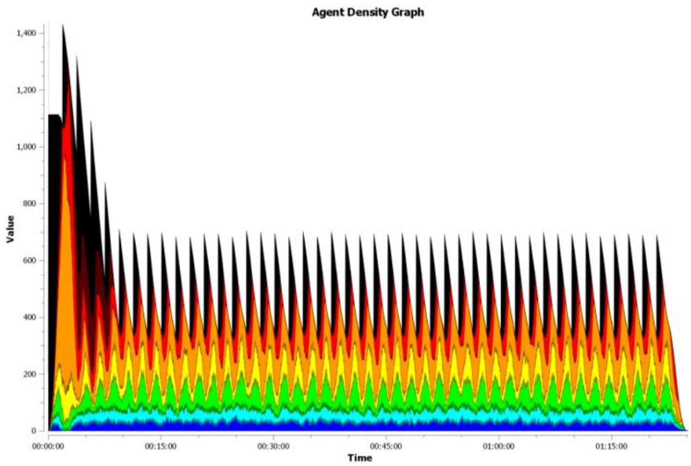

Figure 18. Agent density graph from entrance to Ziara place (16000 agents: A1 setting)

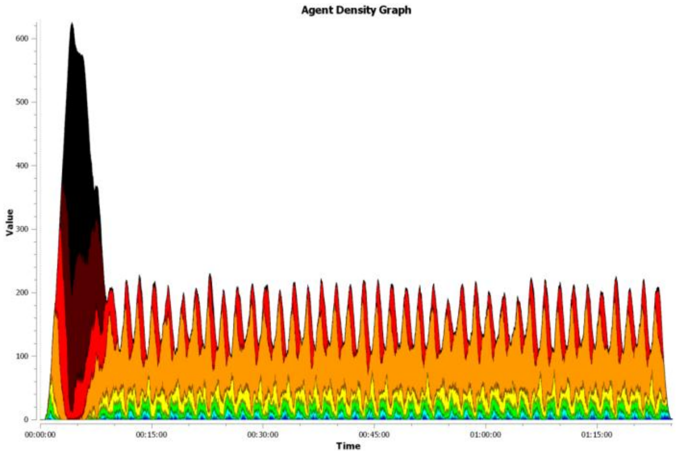

Figure 19. Agent density graph from the start of Ziara place to exit door (16000 agents: A1 setting)

For A1 settings, agent density maps for region 1 (Entrance to Ziara) and region 2 (Ziara to exit) are shown in figures 18 and 19 respectively. Comparing these figures with figures 13 and 14, we can see considerable decrease in the agent density. In the full crowd mode, almost all the agents are experiencing more than four agents per square meter density for most of the simulation time. In this case, the comfort level for the agents is improved quite significantly. Although the total simulation time when all the agents left from the exit door is increased from approximately 53 minutes to 1 hour 23 minutes. Average density map is shown in figure 20. Comparing with figure 14, situation here looks more comfortable as agent density is less than two per meter square even in the ziara place. During sometimes the agent density is increased up to the highest slot as shown in the maximum density map in figure 21.

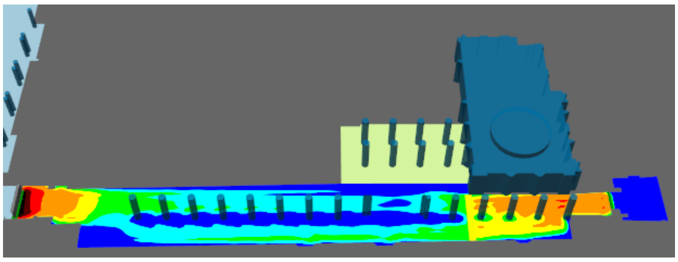

Figure 20. Average density map (16000 agents: A1 setting)

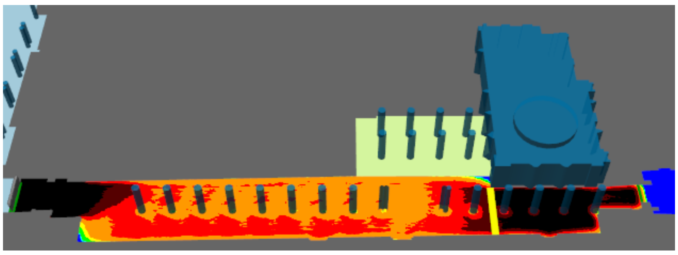

Figure 21. Maximum density map (16000 agents: A1 setting)

Table 5 compares the PDR values of the simulation of 16000 agents in the full crowd mode and under A1 setting (batch mode). It can be observed from the table that in the A1 setting mode, comfort level of the agents is higher as compared to the full crowd mode. Maximum percentage

(25.4%) occurs in the range of 1.075 and 2.174 agents per square meter.

TABLE V. PDR_k FOR SIMULATION OF 16000 AGENTS (FULL CROWD MODE AND A1 SETTING)

Number of Agents	Crowd Density Range							
Full crowd Mode	0.01	0.03	0.05	0.08	0.34	0.44	1.29	97.76
A1 Setting Mode	5.50	7.64	12.25	12.41	25.43	10.97	5.86	19.95

Agent density graphs of rest of the settings are plotted in figure 22. It is evident from the figure that increasing the batch sizes increases the percentage of the persons in higher density regions initially but later becomes comfortable. Hence for different number of agents it is possible to optimize the comfort level of the agents and total time to finish the ziara by changing the batch sizes and time between the batches. Increased comfort level of the agents will decreases the chances of panic situation and will guarantee the smooth flow of the agents. Psychologically, fatigue in the queue is felt less if the queue is moving no matter how slow it the speed is. Moreover higher densities in the crowd become difficult for the aged and sick people to cope with.

Table 6 shows PDRk for all the settings. It can be seen that for settings higher than A3, percentage of highest density slot becomes more than 50%. But it is still much less than 97% in the case of full crowd mode. Average and standard deviation of the time duration spent in both the regions are tabulated in Table 7 for all the settings. In the previous section it was found that for full crowd mode (16000 agents), average duration of time spent in the first region is 22 minutes and in the second region it is 3:22 minutes. Whereas in the batch mode, duration of time spent in the region 1 is below 5 minutes for all the settings. This is also very comforting and encouraging for the agents as region 1 is considered as the waiting region.

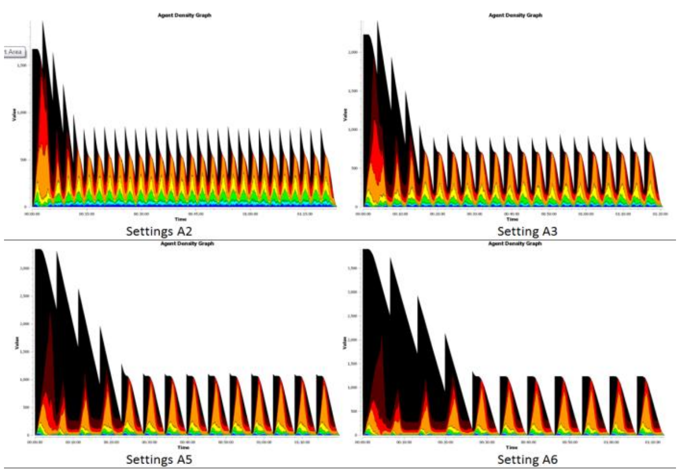

Figure 22. Agent density graph for the whole area (16000 agents)

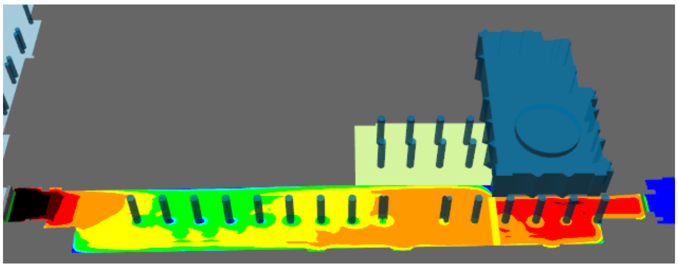

Figure 23. Average density map for setting A6

TABLE VI. FOR SIMULATION OF 16000 AGENTS (FOR DIFFERENT SETTINGS).

Settings	Crowd Density Range							
A1	5.50	7.64	12.25	12.41	25.43	10.97	5.86	19.95
A2	3.24	4.58	8.27	10.49	24.13	12.41	9.01	27.88
A3	1.92	2.76	5.19	7.37	22.82	11.90	12.45	35.60
A4	1.58	2.25	4.29	6.40	21.63	6.22	9.40	48.24
A5	0.79	1.22	2.38	3.82	17.02	9.83	13.14	51.79
A6	0.51	0.84	1.67	2.62	13.29	9.25	12.50	59.32

TABLE VII. MEAN TIME DURATION OF AGENTS IN EACH ZONE WITH EXISTING DOOR

Batch	Zone	Mean Duration (mm:ss)	Standard Deviation
A1	En-Z	1:53	0:35
	Z-Ex	0:56	0:19
A2	En-Z	2:12	0:47
	Z-Ex	1:04	0:26
A3	En-Z	2:35	1:07
	Z-Ex	1:12	0:32
A4	En-Z	3:02	1:34
	Z-Ex	1:20	0:34
A5	En-Z	3:35	2:06
	Z-Ex	1:28	0:37
A6	En-Z	4:15	2:41
	Z-Ex	1:36	0:38

TABLE VIII. TIME TO COMPLETE 16000 AGENTS

Settings						
Total Time (hh:mm:ss)	1:23:00	1:21:00	1:19:00	1:16:00	1:14:00	1:12:00

Figure 23 shows average density map for setting A6. As compared to the average density map in Figure 15 for 16000 agents in the full crowd mode (all the region is painted as black, high density), Figure 23 shows regions having different colors showing different density levels with highest in front of ziara place having red color. Even this region is less crowded as compared to Figure 15.

Table 7 shows total time for each setting to complete the ziara for all the agents. It can be seen that on the expense of increase in the crowd density during some percentage of time, total time is reduced from setting A1 to A6. Comparing with the full crowd mode (approximately 57 minutes), total time of A6 setting (approximately 72 minutes) is quite comparable with more comfortable flow of the agents. The difference between setting A1 and setting A6 is also not big due to the fact that the throughput from the door (width 3.13 meter) is limited and by increasing the batch size does not decrease the total time significantly.

IV. Recommendations

Based on the simulations done and results discussed in the above section, following recommendations are made.

Crowd management should be done in the batch mode with appropriate selection of the batch sizes and timing between batches. To ensure smooth flow of the crowd strong motivation from the security personals especially in the high density cases is recommended. With the existing door, A4 batch mode setting is suggested to compromise the operation completion time and lower crowd density in the regions. It is suggested that following mechanism can be adopted for the batch mode control of the crowd.

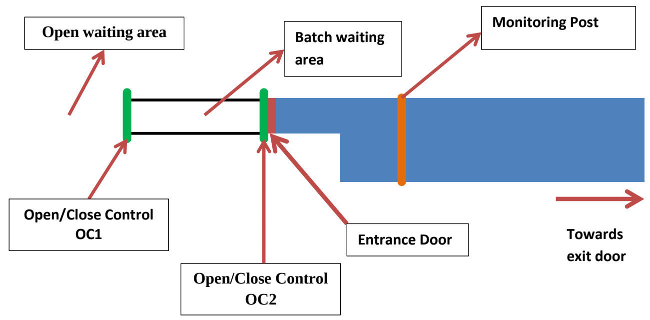

Figure 24. Proposed Batch mode control plan

Figure 24 shows the proposed batch mode control plan. There are two control points outside the entrance door. First control point OC1 brings the people from outside to the batch waiting area. Length of these two points depends on how much will be the batch size. Initially, initial batch is allowed in the batch waiting area by opening OC1 and OC2 is closed. Then OC1 is closed and OC2 will be open to let the batch into the mosque through entrance door. A security personal will be placed on monitoring post. The distance of monitoring post from the entrance door depends on the batch size. Once the whole batch enters in the mosque, OC2 is closed. The OC1 is open to bring another batch in the waiting area. When the security personal signals the crossing of last person of batch from the monitoring line, new batch is entered by opening OC2. This procedure keeps repeating until all persons complete ziara or outside waiting crowd falls below certain threshold. Proper motivation to move is required in front of ziara place to keep the flow smooth.

V. Conclusion

In this paper we showed the comfort that batch mode can bring to people visiting prophet's grave. The simulations show the full batch mode with the increase of agents' number would lead to a high density that can't be controlled. Therefore, Crowd management should be done in the batch mode with appropriate selection of the batch sizes and timing between batches.

Acknowledgment

This project is funded by Transportation and Crowd Management Center for Research Excellence (TCMCORE), Umm Alqura University.

References

[1] [1] G. Ryder and A. Day, "Survey of Real‐Time Rendering Techniques for Crowds," in Computer Graphics Forum, 2005, pp. 203-215.

[2] [2] N. Pelechano, K. O'Brien, B. Silverman, and N. Badler, "Crowd simulation incorporating agent psychological models, roles and communication," DTIC Document2005.

[3] [3] B. Ulicny and D. Thalmann, "Crowd simulation for interactive virtual environments and VR training systems," in Computer Animation and Simulation 2001, ed: Springer, 2001, pp. 163-170.

[4] [4] M. Sung, M. Gleicher, and S. Chenney, "Scalable behaviors for crowd simulation," in Computer Graphics Forum, 2004, pp. 519-528.

[5] [5] S. Jain and C. R. McLean, "Integrated simulation and gaming architecture for incident management training," in Simulation Conference, 2005 Proceedings of the Winter, 2005, p. 10 pp.

[6] [6] N. Pelechano, J. M. Allbeck, and N. I. Badler, "Controlling individual agents in high-density crowd simulation," in Proceedings of the 2007 ACM SIGGRAPH/Eurographics symposium on Computer animation, 2007, pp. 99-108.

[7] [7] J. C. S. Jacques Junior, S. R. Musse, and C. R. Jung, "Crowd analysis using computer vision techniques," Signal Processing Magazine, IEEE, vol. 27, pp. 66-77, 2010.

[8] [8] W. Shao and D. Terzopoulos, "Autonomous pedestrians," Graphical Models, vol. 69, pp. 246-274, 2007.

[9] [9] D. Helbing and P. Molnar, "Social force model for pedestrian dynamics," Physical review E, vol. 51, p. 4282, 1995.

[10] [10] D. Helbing, I. Farkas, and T. Vicsek, "Simulating dynamical features of escape panic," Nature, vol. 407, pp. 487-490, 2000.

[11] [11] J. Pettré, H. Grillon, and D. Thalmann, "Crowds of moving objects: Navigation planning and simulation," in Robotics and Automation, 2007 IEEE International Conference on, 2007, pp. 3062-3067.

[12] [12] B. Yersin, J. Maïm, P. Ciechomski, S. Schertenleib, and D. Thalmann, "Steering a virtual crowd based on a semantically augmented navigation graph," VCROWDS 2005, 2005.

[13] [13] A. Treuille, S. Cooper, and Z. Popović, "Continuum crowds," in ACM Transactions on Graphics (TOG), 2006, pp. 1160-1168.

[14] [14] B. Ulicny, P. d. H. Ciechomski, and D. Thalmann, "Crowdbrush: Interactive authoring of real-time crowd scenes," in Proceedings of the 2004 ACM SIGGRAPH/Eurographics symposium on Computer animation, 2004, pp. 243-252.

[15] [15] S. Patil, J. Van Den Berg, S. Curtis, M. C. Lin, and D. Manocha, "Directing crowd simulations using navigation fields," Visualization and Computer Graphics, IEEE Transactions on, vol. 17, pp. 244-254, 2011.

[16] [16] S. R. Musse, C. R. Jung, J. Jacques, and A. Braun, "Using computer vision to simulate the motion of virtual agents," Computer Animation and Virtual Worlds, vol. 18, pp. 83-93, 2007.

[17] [17] N. Courty and T. Corpetti, "Crowd motion capture," Computer Animation and Virtual Worlds, vol. 18, pp. 361-370, 2007.

[18] [18] A. Kirchner and A. Schadschneider, "Simulation of evacuation processes using a bionics-inspired cellular automaton model for pedestrian dynamics," Physica A: Statistical Mechanics and its Applications, vol. 312, pp. 260-276, 2002.

[19] [19] J. van den Berg, S. Patil, J. Sewall, D. Manocha, and M. Lin, "Interactive navigation of multiple agents in crowded environments," in Proceedings of the 2008 symposium on Interactive 3D graphics and games, 2008, pp. 139-147.

[20] [20] S. J. Guy, J. Chhugani, S. Curtis, P. Dubey, M. Lin, and D. Manocha, "Pledestrians: a least-effort approach to crowd simulation," in Proceedings of the 2010 ACM SIGGRAPH/Eurographics Symposium on Computer Animation, 2010, pp. 119-128.

[21] [21] A. Golas, R. Narain, and M. Lin, "Hybrid long-range collision avoidance for crowd simulation," in Proceedings of the ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games, 2013, pp. 29-36.

[22] [22] T. Sakuma, T. Mukai, and S. Kuriyama, "Psychological model for animating crowded pedestrians," Computer Animation and Virtual Worlds, vol. 16, pp. 343-351, 2005.

[23] [23] G. J. Brostow and R. Cipolla, "Unsupervised bayesian detection of independent motion in crowds," in Computer Vision and Pattern Recognition, 2006 IEEE Computer Society Conference on, 2006, pp. 594-601.

[24] [24] M. S. Allili and D. Ziou, "Object contour tracking in videos by matching finite mixture models," in Video and Signal Based Surveillance, 2006. AVSS'06. IEEE International Conference on, 2006, pp. 35-35.

[25] [25] J. Candamo, M. Shreve, D. B. Goldgof, D. B. Sapper, and R. Kasturi, "Understanding transit scenes: a survey on human behavior-recognition algorithms," Intelligent Transportation Systems, IEEE Transactions on, vol. 11, pp. 206-224, 2010.

[26] [26] V. Rabaud and S. Belongie, "Counting crowded moving objects," in Computer Vision and Pattern Recognition, 2006 IEEE Computer Society Conference on, 2006, pp. 705-711.

[27] [27] A. M. Cheriyadat and R. J. Radke, "Detecting dominant motions in dense crowds," Selected Topics in Signal Processing, IEEE Journal of, vol. 2, pp. 568-581, 2008.

[28] [28] M. Hu, S. Ali, and M. Shah, "Detecting global motion patterns in complex videos," in Pattern Recognition, 2008. ICPR 2008. 19th International Conference on, 2008, pp. 1-5.

[29] [29] J. E. Almeida, R. J. Rosseti, and A. L. Coelho, "Crowd Simulation Modeling Applied to Emergency and Evacuation Simulations using Multi-Agent Systems," arXiv preprint arXiv:1303.4692, 2013.

[30] [30] G. Santos and B. E. Aguirre, "A critical review of emergency evacuation simulation models," 2004.

[31] [31] X. Zheng, T. Zhong, and M. Liu, "Modeling crowd evacuation of a building based on seven methodological approaches," Building and Environment, vol. 44, pp. 437-445, 2009.

[32] [32] A. Schadschneider, W. Klingsch, H. Klüpfel, T. Kretz, C. Rogsch, and A. Seyfried, "Evacuation dynamics: Empirical results, modeling and applications," in Extreme Environmental Events, ed: Springer, 2011, pp. 517-550.

[33] [33] S. J. Guy, J. van den Berg, W. Liu, R. Lau, M. C. Lin, and D. Manocha, "A statistical similarity measure for aggregate crowd dynamics," ACM Transactions on Graphics (TOG), vol. 31, p. 190, 2012.

[34] [34] N. Pelechano, C. Stocker, J. Allbeck, and N. Badler, "Being a part of the crowd: towards validating VR crowds using presence," in Proceedings of the 7th international joint conference on Autonomous agents and multiagent systems-Volume 1, 2008, pp. 136-142.

[35] [35] J. Pettré, J. Ondřej, A.-H. Olivier, A. Cretual, and S. Donikian, "Experiment-based modeling, simulation and validation of interactions between virtual walkers," in Proceedings of the 2009 ACM SIGGRAPH/Eurographics Symposium on Computer Animation, 2009, pp. 189-198.

[36] [36] M. Kapadia, M. Wang, S. Singh, G. Reinman, and P. Faloutsos, "Scenario space: characterizing coverage, quality, and failure of steering algorithms," in Proceedings of the 2011 ACM SIGGRAPH/Eurographics Symposium on Computer Animation, 2011, pp. 53-62.

[37] [37] S. R. Musse, V. J. Cassol, and C. R. Jung, "Towards a quantitative approach for comparing crowds," Computer Animation and Virtual Worlds, vol. 23, pp. 49-57, 2012.

[38] [38] Z. Zainuddin, K. Thinakaran, and I. M. Abu-Sulyman, "Simulating the Circumambulation of the Ka'aba using SimWalk," European Journal of Scientific Research, vol. 38, pp. 454-464, 2009.

[39] [39] S. Sarmady, F. Haron, and A. Z. Talib, "Agent-Based Simulation Of Crowd At The Tawaf Area," 2007.

[40] [40] L. Crociani, L. Manenti, and G. Vizzari, "MAKKSim: MAS-based crowd simulations for designer's decision support," in Advances on Practical Applications of Agents and Multi-Agent Systems, ed: Springer, 2013, pp. 25-36.

[41] [41] L. Manenti, S. Manzoni, and G. Vizzari, "Makksim: Dealing with pedestrian groups in mas-based crowd simulation," in WOA 2011, 2011, pp. 166-170.

Abdullah Alshehri is a reasearcher at Transportation and Crowd Management Center for Research Excellence, Umm Alqura University, Makkah. He received his M.C.S. in wireless networks from University of Ontario Institute of Technology, Oshawa, Canada. He is currently working on crowd management simulation.

Dr.Muhammad Arif received B.E. degree in electronics engineering from the NeD University of S&T, Pakistan in 1990, MS degree from Quid-e-Azam University, Pakistan in 1993 and Ph.D. degree in System Information Sciences from Tohoku University, Japan in 1999. He is currently Professor in the Department of Computer Science Um-Alqura University, Makkah, Saudi Arabia. His research areas include Biometrics, Intelligent Pattern Recognition, Visualization and intelligent monitoring.

Marwan Kheimi received a bachelor degree in Civil Engineering from Umm Al-Qura, Saudi Arabia in 2009, Master's degree in Civil Engineering from California State University, Long Beach, United States of America in 20q3. A faculty of the Civil Engineering Department in King Abdul Aziz University until now. Currently, a Ph.D. student at the University of Central Florida, U.S. Civil Engineering. Research interests are in crowed modeling, data collection.

Dr. Emad Felemban is an assistant professor in Computer Engineering Department in Umm Al-Qura University Saudi Arabia. He graduated with PhD from Ohio State University in 2009. His research interests include wireless communication, wireless sensor networks and Smart City Applications. He is the director of Transportation and Crowd Management Center of Research Excellence.