# AUTONOMOUS TAWAF CROWD SIMULATION

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**ABSTRACT.** *One of the most famous approaches to simulate a large density crowd is by applying the social force model. This model can be successfully used to simulate agents' movement in real-world scenarios realistically. Nevertheless, this is very simple and not suitable to simulate a complex pedestrian flow movement. Hence, this research proposes a new novel model for simulating the pilgrims' movements circling the Kaabah (Tawaf). These rituals are complex yet unique, due to its capacity, density, and various demographics backgrounds of the agents (pilgrims). It also had a certain set of rules and regulations that must be followed by the agents. Due to these rules, the Tawaf can introduce irregularities in the motion flow around the Kaabah. In order to make the simulation realistically, each agent will be assigned with different attributes such as; age, gender and intention outlook. The three parameters mentioned above, are the main problems that need to be solved in this research in order to simulate a better crowd simulation than previous studies. The findings of this research will contribute greatly for Hajj management in term of controlling and optimizing the flow of pilgrims during Tawaf especially in the Hajj season.*

**Keywords. A**utonomous Agents; Crowd Simulation; Hajj.

## INTRODUCTION

Animating motion for large crowds has been an important goal in the computer graphics, movie and video games communities. There has been a considerable amount of work on locomotion, path planning, navigation in large virtual environments and realistic behaviour simulation using cognitive models.

In terms of defining the motion of each agent, we classify three main approaches: social force model, rule based model and cellular automata model. Much effort has been put into improving the behavioural realism of each of these approaches. Nevertheless, the current models cannot realistically animate high density crowds. Social force model tends to give simulations that resemble particle animation rather than human movement. Cellular automata model limits the movement of the agents, with a tendency to look like a checkerboard when the density is high. Finally, rule based model either not considering collision detection and repulsion, or adopting a very conservative approaches through the

use of waiting rules. These rules work well for low densities crowd in everyday life simulation, but have insufficient realism for high density or panic situations.

The current models for crowd simulation in computer graphics cannot realistically handle body-to-body contact for large crowds and while they achieve good results for low and medium density crowds in normal situations (e.g., people walking in a train station, or virtual city), they fail to realistically simulate high density situations, such as an evacuation from a virtual building.

When simulating large groups of agents, it is insufficient to only have realistic low-level movement, but it is also necessary to endow the agents with a high-level behaviour characteristic that can closely simulate the decision making process of real people. Most works in crowd simulation either deal with simple environments, or assumes every agent has a complete knowledge of the environment. Therefore, it is necessary to simulate autonomous agents that can navigate unknown environments, learn their features and communicate with other agents in the crowd in order to exchange relevant information to achieve their goals. Agents within a crowd should interact between each other as real people do; therefore exchanging information is a very important feature in crowd simulation. In addition, agents must use visual cues to detect other agents' positions to perform collision avoidance and to learn other agents' psychological states and react to them accordingly. For example, an agent seeing another agent in panic and pushing through a crowd could trigger panic behaviour which allows us to simulate panic propagation.

Pedestrians come from various different demographic backgrounds, in terms of age, gender, intention outlook, etc. These attributes will influence the pace and direction of each agent. For example, an older pedestrian's movement is much slower as compared to the young ones. On the other hand, each agent path decision making will also be influenced by the social rules. By following the rules, the crowd flow will encounter some irregularities if pedestrians from opposite directions meet each other. As a consequence, the pedestrian's flow will be more complex and challenging.

## RELATED WORK

There are a lot of researches had been done in order to simulate larger crowds such as during Tawaf. They use various approaches for the same objective that is to simulate the circumambulation movement as realistic as possible. Some of them are using the Cellular automata technique, for example researcher from Univesiti Sains Malaysia (Samardy *et al.,* 2011). The research focused on small-scale movement of the pilgrims. They are not able to simulate a very large and dense crowd realistically by using this technique.

On the other hand, some researchers prefer using social force model as their base model to simulate the Tawaf ritual. Researchers from Universiti Sains Malaysia (Zainuddin *et al.,* 2010) use this model to simulate the flow of pilgrims getting in and getting out of the

mosque through the entrance. The flow of the pilgrims are bidirectional and facing towards each other. The research results showed that there is a congested area in the main entrance.

The same researcher also used cellular automata approach to simulate the pilgrims flow during Tawaf (Zainuddin *et al.,* 2010). They use the simulation to calculate the average walking speed, pedestrian density and cumulative evacuees by using response surface methodology (RSM). The results are used to study a more effective evacuation model.

The other researchers that use the same model are researcher from Chapel University (Curtis *et al.*, 2010). They also integrated a high-level finite-state machine (FSM) with a low-level local collision avoidance (LCA) algorithm into their model to simulate the crowd behaviour in a promising way.

Although most of the previous studies show promising result, but none of them was simulating the real event realistically. All of them are just showing their result in two dimensions which cannot be used for training purposes in real-life. The previous studies also do not integrate the Tawaf rites and ritual into the simulation, they just simulate the flow of the pilgrims circling the Kaabah. However, most of the researchers are implementing intelligent agent into their model so that the movement of the pilgrims are dissimilar between one another.

## METHODOLOGY

The proposed method will be discussed in three sections which will be started by constructing the crowd behaviour algorithm. Next, is extending the current heuristic method for crowd simulation. Finally, developing a working prototype of real-time crowd simulation to test the propose model.

### *A. Construct Crowd Behaviour Algotrithm*

Characteristic mean that each agent is different from one and another to simulate the real situation where pedestrians are consists of various backgrounds. However, to simulate the real situations are impossible because it has a limitless possibilities of characteristic, thus only a few main characteristics will be chosen such as age and gender. The age will be distributed into two groups; adult and elderly. These characteristics will decide the agents' movement speed. The younger agents will move faster than the older agent, while male agents will move faster than the female agents.

Next is intention outlook, which means each agent will be given the intention according to its situation. For example, each agent will have the intention to get as close as it gets to the Kaaba and it will have an intention to kiss the black stone when it gets close to it. The intention also important to make sure that at the 7th times of circling the agent has to get out from the crowd and exit the mosque since this research is applying the rules into the simulation.

The next thing that will embed in the artificial brain is experience. Each agent will be given experience according to its surrounding, so that it will know how to response to the situation quickly after whatever happened around them. For example, if the agent traps in the crowd during its try to get out from the crowd after the 7th rounds, the agents will use more force to get out from the dense crowd. Crowd simulation algorithm:-

1) *Start*
2) *Enter Kaabah*
3) *Circumambulate Kaabah*
4) *If meet older pilgrims (Decrease walking speed)*
5) *If meet younger pligrims (Increase walking speed)*
6) *If meet same sex pilgrims (Decrease distance)*
7) *If meet opposite sex pilgrims (Increase distance)*
8) *Get closer to the epicenter (Closer to Kaabah)*
9) *Untilcircumambulate 7 times*
10) *Get out from Tawaf area*
11) *If fail to get out (Increase pushing force)*
12) *End*

### *B. Extending the Current Heuristic Method For Crowd Simulation*

Human movements are usually started because of desire and intentions for a specific reason. As in this research the pilgrim wants to perform Tawaf by circumambulating Kaabah 7 times. This intention results into a decision and a series of actions. These actions follow the ritual rites of performing Tawaf. Performing Tawaf is a macroscopic movement, which needs navigation and way finding behaviours. During these movements, movements like collision avoidance and shortest path selection, which is the microscopic movement, will take place. Other than that, a new decision and action may trigger due to some environmental events and parameters. Thus, to simulate a realistic simulation of this ritual, the crowd simulation model must have the concept of desire, characteristic and experience. It also must include macroscopic and microscopic movements.

An artificial brain need to be created for each agent in this proposed method. It will be used to decide which path is the best path to take for each agent in the simulation. Each artificial brain consists of its characteristic, desire and experience.

Each agent will be given experience according to its surrounding, so that it will know how to respond to the situation quickly after whatever happened around them. For example, if the agent traps in the crowd during its try to get out from the crowd after the 7th rounds, the agents will use more force to get out of the dense crowd.

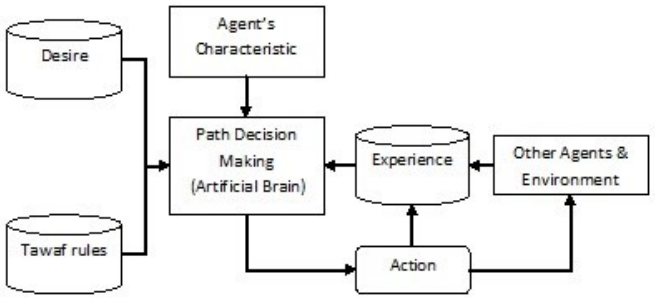


**Figure 1:** Proposed crowd simulation model

### *C. Develop a Prototype of Crowd Simulation*

The proposed method combines all the parameters (characteristic, desire, rules and experiences) to simulate the Tawaf ritual as realistic as it can. Differ from other Tawaf crowd simulation model, which lets the agents move freely as they can, this model will restrict the agents' movements according to the rites and rules of performing Tawaf. The agents in this model also will react with another agent so that some grouping of pilgrim can handle since most of the pilgrim are not performing these rituals alone.

A simulation was designed to test the proposed method of circumambulation of the Kaabah. All the agents were given the direction to move around the Kaabah. For simplicity, the entrance into the Tawaf area is limited to only one.

## RESULT AND DISCUSSION

Based on the testing records with 10000 characters the application has shown good result on simulating Tawaf ritual using crowd simulation. The FPS relatively high and the CPU times is small, this mean the device still able to handle the crowd number with high performance. The experiment is simulated using 1000, 10000 and 10000 characters to see the performance of the simulation. This experiment is using social force model as the testing method. Based on figure 2, we can see that the simulation is not realistic enough to simulate the real situation. It needs more improvement in the algorithm to make it more realistic. The testing simulations are lacking of agents' interaction without any intelligent path decision making, grouping movements and Tawaf rules are not implemented. However, these testing still show some promising results which can be further improve.

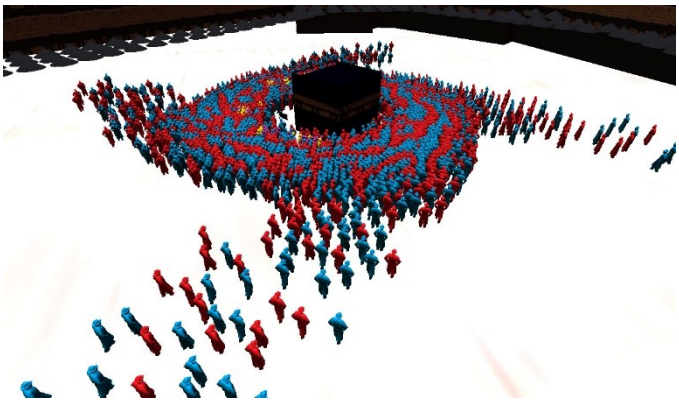

**Figure 2:** Testing with 10000 agents (side view)

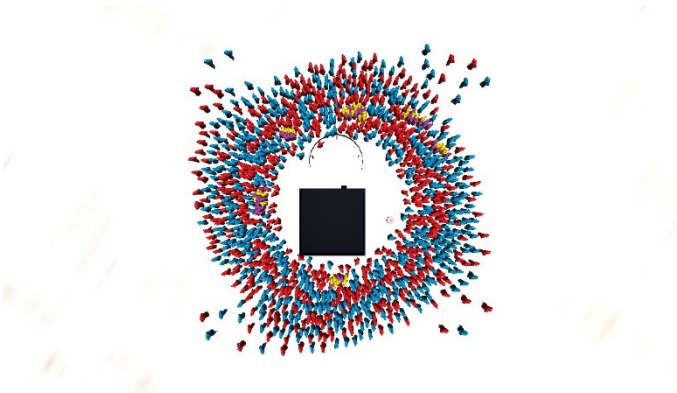

**Figure 3:** Testing with 10000 agents (ariel view)

## CONCLUSION

Hajj pilgrimage is one of the largest religious people gathering in the world that occurs every year. Thus, it is not easy to simulate this scenario through a virtual environment. Each hajj rituals have its rules and procedures. For example, in Tawaf pilgrims have to move in a specific pattern and a certain number of rotations must be achieved which in this case the pilgrims must circle the Kaabah for seven times to complete the Tawaf ritual. This research will implement the crowd simulation according to the rules of performing Tawaf. The early finding results, show that it is able to simulate the rituals and the crowds to a certain level of precision Of course, there are still a lot of improvement need to be done and the algorithm needs to be revised. Nevertheless, the testing has shown a promising result on representing the crowd during hajj.

There is a lot of unique behaviour that only occurs in Tawaf situation, which yet to be explored and to be implemented into the current model. These behaviours can be studied by observation and studying either Tawaf video or real world Tawaf scenarios. Other researchers' model such as holonomic behaviour model also can be added in the future research since this behaviour also normally happen in dense crowd like Tawaf (Hughes *et al.* 2014).

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