Hajj Crowd Simulation Based on Intelligent Agent

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***Abstract*— Hajj ritual involves many pilgrims from more than one hundred countries with more than two million people every year. This paper presents simulation of the hajj crowd based on the development on intelligent agent. The intelligent agent is able to adapt and show rational behavior, to recognize the environment, and to do action. The concept of intelligent agent is applied to the individual pilgrim to build the crowd behavior. The results showed that hajj crowd simulation is able to demonstrate more realistic pilgrims' behavior for three hajj activities, i.e. *thawaf*, *sa'i*, and *jumrah*. Moreover, subjective evaluation revealed that the developed system can be used for training the pilgrim before they perform actual activities.**

Keywords: crowd simulation, hajj, agent, behavior, pilgrim

I. INTRODUCTION

Hajj ritual is one of Islam pillar that obligated to each Muslim who are able (*istitho'ah*). This ability is evaluated from hajj expense, health, safety, and also knowledge about how to perform Hajj (*manasik*) [1]. Ministry of Hajj, Kingdom of Saudi Arabia revealed that every year more than two million Muslim men and women from over a hundred countries gather in Mecca to undertake the Hajj pilgrimage with the tendency of growing up in number year by year. As mentioned in [2], the impact of Hajj is not only to improve the quality of relationship with Allah (*hablumminallah*) but also relationship with other human being (*hablumminannaas*). Furthermore, it is not only to improve the relationship between Muslim but also to increase tolerance with other non-Muslims fellow. Figure 1 illustrates the stages of Hajj ritual which consists of *thawaf*, *sa'i*, and *jumrah*.

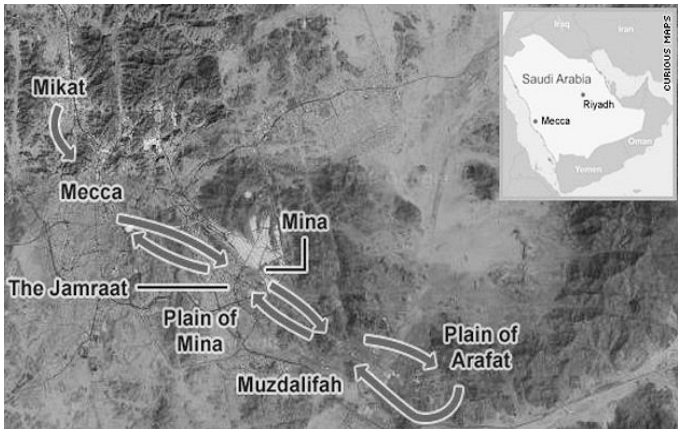

Figure 1. Stages of Hajj ritual

Many researches have been done on hajj crowd simulation. The purpose of the previous simulation is to simulate the fluidity of the Hajj ritual. In 1990, Al-Gadhi and Mahmassani [3] studied on how to model the crowd behavior and movement on Hajj ritual based on fluid particle. Al-Zahrani and Matbouli [4] with the same approach have done simulation using SimWalk to control the crowd especially during *thawaf* ritual.

To best model the crowd, intelligent agent can be utilized as it enables each character in the crowd to have different goals and different behaviors which reflects the real world [5]. To realistically model the real world, the agent model not only must have the capability to make decision, but also must have location specific capability [6]. Kim *et. al* [7] stated that individual or a group of pilgrims can be implemented as agents which have the capabilities to sense, think, and act. These capabilities enable more realistic human behavior and crowd model [8].

The objective of this paper is to develop hajj crowd simulation based on intelligent agent so that it can perform more natural and more complex behavior compare to the one based on fluid particle. Moreover, the developed system can be used for educational aspect (*edugame*) to improve Muslim knowledge about hajj ritual. Lastly, the developed framework can also be used for other crowd simulation because of the existence of reusable components or objects.

II. INTELLIGENT AGENT

A. Concept

Agent is an entity that has the ability to recognize environment via its sensors and do action due to environment condition via its actuator, as illustrated in Figure 2. Agents may also learn or use knowledge to achieve their goals. They may be very simple or very complex.

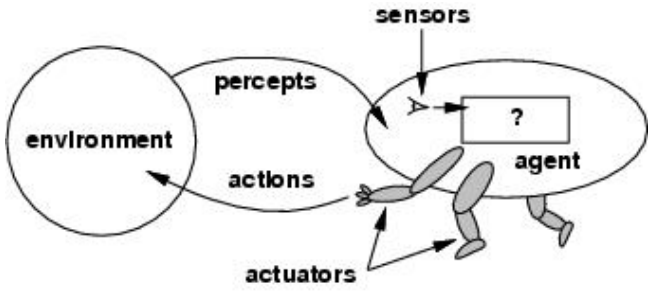

Figure 2. Agent structure [9]

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B. *Agent Design*

In order to make simulation as close as possible to the real world, model of intelligent agent must not only represent its decision making capability but also where its capabilities are based [6]. In this paper, the simulation was developed to provide illusion of hajj crowd. Therefore agent's behavior is designed in such a way to reflect pilgrim behavior in the real world. Nevertheless, hajj is a ritual activity which is not only bound to the time but also to the place [1]. Hajj activity is performed between Mecca, Mina, Muzdalifah, and Arafat (see Figure 1). Therefore, the agent needs to know the current location so that it can determine appropriate behavior according to the location condition. Table I summarizes the design of intelligent agent.

TABLE I. AGENT DESIGN

Agent type	Hajj activities
percepts	▪ *body sensors* (front, left, and right): used for collision detection with environment (other agents or buildings) ▪ *avoid sensor*, used to detect other agent so it can avoid collision ▪ *agent view*, used to detect other agents ▪ *agent action*, agent need to know its own action so that it can determine next action ▪ *environment layout*: used by agent to recognize its environment so that it can determine appropriate hajj activities
actions	▪ idle ▪ walk ▪ brisk walk ▪ stoning ▪ kiss the black stone (*hajar aswad*) ▪ wave hand to the black stone
goals	Do hajj activities according to *sunnah* [1]
environment	▪ floor (walking path) ▪ obstacles (other agents and buildings) ▪ vector field, which will determine agent's movement ▪ specific ritual area/object, such as *thawaf*, *sa'i* dan *jumrah* area

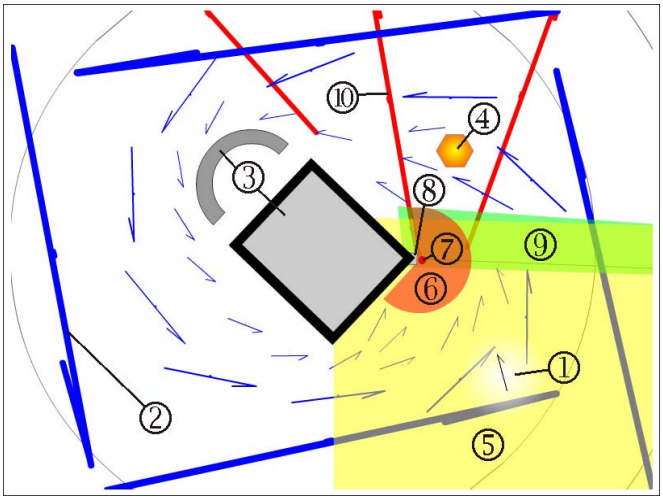


Figure 3. Environment layout for *thawaf* simulation

Agent will be placed in different virtual environment and do specific activities according to its environment or location. For the sake of example, Figure 3 shows the environmental layout for *thawaf* simulation in Kabah. During *thawaf*, each pilgrim will circle the Kabah in counter clockwise direction. Moreover, there are places surrounding the Kabah, such as hajar aswad, maqam Ibrahim and hijr Ismail, with specific movement that need to be taken into account in the environmental layout. There are also specific rituals in the specific place, like prayer and kissing the hajar aswad [1]. These behaviors are modeled in the form of finite state machine as shown in Figure 4. Other hajj activities, like *sa'i* and *jumrah* are modeled the same thing as *tawaf* simulation.

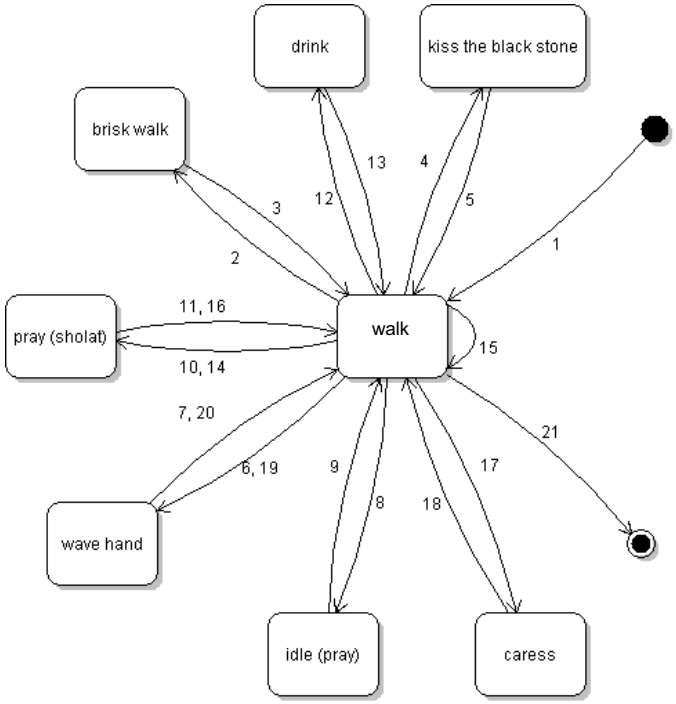


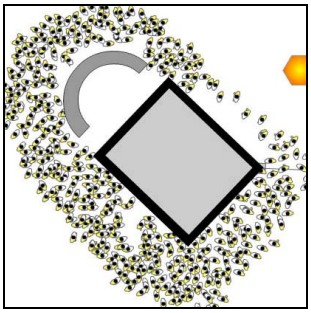
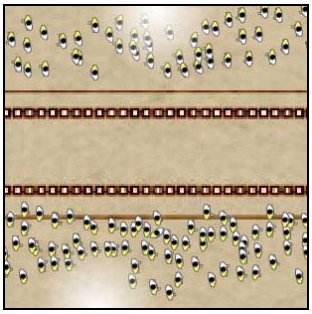
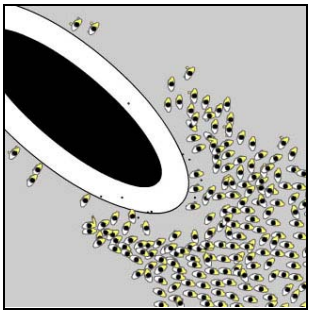
Figure 4. Agent behavior when performs thawaf

III. AGENT VALIDATION

Agent validation is required to compare simulation result with real word data to find if it is matched or not [10]. Zeigler [6] stated that at least there are three types of validation, i.e. replicative validity, predictive validity, and structural validity. The type of validation that is suitable for our simulation is replicative validity in which we try to find out whether our model matches data already acquired from the real system.

To validate the intelligent agent model, the screenshots from simulation will be compared to the actual hajj activities in the real world. Table II provides the replicative validation result. Due to computer processing limitation, not more than 300 agents were used for this purpose compare to two million people in the actual case. Three hajj activities were compared in this experiment, such as *thawaf*, *sa'i*, and *jumrah*. Nevertheless, it was found that our developed model is suitable for hajj crowd simulation.

TABLE II. REPLICATIVE VALIDATION RESULT

Real World	Simulation
	
	
	

IV. SIMULATION RESULTS AND DISCUSSION

As a simulation platform, we used a computer with processor AMD Turion 64 X2 2.0Ghz with 2 GBytes memory and GeForce 7000M graphic card. The intelligent agent was implemented using ActionScript with object oriented paradigm. Figure 6 shows the screenshot of the implemented system in the form of *edugame*.

First, computational time in terms of frame per second (fps) versus number of agents is carried out to objectively measure the simulation performance. It was found that the higher the number of agent, the smaller the number of fps, as shown in Figure 4. Therefore, ideal number of agents for real time evaluation can be deducted from this experiment. It was found that for *thawaf*, *sa'i*, and *jumrah* simulation, the number of agents should be less than 60 to achieve real time simulation (around 15 frame per second). Nevertheless, computer with faster CPU and GPU can be utilized to process higher number of agents. Or parallel processing can be deployed for higher number of agents or faster processing.

To subjectively evaluate the implemented system, questionnaire were conducted. There were ten people participated in the survey. The participant consisted of six male and four female. Four people have performed their hajj, while the other six have not done their hajj. This survey was conducted to evaluate the user perception about hajj crowd simulation.

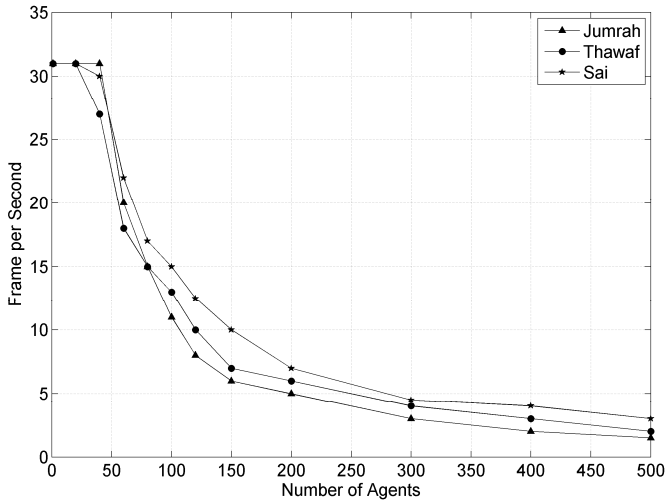


Figure 5. Computational time (fps) versus number of agents

From ten respondents, about 77 percent answered that they get benefit from the *edugame* system on how to perform hajj ritual. Four people who have performed their hajj commented that the simulation closely resembled the real world situation. Finally, more than 90% agreed that the proposed hajj crowd simulation system can help anyone who has intention to perform hajj.

V. CONCLUSIONS

Hajj crowd simulation based on intelligent agent has been presented. The agent has been proven to have the ability to visualize more complex behavior as experienced in hajj ritual. Other benefit of using intelligent agent is that it can provide natural crowd behavior. Objective evaluation and subjective survey have been conducted to evaluate the hajj crowd simulation in the form of *edugame*. The results showed that hajj crowd simulation based on intelligent agent is able to demonstrate more realistic pilgrims' behavior for three hajj main activities, i.e. *thawaf*, *sa'i*, and *jumrah*. Moreover, the developed *edugame* system can be used for training the pilgrim before they perform actual activities. The limitation of the implementation of intelligent agent lies on the number of agents to be simulated which can be alleviated by using more powerful computer. Nevertheless, some optimization can be carried out such as using a better collision detection, applying kinetic data structure, and virtual environment quantization.

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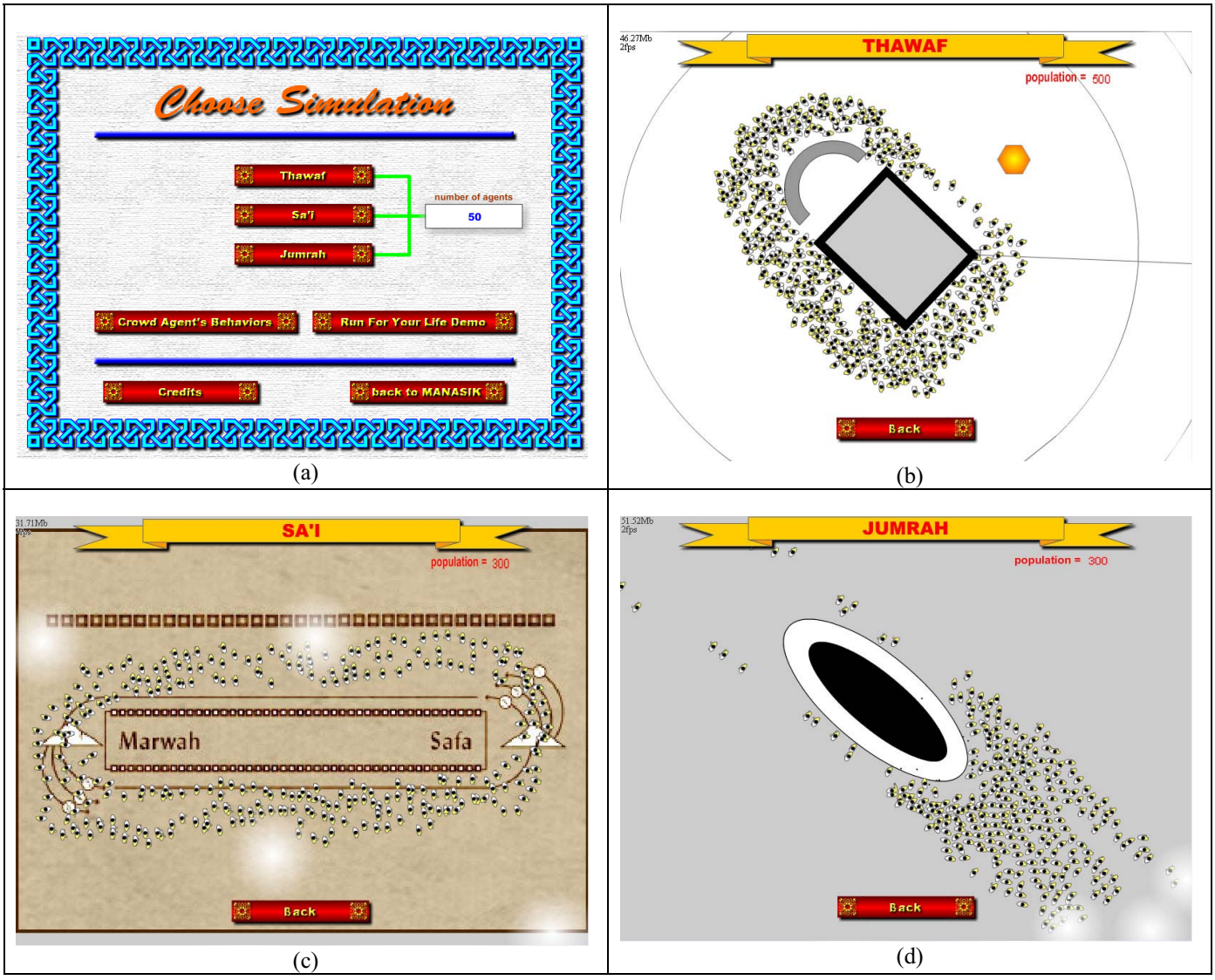

Figure 6. Screenshots of the *edugame* system, (a) main display, (b) thawaf simulation, (c) sa'i simulation, and (d) jumrah simulation