A Crowd Control and Simulation System based on Augmented Reality

Feng Zheng, Hongsong Li, Gangyi Ding

(School of Software, Beijing Institute of Technology, Beijing 100081, China)

Abstract: An interactive simulation and control system for crowd behavior, which is based on augmented reality (AR) technology, is presented. A basic crowd behavior model with good generality is proposed, including three levels of crowd behavior: the stimulus, the psychological processes, and the reactions. *The AR technology controls the crowd behavior by controlling the three levels of crowd behavior. Markers are used to adjust the paths, the environment factors, and the decision-making processes of virtual crowds.* The applications of AR provide more intuitive means of control for the users, promoting the efficiency of human-machine interface. Several examples are provided to illustrate the various crowd control methods and the usability of the system is proved.

Key words: augmented reality; crowd simulation; crowd authoring; human-machine interaction

Introduction

As increase of demands on public safety, urban planning, military simulation, virtual crowd simulation is becoming an important research area of computer simulation. Currently, the majority of research efforts focus on crowd behavior modeling or large scale crowd rendering, while there are few advances on how to author crowd scenes efficiently and intuitively.

Existing crowd simulation systems mainly make use of traditional human-machine interaction methods, i.e., authoring and controlling virtual crowds with keyboard and mouse on 2D interface. There are some drawbacks, and among them, the most distinctive one is the problem of low efficiency, which protrudes as the complexity of the simulation tasks increase. Moreover, it is difficult for users with little experience on virtual reality systems to fully grasp how to operate the complex user interface.

To solve above problems, a tangible augmented reality interface supporting interactive simulation and intuitive control for crowd behavior is presented. Tangible markers are used to control crowds' spatial attributes, behavior characteristics and environmental factors. Hence, users are allowed to get rid of the complex user interface, and can author and control large scale scenes in a highly interactive and efficient way, which also offers a more intuitive experience of interactions between the virtual and the real.

1 Related work

1.1 Algorithms for crowd authoring

Crowd behavior and modeling have always been hot topics of crowd simulation. Latest techniques enable highly realistic simulations of large scale crowd motion, and have been successfully applied to special effects and game making. As crowd behavior models become more and more sophisticated, the problem of creating and authoring crowd scene becomes conspicuous. Promotion and application of these models are restricted for the reason that there are few efficient ways to design and implement the scenes.

Kwon and colleagues proposed an authoring method relying on a novel graph structure to edit group motion, which allows users to author group motion as a whole while maintaining its neighborhood formation and individual moving trajectories as much as possible [1]. Anderson and colleagues controlled crowds' behavior through adjusting constrains on their behavior [2]. In this method, groups can move along curves, within a certain range or maintain certain formations while moving. However, because their constraints setting is agent based, applying it to large-crowd is impractical. CrowdBrush, a tool more suitable to artists' creation habits presented by Ulicny and colleagues, employed a brush metaphor in graphical interface to add crowds and modify attributes of crowds, and authoring results can be shown in real time [3]. CrowdBrush imitates tools used in graphic editing software, which conforms to the users' habits; however, it only applies to modifications in spatial position related attributes, so it has limited control over time and events of simulation process. Sung and colleagues designed a situation-based control structure to control crowd behavior. They devised a graphical interface for users to directly specify position and range of situations, thus to achieve controls over crowd's partial behavior [4].

1.2 Related work of augmented reality

Augmented reality (AR) is a supplementation of the real world, and merges synthetic sensory information into a user's perception of a real world. Azuma provided a commonly accepted definition of AR as a technology which (1) combines real and virtual imagery, (2) is interactive in real time, and (3) registers the virtual imagery with the real world [5].

Milgram is an early investigator of AR from University of Toronto, and he defined a continuum of real-to-virtual environments, in which AR is one part of the general area of mixed reality [6]. Computer graphics and user interface lab of Columbia University has developed a series of AR systems, including a mobile AR user interface for botanical species identification [[7]-[9]], a collaborative mixed reality system for offsite visualization of an archeology dig [[10]-[11]]. Construct3D, developed by Vienna University of Technology, is a three-dimensional geometric construction tool designed for mathematics and geometry education [12]. University of Valencia used AR to treat phobia to cockroaches [13]. Researchers of National University of Singapore also have some research projects about AR, including virtual instruments performance, magic time and so on [14].

To date, there are seldom related works applying AR technique to crowd simulation, especially the authoring and control for crowd behavior.

2 Crowd behavior control based on AR

After analyzing requirements of control and authoring for crowd simulation, an interactive crowd simulation system using fiducial markers to control and author crowd behavior is proposed. Directly manipulation (such as grab & move) of real markers can raise interactivity and usability of the system.

2.1 Basic model for crowd behavior control

Establishing crowd behavior model is an important step for crowd simulation. Currently, there are many crowd behavior models that can simulate multiple crowd behaviors. In spite of their different features, there exist some common features. Crowd behavior models usually need to simulate perception to the outer environment of individuals or the whole of the crowd. Then, based on these perceived information, a virtual individual can judge and decide which behavior to take. For example, Helbing presented a social force model for pedestrian dynamics describing social psychological and physical forces between pedestrians, and between pedestrian and environment [15].

Based on social force model, a basic crowd behavior model is presented, shown in figure 1. The model contains three layers: stimulus, social and psychological process, movement and reaction.

The stimulus layer refers to crowd's motivation and influences exerted by environment. Motivations or personal aims are basic dynamics that drive crowd's action; environment factors include obstacles, danger sources and so on.

Social and psychological process of a pedestrian refers to decision making process by analyzing environment factors, and drives behaviors to begin or change according to pedestrian's motivation. Information processing use the principle of utility maximization to choose the best behavior satisfying the principle, hence a strategy is made. Then, pedestrians generate drive force, reflecting the motivation that pedestrians want to reach the destination at a desired speed. Behaviors types include moving along a specified path or towards a target, running away from sources of hazard, and avoiding collision with obstacles or borders, and so on.

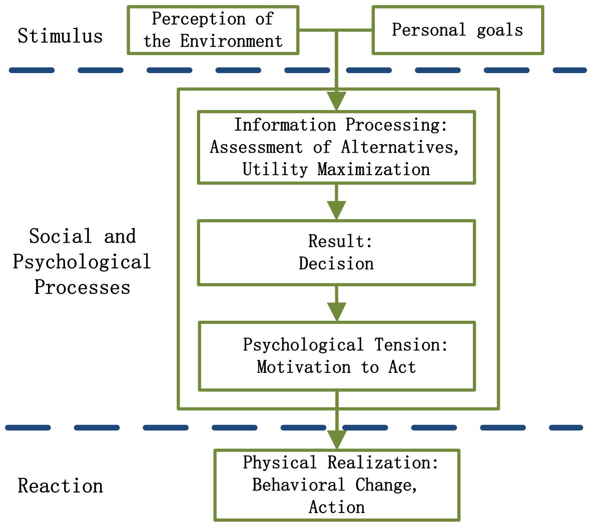


Fig. 1. Basic model of crowd behavior control

Reaction layer is at the bottom of the three-layer model. It is the basic element of pedestrian's action, or called embodiment, which is also a basic part of all behaviors, specifying all the actions of a certain behavior. It transforms "motivations to act" in the second layer to body actions of pedestrians.

Comparing with current crowd behavior models, the proposed model is relatively simple; however, it contains basic elements of the majority of behavior models. In the following, methods using AR technique to control three levels of the model are described.

2.2 Control over stimulus based on AR

Similar to situation-based control over crowd behavior proposed by Sung et al. [4], users can control environments factors by directly grabbing and placing markers in real environments, especially factors that can be defined using spatial position, such as obstacles and sources of danger. Different from traditional interactive means, applying AR to control crowd behavior is intuitive and immediate. Users are allowed to change attributes like position, size, range, and orientation of obstacles and sources of danger etc. in real time.

Likewise, markers can also be used to define starting positions of crowd movement, places of birth, and key points in the crowd's proceeding path so as to stimulate crowd's behavior.

2.3 Control over social and psychological processes based on AR

Reactions of crowds to outer stimulus can be controlled by adjusting several social and psychological factors, involving perception to outer environment, decision strategy, and emotional elements. Those factors can also be controlled by AR. A certain factor can be bound to a certain marker, and add to the scene directly to control crowd behavior.

For crowd scenes that contain multiple groups of different behaviors, it needs more complex control logic to control virtual crowds of different groups. A simple solution to the problem is to position markers which control behavior attributes in adjacent to markers which represent certain groups, hence certain attributes are assigned to certain virtual crowds. In this way, virtual crowds that contain multiple groups can realize different behaviors simultaneously.

2.4 Control over reaction based on AR

Different markers can register different action sequences. Specifically, markers can control behavior types like begin or stop of movement, switching among walking paces, moving along an assigned path and so on.

3 Design and implementation of the prototype system

3.1 System architecture

The purpose of designing the system is to let users edit crowd behavior in an intuitive and interactive way, and dynamic simulation results can be viewed in real time.

The system is composed of three parts. *Control level*, realizes interactive interfaces, receives input events, and displays scenes combining real and virtual. It includes an AR user interface (applied to authoring operations to crowd behavior by fiducial markers) and a WIMP user interface (applied to resource management operations). *Logic level*, realizes marker control logic (includes stimulus control logic, social and psychological processes control logic, and reaction control logic), crowd behavior control logic, and resource management, data persistence by XML files. And *engine level*, includes Virtools 3D engine and AR engine, respectively realizes scene management, bones animation, scene rendering, and marker recognition and registration in 3D. Figure 2 shows the system architecture.

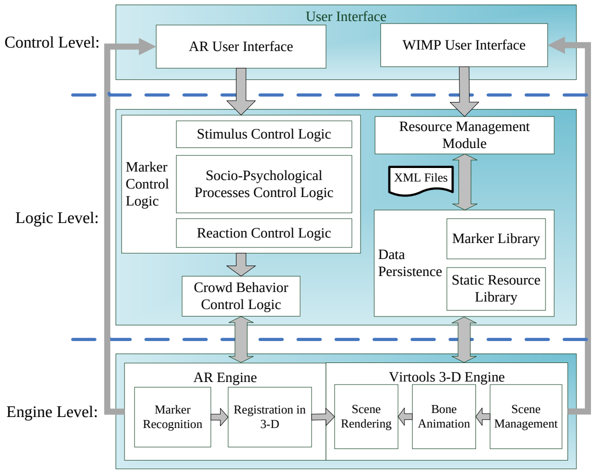


Fig. 2. System architecture

For control level, there are two kinds of interfaces, respectively receiving different types of input events. AR system itself is a user interface, and it is different from traditional WIMP interface, hence, it is a typical Non-WIMP interface. The so-called WIMP interface refers to interface that consists of Window, Icon, Menu and Pointing device. The feature of WIMP interface is serial and discrete, while human-machine interaction in AR systems contains parallel and continuous interaction. Therefore, human-machine interaction in AR systems cannot base on discrete event handling model of WIMP interface. The core of interaction with Non-WIMP interface is a series of temporal continual relation. And for AR user interface, the inputs received are editing operation towards crowd behavior, requiring to continuous specify information related to crowd behavior decisions by fiducial markers, such as crowds' birth place, targets, obstacles and so on.

3.2 Authoring process of crowd behavior

In this part, taking authoring crowd evacuation scenes as an example, the general process for editing crowd behavior from the aspect of three-tier architecture is illustrated.

(1) Environment factors and crowd behavior types can be controlled by positioning or moving fiducial markers. Here, place markers respectively representing place of birth and target, and place markers representing obstacles at the same time.

(2) AR engine realizes marker recognition and vertex extraction, and then registration is performed. The aim of marker recognition and vertex extraction is to obtain the 2D image coordinate of vertexes. Then, 3D registration reconstructs the 3D coordinate based on the 2D coordinate.

(3) According to fiducial markers' corresponding function,

crowd behavior type is determined by control logics. Here, after obtaining position and orientation information, a path for the virtual crowd is generated. The generated path avoids collision between virtual pedestrians, and between virtual pedestrians and obstacles.

(4) Crowd movement scene is rendered by Virtools 3D engine, and result is shown in the output window.

The above four procedures stand for a loop of the crowd behavior authoring. The first step in every loop, namely natural interaction with the system by fiducial markers, is capable of efficiently editing and controlling virtual crowds in real time.

4 Simulation examples

In this section, three virtual crowd scenes developed by the system are provided as examples to illustrate the various crowd control methods.

4.1 Example 1: Control stimulus with AR to simulate crowd evacuation process

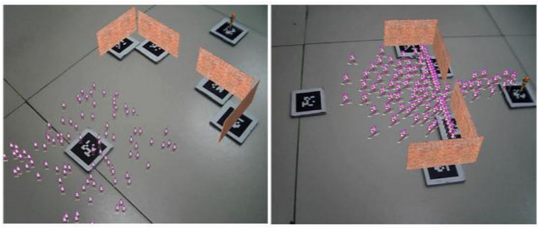
In large public facilities, crowd congregation is a hidden danger of accidents. Therefore, simulation of crowd evacuation process has great practical significance and pragmatic value. The most commonly used crowd evacuation model is the Helbing social force model:

$$m_i \frac{d\vec{v}_i}{dt} = m_i \frac{v_i^0(t)\vec{e}_i^{\,0}(t) - \vec{v}_i(t)}{\tau_i} + \sum_{j \neq i} \vec{f}_{ij} + \sum \vec{f}_{iw} \qquad (1)$$

The equation can be described as: a particle i of mass m_i has got a predefined speed v_i^0, i.e. the desired velocity, in a certain direction $\vec{e}_i^{\,0}$ and to which it tends to adapt to its instantaneous velocity $\vec{v}_i$ within a certain time interval τ_i; simultaneously, the particles try to keep a velocity-dependent distance from other entities j and walls w using interaction forces $\vec{f}_{ij}$ and $\vec{f}_{iw}$, respectively.

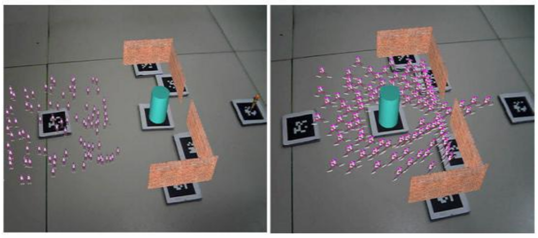
Stimulus level in the crowd behavior model can be controlled by markers, including birth place, target, boundaries and obstacles, etc. A scene where a building narrows abruptly can be simulated by positioning several markers appropriately, and when crowds move towards there, congestion happens, or the so-called “bottleneck effect”. There are 100 virtual pedestrians in the scene, distributed at random, and they are to pass through a gate whose width is 4 meters, as shown in figure 3(a).

Simulation result shows that when pedestrians come to close to the exit, pedestrian density increases, and their flow velocity decreases, then the crowd begins to congest, leading to decline in quantity of flow, as shown in figure 3(b). To reduce the congestion at the bottleneck, Helbing proposed a mitigation measure: erect a pillar prior to the exit, which acts like a levee, to reduce the extent of the congestion, shown in figure 3(c) and 3(d).



(a) Beginning of the 3D scene (b) Occurrence of congestion

A. Simulation of crowd behavior at bottleneck when congestion occurs



(c) Adding a pillar (d) Mitigation of congestion

B. A pillar is added to reduce congestion

Fig. 3. Use AR to control stimulus to control crowd evacuation

4.2 Example 2: Control socio-psychological factors with AR to simulate emergency situations

Conflagration is a typical emergency situation. An important aspect to avoid or reduce casualties is to adopt an appropriate strategy in case of emergencies, so as to safely evacuate and rightly take refuge.

In the following part, an emergency of fire is simulated from the aspect of using AR to control socio-psychological level in the behavior model. Firstly, a crowd is generated by a marker. And then a marker representing fire is placed in the scene. At last, a marker to change crowd’s socio-psychological attributes is placed.

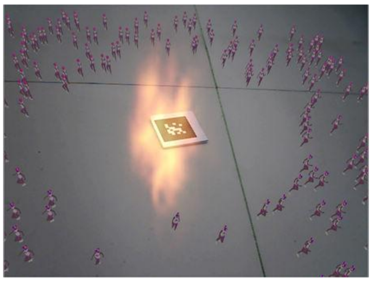
At the beginning, there are 200 virtual characters distributing randomly around the birth place represented by a fiducial maker, as shown in figure 4(a).

Then, a fiducial marker representing fire is placed at the center of the crowd, which drives the crowd to scatter and flee. Figure 4(b) and 4(c) show the simulation result.

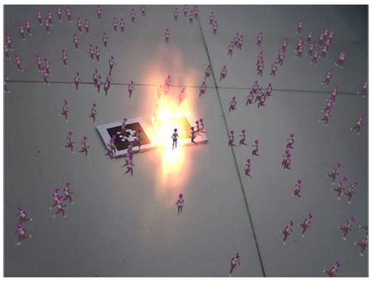
At last, a fiducial maker capable of changing crowds’ socio-psychological attributes is put into the scene. The result is that 50 virtual characters begin to run towards the fire, acting the role of firefighter, as shown in figure 4(d).

(a) Beginning of the 3D scene

(b) Fire is set into the scene and crowd begin to escape (after 3s)



(c) 15s after the fire starts



(d) Add a marker to change socio-psychological attributes

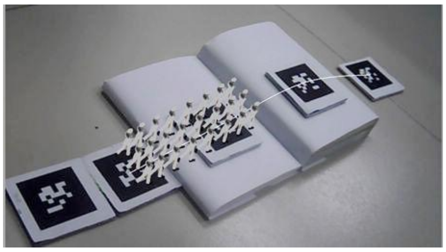
Fig. 4. Use AR to control socio-psychological factors to deal with emergency situations

4.3 Example 3: Control reaction level with AR to specify a path and actions

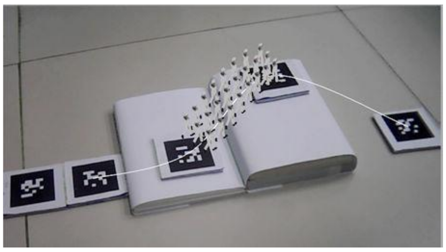
Path planning is a typical microcosmic problem in crowd authoring and manipulation. Fiducial markers placed in the real scene can act as key points along the path for virtual crowds. When known several markers' position and direction, an exclusive and sleek curve or line can be computed by cubic spline interpolation.

Firstly a maker is put in the scene as the birth place, and a 3×8 formation generates in real time, as shown in figure 5(a). At the same time, four fiducial markers that represent a path are placed. When the virtual crowd perceives the generated path, they begin to move as the path, shown in figure 5(b). In the process of crowd movement, the path can be modified by moving fiducial markers in real time. And the crowd can perceive any modifications, and immediately their moving directions, shown in figure 5(c). In addition, fiducial markers can also change crowds' actions or physical realizations. Here, the virtual formation is made to goose-step from original quick march by a marker, as shown in figure 5(d).

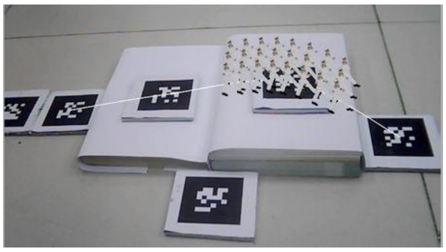
(a) Initial state



(b) Follow the specified path



(c) Interactively modify the path



(d) Reaction control: from quick march to goose-step

Fig. 5. Use AR to control reaction level to specify path and action

5 Conclusion

In this paper, an interactive crowd authoring system, which is based on Tangible AR and designed for edit and manipulation of autonomous crowd scene, is presented. The system realizes control over environment factors and crowd behavior by using fiducial markers. Compared to existing crowd authoring system, the main advantage of the proposed system is that it uses real world entities, i.e. fiducial markers, to realize natural and intuitive interaction, without requirements for users to have any experience with related virtual reality systems. In addition, the system has good generality. It can be applied to other crowd simulation systems with a different crowd behavior model. Apart from this, the system can also be applied to other areas.

In recent years, in the field of artistic performance, virtual and natural interaction techniques between human and virtual performance environment help to solve many pragmatic problems in real rehearsals to great extents, such as the high cost, environment limitations and so on.

Consequently, the proposed system after future improvements can be applied to various areas, such as performance design, public safety, city planning, and special effects.

References:

[1] Taesoo Kwon, Kang Hoon Lee, Jehee Lee, *et al*. Group Motion Editing [C]// ACM Transactions on Graphics, 2008, 27(3).

[2] Anderson M, McDaniel E, Chenney S. Constrained Animation of Flocks [C]// ACM SIGGRAPH/Eurographics Symposium on Computer Animation (SCA'03) ACM SIGGRAPH. New York: ACM Press, 2003: 286-297.

[3] Ulicny B, Ciechomski P, Thalmann D. Crowdbrush: Interactive Authoring of Real-time Crowd Scenes [C]// Eurographics/ACM SIGGRAPH Symposium on Computer Animation, ACM SIGGRAPH. New York: ACM Press, 2004: 243-252.

[4] Sung M, Gleicher M, Chenney S. Scalable behaviors for crowd simulation [J]. Computer Graphics Forum, 2004, 23(3): 519-528.

[5] R T Azuma. A survey of augmented reality. Presence: Teleoperators and Virtual Environments 6:4, 355-385, 1997.

[6] Milgram P, Kishino F. A taxonomy of mixed reality visual displays [J]. IEICE Transaction on Information Systems, 1994.

[7] White S, Feiner S, Kopylec J. Virtual Vouchers: Prototyping a mobile augmented reality user interface for botanical species identification [C]// 3DUI 2006 (IEEE Symp. on 3D User Interfaces), Alexandria, VA, 2006: 25–26.

[8] White S, Marino D, Feiner S. Designing a Mobile User Interface for Automated Species Identification [C]// Proceedings of ACM CHI 2007, San Jose, CA, 2007: 291–294.

[9] White S, Feiner S. Augmented Reality User Interfaces to an Electronic Field Guide [C]// IEEE and ACM ISMAR 2006 CD ROM, Santa Barbara, CA, 2006: 22-25.

[10] Benko H, Ishak E W, Feiner S. Cross-Dimensional Gestural Interaction Techniques for Hybrid Immersive Environments [C]// IEEE Virtual Reality (VR 2005). Bonn, Germany. March 10–12, 2005: 209–116.

[11] Benko H, Ishak E W, Feiner S. Collaborative Mixed Reality Visualization of an Archaeological Excavation [C]// The International Symposium on Mixed and Augmented Reality (ISMAR 2004), 2004.

[12] Hanes Kaufmann, Dieter Schmalstieg. Mathematics and geometry education with collaborative augmented reality [C]// Computers & Graphics 27, 2003: 339-345.

[13] Juan M C, Botell C, Alcaniz M, e*t al*. An augmented reality system for treating psychological disorders: application to phobia to cockroaches [C]// Third IEEE and ACM International Symposium on Mixed and Augmented Reality, 2004: 256-257.

[14] TFarbiz F, Cheok A D, Liu Wei, *et al*. Live Three-Dimensional Content for Augmented Reality [J]. IEEE Transactions on Multimedia, 2005: 514-523.

[15] Helbing D, Molnar P. Social Force Model for Pedestrian Dynamics [J]. Physical Review E (S1063-651X), 1995, 51(4): 4282-4286.

[16] Zhou F, Duh H B L, Billinghurst M. Trends in Augmented Reality Tracking, Interaction and Display: A Review of Ten Years of ISMAR. Cambridge, UK: 7th IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR 2008), 2008.

[17] R T Azuma, Y Baillot, R Behringer, *et al*. Recent advances in augmented reality [J]. IEEE Computer Graphics & Applications (S0272-1716/01), 2001, 21(6): 34-47.