Predicting Future Crowd Motion Including Event Treatment

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Abstract. Crowd simulation has become an important area, mainly in entertainment and security applications. In particular, this area has been explored in safety systems to evaluate environments in terms of people comfort and security. In general, the evaluation involves the execution of one or more simulations in order to provide statistical information about the crowd behavior in a certain environment. Real-time applications can also be desirable, for instance in order to estimate the crowd behavior in a near future knowing the current crowd state, aiming to anticipate a potential problem and prevent it. This paper presents a model to estimate crowd behaviors in a future time, presenting a good compromise between accuracy and running time. It also presents a new error measure to compare two crowds based on local density.

1 Introduction

Crowd simulation has been investigated in many applications over the last years. The presence of huge crowds in current games and movies does not surprise the audience as it did in the first movies, e.g. AntZ [4] and A Bug's Life [5]. In fact, it is actually a very common Computer Graphics effect nowadays. Despite all interest in the entertainment area, crowd simulation tools are also important in security applications. This relevant area aims to investigate the impact of a high number of people behaving in a specific environment to improve people security and comfort, as well as to prevent hazardous situations. In this context, many simulations are typically required to be executed in order to provide statistical information that can be used by safety engineers. An interesting application is the possibility of estimating future crowd behaviors in a certain scenario given its current state. In previous work [2] we proposed a solution which main goal was to *fast forward* (from now on called FF Model) providing a future estimation. We presented a model and evaluated its accuracy based on an error measure that

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[4] http://dreamworks.wikia.com/wiki/Antz

[5] https://www.pixar.com/feature-films/a-bugs-life

takes into account the relative error in position for each agent in the continuous simulation and in the FF method. This paper presents an extension to [2] in order to provide the estimative for future crowd behavior dealing with the possibility that events can happen and behavioral patterns can change, in addition we also present a new metric to evaluate the FF model using the density information.

2 Related Work

Crowd simulation is the process by which the movement of many agents are calculated for the purpose of animating virtual scenes [3] or verifying the security of real environments [1]. In relation to safety, some works have focused on the prediction of future behavior, as in [6], where the authors estimate the time taken by people to achieve their goals. In a previous work [2], we estimate the future individual position of the people based on a prior information of goals and speeds. In that work, previous positions come from a dead reckoning method and positions are later adjusted. Regarding validation, we propose a way to compare simulation and estimation using densities. However, densities are not new in this context. Density is a feature widely used in crowd simulation work because it allows inferring current and future behavior [5]. In addition the density can be used as an evaluation metric, such as in the work of Lerner et al. [4] where they suggest comparing measures based on crowd densities in the output of a simulator with the observed densities in the experimental date.

3 The FF Model for Estimation of Crowd Behavior

In this section we summarize the previous approach [2] to provide estimation for future crowd behavior. A Pedestrian Dead Reckoning method based on Physics (PDR) is initially used to estimate future positions for agents in the crowd. In addition, crowd position estimation should also take into account the environment complexity (EC), i.e. the free region and presence of obstacles. Also, agents can be affected by others. We called this step as IP (interaction among people), that aims to describe how individual velocities should be affected by the presence of other agents. In this case, the previous approach used Weibull distribution [2]. Finally, the last step, called *Repositioning*, is responsible for fine tuning the agents' positions in the environment avoiding collisions [6].

3.1 The Inclusion of Events in Fast Forward Model (FF-E)

In this paper, we develop a method that can easily and quickly estimate possible future behaviors for crowds when events happen. For proof of concept, we used BioCrowds, as related in [2]. However, the method could be integrated in any crowd simulation platform. An event is given as the possibility of changing the environment by adding, changing or removing obstacles and exits. An event k is defined by $e_k = \{t_k, \Delta t_k, \boldsymbol{O_k}\}$, where t_k is the event start time, Δt_k is the event duration, $\boldsymbol{O_k}$ is defined as $\{o_k, \boldsymbol{p_k}\}$, where o_k is the number of obstacles, and $\boldsymbol{p_k}$

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[6] Please refer to [2] for further details.

is the geometry for each obstacle (list of vertices). After having defined an event, we explain how we consider them in our method FF-E. Firstly, we assume that events starting during the simulation, i.e. before the FF behavior, are already dealt with in work proposed by [2]. Hence, we are interested in events that are triggered during the period of time when behaviors are going to be predicted (i.e. not simulated beteen times t and $t + \Delta$). We consider events e_k for which $t < t_k < t + \Delta t$. The endpoint of e_k, given by $t_k + \Delta t_k$, can be greater than $t + \Delta t$. Let us consider a single event e_k, starting at frame t_k. The estimated initial position ($\boldsymbol{X}^i_{t_k}$) for each agent i is computed using Physics at frame t_k, based on [2], is described in Equation 1:

$$\boldsymbol{pdr}^i_{t+\Delta t} = \boldsymbol{X}^i_{t_k} + \left(s^i \frac{\boldsymbol{g}^i}{||\boldsymbol{g}^i||} \right) (\Delta t), \tag{1}$$

where $\boldsymbol{g}^i = (g^i_x, g^i_y, g^i_z)$ is the agent goal and s^i is its desired speed. An event e_k should impact the environment complexity to be considered. We use an environment complexity function (EC) that works as a speed reduction factor and is modeled as:

$$EC_{t_k} = \min \left\{ 1, \frac{a_k(t_k)A_a + o_k(t_k)}{A_w - A_o(t_k)} \right\}, \tag{2}$$

where A_a is the area of each agent, A_w represents the area of the world (that does not change during the simulation), and $A_o(t_k)$ is the sum of all obstacles areas at frame t_k. If the number of agents and/or area occupied by obstacles are too large and there is no free space to allow individuals to move, then EC_{t_k} is truncated at 1 and no motion is allowed in frame t_k. The reduction factor is applied to all agents i (i.e., EC does not depend on i).

3.2 Proposing a Metric to Compare Crowds

In this paper, we propose a new method to compare the result of FF-E to estimate crowds and the continuous simulation based on local densities in order to provide a global error estimation of crowds. The main idea is to divide the world into uniform regions in the simulated environment, called *cells*. The global crowd comparison metric is an average of the relative differences across cells, given by:

$$Dif(t) = \sum_{c=1}^{N_{cell}} \frac{|s_c(t) - e_c(t)|}{Avg\left(s_c(t)\right)} \tag{3}$$

where $s_c(t)$ and $e_c(t)$ are the density of agents in each specific cell c in the crowd simulation and in the FF method at frame t and N_{cell} is the number of cells for which either s_c or d_c are different than zero (to avoid computing the relative error at empty cells) and $Avg(\cdot,\cdot)$ is the average operator.

4 Experimental Results and Final Considerations

In order to verify the impact of the events during the simulation, we performed some experiments in one environment with 920sqm (23 × 40meters) and with populations of $8, 80, 160, 240$ and 320 agents (each one has a diameter of 0.456m). We simulated the crowd from frame 1 to 1000 and compared with FF-E method that estimated the crowd motion from frames 300 and 500. We measured errors, using the metric of the Equation 3, in three different times: frames 500 (time 1), 700 (time 2) and 800 (time 3). The occurred event is described according to definition $e_1 = \{t_1, \Delta t_1, \boldsymbol{O_1}\}$, $\boldsymbol{O_1} = \{o_1, \boldsymbol{p_1}\}$, where $o_1 = 1$ and $p_1 =$ object coordinates - in this case it is a quadrilateral shape of $49m^2$ and where t_1 and Δt_1 are defined depending on the simulated populations: for 8 agents t_1=150 and Δt_1=300, for 80 ag. t_1=200 and Δt_1=500, for 160 ag. t_1=300 and Δt_1=600, and 320 ag. t_1=400 and Δt_1=700. Two comparisons w.r.t. the computed errors were analyzed. *i)* Simulation with and without the event; *ii)* Simulation and FF-E method with event. Figure 1 shows the result of our metric. The error at time 2 in all analysis is larger than at time 1 (during the event) and time 3 (after some time the event finishes). It happens because comparing these three frames, higher impacts exist when more sequential frames propagates the estimation.

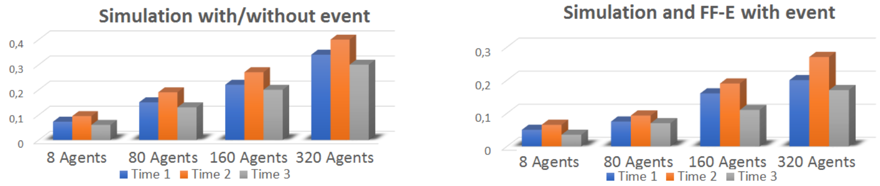

Fig. 1. Error computation observed in two case-studies related

Final Considerations This paper presents two main contributions,the first one is an extension of [2] to estimate crowd motion in a future time (fast forwarding), while treating events. The second one is a new error measure to quantitatively evaluate the error caused by the estimation. The maximum errors observed in the case studies were 30-40%person/sqm.

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