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Controlling the movement of crowds in computer graphics by using the mechanism of particle swarm optimization

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ABSTRACT

This paper presents a uniform conceptual model to co-operate with particle swarm optimization (PSO) for controlling the movement of crowds in computer graphics. According to the PSO mechanism, each particle in the swarm adopts the information to automatically find a path from the initial position to the optimum. However, PSO aims to obtain the optimal solution instead of the searching path, while the purpose of this work concentrates on the control of the crowd movement, which is composed of the generated searching paths of particles. Hence, in order to generate seemingly natural, appropriate paths of people in a crowd, we propose a model to work with the computational facilities provided in PSO. Compared to related approaches previously presented in the literature, the proposed model is simple, uniform, and easy to implement. The results of the conducted simulations demonstrate that the coupling of PSO and the proposed technique can generate appropriate non-deterministic, non-colliding paths for the use in computer graphics for several different scenarios, including static and dynamic obstacles, moving targets, and multiple crowds.

1. Introduction

Nowadays virtual crowds created by using the technologies of computer graphics can be frequently seen in games, movies, commercials, and the like. Creating computer animations for crowds is largely applied to movies and games but in fact, it is not an easy task to create virtual human beings behaving like real human beings. Many research fields and sophisticated techniques are involved to achieve acceptable results. In order to create high quality virtual human beings or animals, at least three facets must be taken into consideration [1]: The first one is appearance modeling. Lots of computer graphic techniques have been developed to create a vivid human including the shapes of face and body, skin textures, hairstyle, and clothes. Appearance largely affects people to judge how much the computer creation is similar to a real person. Then, the second facet is to produce realistic, smooth, and flexible motions in possible situations. Most existing methods for creating motions are parameter-based models with numerous parameters for controlling the motions. It is difficult to have a single flexible, versatile model which can fit in all scenarios. Finally, realistic high-level behavioral actions have to be generated for the virtual human being. It is undoubtedly an extremely difficult problem because defining what kinds of behaviors are human itself is worth a philosophical debate. To resolve the issue technically, many artificial intelligence and agent-based techniques are adopted to achieve the goal, while the techniques are still being developed and improved.

Particle swarm optimization (PSO) [2] is an optimization paradigm proposed in the field of evolutionary computation for searching the problem domain and reaching the global optimum. The concept of PSO is easy to comprehend, and the mechanism is easy to implement. The ability of PSO to reach the position of the optimum creates the possibility to automatically generate non-deterministic paths of virtual human beings from one specified position to another. In this study, we focus on creating a realistic smooth and flexible moving pattern for virtual human beings by utilizing the computational facilities offered by PSO. Particularly, we present a uniform conceptual model to co-operate with PSO to simulate the movement of all the persons in a crowd based on the analogy between a particle swarm and a human crowd. By "uniform," we mean that functions of a single family is used to describe all kinds of objects in the simulation system, including the target, static obstacles, dynamic obstacles, as well as persons. A person can be considered as a particle, which would like to find a way to reach the best solution. The proposed model can be used in several different scenarios, including static obstacles, moving targets, and multiple crowds. The figures as well as the video clips for the simulations in those scenarios are presented.

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The remainder of this paper is organized as follows. Section 2 describes the related studies on the control of crowds in computer graphics to give the readers some background information. Section 3 briefly introduces swarm intelligence and the methodology of particle swarm optimization. Section 4 proposes the key idea as well as the framework to utilize PSO for controlling the movement of crowds. Section 5 demonstrates the simulation results in several common scenarios. Finally, Section 6 concludes this paper.

2. Related work

Collective behavior had been studied for a long time in many research domains but was applied to computer graphics and computer simulation only recently. In the field of computer graphics, Reynolds [3,4] created a distributed behavior model to simulate the aggregate motion of the flock. Bouvier and Guilloteau [5] presented an application specifically oriented to the visualization of urban space dedicated to transportation. Brogan and Hodgins [6] described an algorithm for controlling the movements of creatures that travel as a group. Still [7] developed a model to simulate the crowd as an emergent phenomenon using simulated annealing and mobile cellular automata. Helbing et al. [8] used a model of pedestrian behavior to investigate the mechanisms of panic and jamming by uncoordinated motion in crowds.

Moreover, there are many studies on the realistic and real-time performance for crowd control. Aubel and Thalmann [9] used a multi-layered approach to handle muscles of varying shape, size, and characteristics and does not break in extreme skeleton poses. Tecchia and Chrysanthou [10] showed a real-time visualization system based on image-based rendering techniques for densely populated urban environments. Aubel et al. [11] presented a hardware-independent technique that improves the display rate of animated characters by acting on the sole geometric and rendering information. Ulicny and Thalmann [12] defined a modular behavioral architecture of a multi-agent system allowing autonomous and scripted behavior of agents supporting variety. Treuille et al. [13] presented a real-time crowd model based on continuum dynamics. Stylianou and Chrysanthou [14] used a flow grid to measure flow over an area and navigate the crowd.

Although there are many approaches for controlling the movement of crowds in computer graphics, only a few researchers try to use evolutionary algorithms for this purpose. Kwong and Jacob [15] presented breeding experiments of dynamic swarm behavior patterns using an interactive evolutionary algorithm. Kim and Shin [16] incorporated several specifically designed mechanisms into the conventional particle swarm optimization methodology for simulating decentralized swarm agents. Instead of modifying the conventional PSO and designing different mechanisms for different issues, in this paper, we propose a conceptual model to work with PSO for creating a stochastic, non-deterministic, non-colliding path for each agent with a uniform approach. With the proposed framework, there is no need for sophisticated mathematical models and complicated algorithmic implementations. Generating paths for each person in the crowd can be flexible and easy to control.

3. Particle swarm optimization

Swarm intelligence is a concept and a methodology used in artificial intelligence, possibly first proposed by Beni and Wang [17] in 1989. It studies the collective behaviors of agents interacting in the environment. There is no centralized control to manage the agents, but all agents or some of the agents, depending on the adopted neighborhood structure or other equivalent algorithmic design, exchange their information to cooperate and emerge group behaviors. Many swarm intelligence systems are inspired by nature, including ant colonies, bird flocking, and fish schooling. They have been adopted in a lot of research fields, such as ant colony optimization (ACO) [18], stochastic diffusion search (SDS) [19], PSO [2], and the like. For many hard, real-world problems, methods developed based on the idea of swarm intelligence can deliver acceptable or good results. Among these swarm intelligence systems, PSO models a solution as a flying particle on a hyperplane and conducts continual movements in the search space.

PSO was proposed by Kennedy and Eberhart [2] in 1995, inspired by the social behavior of bird flocking or fish schooling. PSO is a population-based optimization method and considers each potential solution as a particle. In a D-dimensional problem, a particle is represented as

$$x = [x_1, x_2, \ldots, x_D]^T.$$

Each particle has a position, a velocity, and an objective value determined by the objective function. It uses the experiential and social metaphor to move toward the expected and currently known best solution. The velocity is varied according to Eq. (1):

$$v_i(t+1) = \omega * v_i(t) + c_1 * r_1 * (p_{BLS} - p_i(t)) + c_2 * r_2 * (p_{BGS} - p_i(t)), \quad (1)$$

where v_i and p_i are the velocity and position of the ith particle. ω is the weight for the previous velocity. p_{BLS} is the best position where this particle had been, and p_{BGS} is the overall global best position ever achieved by the swarm. c_1 and c_2 are the cognitive and social parameters, controlling the level of influence of p_{BLS} and p_{BGS} to make different movements. r_1 and r_2 are random numbers uniformly distributed in $[0, 1]$. The stochastic scheme makes the velocity more diverse.

After computing the velocity, the position can then be updated according to Eq. (2):

$$p_i(t+1) = p_i(t) + v_i(t+1). \quad (2)$$

For every iteration, each particle updates its velocity and position. The new position is evaluated by the given objective function, and an objective value is assigned to the particle accordingly. Based on the objective value, p_{BLS} and p_{BGS} might be updated and have influence in the next iteration. Because the fundamental concept is quite similar to that of the movement of pedestrians, in this study, we would like to simulate a crowd with the optimization process in which particles move toward the expected and currently known best solutions.

Although PSO does possess certain characteristics of the crowd behavior, it is still incompatible with the use for controlling the crowd movement in computer graphics. Firstly, the particle in PSO is absolutely free to fly everywhere in the given multidimensional space, i.e., the search space. However, the given environment for a crowd may have obstacles, and the pedestrians in the crowd must avoid collisions, including the collision with the given obstacles and the collision with their fellow pedestrians, where other pedestrians can be considered as dynamic obstacles. These dynamic obstacles are not predictable and may appear and disappear in the environment at any moment. Moreover, it is important to make a virtual pedestrian to walk smoothly and naturally, instead of just oscillate uncertainly and strangely. The walking path must be reasonable and appropriate. For these essential reasons, we propose a uniform model to work with the original PSO for path creation in the next section.

4. The proposed framework

In the light of the analogy between swarms and crowds, we may consider a person as a particle and a group as a swarm. To resolve the aforementioned incompatibility issues, we propose a framework to