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Geometry-constrained crowd formation animation

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ABSTRACT

Formation control technology can exhibit the collective flock behaviors of a crowd for simulation and animation purpose, and thus, can be applied in various fields. In this paper, an innovative geometry-constrained framework for smooth formation animation of regulated crowds is proposed. We employ the morphing method to generate a series of in-between constrained shapes as key frames to impose process control and ensure smoothness of formation transformations. We also introduce centroidal Voronoi tessellation (CVT) to calculate optimal distribution of agents, and present an improved Lloyd descent method to perform path planning by utilizing its fixed point iteration feature. As extensions, the proposed framework can handle environmental obstacles avoiding problems for the whole crowd to preserve certain formation extremely by utilizing a domain modification method, and can also be adapted to 3D spaces and density-based domains. Experimental results show that the proposed method can generate stable, smooth, orderly, regular and elegant crowd formation animations.

1. Introduction

Crowd formation, also known as flock or group formation, is an arrangement or deployment of a group of individuals which form a certain pattern or shape. Flock's collective behaviors are often visually expressed as their general formations that are vital in many real-world scenarios such as battles or football games [1]. Crowd formation animation is defined as the process of deforming a crowd from an initial formation to a target one, and is widely used in games for interactive group control, in movies to produce graceful animation, and in multi-agent control systems where agents coordinate and cooperate to perform difficult tasks. One common practical example of such a multi-agent control system is formulated as a swarm robotic system in [2] in which hundreds or thousands of autonomous robots perform subtasks in a parallel manner.

Formation control has been under intensive studies recently in the domain of multi-robot control system. Although existing popular methods are available for applications in this domain, they all have some downsides. The *behavior based method* is intuitive and straightforward, but it suffers from parameter tuning problems. This kind of method cannot be used to define flock behaviors explicitly and guarantees no stability and regularity [3,4]. The *leader-follower method* [5] and *generalized coordinates method* [6] usually impose location constraints to maintain a formation through a set of rigorous control theories and differential equations. These types of methods have a solid theoretical basis, but they are prone to modeling and implementation difficulties and robustness issues [5]. In addition, exact knowledge of the animals' behaviors and complicated implementation techniques are often needed [7]. The *geometry constrained method* [8,9] utilizes geometric structures as profiles to construct certain formation. This kind of method is simple and easy to be implemented, but it faces a variety of problems in existing attempts, such as sampling uniformity, matching accuracy, path planning with collision avoidance [10].

This paper focuses on regulated crowds, which are often found in scenarios of battles, mass performances and team sports. These applications require smooth and well-organized transitions to achieve artistic layouts and tactical arrangements, as shown in Fig. 1. In addressing these desirable features, the geometry-based method is inherently more advanced than other methods. [3] indicates that rigid constraints in crowd animation are often difficult to be imposed on agent behaviors due to the fact that they are massive, autonomous and intelligent. To solve this difficulty, Schuerman et al. introduced a class of situation agents, in which specialized controlling logics as well as constraints can be implemented to impact regular agents [11]. In general, the shape-constrained method is a very good solution.

Our major contribution is that we propose a pure geometry-based framework to animate the deformation process of regulated crowds. The existing geometry based approaches are often used in

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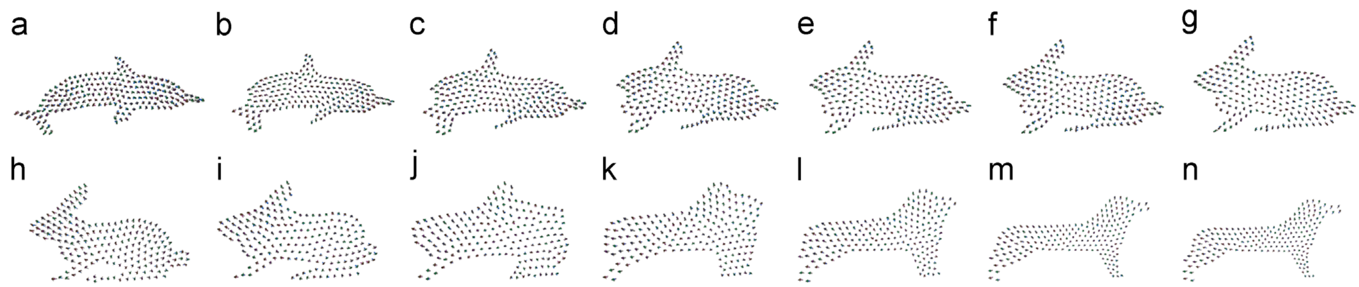

Fig. 1. Formation animation snapshots of a 200-agent crowd deforming from a dolphin to a rabbit and then to a dog. The deformation process is very smooth, orderly and elegant for regulated crowd animation.

conjunction with behavior based methods for collision avoidance [12], or with control theories for adaptive navigation [13], raising robustness and disorder problems. The proposed approach inherits the advantages of the geometry-based method, overcomes the shortcomings of conventional shape-constrained methods and extends the current virtual structure approaches to achieve a tradeoff between rigid and flexible constraints. The result, shown in Fig. 1 as an example, exhibits a smooth, orderly and regular transition and proves the potential of our method in applications in many domains such as games, movie animations and massive sport design.

There are, however, some limitations. First, our method is restricted to agents in regulated crowds in which they form particular formations under certain constraints. Unlike general crowds where agents are autonomous and intelligent to choose paths , individuals in regulated crowds are tightly constrained by the intermediate shapes and navigated by Lloyd descent directions to generate regular and orderly results. Also, as a side effect to achieve an exactly optimal and homogeneous distribution, the results of our method may look somewhat artificial for real-world crowd animations. Perturbations can be introduced to relieve such an issue by, for instance, composing a density field as shown in Fig. 10, as well as using a capacity-constrained CVT method.

2. Related work

In contrast to the general crowd simulation, formation control emphasizes on spatial, temporal and correspondence constraints to assure the crowd's conformity to a predetermined formation. According to [14], conventional formation control approaches can be roughly categorized as the *behavior based approach* [4,12], the *leader-follower approach* [5], the *generalized coordinates method* [6], the *geometry-based method* [8,9], etc. The method proposed in this paper is classified as a descendant of the geometry based method, which can be further divided into the *virtual structure approach* and the *shape-constrained method* depending on the research domain.

In the domain of mobile robots control, the *virtual structure approach* is applied to formation control for AGVs (Automated Guided Vehicles), UAVs (Unmanned Aerial Vehicles), and AUVs (Autonomous Underwater Vehicles). In order to improve control performance and efficiency, the virtual structure approach has been utilized to maintain UAV formation with synchronous technology to keep the relative position tracking motion of the aircrafts [15]. [8] proposed a combination of the Lyapunov technique and graph theory embedded in the virtual structure. In this way, the knowledge derived by localization of the robots in the group allowed for efficient coordination and trajectory following, which could then create useful robot formations. Sadowska et al. [16] presented a distributed unicycle formation control algorithm based on the virtual structure approach from [17]. The advantages of their algorithm reside in that for each robot only its neighbors were needed to be contacted and then a simple linear formation control feedback mechanism was introduced. The virtual structure can also be flexible. [9] extended the allowed flexibility of classical virtual structures, and presented a formation control method for nonholonomic fixed-wing UAVs to enable the formation to turn continuously and smoothly along the planned curve trajectory.

The *shape-constrained method*, on the other hand, is prevalent in applications in games and animations. Anderson et al. proposed a technique to support individual constraint, group centroid constraint and flock outline constraint by defining a complex behavior model and conducting a time-consuming sampling process [3]. [18] associated a graph with a formation for determining the adjacency relationships among individuals, adopted a spectral-based approach to generate the trajectory of each individual, and a social forces method to locally adjust the trajectory. However, the agent distribution of the formation needs to be set manually and exhaustively. Xu et al. proposed a shape-constrained flock animation system to enforce static and deforming shape constraints on the spatial distribution of a flock [10]. The method used sampling and a spherical projection method to establish correspondences between flock members and sample points, and the guided flock migration by Boids model, but it had to turn to a fuzzy control logic approach for solving the parameter setting problem. Utilizing sketches as formation constraints, [19,1] introduced a flood-fill algorithm to sample the shape and formation coordinate to maintain the adjacency relationship, and applied HiDAC technique for collision avoidance, but the intermediate distributions in their results were not optimal. Ho et al. [20] resolved the problems of global navigation of a flock along a predefined path through an adaptive formation adjusting process according to the curvature of the given path, and an obstacle avoiding force based method which could disengage and regroup a crowd so that it can squeeze pass a narrow space. Later they presented a software library package for soft formation control, which handled formation shape deformation by a uniform sampling and a one-to-one mapping process in attempt for the minimum time [21]. Like animation applications, Alonso-Mora et al. [22] proposed a formation transition method for multi-robot control. CVT, Hungarian algorithm and optimal reciprocal collision avoidance method are used for optimal positioning, matching and path planning respectively. The paper focuses on generating smooth and oscillation-free trajectories of robots while our method aims at smooth and neat transformations between formations.

Aiming at a smooth formation animation as in Fig. 1, this paper presents a pure geometry framework. It tries to exploit the advantage of the geometry-based method, and avoid the downside of conventional shape-constrained methods by introducing CVT sampling and Lloyd based navigation method. In addition, our method relaxes the current virtual structure approaches by using morphing technology to achieve a balance between rigid and flexible constraints.