Path-based Control of Smoke Simulations

Yootai Kim\textsuperscript{1} and Raghu Machiraju\textsuperscript{1} and David Thompson\textsuperscript{2}
\textsuperscript{1}The Ohio State University, Columbus, OH, USA
\textsuperscript{2}Mississippi State University, Mississippi State, MS, USA

Abstract

In this paper, we propose a novel path-based control method for generating realistic smoke animations. Our method allows an animator to specify a 3D curve for the smoke to follow. Path control is then achieved using a linear (closed) feedback loop to match the velocity field obtained from a 3D flow simulation with a target velocity field. The target velocity field can be generated in a variety of ways and may include the small scale swirling motion characteristic of turbulent flows. We provide several examples of complex smoke paths to demonstrate the efficacy of our approach.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism Animation

1. Introduction

Fluid phenomena such as flowing water and rising smoke are common occurrences that are observed in everyday life. Consequently, realistic depictions of such motions are desirable in modern animation. Remarkable visual realism has been achieved in the animation of smoke, flame, and water by exploiting techniques from Computational Fluid Dynamics (CFD) \cite{FSJ01,FF01,NFJ02,MCG03,SRF05,PK05,AN05,FOK05,HK05}. It is well known and appreciated that the primary impediment to employing CFD simulation for animation is control of the resulting flow field.

Flow control falls into two classes: forward and inverse control. In forward control, a fluid flow is obtained via user specification of indirect quantities such as a force field or a pressure field (most notably \cite{FM97}). To obtain the desired effects, the animator must change the parameters of the simulation in a costly trial-and-error process. In an inverse control approach, control parameters are determined to drive a fluid simulation to achieve the animator’s goals. The initial and final shapes of the fluid mass serve as inputs to the simulation. Examples of such an approach are described in Treuille et al. \cite{TMPS03} and Fattal and Lischinski \cite{FL04}.

In some instances, however, an animator wishes to make a mass of fluid to follow a specific path in a physically realistic manner. Consider the example shown in Figure 1. In this case, it is desired that the bulk motion of the smoke follow each letter while simultaneously exhibiting realistic, small-scale swirling motion similar to a turbulent flow. Existing techniques would be hard pressed to deliver a similarly controllable animation in an efficient manner. Moreover, the motion that is suggested by our animation captures the essence of the phrase that was etched in the skies over the Emerald City!

This paper presents an intuitive, path-based strategy to control simulated fluid motion that is described in Figure 2. An animator directly specifies a path for the bulk fluid motion using a NURBS curve. Instead of matching shapes, we match the velocity field from the simulation against a procedurally generated target velocity field defined in the region surrounding the specified path. Our control strategy produces a physically realistic flow by driving a simulated velocity field toward a specified target velocity field. The target velocity field includes various desired effects but may not be physically realistic. The simulated velocity field represents a compromise that is physically realistic, because it satisfies the equations that govern the motion of an incompressible fluid, and incorporates the characteristics of the target field. We demonstrate the generality of our approach by generating target velocity fields that include effects such as...