Investigating Hurricane Isabel using Texture Advection

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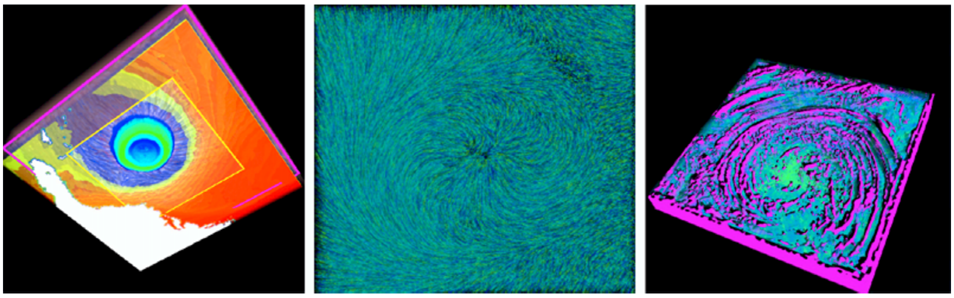

Figure 1: **left:** *pressure and flow* **center:** *rotation* **right:** *vortices*

1 Introduction

Hurricane Isabel was a long-lived Cape Verde Hurricane (6–19 September 2003) which is considered to be one of the most significant cyclones to affect portions of North Carolina and east-central Virginia. This short paper describes the visualization of the numerical simulation of Isabel, provided for the IEEE Visualization 2004 Contest.

The goal of our visualization system is an interactive, time-dependent, 3D multi-field representation which allows the user to investigate a combined visualization of scalar field and vector field information. By this combined representation of the multiple attributes, the user is able to adjust the different views of the data set to get more detailed results. We address the perception problems that are inherent in a dense 3D vector field representation. In particular, clipping and 2D selection planes are used to overcome some of the occlusion issues. This 2D approach is combined with the full 3D view to provide a focus-and-context visualization.

2 System Description

We use a standalone GPU-based flow visualization system that is based on 3D texture advection [4, 3]. At the moment this approach seems to be the most powerful method to achieve the complete visualization process for unsteady flow at interactive frame rates—without the need for time-consuming pre-processing. The final display is generated by direct volume rendering (texture-based volume rendering with a stack of 2D slices).

The system is implemented in C++, with DirectX 9.0 and Effect Files 2.0. The implementation runs on current GPUs like ATI Radeon X800 and GeForce FX. Texture advection and volume rendering make use of pixel shader 2.0 code. All the example images and the live recording for the accompanying video (http://www.vis.uni-stuttgart.de/∼schafhts/viscontest) were generated on an ATI Radeon X800 (256 MB).

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3 Exploration

This section describes different visualization aspects that are important for our visualization approach. The system is separated in a number of basic techniques which can all be combined with one another.

3.1 Different Viewpoints

The big advantage of a 3D representation is the spatial perception of the complete data set. In this way, the user is able to realize the spatial relations of a part of the scene at a glance. The 3D representation allows the user to explore different areas of interest. In addition, the motion parallax from interactive camera motion results in an effective depth cue.

3.2 Time Dependency

The time dependency of a data set builds an additional dimension. Our system allows the user to view the animation of the data set at interactive frame rates to explore the behavior of Isabel along different time steps. The 3D representation is of advantage because the user can perceive changes of data along the time steps in all three dimensions at a glance. Investigating Isabel along the 48 time steps allows the user to become an impression about the behavior and the magnitude of the flow, pressure, temperature etc.

3.3 2D Planes

3.3.1 Clipping Plane

Clipping is used to achieve the occlusion-free representation of an area of interest. By the insertion of a clipping plane in the 3D space the user can interactively extract flow features on (possibly oblique) clipping planes. For example, the use of clipping planes allows us to get information of the hurricane's center and avoids the loss of the information outside the hurricane's eye. Therefore, we are able to perceive relations of the flow or the other attributes (e.g. pressure, temperature...) along their different positions in physical space.

3.3.2 2D Selection Plane and 3D Representation

While clipping is a good method to get information at a user-defined position by removing out uninteresting data, getting the information of a user-defined position will become more difficult if the data which occludes the interesting point is also of importance. In this case clipping will be very ineffective, so another method must be used. A 2D selection plane can be employed to overcome this problem. This selection plane provides a detailed 2D representation of the vector field in combination with the 3D semi-transparent volume rendering of the complete data set.

The selection plane leads to a cutout of the vector field. Without any restrictions, this cutout can be used as a vector field for a 2D representation. Because of the lower costs of a 2D advection the user can benefit of a much higher detail of the representation. Therefore, a LIC-like ([1]) representation can be achieve by advecting a high resolution texture. Furthermore, the selection plane can act as a zooming plane by coupling the texture coordinates of the zoom selection with the 2D representation. This zoom selection leads to a high degree of detail for selected areas of interest and keeps an overview of the behavior of the whole scene.

The 3D representation also benefits from a high-detailed 2D flow visualization: The user has the opportunity to map the result of the 2D representation back to the selection plane. The consequence consists of a high resolution visualization which is impossible to achieve by the conventional way of 3D texture advection. Indeed this high-res representation is restricted to one plane, but in a combination with a scalar representation this method can be very powerful. For example, the user can investigate the behavior of pressure along the time steps with an additional high-resolution representation of the flow.

3.3.3 2D vs 3D

A major restriction of 3D texture advection is the limited resolution imposed by the amount of texture memory. Unlike to the 3D texture advection the consumption of memory is much lower for 2D texture advection. In the practical use, both representations have their advantages: Only 3D can help the user with the spatial perception of a scene. If a higher detail is required, 2D flow visualization is the better solution, regarding the performance and interactivity. Combining this two methods is a good solution because both alternatives described above can be solved by it.

3.4 Scalar Field Visualization

Our multi-field approach allows us to combine the above vector field visualization with an addition visualization of a scalar attribute. Two different sources for scalar fields have to be distinguished: External attributes (such as pressure or temperature provided in the data set) and derived attributes (computed from the data set).

3.4.1 Derived Scalar Fields

During the startup phase of our system some derived scalar fields like vorticity or lambda-2 ([2]) can be precalculated. This part of the system is arbitrarily extensible in a way the user is interested in. The system swaps out the derived information and transfer them into textures on demand. The scalar fields are visualized by the use of slice-based volume rendering, which can be used on its own or in combination with the vector field representation. Using this feature the user is able to investigate special regions, e.g., regions with a high appearance of vortices without the loss of the information of the flow.

3.4.2 External Scalar Fields

Some data sets, like the Isabel data set, contain additional information on the flow. This information is typically held in scalar fields which can be included to our multi-field system. The system only requires that the scalar fields consist of the same number of time steps like the vector field. In the final representation these scalar values are visualized by volume rendering and can be combined with the vector field representation as described before (for derived attributes). With user-defined transfer functions, it is possible to cutout areas of interest, like regions of pressure, temperature etc. With this functionality, the user is able to account all the information of the data set and their relations.

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4.1 The Data Set

Investigating the data set of hurricane Isabel with our system, we are able to make some statements about the behavior of the storm:

Considering the flow with an unnormalized vector field brings out the rotation of the hurricane (*Figure 1, center*). Also the velocity in the different areas of the data set becomes visible. Whereas the use of an normalized vector field provides information about the direction of the flow.

By analyzing the velocity, we identify a high-velocity ring which is stretched around the center of the hurricane. In the center itself, only low velocity but a high suction effect is noticeable. Considering this behavior from the 3D view, we can see that the highest velocity exists at the bottom (later the land-contact) of the storm and that the speed alleviates slowly towards the top. Along the time steps the velocity falls off barely.

From the beginning an amount of vortices were created. If we analyze the whole structure of the vortices an anti-clockwise, inwards narrower constitution will be noticeable (*Figure 1, right*). After the hurricane contacts the land this structure is removed.

Nearby the hurricane three regions of temperatures exist: The center-region, which is warmer than the cold hull of the storm. Outside the hull the temperature seems to be stable and warmer than the hull. Analyzing the temperature nearby the coast we can observe strong fluctuations.

A big blast wave is pushed by the storm and the pressure strongly falls off nearer to the storm (*Figure 1, left*). The pressure nearby the storm is very low, also a ring of pressure is composed with a low vacuum, pressure nearby 0 and a low vacuum becoming higher to the center of the storm. This would explain the suction effect in the center and the falling off behavior of the flow in the hull of the storm. The highest pressure appears to the lowest layers with a high diameter and a low height.

The clouds are very compact at the beginning. But the structure will be destroyed a little more every time step. After a few time steps, the same structure as the vortices' is noticeable.

4.2 Advantages and Disadvantages of Our System

The advantages consists of the interactive, 3D representation of the (unsteady) flow and any (unsteady) scalar data. All the parameters of the representation can be edited by the user interactively. Also the user is allowed to combine the different visualization techniques, like the flow visualization and the representation of the scalar data.

The use of 3D textures implies a high dependency of the texture memory. At the moment, the vector field of Isabel must be downsampled to a resolution of $256 \times 256 \times 64$. Also, the power-of-two restriction of textures may be a disadvantage. We confronted the restriction of the resolution with the insertion of a separate 2D advection which allows to advect on the full 500×500 grid cells (of a 2D section of the data set). The system can be extended with any precalculation method; at the moment only vorticity and lambda-2 are precalculated. The disadvantage of this precomputation is the high amount of data that needs to be transferred to texture memory for a new time step. This becomes noticeable in form of little delays for time-dependent data sets.

4.3 Further Information

Images and a video can be found on the project web page:
http://www.vis.uni-stuttgart.de/∼schafhts/viscontest

REFERENCES

[1] B. Cabral and L.C. Leedom. Imaging vector fields using line integral convolution. In *Proc. ACM SIGGRAPH 93, pp.263-272*, 1993.

[2] J. Jeong and F. Hussain. On the Identification of a Vortex. In *J. Fluid Mechanics 285, 69-94*, 1995.

[3] A.C. Telea and J.J. van Wijk. 3D IBFV: Hardware-Accelerated 3D Flow Visualization. In *Proceedings IEEE Visualization 2003, p. 233-240*, 2003.

[4] D. Weiskopf and T. Ertl. GPU-Based 3D Texture Advection for the Visualization of Unsteady Flow Fields. In *Procceedings of WSCG 2004 Short Papers, pp. 259-266*, 2004.