Texture-Based Flow Visualization in Augmented and Virtual Reality Environments

Paul Benölken Holger Graf André Stork

Fraunhofer Institute for Computer Graphics
Fraunhofer Str. 5
64283 Darmstadt, Germany
paul.benoelken | holger.graf | andre.stork@igd.fhg.de

ABSTRACT

Virtual and Augmented Reality allows a new way of result exploration of numerical simulations, its analysis and interpretation by immersing the user into the data sets and/or by keeping the relationship and context to the real environment. Up to date only a few approaches targeting the deployment of augmented reality during the analysis stage have been published. New texture based visualization tools emerged and conciliate a better understanding of the flow fields. This paper describes our approach for integrating texture based visualization methods within a mixed reality set-up by introducing a 'low cost', fully 3D interactive post processing unit for CFD data sets.

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Keywords

flow visualization, texture based algorithms, virtual reality, augmented reality.

1. INTRODUCTION

The numerical analysis and visualization of flow phenomena has become an indispensable part of many different research and application fields. VR based solutions as the pioneering work of Bryson [Brys92] or the flow field analysis presented in [Schu99] have shown how to ease the understanding and interpretation of complex 3D data sets.

For visualization vector fields vector fields, glyphs, path-, stream, streak lines or particle animations are commonly used. Nevertheless these methods are either limited to local vector field analysis or provide a rather coarse spatial resolution. Hence even in combination with advanced 3D interaction techniques relevant flow characteristics may be missed without any deeper knowledge of the flow field. This problem is addressed by texture-based visualization methods, which provide means for displaying the global characteristics of a flow field in an intuitive way with a sufficient resolution and density.

Virtual reality systems increase the efficiency during the analysis stage but still lack the integration with real environments. Here AR offers a challenging and promising technology enabling the engineer to superimpose simulation results to the real environment in which he works.

In this paper we present our solution for integrating a texture-based visualization method into a virtual and augmented reality environment. Our application combines traditional methods for visualizing vector fields with the Oriented Line Integral Convolution approach introduced by Wegenkittl et.al.[Wege96]. The presented system is based on a 'low cost' solution of a client server architecture and runs on a common PC.

2. Related Work

The visualization of flow fields has been subject of numerous developments and publications. Hauser et al [Haus02] give an extensive overview and

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categorization of existing solutions and recent research issues.

Alternatively to integral objects, texture-based or dense integration methods as the spot noise method, introduced by van Wijk [Wijk91] were successfully applied for visualizing vector fields. Line integral convolution (LIC), first published by Cabral and Leedom [Cabr93] is a very popular and powerful method for visualizing dense vector fields.

With their Fast LIC method Stalling and Hege [Stal95] obtained a significant improvement in LIC performance by exploiting the coherence along streamlines. An additional improvement was achieved by the Integrate&Draw method [Pere98], which produces images with more contrast and a time saving of ~ 50% compared to Fast-LIC.

Forsell and Cohen [Fors95] extended LIC for curvilinear surfaces with animations techniques, directional and magnitude information. The LIC extension presented by Teitzel et al. [Teit97] works on 2D unstructured grids as well as on triangulated surfaces in 3D. With their OLIC approach Wegenkittl et al. [Wege97] address the problem of visualizing the orientation of the flow. Extensions were made for speeding up this method (FROLIC) and for animating the flow via the internet [Berg00].

For extending LIC to 3D Interrante [Inte97] presents a combined approach of direct volume rendering and LIC. Rezk-Salama et al. [Resk99] use 3D textures mappings for achieving interactive performance rates.

A significant performance gain was achieved with the image based flow visualization technique (IBFV) introduced by van Wijk [vanWijk 2002]. Laramee et al. [Lara03] recently extended this method for flow field visualizations on surfaces. However this technique has not yet been integrated into an AR or VR environment

In fact, research efforts for interactive exploration of simulation results for flow fields in an AR set-up just started to evolve. To our knowledge, the generation of texture based visualization methods for an interactive exploration of flow fields in a mixed reality set-up has so far not been presented. Most applications are placed within the area of medicine, architecture, edutainment or cultural heritage. An overview can be found e.g. in [Azum01].

The closest work to this publication has been investigated within the ARVIKA project [ARVI]. To overcome the limitations of current simulation packages namely the loss of the relationship to the real environment Regenbrecht and Jacobsen [Rege02] make use of augmented reality to lead 'on-site' inspections of simulation results within an airplane cabin.

3. Texture based Flow Visualization

Beside the conventional technique for interactively computing and displaying 3D stream curves (lines, tubes, faces) isosurfaces and cross sections (see [Beno03]) we implemented an algorithm for generating and mapping flow textures onto polygonal surfaces like cross sections or isosurfaces.

As the orientation of the underlying vectors is an important feature for the perception and understanding the 3D flow characteristics we modified and extended the fast oriented LIC (FROLIC) method for polygonal surfaces.

The original FROLIC algorithm operates on regular grid structures where the topological information is given implicitly. Hence, for efficiently processing triangulated surfaces additional spatial data structures are required. In our implementation we used a binary hash table for storing the surface edges and enabling a fast access on adjacent triangles. Furthermore the triangles are mapped into local Euclidian space for achieving an efficient point localization, rasterization and integration. A 4th order Runge-Kutta scheme is applied for performing the numerical integration. As the computation of streamlines on triangulated surfaces implies multiple crossings of triangle boundaries the integrator needs to check whether the current triangle has been left or not. From the Euclidian representation of the triangles we computed barycentric coordinates for fast point localization.

Beside the flow orientation within the polygonal mesh the orientation of the 3D vectors with respect to the surface has to be reflected for achieving a correct spatial visualization of the flow. Thus, vectors with a tangential orientation should cause longer traces as orthogonal vectors. This is accomplished by adaptively computing the filter length L_i by applying the following exponential function:

$$L_i = L_{max}^{\frac{|v_{2D}|}{|v_{3D}|}}$$

Here $|v_{2D}|$ is the length of the projected 2D vector and $|v_{3D}|$ denotes the 3D vector length. L_{max} is the user defined maximal filter length.

The selection of seed points is another critical issue in computing streamlines. Especially for the oriented LIC method the initial positions of the droplets have to be selected carefully for avoiding overlaps, which cause artifacts in the output image and performance losses. We evaluated different strategies for selecting seed points (see Table 1). For the random selection we implemented a modified sobol scheme, which delivered the best performance with minimal artifacts.

Figure 1: Texture based flow field visualization in AR setup. The users view is displayed in the right top corner.

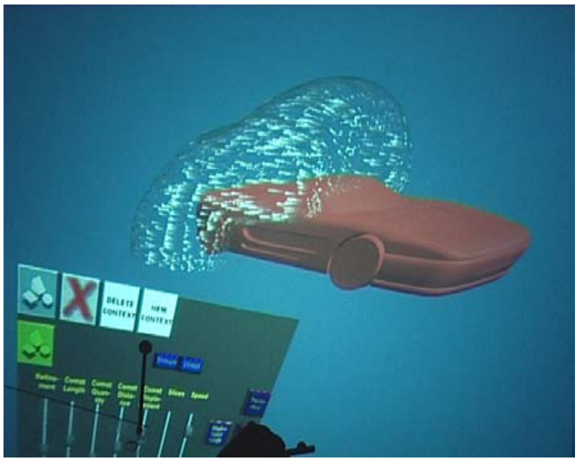

Figure 2: Mapping flow textures on isosurfaces. 3D manipulation widgets are used for parameters changes.

The animation of the original FROLIC method is either accomplished by a cyclic variation of the streamlet intensity or by color-table animation. Nevertheless additional filter operations have to be applied for suppressing pulsation effects.

Our implementation for animating FROLIC images is based on a variation of seed points for each frame. The seed points of frame i are shifted with a constant factor along the streamlines. These output seed points are used as an input for the streamline computation in the subsequent frame i+1.

For this purpose the seed point selection is prepared within two steps: First, a set of seed points is selected using the random selection mechanism. Afterwards, a subset from the computed set of seed points is selected by evaluating the neighborhood of a seed point such that no other streamlet is found in a predefined region.

4. Results

The augmented reality setup we used for exploring the flow field of a car is shown in figure 1. The user is wearing a head mounted display with two integrated micro cameras. The video see-thru mode is accomplished by placing a video texture onto the backplane of the virtual environment. An A.R.T. Dtrack system is used for tracking the user's head-, PIP-, pen- and model positions with high quality. This system uses retro-reflective markers, which are tracked by two self-flashing infrared cameras.

In our client server architecture [Beno03], the rendering client was running on a 1.2GHz Windows PC with 512MB main memory, a PNY NVIDIA Quadro 750 Graphics board. The compute server was running on a 2GHz PC with 2GB main memory.

The interactive generation of the texture based visualization methods can be achieved in providing different manipulation mechanism. Several parameters, such as resolution and filter length, transparency, number of animation images, etc., for the manipulation of the texture based image generation can be interactively modified using 3D direct manipulation widgets as illustrated in Figure 3 and 4.

Some results of the work described so far are shown in the figures 1 and 2. Figure 1 shows a texture based flow-field visualisation using a FROLIC –texture for the representation of the vector field. This texture is mapped onto a cutting plane, whereas figure 2 shows the same visualization method mapped onto an iso-surface representation.

The system set-up has been tested with different data sets in different sizes and different resolutions. To investigate the flow field interactively, a fast retrieval of the starting ('seed-') points is inherent for streamline computations at interactive rates. The following table (table 1) shows the performance of the texture based streamline computations using different strategies for setting the seed points.

Dataset	ScanLine	Diagonal	Block	Random
2482 Triangles	371ms	361 ms	380 ms	341 ms
5832 Triangles	7971 ms	7942 ms	7992 ms	7612 ms
1346 Triangles	260 ms	271 ms	270 ms	218 ms
7280 Triangles	2624 ms	2654 ms	2533 ms	2508 ms

Table 1: Seed-point selection performance

5. Conclusions

Within this paper we presented our solution for texture based flow visualization on triangulated surfaces. State of the art texture based visualisation algorithm have been modified and extended for polygonal surfaces. The system set-up for an interactive exploration of flow fields in a mixed reality scenario is promising new application areas within the engineering domain.

Faster computations will be achieved by image space based methods. However, as the order of operations (texturing, projection) completely differs from conventional approaches, the integration into a video-mixing AR environment is still an open issue.

Alternatively, higher frame rates might be achieved by exploiting more flexible programmable graphic boards such as the NVidia FX series. Moreover, within an augmented reality set-up using video-mixing technology, the used framegrabber boards still impose a bottleneck in respect to performance and image synchronization between the video image and the generated virtual objects. Our future work concentrates on the enhancement for texture-based visualisations at interactive rates and optimize the augmented reality set-up exploiting more hardware features offered by the new generation of graphic boards.

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