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A.C.T.I.V.E.: A scalable superellipsoid-based CFD visualization for virtual and desktop environments

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Abstract

The paper presents a flexible software (A.C.T.I.V.E.) able to visualize the superellipsoidal glyphs describing the orientation of short fibres during the dynamic process of casting a short fibre reinforced composite in a container. The software is designed to run on the VRUI framework and it features an optional face-tracking to grant a more natural interaction also on standard non-3D displays. Due to its flexibility it can be used on a wide range of environments, from desktop computer to multi-screen CAVE-like systems.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—Line and curve generation

1. Introduction

Virtual Reality Environments (VRE) are nowadays more and more a fact, not only for a niche of researchers and rich private institutions, but also for more limited budgets and for the public. What no less than ten years ago could have only been achieved with a budget of hundreds of thousands of Euro, is now available for a small fraction of that price. With consumer HMD and 3D Screens getting lower in prices and available in a wider offer, simple personal VREs are now a reality often only slightly more expensive than common desktop computer. Obvious and unavoidable differences in size and performances between small VREs and the large ones exist, but the gap between them is slowly being filled by the advancements in hardware technologies.

1.1. Our VRE

At the visualization group of the Institute of Cybernetics of Tallinn, we began our way towards Virtual Reality in 2010 with a graphic workstation endowed with a 3D Planar Display (linear polarization) to explore 3-dimensional data, to continue in 2012/2013 with the design of construction of our CAVE-like [CNSD*92] system, the Kyb3 Fig. 1 [PH13].

Conceived to abide to strict constraints of budget and space, with an occupied space of only 2.35m $\times$ 2.04m $\times$ 1.77m, the Kyb3 features three 1.1m $\times$ 0.8m screens and a full magnetic tracking of the user position and interaction, for a total cost of approximately € 35000. The Kyb3 is currently used at the Institute of Cybernetics for a wide range of scientific applications.

1.2. Short Fibre Reinforced Composites and Tensor Visualization

Short fibre reinforced composites are very popular in many application areas from glass fibre plastics to steel fibre reinforced concrete (SFRC) in civil engineering. The mechanical properties of these composites strongly depend on the distribution of the fibres, i.e. they depend on both the spatial and *orientational* distribution [HEBP14, SKE*13, PH14]. Therefore simulations of the production process, e.g. injection molding, are necessary. These simulations involve the CFD simulation of the matrix material (plastic, concrete, metal, etc) and the fibres, which can be either included as individual particles or by use of a tensorial equation. The orientation distribution of the fibres can be characterized by orientation tensors or alignment tensors (the traceless part of the orientation tensors).

Therefore the visualization of the orientation tensors is important for the analysis of the computer simulations. The second order tensors can be visualized using superquadric or superellipsoid glyphs [Kin04, JM06, SK10]. To be able to visualize a large number of tensors in a VRE, the visualization of the parametric glyph surfaces needs to be fast, this is

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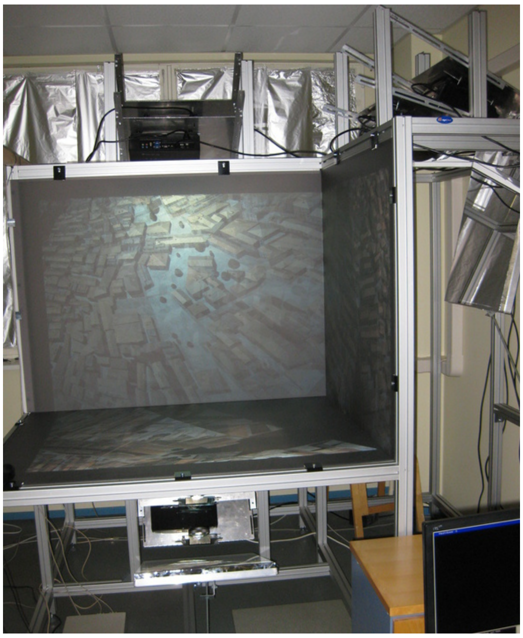

Figure 1: *The Kyb3 VRE at IoC*

a problem of several of the available visualization tools. A reason for this can be, that the shape of the glyph, and the vertices to display, is calculated on-the-fly.

2. A.C.T.I.V.E.: Anisotropic Composite Tensor Interactive Visualization Environment

Our goal for this project was to visualize datasets of tensor fields for visual inspection and analysis, while making the process reproducible on many machines with different Virtual Reality set-ups such as different displays and trackers. Additionally we wanted to extend the possibilities of experiencing (in a limited way), a partial data immersivity on any desktop setup, by creating a 3D-tracker that could work on many common desktop set-ups. In the end we wanted a cost effective visualisation with a virtual experience that could run on a wide range of system, such as CAVE-like environments, 3D monitors, HMD or regular displays (the latter with anaglyphic stereo).

One of the main research fields, involving the visualization of data and results through the Kyb3 VRE, is the study of micro-structured composite materials and their physical properties [PH14]. The data used for the visualization is obtained from an OpenFOAM simulation, Fig. 2, representing the casting of SFRC (steel fibre reinforced concrete) into a box-shaped container. The fibres themselves are not represented as single elements in the simulation, but their orientation equation is coupled with the fluid rheology. The simulation allows us to obtain, for each time step, a tensor field describing the properties of the fibres' orientation in the concrete.

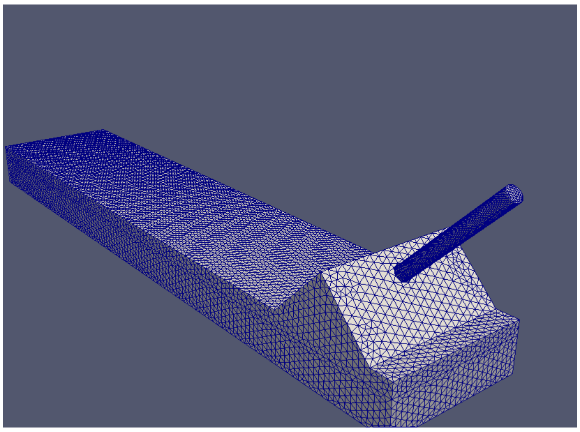

Figure 2: *The OpenFOAM SFRC casting setup (including the pipe through which the concrete flows in the container)*

Each tensor is used to calculate the shape metrics from which the parametrization of the corresponding superellipsoid glyph is determined. OpenGL is eventually used to draw the parametric surfaces of the glyphs in the 3D space, Fig. 3. Due to the high amount of small Glyphs with different sizes and shapes visualized for each time step of the simulation, it becomes increasingly hard to see their 3D relative positions towards each other on a static 2D screen. As a solution, we ported our OpenGL code to the VRUI (Virtual Reality User Interface) [Kre08] framework, mainly in order to take advantage of its ability to hide the characteristics of the system on which it will be executed from the developer. User input and tracking, 3D stereoscopy and scene manipulation are also directly managed by VRUI . Additionally, in its last release, VRUI also has the possibility to be used with an HMD as well, for example with the Oculus Rift.

2.1. Superellipsoidal Glyphs

Superellipsoids, whose definition is often ambiguously mixed with that of superquadrics, are a group of solids whose domain partly intersect the domain of the superquadrics but also extends towards a range of different shapes. Although also built through the use of two parameters (one defining the exponent of the super-ellipses representing their horizontal section and the second the exponent of the ones constituting their vertical sections) as for the superquadrics, the shapes obtained in the extremes of the domain range of superellipsoids, tend to be more easily identifiable, less prone to visual ambiguities and to allow a smoother and recognizable transition among shapes [JM06]. Due to this properties, each glyph can be more expressive about the properties of the related tensor at the given location. To speed up the computation, since the datasets involves the plotting of several thousand glyphs for each time-frame of the simulation, we created a discrete set of pre-computed super ellipsoid vertices with a range of parameters fine enough for the human eye not to notice. From the OpenFOAM simulation data we compute the positions, orientations and parameters of the glyph once and store them in separate files.

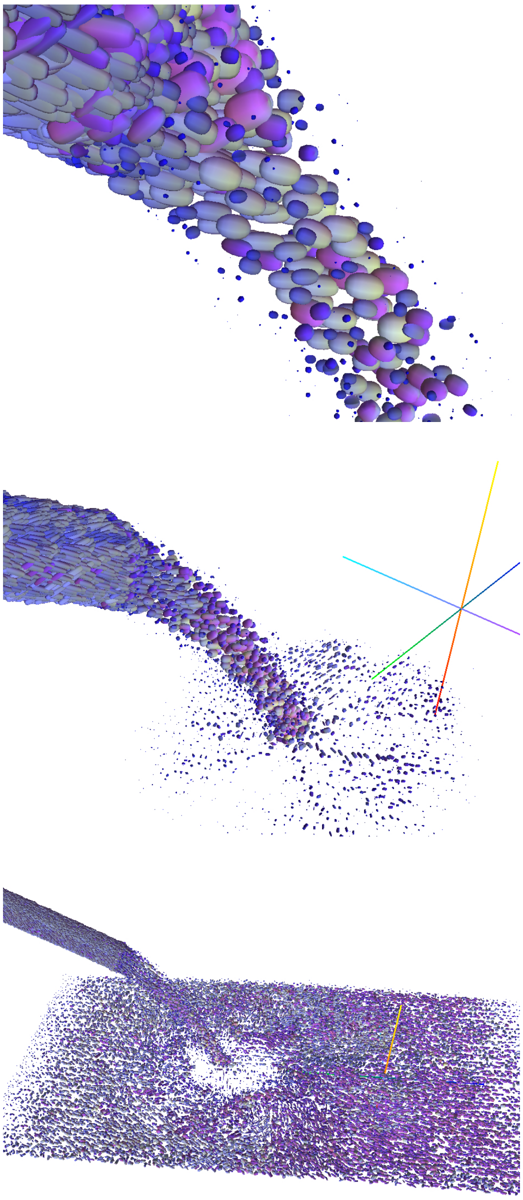

Figure 3: *A.C.T.I.V.E. Tensor Glyphs Visualization*

2.2. User Tracking on Desktop Environments: Camera Facetracking

The A.C.T.I.V.E. software can be used on anything from a full-size CAVE-like environment over Oculus Rift, over desktop 3D monitors down to standard 2D monitors. However, the degree of immersivity is obviously reduced. True 3D impression needs perspective, the correct viewing frustrum and stereoscopic images. While the first one is easy to achieve, even on 2D screens, the latter two require specialized hardware.

On 2D screens it is still possible to obtain a good 3D impression, if the scene is rotated or is constantly adjusted to changes is the user position. However, the adjustment to the changes of user position require the user to be tracked, so that the camera in the scene is in sync with the movement of the users head.

By tweaking the view frustum with the input of a head tracker we can create the illusion of looking through a window. To reach a true virtual reality we will always need both: stereoscopic views and a tracker for the user's eyes. While this doesn't represent an issue on our Kyb3 system, where the user head position and rotation is constantly tracked by electromagnetic sensors, the same feature was not available for our Planar 3D display and other, normal desktop monitors.

Tracking hardware is usually quite expensive and not yet widespread enough. Therefore, for the convenience of all users we decided to create a tracker that only relies on a device easily accessible for every laptop and desktop computer: a front facing camera parallel to the display. This means that most users would probably not require any additional hardware to benefit of this feature of our software. To implement the whole face-tracking component, we relied on the OpenCV library [Bra00] and its feature detections in images, by continuously reading the pixel location and pixel size of the biggest face found in the camera. With knowledge of the pixel resolutions, the field of view, angle of the camera and approximate height of the face we can estimate the absolute position of the eyes in the face relative to the camera itself, Fig. 4.

The tracker has been implemented in C++ and is endowed with configurable smoothers for the raw pixel data and the final tracking data. If the tracking was successful in the last frame, we also predict the size of the face and focus on the area of the image where we expect the face to be next. All of these features result in a smooth tracking experience that is reliable and fast when used in a common desktop environment. The limitations, that this approach holds, are that it only tracks 3D positions and not rotations and that the facial detection is limited to frontal and profile faces. However, the detection protocols are easily swappable in the configuration file and can therefore be easily updated when better ones become available [VJ01]. The frame-rate is kept at 60 fps, which is essential since a high frame rate is always necessary

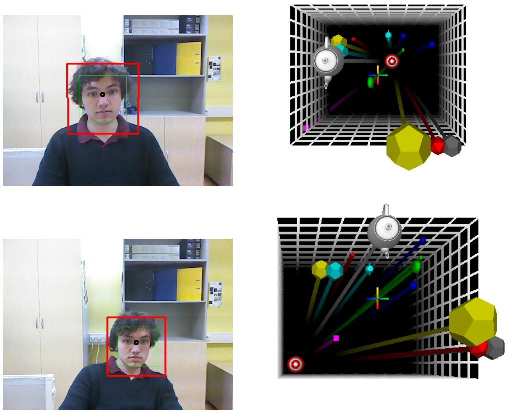

Figure 4: *Face tracking*

to have a comfortable tracking experience. It is not meant to track a user walking around a room or complex motions, the user has to stay in the camera viewing volume and show his face to the camera without rotating or his head too far.

Finally, in order to grant the face-tracking component the maximum flexibility of use, we created a VRPN (Virtual-Reality Peripheral Network) [THS*01] server using our face-tracking features for the convenience to easily connect it to any client that reads VRPN tracker inputs. VRPN is a very helpful tool to connect multiple tracker, analog and button input devices with client software while maintaining a simple interface for clients and being available on windows and linux. VRUI, that we used as a framework for our tensor field visualisation, can launch a device daemon specifically for any VRPN input.

Conclusions

The A.C.T.I.V.E software represents one of our several sub-projects aimed towards building a complete research environment for micro-structured composite materials analysis and visualization. Other software elements are being developed or are already functional [PH14], and all of them are meant for flexibility and portability among different types of platforms.

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