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Use of Shader Technology for Realistic Presentation of Train Prototypes in Virtual Reality

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Abstract
The aim of the paper is to make up a virtual showroom and work-through of a train model in order to allow railway companies showing new trains prototypes, in phase of concept, and present their new design in more exhaustive way than simply technical documentation. The possibility of applying Virtual Reality (VR) methodologies to make a scene more realistic as possible is a great advantage for the effectiveness of the presentation, in order to increase their competitivity. Shader technology allows the programmers to have control over shape, appearance (such as colour, lighting, reflection) and animation of objects, in order to make very realistic real-time rendering. In the paper the authors describe the use of shader technology in Virtual Design 2 (VD2) for realistic presentation of train prototypes in VR. The software VD2 is an extensive tool that allows following many phases of product development, from the creation of showroom for realistic presentations supporting shader technology to the assembly simulation or ergonomics analysis. Moreover, the possibility of interfacing with a wide range of input/output devices and the possibility to access to the API made this software to be chosen for Virtual Reality applications in the VR laboratory of the Competence Center for the Qualification of Transportation Systems founded by Campania Region (www.centrodicompetenzatrasporti.unina.it).

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

1. Introduction

One of the objectives of the continuous development of Virtual Reality techniques is to improve the photorealism of the scene, in order to give an even more realistic sensation to the operator immersed in the artificial environment.

Researchers worked to assign all the attributes to the objects represented in the scene necessary to appear as in real world [NT05].

A promising way to reach this result is the use of the new *shader technology*, a technique for programming the appearance of the objects in a virtual scene, including lighting and reflections of surfaces.

The great advantage of this technology in terms of improvement of the realism is already known in the automotive field (Figure 1), in which the employment of Virtual Reality techniques for the phase of Concept Design is widespread by now: such advanced design systems allow a remarkable saving of costs and time for the evaluation of several design solutions, which, until few years ago were possible only through the production of many physical prototypes.

Figure 1: *Shader technology applied to realistic representation in automotive field [VWS]*

Not so diffuse is the application of these techniques in the railway industry, which is still characterized by traditional design methodologies.

In the last years railway transport industry has undergone a strong development, pushed by the process of liberalization and globalization of the market. The partecipation of international competitors to the contract contests caused the design standards to be adapted to infrastructures also different from those of the country of origin [CC*05]. In particular, the entry of Asiatic competitors in European contests forces the companies to answer their favourable offers with innovative and technologically advanced projects: if the point in favour of Asiatic competitors consists in the competitive prices, the added value, European companies must take advantage of, is the fund of technological knowledge and innovative methodological approaches [AV03].

Unlike the automotive industry, train design is not bound only by design requirements, but it must respect also the directives, present in contracts, imposed by the transport company who calls for tenders.

Virtual Reality techniques allow the designer to simulate their complete concept, in terms of design, ergonomics and safety, and then to present a realistic project that respects such requirements for the evaluation during the contest.

Using an innovative methodology for the concept evaluation in virtual environment [DLV06] it is possible to utilize virtual prototyping to screen, by means of virtual experimentation, the design solutions maximizing the customer satisfaction in terms of quality, comfort and safety.

In this work an innovative approach for train industry is developed for presenting in realistic way, using shader technology, the design solutions to the examiners in an interactive immersive environment.

2. Shader technology

During the last few years the possibility for programmers to control the real-time rendering increased remarkably. The execution of rendering algorithms passed from being controlled in the CPU by assembly language to be written in high-level language and processed by graphic processors. This process followed the considerable improvement of GPU during the years and saw the employment of standard 3D programming interfaces, such as OpenGL and Direct3D.

The control of the effects with this interfaces were still limited to fixed features. The new programmable GPUs have been improved into powerful and flexible streaming processors able to operate with floating-point precision [GWH05].

The request of more programmability brought to the creation of a dedicated high-level language, known as shading language, which gave the programmers some of the advantages, in term of programmability, of traditional high-level languages. Shader technology allows the programmers to have control over shape, appearance (such as color, lighting, reflection) and animation of objects to make very realistic real-time rendering.

By means of a language, such as Cg (NVIDIA Corporation), based on a general-purpose language for programming, like C language, 3D application programmers can write simple code to obtain special effects managing vertex and fragment transformations, which will execute within the GPU [FK03].

Since GPUs are dedicated to image processing, they can reproduce real-time rendering with tens of millions vertex transformations per second: 3D geometries are made of many vertices that will be transformed in the correspondent pixel to be rasterized and this task has to be performed tens of frames per second to give real-time impression.

The shader code written in this language will be called by the application, typically written in C or C++ [Sch96], by means of the shading language runtime, a set of subroutines able to compile shader program in a form acceptable by the 3D programming interface, either OpenGL or Direct3D, which translate and execute it into the GPU [FK03].

Vertices and fragments are processed by the relative vertex shader and fragment shader programs in GPU following the well-known graphics hardware pipeline (Figure 2).

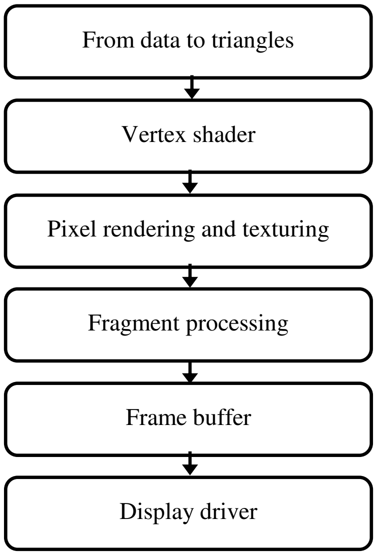

Figure 2: *Graphics hardware pipeline*

The pipeline starts when the 3D application sends objects data to the GPU; then, all data are broken down into triangles. In this way, data are ready to be processed by the vertex shader by means a set of operations, such as calculating the correct position of triangles for rendering and color and depth of each vertex. In the next step triangles are broken down further, calculating the corresponding representation for each pixel on the screen and determining the textures associated. Mathematical data now start to be processed by the pixel shader, setting color, special lighting and textures to each pixel. Finally, pixel data move to the frame buffer memory and GPU moves data from the frame buffer to the display driver, in which scene is displayed [AV05].

3. Shader technology in VD2 (vrcom GmbH)

The Virtual Design 2 software is an extensive tool that allows following many phases of product development, from the creation of showroom for realistic presentations to the assembly simulation or ergonomics analysis. Moreover, the possibility of interfacing with a wide range of input/output devices made this software to be chosen for Virtual Reality applications in the laboratory described in the following.

The two environments of VD2 software consist in a scene editor (VDSE), where there are all necessary tools to prepare the scene, comprehending geometries files, materials, lights, animations and other effects, and the "manager" of the simulation (VD2), in which the parameters to launch the simulation in one's own laboratory, such as with allowable input/output devices, are set.

The scene, prepared in VDSE, will be loaded in VD2 and then real-time rendering and user interaction can start.

The other way to work, typically during a concept presentation, is to use the two tools in coupling mode: this means that, while the scene is visualized in VD2 on the output system, such as a powerwall, it is still possible to control it by means of the functions of VDSE, for instance from a workstation.

Setting one's own scene in order to prepare the application, such the train presentation in a showroom, is made easy in VD2 by meaning of several wizards, which accompany the user to each step of parameters setting for the interested module. At the end of the wizard a code is generated, which will be passed through at the launch of simulation; this config-code can be also written manually without utilizing wizards [VPG05].

The material editor module, in VDSE, allows adding a shader to a material definition and treating it like a texture, storing shader parameters into the extensions of the material [VUG05].

4. Laboratory of Virtual Reality (University of Naples Federico II)

The evaluation in virtual environment of concept of industrial products that present large dimensions, such as trains, needs the use of a virtual reality laboratory able to visualize such products in 1:1 scale.

In May 2005, the researchers of the Department of "Progettazione e Gestione Industriale" of the University of Naples Federico II have completed the installation of the Virtual Reality laboratory [CDP04], named "VR Test", realized for the Competence Regional Center for the qualification of the transportation systems (CRdC "Trasporti" - www.centrodicompetenzatrasporti.unina.it). The "VR Test" has been founded by Campania Region with the aim of delivering advanced services and introducing new technologies into local companies operating in the field of transport.

The laboratory is, to date, one of the most innovative in Europe respect of hardware components, screen dimensions and software availability. It allows developing products and complex systems and simulating their configurations and performances in virtual environment. Therefore, it represents the ideal theater for the immersive visualization of railway carriages, in real dimensions (figure 3), and for their evaluations by the examiners.

Figure 3: *The "VR Test" laboratory*

Its main characteristics are described in table 1:

Table 1. VR TEST

Workstation	SGI Onyx4 with O. S. Irix 6,5 (10 CPU, 10 GB Ram, 6 graphical pipes, 1500 GB Hard Disks); Cluster of 3 PC with O.S. Windows/Linux.
Visualization System	Powerwall (7.5m x 2.4m) BARCO ACTCAD
	3 DLP Projectors for active stereo BARCO Galaxy 6000 AL
Tracking system	Optical ART Track 1 (3 cameras).
3D Input Systems	Cyberglove with 22 sensors, 5DT with 14 sensors, spaceball, flystick e joystick
Software	Virtual Design 2 by VRCOM (with modules: Showroom, Assembly/Disassembly simulation, Interior design, Lightsimulation, Developer Toolkit); CATIA V5 R16 P3 by Dassault Systems (completed with all the modules); Alias StudioTools R12; Classic Jack (with Occupant Packaging Toolkit, Task Analysis Toolkit modules), TeamCenterVisualization 2005 and Unigraphics NX by UGS.

5. Application to a new regional train concept

The case study deals with the concept of a new regional train and its presentation in virtual environment. Railway field is still characterized by traditional design methodologies, such as two-dimensional technical sheets and huge use of paper documentation.

So, the target was to realize a virtual presentation of the new product, taking care to most important aspects of the real world in order to give a very realistic impression to observers and potential customers.

To do that, the VD2 software described above was used, in both components VDSE and VD2.

Virtual Design Scene Editor (VDSE) was used to prepare all the components of the scene, such as geometries, textures, lights, animations [VSE05]. Therefore, VD2 was used to load the prepared scene and to show it in the virtual environment of the Laboratory of University of Naples Federico II. VD2 is the tool used to set the interface with all allowable devices and, then, to launch final simulation to the output system, in this case a powerwall.

Since VDSE has no CAD functionality, except for simple transforming objects or creating primitives, the complete model of the train and of some additional furniture was imported in VDSE using wrml format.

The model was created in Pro Engineering Wildfire 2 CAD system, and then exported in wrml format without using the capability of exporting texture of this format, as they were applied later in the material editor of VDSE.

Once loaded the train geometry, it was positioned in a three-dimensional environment reproducing an outdoor train-stop with several lamps to illuminate it.

The first aspect it has been implemented is the position of the lights, on which also material effects depend. A light was set to simulate sun effect: VDSE allow reproducing directional light with parallel rays independent by light position.

A different kind of lights, "spot" type, was used to simulate lamps in the scene: setting the spot angle it is possible to simulate rays coming out in conic shape, like lamp lights behaviour.

The characteristics of the lights affect the resulting appearance of the material assigned to the geometries. The material editor module is used to define the material of each geometry by the combination of the four terms of surface colour (emissive, ambient, diffuse and specular), the material properties (shininess and transparency) and applied texture and shaders.

Shaders in VD2 and VDSE work as a material extension, defining material and light parameters by variables in a special syntax. In VDSE it's possible to load a shader simply accessing to FHS, FHB and FX-shader files in the load dialog. However, in advanced mode, it's also possible to choose among the three possible shader API's, loading one or more shader files depending on it.

API's for CG and the GLSL (OpenGL) [Ros04] need separate shader files for vertex and fragment programs to be loaded, whereas only one file includes all information in CgFX .fx format [VSE05].

A CgFX file includes any individual vertex and fragment programs needed to define a complete rendering appearance or effect, allowing encoding complex shading algorithms requiring multiple rendering passes [FK03].

The possibility to programme some sliders to control shader parameters allows, for example, setting a different level of reflections (Figure 4).

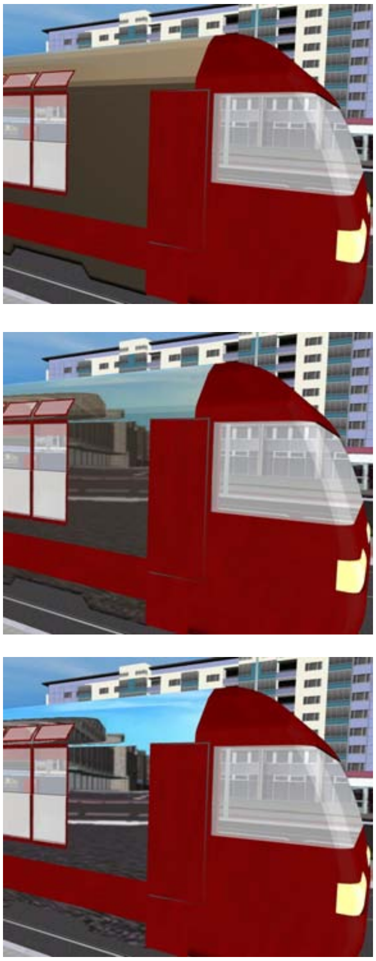

Figure 4: S*hader applied to the train prototype with different levels of reflection (0, 0.5, 1).*

Shaders were applied just only to the outside of the train, presuming a metallic nature of the material, otherwise the inside object were imagined in plastic or textile nature, with no reflection, such as seats or floor. The textures used for textile simulating were captured as shots from real world to increase realistic effect.

The reflection of materials is controlled by means the call to the cube map texture, featuring the environment mapping for the relative geometries.

Looking to a highly reflective object the appearance of the surface is the result of the reflection of the view ray into the surface itself, depending on the normal in that point, and reflecting to the object's surroundings, assumed infinitely distant from the object.

The cube map texture is a cube made of six texture images forming an omni-directional image: the color of the point in which the view ray reflects into the surface is the one reflected from cube map [FK03].

A characteristic of train simulation is the large presence of transparent parts (e.g. the number of windows is quite bigger than in automotive field), so the characteristic of transparency was applied to the material representing the glass and it is calculated many times during simulation, being one of the causes of a large use of resources and reduction of performance.

Figure 5: *Train rendering with applied shader.*

In order to simulate the real functioning of the train, in VDSE was possible to realize a sequence of events to produce an animation: the arrival of the train to the station, the opening of the doors, the closing and the departure of the train were "recorded". The possibility of changing camera views in a predefined sequence during animation or just in real time really increases the realistic and immersive effect.

After prepared the scene it can be loaded in VD2, in order to show it in the virtual laboratory by setting its characteristics, such as input/output devices [VUG05].

The figure 5 shows the realistic train rendering with applied shader.

6. Conclusions

The paper offers to rail companies a really more realistic way, than technical bi-dimensional documentation, to present train prototypes in phase of concept and call for tenders.

Improving the realistic effect in the train concept presentation is the future aim of the work. In particular, the possibility of using collision detection between objects will be used. VD2 allows setting some events to trigger some action within the scene. Next phase will be to set realistic actions to give the observer the possibility of interacting with the scene and feeling a bigger sensation of immersivity. For instance, the event of opening the door will be caused by the pressing of a button added to the train geometry [VUG05].

Moreover, the characteristic of the software to be customized in the developing module will be enjoyed to create special features for railway field, such as the simulation of a digital factory to show innovative systems to produce the train.

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