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SURFACE DESIGN IN VIRTUAL REALITY AS INDUSTRIAL APPLICATION

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1. Introduction

Far away from the initial hype of the seventies, Virtual Reality (VR) technology is proceeding with his course in a evolutionary, not revolutionary fashion. Significant improvements in computational power, input devices and interface design have been pursued in the last twenty years, and VR systems are getting more and more widespread in industry. Previous works ARCADE [Stork 1995] and COVIRDS [Dani 1997] have shown the advantages of real-time interaction, stereo visualization, and a specific 3D interface in the early stages of design. Conceptual Design or "Styling" need specific tools to experiment ideas and visualize forms in an intuitive, unconstrained way. Commercial CAD applications support and integrate great part of the manufacturing processes, but not the first imaginative and artistic phase. In fact, the creation of geometry is only possible at detailed level, and consequently designers prefer to realize their models on paper or clay [Purschke 1998]. Styling and ergonomic design should be preserved along the product development process, but converting physical data to digital is usually done by others, introducing the risk is of misunderstanding and error. According to our vision, VR can offer the ideal unconstrained interface for free artistic expression and bridge the gap between creative experimentation and precise manufacturing-oriented modelling. The main contribution of this article is to present a VR-based Free-Form Surface modeller called SpaceDesign, which is seamless integrated in the manufacturing process and do not require any specific knowledge about the mathematic of the generated surfaces, because the software handles such complexity in transparent way. Spacedesign is historically based on ARCADE, from which inherits most of the functionalities related to the surfaces, but introduces many new features: a navigation tool, a improved real-time visual feedback, an enhanced algorithm for the Coons Patch tool, an interactive help, and support of industry-standard file formats. Moreover, previously made engineering models can be imported and used as a visual reference, a kind of "soft" constraint. The article is organized as follow: in the second section is presented the state of the art in VR-based free form modelling, then in the third the industrial requirements are explained. The fourth section describes the implementation of SpaceDesign, focusing on the new functionalities introduced. At the end an example of application and conclusions are provided.

2. Related Work

One of the first systems that used 3D interfaces for free form modelling was 3Draw, developed by Sachs et al. [Sachs 1991]. In 3Draw a palette and a pen are connected to 6 degree-of-freedom (6DOF) tracking devices, and a normal monoscopic monitor is used for visualization. The orientation of the tablet forms a reference frame and the pen is the sketching tool for drawing curves directly in space. However, 3Draw can not generate surfaces from the given curves. Usoh et al. [Usoh 1996] experimented the Head Mounted Display for modelling surfaces in a immersive environment. In their

collaborative modeller, hand gestures can directly deform surfaces according a physically simulated elastic behaviour. The drawback of this approach is the complexity of the calculations, which not allow real-time interaction. Hummels et al. [Hummels 1997] examined the activities of automotive designers and suggested a two-handed gesture recognition interface in the Fishtank, a desktop on which the image of a stereo display is projected through a mirror. No implementation details and results are provided. Conceptual Virtual Design System (COVIRDS) by Dani et al. [Dani 1999] explores the multi-modal use of different input streams, like speech, gesture-recognition and 6DOF input devices for modelling. The user steps in front of a projection wall and can interactively modify the shape of the surfaces by moving a set of control points previously selected with a virtual ray. Wesche et al. [Wesche 2000] proposed a 3D styling system for free-form surface in a table-like Virtual Environment, called Responsive Workbench (RWB). A combination of automatic and user-controlled topology extraction is used to generate surfaces form previously sketched curves. A variational approach is followed for the editing, and three virtual tools are described: the smoother, the sharpener and the puller. No mention is provided about the interactivity of the interface. ARCADE [Stork 2000], acronym of Advanced Realism Computer Aided Design Environment, is a very useful and intuitive system for modelling surfaces on the Virtual table. It offers a wide set of different functions for surface creation: skin, Coons patch, and net surfaces. Only during the skin function, a very simple preview is provided, but it differs significantly from the real shape. 3DIVS by Fiorentino et al. [Fiorentino 2001] is a two-handed, gesture-based NURBS modeller in a semi-immersive environment. The workspace is composed of a stereo display, and two magnetic trackers connected to the Fakespace Pinchgloves for gesture recognition. Three different virtual tools, the Picker, the Twister and the Weighter, modify respectively position, torsion and weight of the control points lattice. The distance between the hands adjusts in real time the spatial influence of the tools. From the related work presented, it can be summarized that approaches to free form modelling are manifold. Interesting features are presented, but are not specifically addressed to the industrial application. This work tries to give a contribution in this direction.

3. Industry requirements

Several reasons limit the application at present of VR in industry. First of all, VR vendors offer just raw tecnology instead of specific on-the-shelf solutions. Standards in hardware and software should be defined, and the integration in the manufacturing process is often difficult, because of different data formats. In addition, set-up and maintenance costs of VR is usually over the possibilities of small companies, and is even hard to find professional profiles in this field. As solution to the aforementioned problems, we present Spacedesign: a low-cost, PC-based, integrated VR application for aestetic and ergonomic modelling. Spacedesign supports in a very simple way design tasks, like creation, visualization and editing of surfaces. For instance, is common practice in styling to enclose with a good-looking and ergonomic shell a well defined functional object: in automotive industry, for example, the car body must contains the engine, the living space and the weelbase. Avoiding inconstintencies between aestetic and functional design is a very difficult task to realize in practice, especially for complex, 3D shapes. Traditionally a trial and error approach is used: designers sketch freely on paper their ideas, modellers convert them to digital, and finally constraint are inserted and tested. Mistakes are extremely expensive, because is necessary to repeat the cycle from the beginning, till the final solution. For this specific purpose we introduce a visual constraint verification, which is immediate, integrated, and not restrictive for the designer. That is possible only thanks to the enhanced 3D stereo visualization offered by VR. In this way, we grant full availability of CAD data from the very early phase of the Design, and therefore seamless integration in the product engineering cycle. For this purpose, Spacedesign supports all the corporate CAD file standards: Catia, Pro-E, Rhino, sat, iges, vrml. The following advantages can be gained: shortening the time to market, reduction of physical prototypes, lower cost, and better quality of the product.

4. Set up

Virtual Reality hardware components can be divided in three basic groups: visualization system, input devices and rendering engine.

4.1 The visualization system

For aesthetic design the Virtual Reality visualization system should provide high quality images, presence in the virtual workspace, and immersion. Spacedesign uses a non-immersive, table-like display with a diagonal of 1.7 meters, which allows to create e.g. parts of a car body in scale (fig 1). In stereoscopic mode, the user wears a pair of shutter glasses and his point of view is displayed. In this way the virtual objects appear as floating in the space. Moreover, participants can see gestures and interactions of others and collaborate together on a common application.

4.2 Input devices

In Spacedesign are used four tracked objects: the glasses, the pen, the palette and the so-called "Navigator Axis" (fig 2). Magnetic Tracking systems are commonly used in VR, but they do not provide the accuracy and repeatability necessary for sketching precisely curves and surfaces. For this reason in Spacedesign we have tested optical trackers, which offer superior performances. The only drawback is the necessity to keep the line of sight always clear, but this problem can be solved with a redundant number of cameras. We experimented that a minimum number of three cameras allows full time tracking during all the common interactions. We dispose the cameras in front of the table, for a tracked volume of 3.5m x 3.5m x 1.5m. Being wireless, the user experiences the freedom of the interface in a very comfortable way. The pen, because of the three buttons, is the only device that is tethered (fig.3), but we are working to make it wireless using radio or ultrasound signals.

**Figure 1. Set-up on VT**   **Figure 2. Input Devices**   **Figure 3. The Pen**
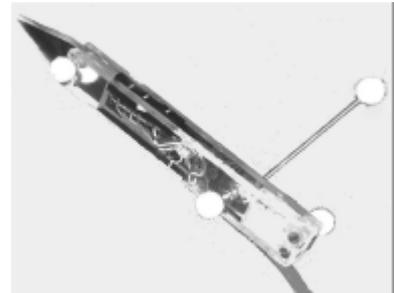
4.3 The rendering Engine

Nowadays, thanks to the game industry, the increasing performances of personal computers is leading to the so called PC-VR, a very low cost solution affordable even from the small enterprises. We firmly believe in such development, and for our system we used a WindowsNt, Dual Pentium III PC with FIREGL4 graphic card.

5. Implementation

Caracterized by a open, modular architecture, Spacedesign is built upon the Studierstube library (www.studierstube.org), which provides the Virtual reality interface, and ACIS kernel (www.spatial.com), for the modelling functionalities. Studierstube uses the so-called "Pen and tablet" methaphor for VR interaction: the non-dominant hand holds the transparent palette on which are displayed all the menus and buttons, the other handles the pen for application-related tasks. ACIS is used for the modelling operations and to keep the mathematical representation of the geometries created. Intuitive and simple sketching functions, are provided as described in table 1.

Table 1. Functionalities of Spacedesign

File	2D	Surfaces	Tools
Load-Save ProE	Free Sketch	Planar surface	Erase All
Load-Save Catia	Closed Free Sketch	Extrude	Erase Selected
Load-Save Rhino	Line	Net	Selection
Load-Save iges	Polyline	Skin	Copy
Load-Save sat	Closed Polyline	Coon Patch	Move
Load-Save vrml	Nurbs Curve	Pipe	Mirror Plane

5.1 Interactive skinning

Skinning is one of the most important and used tools for free form generation: it fits a surface through a series of given profiles. ARCADE presented this functionality with a simplified preview, but the discrepancy between the provided visual feedback and the final shape was frustrating for the designer. To overcome this problem, Spacedesign displays a consistent preview of the final surface (fig. 4), using an optimised architecture that minimizes the data flow between the modeller and the application, and an interactive mesh generator, which changes in real time the complexity of the tessellation.
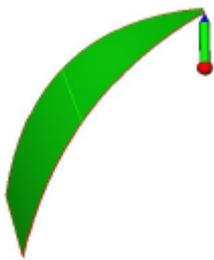

Figure 4. Interactive Skinning   **Figure 5. Coons Patch**
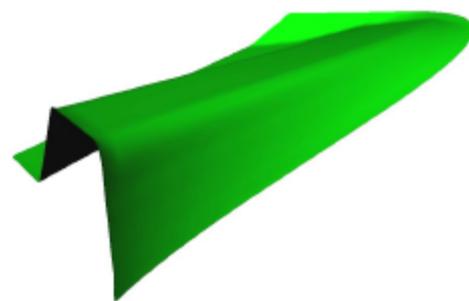
5.2 Coons Patch algorithm

ARCADE presented a simple tool for creating complex free form shapes in a intuitive way: a closed non self-intersecting contour is covered using a Coons patch. The mathematic concepts behind the surface generation, which requires four oriented curves for the interpolation, are completely handled by the application in a transparent way. The intuitiveness of the interaction method is reached by performing some reasoning on the input data: the outline of the 3D stroke is automatically splitted into two pairs of curves. The resulting shape of the Coons patch heavily depends on the position of the split points. This function has been imported in Spacedesign and improved to provide a surface that better conforms to the user's expectations. Starting form the splitting points of the ARCADE´s "smaller bounding box method", the enhanced algorithm searches in the respective neighbourhoods relative maximum values of the first derivative along the curve. Using such points avoids undesired wrinkles, which appeared in the previous implementation (fig. 5). In addition, Spacedesign visualizes an approximate preview of the realized surface during the sketching phase.

5.3 Navigation

Scene navigation is one of the most prevalent action during the creation and evaluation of the model. In some commercial CAD applications, the coordinate axes are displayed on the screen, and can be used to change interactively the point of view. We realized a 3D analogue of this widget, called "Navigator Axis", by means of a L-shaped tracked body permanently connected to the position and orientation of the modelling coordinate system (fig. 2). The user can hold the Navigator Axis in his dominant hand for precise scene navigation or in the non-dominant hand as reference frame during the sketching phase. We have experimented that users find really comfortable the navigator, even during the drawing phase.

5.4 Message Bar

In virtual reality is difficult to communicate information to the user: floating messages or external object can be unfriendly and confusing. Following the idea of Windows-like applications, we decided to reserve a specific area of the Pip called "Message Bar" for this task (fig. 7). Therefore, access to informations is simple, and not intrusive in the virtual workspace. The Message Bar has different functions: guide step by step the user during the sketching, explain not allowed operations, and display error messages. Our tests have shown Message Bar very helpful, especially for the beginners.

6. Example: Sketching a car body

The following example shows all the functionalities of Spacedesign: at the beginning a car chassis is imported in the workspace as visual constraint (fig. 6). Then all the tools for surface creation are used: extrude for the bonnet, skin for the sides and Coons patch for the roof and the fenders (fig .7). All the created surfaces can be selected, moved and cancelled. Moreover, during all the working session, the user can navigate the drafted model like a real object using the navigator axis, and visually check collisions with the reference geometry.

Figure 6. The reference   **Figure 7. Sketched Car Body**

7. Conclusions and Future work

This work is a step further in the difficult task to provide a Virtual-Reality-based CAD solution that is used for industrial application. Advantages and weak points of VR technology have been highlighted and the industrial requirements for aesthetic and ergonomic free form sketching investigated. Our solution, called Spacedesign, introduces new interesting features: a real time preview during the sketching, a navigation tool, an improved coons patch algorithm, compatibility with industry standards, and a user-friendly interface. Moreover, we present a "visual approach" to constraint the styling phase. Optical tracking system has been tested with success, providing superior precision and usability. The results are remarkable and lead to continue the research on this topic for a possible application in the short future. Further improvements should be done at the interface level, for a gesture based topology selection, and a powerful surface modification.

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