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Interactive Immersive Design Application: Analysis of Requirements

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Abstract: In this paper we report on the progress of an international EU/IMS research project to develop an Immersive free-form Design Application using Virtual Reality and Haptic Immersion Technologies. The results of a detailed Requirements Analysis for the application interaction are presented. The application uses a Virtual Sculpting metaphor to interactively define arbitrary formed shapes as they are used in the area of industrial design prototyping of consumer electronic products. The implementation is based on a Enhanced Direct Manipulation Free-Form Deformation Algorithm.

Keywords: Virtual Sculpting, Haptics, HCI, Direct Manipulation Free-Form Deformation

1 Introduction

Project IRMA (www.project-irma.com) is an international EU/IMS research project for the development of a Configurable Virtual Reality System for Multi-purpose Industrial Manufacturing Applications. The project involves international partners from Japan, Europe and Switzerland.

The objective of this project is to develop configurable low-cost, PC-based generic modules, which will integrate and enhance existing technology with modelling and simulation tools to create a suite of industrial Virtual Reality software solutions for primary use in the Small to Medium Manufacturing Enterprise (Sounders, 2001). The project started in March 2000 and is expected to be completed in 2004. The EU overall total project budget is 5.7 million Euros. The Swiss project part is financed through the Swiss Federal Office for Education and Science (OFES) and amounts to 0.8 million Swiss Francs.

The Swiss contribution to the IRMA project finds itself at the very beginning of the manufacturing process chain. In collaboration with an industrial partner (Iseli Design Engineering AG) the Berne University of Applied Sciences is developing an interactive Immersive Design Application (IDA) for free-form industrial design prototyping using Virtual Reality (VR) and Haptic Immersion Technologies. The focus of our investigation is to develop a suite of virtual tools for the interactive creation and manipulation of free-form design shapes, which allow for a user-friendly and efficient design process.

At the successful completion of the project the products developed will be commercially exploited and the technology will be disseminated to companies throughout the countries of the project partners.

2 Industrial Design Requirements

2.1 Conventional Design Process

For preliminary, conceptual work, many industrial designers still prefer to use only paper and pencil to sketch the initial 2D design, called “Scribble”, of a new product. For comprehensive 3D design evaluation and verification there is often the additional need to hand-built a foam model.

Although these means provide a very direct and immediate response when designing a new shape, they only offer very limited 3D feedback and 3D manipulation options. Rapid design prototyping therefore becomes very time consuming and expensive. Furthermore is it extremely difficult to digitise these foam-based designs into CAD systems that are used to engineer and manufacture these products.

A Virtual Reality Immersive Design Application therefore should provide virtual tools and helper functions, which support powerful 3D shape visualization and manipulation features, but nevertheless should be similar in usage and feedback to conventional tools a designer is familiar with. Additionally such a free-form design application must fit seamlessly into today's product manufacturing process by simple integration into the current CAD/CAM environment.

By bridging the gap between 2D sketching and 3D CAD modelling the time needed for product design prototyping and the consecutive CAD refinement can be considerably reduced.

2.2 Analysis of General Requirements

Based on a detailed case study for the design prototyping of an actual cordless phone product, we concluded the following three Human Computer Interaction key requirements for general application operation and the hardware devices needed for an Immersive Design Application:

2.2.1 Two-Hand Operation

The analysis of drawing and application interaction tasks showed, that a two-hand operation seems most efficient for interactive and uninterrupted free-form design drawing. A two-hand operation allows the designer to clearly separate drawing input done with one hand (3D Tracking Device), from general non-pointing software operation done with the other hand (IDA Operation Device):

The **3D Tracking Device** should be freely movable in space and provide the 3D coordinate input, which is primarily used for the actual drawing and manipulation of free-form design shapes. This device needs to have at least 3 Degrees of Freedom (DOF) but a 6 DOF device is preferred, since this allows for additional orientation input, which can be used to set the orientation of virtual tools.

A (wireless) stylus-shaped 3D tracking device would best fulfil our IDA requirements, as the operation of such a device would closely resemble the conventional drawing activity, where a designer uses continuous and unhindered pencil drawing for free-form design creation.

The **IDA Operation Device** will be operated by the user’s other hand and is solely used for non-pointing IDA software interaction, such as executing undo/redo commands or navigating through pop-up menus. For easy operation, such a device needs to have at least three buttons. It could either be the computer keyboard or a special purpose device for which a design study has been worked out by the team of Iseli Design Engineering AG (Figure 1).

A low-cost commercially available wireless mouse trackball device from Acrox Technologies (www.acrox.com.tw) closely resembles our design study and has been evaluated and tested for integration into the IDA system. The device can easily be used for the IDA operation with only minor software modifications.

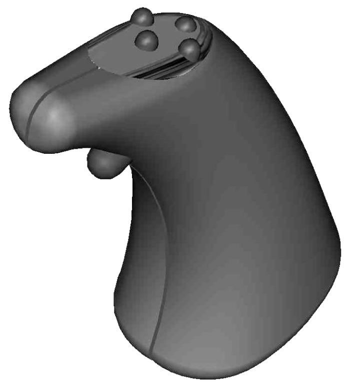

Figure 1: IDA Operation Device Design Study.

2.2.2 Wireless Input Devices

The above considerations led us to the conclusion, that the designers interaction with the application should be wireless whenever feasible. Conventional input devices like keyboard and mouse are also supported by the IDA system, but wireless input is preferred in order to achieve high acceptance of VR technology for free-form design.

2.2.3 Support of Haptic Feedback

To improve a designer's 3D response while creating and manipulating a free-form design shape, the Immersive Design Application should also provide haptic feedback. This allows for an easy shape refinement of 3D objects and permits us to provide additional helper functions such as the accurate drawing of planar objects in virtual 3D space or a precise 3D point or line snapping mechanism.

SensAble's PHANTOM Desktop product (www.sensable.com) is a stylus-shaped 3 DOF haptic feedback device, which optimally fulfils the requirements of our IDA system. Additionally this device can also be used as a mechanical 6 DOF tracker and therefore can provide very accurate 3D position/orientation input for exact shape definition.

2.3 Analysis of Use Case Requirements

For the specification of the IDA system software functionality we conducted a comprehensive analysis of all Use Cases required to build a complex shape object, called Design, out of several small free-form elements, called Design Primitives (DP). During this process we elaborated a catalogue of 61 typical use cases, which can be organised into the following four categories (Table 1).

Use Case Category	N
(1) Design Creation and Import / Export	8
(2) DP Creation and Manipulation	26
(3) General Viewing / Interaction Setting	22
(4) Usability Testing of Design Ergonomics	5

Table 1: Number (N) of Use Cases per Category.

An overview of these Use Case Categories and their interrelation can be found in the accompanying Use Case Diagram (Figure 2). A brief description of each category is given in the following paragraphs:

2.3.1 Design Creation and Import / Export

These Use Cases are mainly taking care of the integration and interfacing with the existing CAD/CAM application environment. Through the support of common CAD data file formats, roundtrip engineering between immersive design prototyping and CAD refinement becomes feasible.

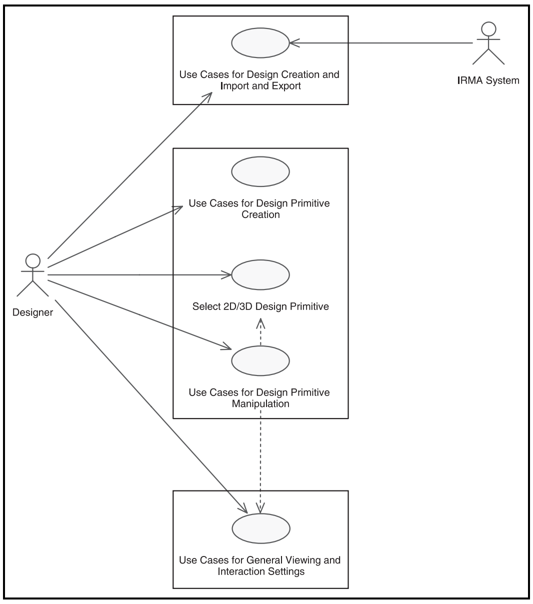

Figure 2: Use Case Diagram.

2.3.2 DP Creation and Manipulation

Use Cases for DP Creation and Manipulation will provide the main functionality for the interactive drawing and manipulation of free-form DP shapes. To start with, the designer may select a predefined DP from a shape library, which can be altered to the specific needs with a variety of virtual tools.

2.3.3 General Viewing / Interaction Setting

These Use Cases are used to set-up and configure the IDA system. This includes the activation and deactivation of specific virtual helper tools or snapping algorithms as well as application global settings such as input device configuration or graphic rendering mode.

2.3.4 Usability Testing of Design Ergonomics

Use Cases in this category (not show in Figure 2) are different from the remaining ones, as they are not used for the free-form design drawing, but for the set-up and evaluation of virtual usability tests. These tests allow for a preliminary validation and assessment of the ergonomics of a specific design draft for a new product. Through the additional use of haptic feedback the 3D shape perception can be significantly enhanced and improved.

Although these haptic supported virtual usability tests may not replace the conventional mock-up based usability testing, they nevertheless might help in recognising obvious usability flaws in a very early stage of the shape design process.

3 IDA Implementation Results

Based on the above requirements analysis we elaborated the software design specification and realised a first IDA prototype for a proof of concept and feasibility verification (Figure 3 and 4).

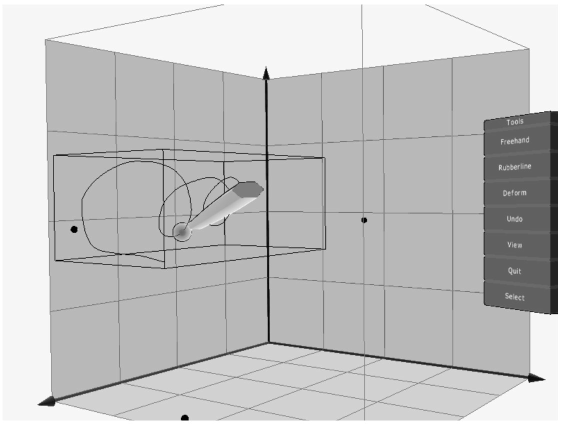

Figure 3: Free-Form Line Haptic Snapping and Guiding Mechanism

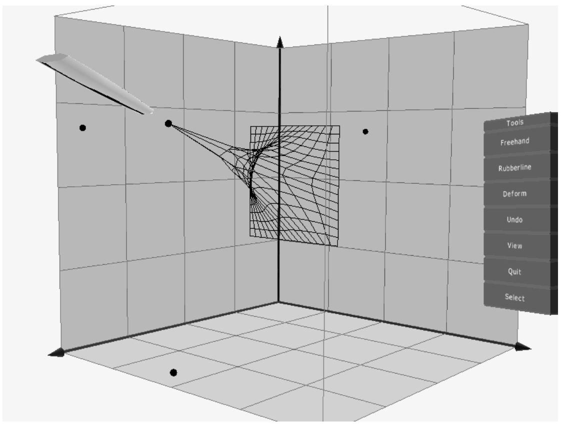

Figure 4: Directly Manipulated Free-Form Deformation with Haptic Feedback Control

Besides the IDA specific requirements the following technologies and considerations were used for the implementation:

- The IDA system needs to be highly interactive by providing real-time visual and haptic feedback wherever feasible.
- The main IDA interaction concept is based on a Virtual Sculpting metaphor, which proved to be the most appropriate for our application context.
- The free-form shape drawing uses an enhanced Directly Manipulated Free-Form Deformation (DMFFD) algorithm (Gain J. E. 2000, and Hsu et al, 1992).
- The Object surface representation is based on a spring-model triangle mesh implementation.
- Additional consideration is given to general guidelines for good software usability (Nielsen, 1994)
- IDA is designed and built as an object oriented C++ application, which allows maximum extensibility and performance.
- The application is built on top of the Reachin API Library (www.reachin.se), which provides a C++ interface for a unified, VRML based graphic and haptic scene graph rendering. The library is also highly extensible by enhancing existing shape or surface nodes through customised geometry or haptic surface effects.

As this project is still in progress, these are only intermediate results. More details about the algorithms for the virtual design and sculpting tool implementation will be given in a follow-up publication.

4 Future Work

Our future work will include investigations in the following areas:

- Enhancement of the DMFFD algorithm.
- Development of a haptics supporting 3D widget library for efficient HCI in a VE.
- Elaboration of a virtual usability test scenario manager and player.

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