INTERNATIONAL DESIGN CONFERENCE - DESIGN 2002
Dubrovnik, May 14 - 17, 2002.

TOWARDS 'VIRTUAL CLAY' MODELLING - CHALLENGES AND RECOMMENDATIONS: A BRIEF SUMMARY OF THE LITERATURE

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Keywords: haptics, 3D modelling, CAID, virtual clay

1. Introduction

In industrial design, modelling plays a vital role in the development of products and is involved in different phases of the design process [Bairstow, Barber & Kenny, 1999]. The design of a new artefact begins with incomplete knowledge about the final product and the design evolves as it progresses from the conceptual design to a more detailed design. Traditionally, designers sketch, make collages and models. When modelling, designers choose from a wealth of techniques, tools and materials. Over the last decade, the industrial designer's workplace has been changed by Computer Aided Industrial Design (CAID) tools. Accordingly, the situation now exists where the design form could evolve in steps alternating between development with traditional tools and with CAID systems.

The nature of traditional modelling tools is an important factor in determining the suitability of CAID tools for three-dimensional (3D) modelling. The tools provided by computers should meet the practice of the industrial designer in the form creation phase. However, current CAID systems exhibit a shortcoming in that they do not allow a designer to employ all the skills [Sener & Wormald, 2001] that traditional tools, like clay modelling tools, do [Gribnau & Hennessey, 1999]. Attempts have been made to overcome this problem using 'virtual clay' offered by haptics (or force-feedback) technology. This new technology gives industrial designers the illusion that they are dealing with real, physical clay objects and has the potential to radically change the future of design computing. Despite the progress made in the last two decades, haptic interfaces have not become commonplace. An analysis of the use of haptic modelling tools will help in the implementation of enhanced CAID tools for industrial designers. For that reason, a comparative study of literature in areas of relevance would be of great value in this early stage of virtual clay modelling.

In relation to this, in this paper, an effort has been made to give a structural framework, through a literature search, to the use of haptics technology in 3D modelling in industrial design. The paper begins with a brief history of haptics research and continues with projects in different areas of haptics technology in relation to haptic devices with selected examples. Then, the challenges which exist for virtual clay modelling in supporting the industrial designer in the development of innovative and creative product form are discussed. Lastly, based on the discussion, intended future work is described.

2. Definition of haptics

The word 'haptics' has grown in popularity with the advent of touch in computing [Brewster, 2001]. In its broadest sense, 'haptics' relates to sensing and manipulation [Tan, 2000] through the sense of touch (Figure 1). The haptic senses may be categorised in a number of ways. However, the active tactile senses in the human body are generally associated with the concept of touch, with which to

‘feel’ and ‘interact’ directly with the external environment. Hands are the key locations for this group of senses. These senses link most closely with the kinesthetic senses, the brain’s awareness of the position and movement of the body by means of sensory nerves within the muscles and joints [RIADM, 2002].
Haptics or ‘force-feedback’ technology opens the door to a new level of interactivity between humans and computers. Prior to haptics, computer users only had the chance to interact with the machine through sight and sound. The sense of touch has been conspicuously absent in typical computer interfaces like keyboard and mouse. However, haptic interfaces bring profound changes to the way humans interact with information and communicate ideas, by permitting the users to touch and manipulate virtual computer-generated objects in a way that create a compelling sense of tactile realness [Purnomo, 2002].

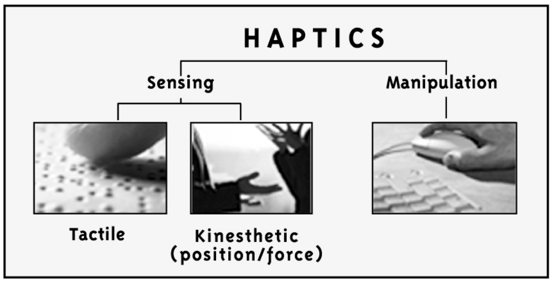

Figure 1. Haptics definition

3. Haptics research

Today, the commercial viability of haptics is established in several areas [Winkle, 2000] and the haptic systems have a wide range of application fields, such as assistance of disabled individuals, entertainment, medical, educational and military training applications. The training of pilots is one of the key areas that could be opened up to include training and simulations for other means of transport, such as increasing the safety of training car drivers. Force feedback is already becoming a predominant feature in the range of handheld controllers available from laser guns to keypads and pilot’s joysticks. Therefore, the entertainment industry is another key area that would benefit from haptic technology and research funding for improving gaming systems to provide force feedback or physical communication over the Internet [HP, 2001].
Haptics technology research has become a significant issue in industrial design recently. Despite the progress made in the past two decades, haptic devices have not yet become commonplace in industrial design [Tan, 2000]. In industrial design, there are broad areas of potential research on this technology, using different kinds of haptic devices on different applications, from a simple painting application to a more complex application like 3D CAD modelling for virtual prototyping [Purnomo, 2002].

4. Haptic devices

Haptic devices allow users to experience a sensation of touch and physical properties when they interact with virtual materials. They exert force in response to a user’s manoeuvre at the point of action. Haptic devices enable two-way interaction with virtual objects, where action and perception are brought together [McLundie, 2002].
Historically, work on haptic devices has been motivated by the desire to develop sensory-substitution systems for the visually or hearing impaired [Tan, 2000]. These devices were mainly for people with disabilities or people who learn best through tactile or kinesthetic experiences. Then, other specialised haptic devices have been built for the medical market for different surgical simulations and training. Although these devices can deliver excellent force feedback, they are not appropriate for desktop use and they all suffer from workspace limitations.
After many years of emphasis on the visual elements of computing, for example in PCs and videogame consoles, the other senses are beginning to become important [Paterson, 2001]. It is only quite recently that haptic technologies have appeared at a reasonable cost, using human interface devices of a practical size [Brewster, 2001]. It is more recently still that these devices have become

commercially available and robust enough to be used by the general public. Haptic devices, nowadays, are incorporated into mainstream computing devices, such as the Microsoft Force Feedback joystick (Figure 2), which promotes the acceptance of this technology into the ‘daily computer experience’ of people with and without disabilities. Effectively, this adds a further strand to human-computer communication so that data can be accessed and literally manipulated not just through visual means, but also through tactile senses [Hayward in Paterson, 1998].

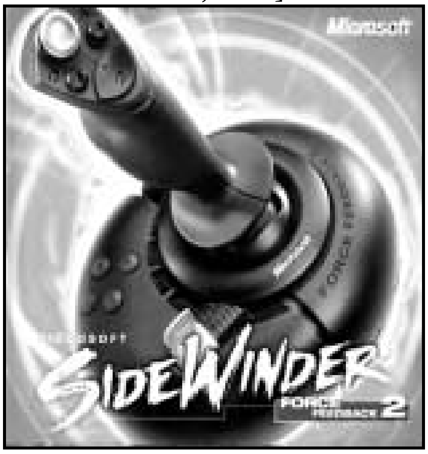

Figure 2. The SideWinder Force-Feedback joystick from Microsoft

Haptic devices are making an appearance in high-end workstations for CAD as well as at the lower end on home PCs and consoles. These devices can deliver both force feedback, such as simulating object solidity, weight, and inertia, and also tactile feedback that can simulate surface contact geometry and smoothness. Therefore, haptics can enable a more active exploration and can allow the designer not just to see 3D shapes on the screen visually, but also to feel and manipulate objects on a computer screen with a sense of presence in the location [Paterson, 2001].

Haptic devices can be categorised into two-dimensional (2D) and 3D [ATRC, 2001] as:

- devices that allow users to ‘feel’ textures of 2D objects with a pen or mouse-type interface,
- glove or pen-type devices that allow the user to ‘touch’ and manipulate 3D virtual objects.

4.1 Two-dimensional haptic devices

The 2D haptic devices can be used to aid computer users who are blind or visually disabled, by providing a slight resistance at the edges of textures in computer images which enables them to ‘feel’. There are quite a number of mainstream haptic devices, which have been developed to offer one or 2D tactile sensations, such as special-purpose joysticks, steering wheels and computer mice. These devices are mainly aimed at home users.

The hand-based haptic devices, such as the Force Feedback joystick that was brought into mainstream computer market first by Microsoft, are relatively new class at technology. This joystick is the first breakthrough of gaming force feedback device to reach the home computer user [Purnomo, 2002]. It aims to give a new dimension of realism in playing computer games through a new experience that a normal joystick cannot give, such as feeling the force, resistant or any other program feedback. The latest addition to the haptic devices for home users is the force feedback mouse. This mouse-style haptic interface gives the user tactile and verbal feedback to the user, such as ‘iFeel Mouse’ from Logitech [2002]. Another example is PenCAT/Pro, a 2D haptic device with a pen shaped grasping tool, from Haptic Technologies which is aimed at designers, artists and CAD users.

There are many other mouse-style haptic devices provided by different companies. However, the mechanics operations of these devices are similar to the force feedback joystick. With the help of the feedback, the mouse can guide the user to the areas of a programme with a graphical interface, such as to feel the texture of some surface on the window through vibration. Nevertheless, all these 2D devices provide the sense of force feedback in two degrees of freedom, and they are limited in use [Purnomo, 2002].

4.2 Three-dimensional haptic devices

3D haptic devices are an area of current growth and all the products on market are relatively new. Several additional products are expected to be released in the near future. The motivation behind these devices is to allow users to manipulate a virtual environment in a similar manner the way in which they would manipulate a real environment (Scievw, 2002). The key factor with 3D haptic devices is that they give the high ‘degree of freedom’ (DOF). Depending on the DOF they provide, 3D haptic devices can range from simple to a very sophisticated. They can be used in a broad area of applications, from surgical simulation to a painting system in a CAD environment.

3D haptic devices vary in shape, size, price, features and some are even wearable, like tactile bodysuits and gloves. For applications requiring 3D-position sensing and feedback, a finger thimble and pen-like stylus have been designed. For tasks requiring hand-grasping actions or whole-hand sensitivity, gloves with sensors embedded in their fabric have been provided.

Gloves have been currently used in Virtual Reality (VR) applications since the early 1990s [Winkle, 2000]. The CyberGlove, an instrumented glove from Immersion, is a good example of a 3D haptic device which gives the user the ability to sense the position and movement of the fingers and wrist. The CyberGrasp is a full hand force-feedback device, which is worn over the CyberGlove. When the wearer makes contact with a virtual object, resistive force is exerted on the fingers through a series of ‘tendons’ allowing them to ‘feel’ the object. This force is hand-referenced, for example it can prevent the user from crushing a virtual object in their hand, but it cannot prevent them pushing through a wall, or allow them to feel weight [Immersion, 2002].

4.3 Phantom haptic device

The PHANToM, a 3D desktop haptic device from SensAble Technologies, is one of first devices that offers significant changes to the way in which design and modelling with computers is achieved through a force-feedback interface. In this section, therefore, it will be illustrated in more detail.

The PHANToM provides single point, 3D force-feedback to the user via a stylus attached to a moveable arm (Figure 3). It can be used not only to interact intuitively with virtual models, but also to interact with such models in 3D space, allowing hand and eye to work together on the model. The position of the stylus point/fingertip is tracked, and resistive force is applied to it when the device comes into ‘contact’ with the virtual model, providing realistic force feedback. The physical working space is determined by the extent of the arm [SensAble, 2002].

Figure 3. The PHANToM haptic device from SensAble Technologies

A significant amount of work has been put into the development of haptic interaction devices and the software that is used with the devices to carry out modelling tasks. Haptic devices and 3D displays are of little value without software to model the ‘physical’ properties of the virtual material and its response to interaction, both haptically and visually. The concurrent development of the devices and the software allows for a close coupling between the two.

SensAble Technologies’ FreeForm modelling software provides a ‘clay sculpting’ based technique for 3D modelling based around the PHANToM haptic device. Briefly, the software mimics the modelling techniques traditionally used in clay modelling. An imported model or a user-defined block of ‘clay’ can be modified using different tools such as a ball, square block and scrape via the PHANToM haptic device. The model will deform in 3D as a result of touching the 'clay' with any selected tool and the amount of deformation is proportional to the force applied. By getting instantaneous haptic, as well as visual feedback, precise and intuitive changes can easily be made [Petersen & Rydmark, 2000].

5. New challenges in 3D modelling

In 3D-form creation, clay and foam modelling are still the preferred techniques during form conceptualisation [Lee, Stappers & Harada, 1999]. In fact, the difficulty of interaction with the digital world has kept many designers working with the more familiar, real clay or foam models. Traditional methods tend to lend themselves to explorative shape creation that is needed in the generation of 3D forms [Potts, 2000]. As design is an iterative process and because touching and feeling encourages experimentation, this level of freedom has a beneficial effect on the quality of designs. It is only with the appreciation of what tactile modelling can achieve that the restrictions inherent in traditional 3D form giving and CAD systems become apparent. The traditional systems are dedicated to providing specialised tools to overcome problems that are automatically resolved by the sense of touch [Dransfield, 2000]. For example, direct interaction with the 3D physical form helps designers to resolve ergonomic features (e.g. hand relation) which are difficult to notice in digital form.

Touch also provides many benefits to the designer for interacting in virtual 3D environments, such as: providing feedback to help position objects accurately in 3D space, resolving visual ambiguities by letting users feel the models, communicating physical properties of objects, and letting users naturally and continuously manipulate models. For these reasons, computer-aided 3D modelling packages that incorporate even limited touch systems should have many benefits over classic modelling software [Kling & Rydmark, 2000].

Until recently, none of the CAID tools available have allowed industrial designers to physically get in touch with the design while working on a computer. However, research, with input from both academic and commercial groups, is still continuing to provide industrial designers with computer-aided 3D-form generation tools combining the interaction techniques being used in the physical 3D modelling. SensAble's FreeForm modelling system, combined with PHANToM, is the first CAID tool which lets designers to sculpt and form virtual clay and foam using similar tools and techniques that are employed in the physical world. While this paper is not intended to discuss all FreeForm's features, it is highlighted as the CAD tool with the most promising tool for aiding 3D-form creation in industrial design.

Shape sculpting is one of the advantages that this system provides. It is as intuitive and expressive as physical modelling with clay or foam, yet with most of the advantages of a CAD tool. For example, when a change needs to be made to a digitally carved model the designer does not have to carve another one from scratch, since it can be easily modified [SensAble, 2002]. Also unlike real clay, the designer can also work from the inside out. FreeForm modelling lets users model the way they want to, without constraints on creativity. The resulting objects can then be delivered downstream to other design or CAD packages for refinement and further development, or to a rapid prototyping device to create a physical part from which moulds can be made. In addition to this, it also enables designers to experiment with shapes that they could not easily achieve using traditional CAD tools [Mahoney, 2000].

Virtual prototyping has its main focus today in the late concept stages and the engineering analysis stages of the product development process. Industrial designers, especially in the automobile industry that is moving from expensive physical models of complex designs to digital designs need effective ways to test the assembly and maintenance of virtual prototypes [Salisbury, 1999]. The aim is to get the virtual prototypes used earlier in the concept stages, before the product parameters are too rigid, in order to really evaluate as many concepts as possible. In the design of any product, it is also important to ensure that it can be assembled and disassembled speedily and without problems. If haptics technology were packaged into major CAD systems, it would speed up the product development cycle and allow better products to be designed and prototyped with less time and cost [Larsson & Törlind, 2001]. Using haptic devices opens up into a range of other areas in the design and development of a product, such as exploration of product form, feel and functionality, conceptual design, new design

and surface styling tools, virtual prototyping, assembly and maintenance training, testing and evaluation of product functionality and ergonomics.
With many new PHANToM haptic devices being sold to industrial companies, designers around the world are already discovering the benefits of the FreeForm system. These companies range from toys and games, giftware and shoes to consumer electronics, appliances and automotive interiors, such as Adidas, Ford, Honda, Motorola and Toyota, as well as leading universities world-wide.

6. Conclusions and future work

Haptics technology offers a revolutionary approach for combining physical and digital modelling in industrial design. In spite of the recent progress, the incorporation of haptics into industrial design software is in its infancy. Sophisticated 3D modelling techniques are typically needed to master traditional 3D modelling software. Advanced haptic interfaces, like the PHANToM, can create entirely new opportunities for CAID. Given the continued rapid development of 3D modelling and visualisation with computers, the challenges for the future are likely to be the integration of the haptic devices in industrial design.
The core of the proposed research is to better combine the advantages of different manual modelling techniques with CAD techniques in order to enhance the usability of CAD tools. Case studies with industrial designers will be made in order to generate and analyse data on 3D-form creation using the PHANToM haptic device. The outcomes of the study are anticipated to comprise tangible recommendations for the FreeForm software and for the input hardware. Consideration will also be given as to how Freeform can be better integrated into the product development process.

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