Create Free-form Digital Shapes with Hands

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Abstract

Current tools aimed at supporting the conceptual phase of product design are not intuitive to use, and do not exploit designers' skill and creativity. This paper presents the results of a research work aiming at integrating user-friendly and effective ways of interaction based on ad-hoc haptic interfaces into free-form shape modeling systems.

CR Categories: I.3.6 [Computer Graphics]: Interaction.

Keywords: Haptics, haptic modeling, free-form shape modeling, virtual prototyping, concept product design.

1 Introduction

The success of a computational system is not only dependent on its technical developments, but it also depends on its capacity to satisfy users' needs and competences. If a system fails in satisfying these requirements, it will lead to severe cognitive difficulties, and finally it will encounter difficult acceptance or even rejection from users. Therefore, the design of a new system requires satisfying the major criterion of usability, defined as "the capacity of a system to be easily used by a given person in order to perform the task for which this system has been designed and developed" [Nogier 2003]. The research work presented is aimed at developing a novel free-form shape modeling system based on haptic tools oriented to the concept phase of design of industrial products, ranging from domestic appliances to cars. For addressing the usability criterion, the system design has initially addressed the types of end-users (modelers and designers) and their skills, the users' tasks (design a product), and the interaction modalities that may satisfy at best users' skills and tasks.

The conceptual design of a new product starts from an initially incomplete and imprecise mental representation the designer has about the object shape. The designer's mental representation evolves as the object takes concrete shape through an externalizing process. The idea of the object is made more concrete and understandable transforming it into a three-dimensional representation. That happens in two ways. Common practice in the industrial design sector consists of building physical models that at best translate into a tangible object the styling lines of a sketch [Yamada 1997].

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The process of physical modeling is extremely creative, and requires a highly skilled operator that uses his manual capacity for creating the desired shape starting from an initial shapeless piece of material. The final shape of the physical model does not necessary represent faithfully the initial mental idea of the object the designer had in mind. The iterative loop for evaluating and modifying the physical object ends only when the designer is fully satisfied with the shape. The process is not efficient and quite long, and therefore expensive. In addition, a subsequent reverse engineering phase is required for translating the physical shape into a digital model that is used for downstream engineering activities [Lee 1999]. The second option is using a CAIDS (Computer Aided Industrial Design and Styling) tool for directly generating a 3D digital representation of the object. Actually, there are not very many creative designers who are tempted to use digital tools for creating new shapes, since the cognitive load required to be able to use the tools at a fruitful level is too high [Wiegers and Vergeest 2001].

The proposed idea of the research work described in this paper aims at maintaining the effective and performing aspects of digital modeling by integrating tools offering new modalities of interaction oriented to exploit designers' skills. The paper presents the results achieved so far by the research project T'nD – Touch and Design (www.kaemart.it/touch-and-design) whose goal is to develop a system that allows the generation of digital shapes in a natural and intuitive way by manipulating haptic tools that closely resemble the physical tools designers use in everyday work.

2 Shape modeling operations

The aim of the research work presented in the paper is to develop a system supporting ways of interaction that are easy, intuitive and pleasant to use so as to convince designers to adopt the system as a daily working tool. Therefore, great attention has been put on the usability and on intuitiveness aspects of the interaction modalities with physical models. The idea is to provide a system that resembles the manual way of working that is typical of designers. Differently from other research works related to haptic modelling and virtual clay modelling [Cheshire et al. 2001; Dachille et al. 2001; Dewaele and Cani 2003], the aim of this work is to develop haptic interaction and modeling modalities that are dedicated and specified, and also evaluated by designers. Therefore, the initial activity of the project has consisted in observing designers while making physical prototypes of products using their hands, and subsequently deriving some specifications for the system.

Cognitive psychologists participating to the research project have observed and analyzed the modelers' skill while modeling physical prototypes using their hands and craft tools. Industrial design partners of the project have been video recorded and interviewed while creating physical models of some selected objects (vacuum cleaner and car C-pillar) by working malleable materials (like clay, foam material, etc.) directly with their hands and using tools like rakes, sandpaper, templates, cutters. Subsequently, the collected data have been quantitatively and qualitatively analyzed in order to understand the advantages derived from operating manually when creating shapes, and to understand designers' knowledge hidden in their hands.

The analysis of hand gestures has highlighted the fact that visual, tactile and kinesthetic feedbacks are equally important in the shape creation and evaluation process. The skilled hand motions performed by the modelers allow for a precise creation of the shape; the tactile interaction with the object helps in comparing adequacy of the physical prototype with the drawings, in providing early clues about shape features, and in improving the 3D mental representation of the shape. From this analysis we have pointed out the most recurrent, common and effective users' hand operations. They are those actions that are going to be reproduced in the system: *scraping, surface quality testing and finishing*; and related tools: rakes for scraping material, hands for surface quality check and sandpaper for surface finishing (Figure 1).

Figure 1: Manual modeling operations and tools.

3 Interaction tools and modalities

According to the analysis of designers' operations the system has to provide tools like rakes and sand papers that allow the users to feel, touch and model the object surface. The sense of touch in virtual environments is provided by haptic devices [Burdea 1996]. The past five or ten years have seen a considerable increase in the number of commercially available force feedback products. Besides, several prototypes have been studied in research labs. In order to identify and specify the appropriate force feedback tool satisfying our system requirements, an overview of state-of-the-art devices has been performed [Bordegoni 2004], also considering recent developments of haptics and applications [Hayward 2004].

The PHANToM devices produced by SensAble Technologies, Inc. (www.sensable.com) have been the first commercial haptic products and are still the most popular devices. They are point-based devices having from 3 to 6 DOF and using stylus or thimble as haptic interface. The working space is rather limited, at least in the standard model, and the maximum feedback force is low (10N). Some other similar devices have been developed like the HapticMaster device developed at the University of Tsukuba actuating three fingers. Rather recent more industrial oriented point-based devices are the HapticMaster produced by FCS-CS (www.fcs-robotics.com) and VIRTUOSE produced by Haption (www.haption.com). A different class of devices covers exoskeletons on user's hand, like the Sarcos Dextrous Arm Master (www.sarcos.com), the PERCRO device (www.percro.org) and actuated gloves like the CyberForce device by Immersion Corp. (www.immersion.com). These devices are quite cumbersome, difficult to wear and to operate, and therefore little effective and seldom used.

There are very few haptic systems developed for sculpting virtual shapes. At the moment, the most popular is FreeForm by SensAble (www.sensable.com). Users can see and feel the shape of the object they model, and can also have a feeling of the type of material they are modeling (clay, foam, hard material, etc.). This system simulates a spherical sculptor's tool used to remove or add "matter" from/onto an initial block of matter. Its major limit considering our project requirements is that the physical interaction is purely point-based, and high aesthetic quality level required by several industrial design sectors (like, the car industry or high-end customer products) –named class A surfaces- is not reached since the spherical tools provided by the system are not sufficient for complex models.

We conclude that purely point-based haptic interaction that is provided by most of the haptic devices is not sufficient to appreciate and modify the surfaces in an intuitive way. Designers wish to interact with the full hand with virtual models of products including a true size car body. In order to meet these requirements, we have decided to realise an extended version of the FCS HapticMaster (www.fcs-robotics.com). The device has been selected since it provides an adequate workspace (66 litres) and rendered force (250 N). The FCS HapticMaster is used as basic platform, equipped with a strong and stiff 6 DOF device carrying force-feedback clay modeling tools.

4 System overview

The developed system is based on haptic technology and interaction modalities that replicate the physical tools and actions performed by designers in real life for modeling malleable material. The following sections present the system architecture, the haptic tools designed for virtual clay modeling and the shape modelling operators.

4.1 System architecture

The architecture of the system is shown in Figure 2. It consists of the following main components:

- The FCS HapticMaster is operated by the user. The device is equipped with innovative haptic tools that are oriented to modeling operations. In response to the collision with the virtual object the device renders appropriate contact and reaction forces. The rendered forces depend on the type of collision and on the type of material being simulated.

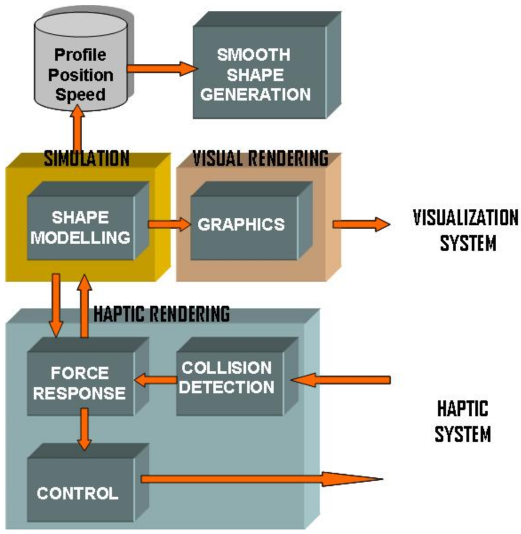

Figure 2: System architecture.

- The haptic rendering system includes a collision detection module for detecting contacts between the virtual representation of haptic interface (avatar) at position X and the virtual object; a force response module that returns the interaction force between the avatar and the virtual object; and the control module that returns a contact force to the user (that is the ideal interaction force approximated to the haptic device capabilities).
- The simulation system updates the geometric and haptic model of the object on the basis of the shape, position and speed of the haptic tool. The simulation engine operates on a simplified geometry that is converted into a smooth shape at the end of the interactive session.

4.2 Haptic tool for virtual clay modeling

The newly designed haptic interface physically simulates one or more of the tools used in actual clay work. Two tools have been studied: a scraping tool for removing virtual material, and a sandpaper tool which allows virtual sanding of a gently curved surface. At the moment, the first tool has been implemented and tested. It consists of a strip of metal, which is typically handled by the user by gripping it between the thumb and fingers in two places, with both hands, while scraping the surface of the virtual clay. Movement and force feedback on the tool is needed in at least all the 3 translational degrees of freedom (DOF) that a body has fore-aft, left-right, and up-down. The workspace needed is on the order of the reach of the human arm, or the size of a quarter (say, the front left side) of a 40 % car model. The tool needs to be powered in only two of the three axes of rotation available to any body in space. The resistance of the tool perceived by the user must be either the same as using the actual physical tool on real clay, or the differences must be acceptable and easily accustomed to. Finally, tool forces presented to the user when moving free of the virtual clay surface must be as light as possible.

The FCS MapticMaster (HM) selected for the implementation has 3 DOF. According to the above requirements, the system is required to have a higher number of DOF. The solution implemented consists of two HMs that are (conceptually) connected to the scraping tool by means of spherical joints, as shown in Figure 3, with the joints axis coincident to the lower tool edge. The scraping tool has 5 fully measured and actuated DOF (3 translational plus 2 rotational). The tool has also one further DOF, which is free, but, due to the way the tool is used, it can produce a feedback torque consistent with the simulation. According to this “5+1 DOF” configuration the tool can reach any position in its workspace and can be rotated by a certain extent; relatively to the scraping simulation purpose, it can be considered a reasonably good approximation of a full 6-DOF device and it is simpler to implement or what concerns both hardware and software.

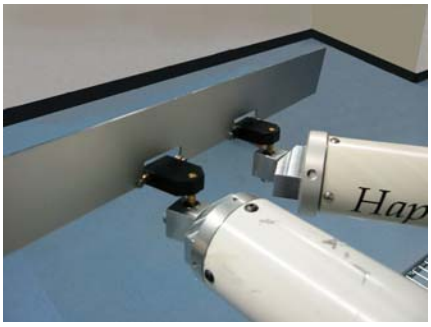

Figure 3: End-effectors built by FCS-CS.

The project will also develop a sanding tool that is more appropriate to foam models. It may require more DOF in the tool handle, because the curvature of the surface can be felt through an unsupported piece of sandpaper. The haptic device being studied is a versatile platform for these kinds of tools, ideally with a higher haptic quality than current haptic technology, and will perform better especially in the range of forces and torques that can be rendered faithfully and without introducing artifacts such as spurious frictional and mass forces on the simulated tool.

4.3 Shape modeling methods

For what concerns shape modeling methods, the project has focused on the study of generic sweeping motions of profiles [Abdel-Malek et al. 2002]. Six meaningful motions used in the shop floors by designers when scraping clay using shaped templates have been studied. The motions considered are the following: “constant”, “constant axis”, “Frenet”, “enhanced Frenet”, “along a plane” and “surface based”. These motions are independent from the profile and cover several cases of actual sweeping. The user’s haptic based motions are supported by a tessellated model for flexibility reasons. In fact, tessellation is used in several contexts where the treatment of such basic elements makes computation faster than other mathematical representations. The shape representation is then translated into NURBS data so as to be used straightforward for downstream engineering activities.

The shape tessellation task supports high frequency rendering loop (around 50 Hz) required by the interactive simulation of the users’ interaction with the shape. The computational loop consists of the following tasks:

- Detection of collision, computed as intersection between the tessellated shapes and the tessellated tools.
- Computation of the resulting haptic forces, using geometric computation of the collisions based on tessellation (scraped volume, area of collision); the system provides contact feedback to the users according to the physics-based model simulating the real clay [Baraff et al. 2003] and the action performed.
- Visualization of the resulting scraped surface, using the above tessellations to render in the graphic module.

Figure 4 shows the resulting scraped surface obtained when the tool follows the shown curve. The scraped surface is computed by cutting and updating only a tessellated model of the surface. The bold segments are the intersections of the tool displacement between two subsequent positions.

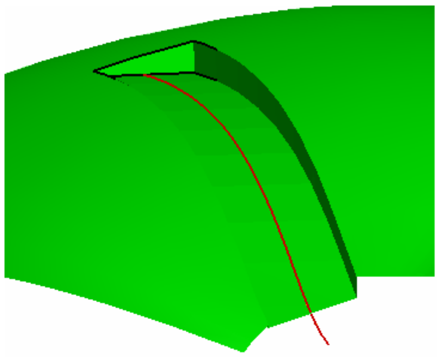

Figure 4: Scraped surface.

5 System prototype and evaluation

The idea of using a haptic tool for modeling shapes in the industrial design field is quite new. Therefore, we have considered very important testing the concepts and interaction modalities proposed by the research with designers in order not to build a system that users won't like, and consequently won't use. Therefore, in order to test the concept of haptic "scraping" in the virtual environment, we have developed a prototype that can be evaluated by end-users.

The system set-up consists of the scraping haptic tool driven by two integrated HapticMaster devices of the product (a car body in the example), and a monitor showing the object virtual model (Figure 5). The developed example aims at just validating the general idea. The user handles the haptic tool with two hands like in the real case when using a scraping tool, and moves it for removing material. When the haptic tool gets in contact with the virtual object, it gives back the user a haptic feedback. The tool is equipped with some buttons on its back side that allow the user to change some physical parameters of the models. The two buttons placed on the right hand side of the tool allow the user to set the stiffness of the material. The two buttons on the left hand side allow changing the resistance of the material when scraped.

Twenty testers (designers and CAD engineers) have been invited to try and evaluate the prototype. They all agree on the fact that the system is suitable for rough shape creation. In general, all the testers have expressed the opinion that the system might be a very helpful tool both for modelers and designers. They all seem quite positive in the possibility of integrating this new tool with other modeling tools within the design process. At the moment, testers do not see the possibility to replace 2D sketching or 3D CAIDS tools, but rather they confirm the effective use of this tool for substituting the physical model making. Concerning the system usability, they all agreed in confirming its extreme intuitiveness for creating shapes, also because of the intrinsic naturalness of the hand gesture. An important achievement to be noted is that all participants considered the motion they were making and the forces implied of extreme good quality, absolutely similar to the ones of the physical clay model making.

Figure 5: System prototype tested by a user.

6 Conclusion

The paper has presented the results achieved by the research project T'nD –Touch and Design aiming at studying a free-form shape modeling system resembling ways of operating of designers and modelers when modeling malleable materials directly with their hands and using craft tools. The paper has described the system architecture, the study of the haptic tools and operators for clay modeling, and the implementation of the first prototype. The prototype has been tested by some end-users (designers, modelers and CAD engineers) in order to get feedback about the concepts developed in the research. The comments of the testers about the system concepts and the tools have been very positive. On the basis of the prototype evaluation results a new version of the system is being developed, and a sand paper tool is currently under development.

Acknowledgement

The research work presented in this paper is financially supported by the European Commission, under the FP6 IST-2002-001996 T'nD – Touch and Design project (www.kaemart.it/touch-and-design). The authors would like to thank all project partners for their contributions to the research.

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