The 6th International Conference on Computer-Aided Industrial Design and Conceptual Design (CAID&CD'2005)
May 30~June 1, 2005, Delft, The Netherlands – pp. 612-617

HAPTIC SYSTEM FOR SHAPE GENERATION

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ABSTRACT: The paper presents the first results of the EU funded research project T'nD – Touch and Design that aims at developing a system based on shape manipulators and haptic tools for the creation, modification and evaluation of product shapes. The system offers modeling functionalities that resemble the actions modelers perform when molding malleable material for creating physical prototypes of products.

KEYWORDS: industrial design, product design, shape modeling, haptics, skill analysis.

1. INTRODUCTION

The conceptual design phase of new products having aesthetic value presents several critical issues that contribute in making the overall design process costly and time consuming. Two main practices are used for representing concepts of new products: hand-made prototypes and 3D digital models. Hand-made prototypes are created by skilled modelers who interpret designers' concepts and ideas expressed through 2D sketches and drawings and make physical prototypes molding malleable materials with their hands, and/or using very basic tools. This practice is expensive, requires long time and several loops of executions (made by modelers) and modifications (required by designers), requires skilled craftsmen, and needs downstream activities, like digital model reconstruction through Reverse Engineering, that are not well consolidated practices.

The other practice consists of designers making digital models using a CAS (Computer Aided Styling) or CAD (Computer Aided Design) tool. The designers using 3D tools for representing their ideas are still very few, and anyway, after producing a digital model of the product they are used to produce physical prototypes for the final evaluation of their ideas. In general, designers are not able to produce physical prototypes themselves; they usually ask modelers to make them on the basis of their digital models, or they ask engineers to make physical models using some rapid prototyping technique.

Both these practices are expensive in terms of costs and time, requires the production of several prototypes, and several iterations to reach a final accepted product concept. Therefore, companies are interested in improving the design process by reducing the number of physical prototypes and the number of iterations and in providing tools that can be used more efficiently and effectively by users so that they can concentrate on the design activities rather than bothering about tools technicalities.

The research work carried out under the context of the project T'nD – Touch and Design (www.kaemart.it/touch-and-design) financially supported by FP6 IST Programme of the European Union proposes a new practice based on the concept of *Virtual & Haptic Prototype*. The project is developing a system based on shape manipulators and haptic tools for the creation, modification and evaluation of shapes. The major benefits provided by the system are that that both designers and modelers can make and validate product prototypes using the same system, and that physical models are always the results of virtual prototyping.

The paper presents the first results of the research work carried out so far in the first phase of the T'nD project. The project is coordinated by Politecnico di Milano (expert in shape modeling, haptics and system integration), and involves two technology providers think3 (provider of shape modeling technology) and FCS-CS (provider of HapticMaster system), two academic partners Universitè Aix-Marseille I (expert in cognitive ergonomics) and Universitat de Girona (expert in product design sector), and three end-users Pininfarina (end-user operating in car design sector), Alessi and Eiger (end-user operating in the domestic appliances and household articles design sector).

2. DESIGN PROCESS

Typical design processes in the industrial design sector have been described collecting information from, and through interviewing the end-user partners of the project that represent two industrial sectors (automotive and domestic appliances) and are of different industrial dimensions (large, medium and small). The analysis of the processes and a series of interviews to companies' designers have highlighted a list of issues that need to be addressed in order to improve the performances of the whole process.

2.1 Current design processes

The information collection and interviews performed with end-users have pointed out three types of processes (As-Is processes) that are typical of the industrial design sectors. More details about the processes modeling and analysis can be found in Deliverable D6 in the "Dissemination" section of the project web site.

As-Is process 1

Three users are involved in the process: designer/stylist, modeler and engineer. The designer produces sketches, 2D renderings and 2D technical drawings for describing his ideas. After a comparative analysis and evaluation, a few of them are selected and given to the modeler who makes physical models (PM) out of them interpreting the sketches content. PMs are made with different malleable materials (clay, foam material or other) according to the type of product and the company practice [8]. In the information collection sessions organized with end users, domestic appliances modelers were asked to create a vacuum cleaner using clay, and car designers were asked to create a car C-pillar, also using clay. Each physical model is then given back to the designer/stylist for evaluation and validation. The designer might require some modifications that are communicated to the modeler using informal and not codified input. The number of loops required for product style improvements might be several. The physical model is accepted by the designer when it reflects at best his initial design intent. At this point, the physical model is passed to the engineer for producing the CAD model. This last activity is frequently performed using Reverse Engineering (RE) techniques that allow the reconstruction of the object shape, or at least of the main shape features of the object (styling curves). The RE model is a faceted model, not precise, that require to be further elaborated in order to obtain high quality CAD surfaces (usually NURBS). Once the high quality virtual model is ready, it has to be tested in respect to initial designers' ideas regarding the product. This is often done by making a physical prototype out of the virtual model using some Rapid Prototyping (RP) techniques (stereolitography, LOM, multi jet printing, etc.) or CNC techniques that allows designers to evaluate and check the final representation of the product [2]. It is often the case that the RP model is very close to the initial designer's intent. However, in case modifications are requested by the designer, they are not formally described with reference to the RP model, and have to be implemented into the CAD model, and tested again. This is a very critical issue that at the moment has not optimal and consolidated solutions. The output of the overall activity is a CAD model that has been validated and accepted by the designer.

As-Is process 2

Two users are involved in the process: designer/stylist and engineer. The designer produces sketches, 2D renderings, 2D technical drawings and also physical models for describing his ideas. The physical models are directly evaluated and modified if necessary by the designer himself in order to satisfy at best the design concepts. Once the physical model is accepted, it is passed to the engineer for producing the CAD model, and the subsequent activities are the same of the previous process. Also in this case, the output of the overall activity is a CAD model that is validated and accepted by the designer.

As-Is process 3

Two users are involved in the process: designer/stylist and engineer. The designer produces sketches, 2D renderings and 2D technical drawings for describing his ideas. In addition, he produces a CAS model representing the product. Some variants of the product may be directly evaluated through the 3D virtual model. Once the model satisfies the design concepts, it is passed to the engineer for detailing. RP techniques are used for producing PMs used for validating the product design. As in the previous cases, the output of the overall activity is a CAD model that is validated and accepted by the designer.

2.2 Major problems

The analysis of end-users' processes points out that the third process is the most efficient compared to the other two. However, it does not offer the possibility to constantly evaluate the design intent during the whole design process, since some aspects (like ergonomics and usability aspects) still require physical models to be properly evaluated. Besides, some physical prototypes are in any case requested by designers at the end of the conceptual design process, in order to evaluate the full correspondence of 3D product representations with the initial design intent, since they are not able to check this aspect through the 3D virtual model.

The following major issues have been identified in the three As-Is processes:

- The designer makes several sketches and technical drawings representing his product concepts, but for economical reasons –in terms of costs and time- only a few are selected for physical prototyping. This does not allow designers to fully evaluate all their ideas, and sometimes the best ones might not

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be considered.

- There is a cognitive load of the modeler since he is required to interpret the designer's sketches that most of the times are incomplete, ambiguous, and vague for making physical prototypes. This activity is often subject to errors and misunderstandings that require several subsequent modifications.
- Requests made by designers to modelers for styling modifications to implement onto the physical prototype are difficult to communicate, and are expressed in an informal and not codified way. Therefore, modification loops for style improvement might be several, and the iterations often cause delays, since the evaluation and modification activities are performed by different actors, at different times.
- Several CAS tools use "mesh" representations that are of a low quality, and require to be translated into high quality surfaces used by CAD tools. Surface reconstruction is often critical and produces errors and inaccuracy in surface reconstruction.
- Not many designers are used to, or are willing to use CAS modeling for representing their ideas since they are not intuitive to use and far from users' way of operating.
- After the engineer makes CAD models starting from RE data or CAS models, the designer has to check the CAD resulting model versus the initial product concepts. This activity is often done by producing additional physical prototypes (using RP techniques) that are given to the designer for testing. Again, requests for styling modifications are difficult to communicate, and are expressed in an informal and not codified way. Besides, practices for importing and implementing requests for shape modifications into the digital model are not consolidated yet, and often require the use of RE techniques.

3. PROPOSED SOLUTION FOR IMPROVING THE PROCESS

In order to overcome the problems of the design processes listed in the previous section, a system satisfying the following requirements has been conceived. The system should:

- be usable by both designers and modelers, exploiting users' skill;
- allow to create, modify and evaluate a shape using a monitor or a 3D display for seeing the product, and some haptic tools for touching it;
- provide shape modeling operators that are intuitive to use, and provide in output high quality surfaces (class-A surfaces) immediately re-usable with CAD tools.

The conceptual design process based on the use of the T'nD system is shown in Figure 1. The system is used by designers or modelers for creating, modifying and evaluating the product concept. They operate using vision and touch for creating shapes starting from initial ideas and concepts. The system generates models that are physical and digital (high quality surface). To note that in the proposed process physical models are always the results of virtual prototyping.

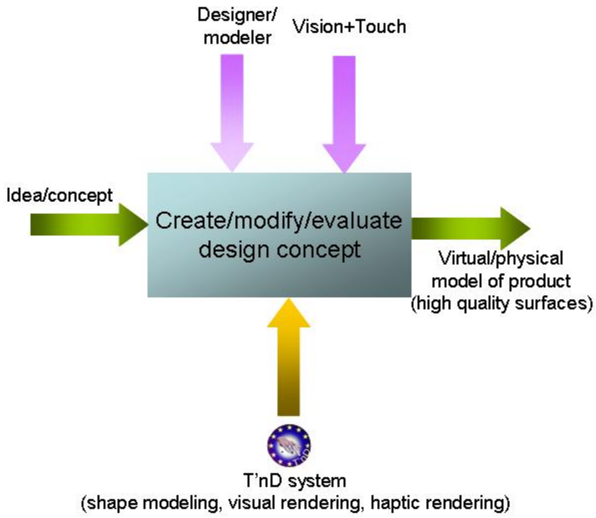

Figure 1. Conceptual design process based on the use of the T'nD system.

3.1 Expected benefits

The use of the system would bring benefits to users and to the overall design process.

The system provides some operating modalities that are familiar to modelers, since it resembles the actions they do in the workshop for building physical prototypes. The T'nD system is conceived to be an everyday working environment that designers and modelers find easy and intuitive to use, useful and productive, and without having to bother about technological aspects, but instead being concentrated on creative activities. Users have continuous contact with the object shape during its creation and evaluation. Easy-to-use and natural interaction techniques will convince designers to make use of digital tools on the basis of physical skills that can be used in an efficient and effective way for performing their job.

The T'nD system also improves the product design process making tighter the integration of creation and validation activities, allowing for the creation and validation of more ideas and therefore improving product design quality, and finally reducing time and efforts devoted to making physical prototypes, and for surface reconstruction since the digital model is ready to use for subsequent detailing design activities. Furthermore, the system facilitates communication between different departments (mainly design, engineering, and marketing) since a unique digital object is provided, instead of supplying physical and digital prototypes made with numerous and different types of techniques.

4. SYSTEM CONCEPTION

In order to design a shape modeling system that satisfies the mentioned requirements, we have 1) analyzed the users' skill while molding physical prototypes using hands and identified actions to reproduce in the system; 2) designed innovative haptic tools supporting the modeling actions; 3) study new shape generation methods. On the basis of these studies, the system architecture has been defined, and a first prototype of the system has been implemented.

4.1 Users' skill analysis

In order to design a system that can be easily used by modelers and designers its functionality should resemble the usual actions performed by those users.

To acquire information about users' actions modelers of end-user partners have been recorded and interviewed while creating physical models of some selected objects by working malleable materials (like clay, foam material, etc.) with their hands. Subsequently, the collected material has been quantitatively and qualitatively analyzed in order to understand the advantages derived from using hands when creating shapes, and to understand the modelers' haptic knowledge that is tacit and difficult to capture. The tools used (manual tools, machines), the gestures and hand motions performed (for shaping the object, for feeling the surface quality), the process tasks (template preparation, preliminary material removal, precise sculpting, surface finishing, comparison and measurement, visual and tactile assessment) have been analyzed and classified. Modelers and designers claim that visual, tactile and haptic 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

Figure 2. Users' actions implemented in the T'nD system.

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. At the end of this phase the following manual operations of interest for the project have been selected: *scraping*, *surface quality testing and finishing* (shown in Figure 2).

4.2 Innovative haptic tools

In order to define the appropriate haptic tools satisfying the system requirements, a survey of state-of-the-art devices has been performed. Some benchmarking has been performed on current available technology, considering haptic performance indicators such as workspace, position resolution, stiffness, nominal forces, and tip inertia, and also some non-dimensional performance indicators [5].

Since the objective of the project is to create an interface that allows designers to interact haptically and graphically with virtual models of products including a true size car body, purely point-based haptic interaction is not sufficient to appreciate and modify the surfaces in an intuitive way. Designers wish to interact either with the full hand, or with a virtual version of typical material modeling tools.

Satisfactory full hand interfaces (haptic gloves) have not been built so far, despite a number of attempts and one commercial product, the Immersion CyberGlove (www.immersion.com). This is probably a bridge too far at the current state of the art.

On the basis of the state-of-the-art [1], the final conclusion highlights that an extended version of FCS HapticMaster (www.fcs-robotics.com) is the most appropriate hardware solution for the project. Currently, it is the only device which offers adequate strength in an acceptable price bracket, but it is currently a 3-DOF to 4-DOF device. Within the context of the project, the FCS HapticMaster can be used as basic platform, equipped with a strong and stiff 6-DOF device carrying a simulated clay modeling tool.

A first prototype of the haptic system has been developed using two HapticMasters to drive a 5/6-DOF end-effector.

4.3 Shape generation methods

From the point of view of shape modelling, the project aims at defining a technique for shape generation and modification allowing a fine control of aesthetic properties of shapes. The technique should support the integration to the T'nD haptic system, and on the other side should interface to standard CAD data models. Several approaches for shape modelling techniques exist in literature, ranging from purely geometrical representation up to physics-based approaches. Some recent techniques for shape generation/modification are particularly interesting for T'nD project: voxel modelling and "swept volumes" techniques [2, 7]. There are also some commercial products that use methods for shape generation, as said, sweep or voxel-based. In particular, one commercial CAS system exists that is based on a haptic exploitation of a voxel representation, namely *Freeform* of *SensAble technologies* (www.sensable.com). It uses classical shape generation tools, based on extrusion or rotation of profiles in order to "save time" by allowing the user to define an initial block closer to the final expected shape. Considering the types of objects that can be modeled it is clear that the high aesthetic quality level required by the car industry or high-end customer products is not reached.

Besides, some recently developed physics-based methods represent any object as a dynamic system subjected to internal interactions depending on materials, and external forces/stresses [3].

On the basis of the state of the art analysis, we conclude that the emerging technologies that the project investigates and develops include sweep-based and voxel-based techniques. The major open issue concerns the definition of an appropriate theory allowing discrete schemes to support fine quality shape generation. The project is developing haptic-based motions and sweep methods supporting the identified actions.

4.4 System architecture

The architecture of the system is shown in Figure 3. It consists of the following main components:

- The FCS HapticMaster is operated by the user. The device is going to be equipped with innovative haptic tools that are oriented to design and 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.
- 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 in a smooth shape at the ned of the interactive session.
- The visual rendering system renders the graphic representation of the object on the screen.

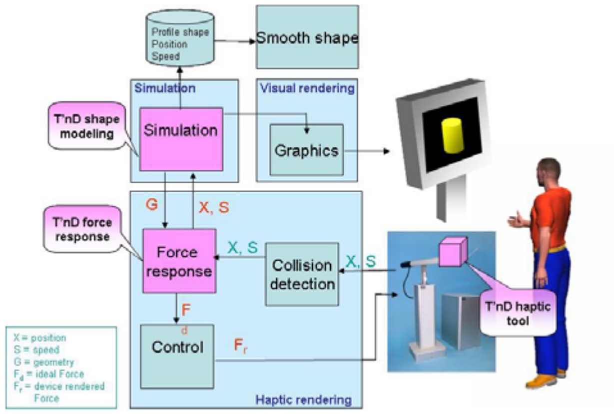

Figure 3. System architecture.

5. SCENARIO

In order to show the system components and how it operates, some scenarios are defined on the basis of system requirements and short-term and long-term technological goals. Two types of scenarios are proposed: short-term and long-term scenarios.

The *short-term scenario* demonstrates the use and performances of the T'nD system in shape creation and evaluation. The scenario shows the improvements in the process and in the ways of doing things, and the improvements in exploiting skills due to integration of shape modeling and haptic technologies extended with novel interaction metaphors and devices. Figure 4 shows a snapshot of the animation developed for showing the scenario. The short-term scenario is going to be used to demonstrate, validate and assess with end-users the concepts behind the T'nD system.

The *long-term scenario* describes how a shape modeling system based on haptic interaction might be according to technology providers' long-term vision about technological evolution in the two addressed fields. The scenario implements a completely innovative way of interacting with the application, where technology is as much as possible invisible and transparent to users. The interaction with system functionalities is not mediated by the technology, or it is not intrusive and the users are able to freely and intuitively work without caring about devices manipulations. One example of such technology is offered today by tactile display [6]. The long-term scenario is going to be used to check if the evolution trend of technology is such that users' expectations will be fully or partially satisfied.

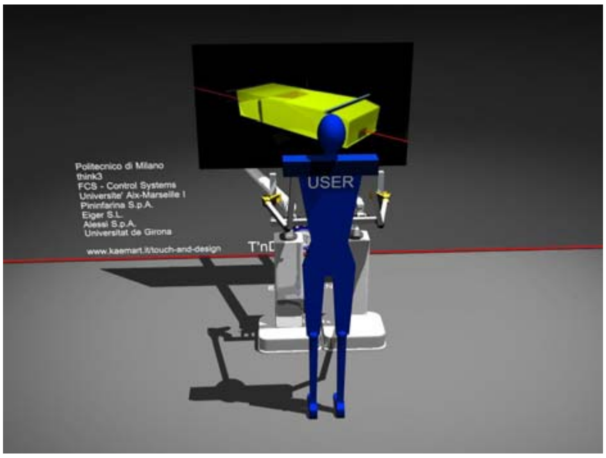

Figure 4. Snapshot of the short-term scenario showing the user scraping a piece of material using the T'nD system.

6. CONCLUSION

The paper has presented the first results of the research project T'nD funded by the European Union. The paper describes the motivations that justify the project, the objectives and relevance of the research topics in the industrial design sector, the requirements collected by interviewing and observing designers and modelers at work, and the analysis performed for designing the system. Furthermore, the paper presents the first achieved results that consist in the identification of the system functionalities resembling ways of operating of designers and modelers, the study of the haptic tools and of the shape modeling techniques, and the system architecture. Finally, some scenarios are described presenting the characteristics and use of the system, and longer vision about evolution of shape modeling system based on the used of haptic tools.

The system under development is expected to be a major improvement for industrial design companies that will be able to shorten product design lifecycle, improving design quality, while preserving valuable skills of operators.

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