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A novel form design and CAD modelling approach

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Abstract

This paper presents a novel form design and CAD modelling approach to simultaneously support intuitive physical model development such as 3D sculpting, and CAD surface modelling for effective design communication, evaluation and collaboration. The concept of creation of 3D form profiles by simply projecting a set of 2D drawing on a physical model is utilised for generating 3D constraints and converting a single perspective image of the physical model captured by a web camera to a CAD surface model. This method has been implemented and tested in our prototype design desktop system.

Keywords: Conceptual design; 3D form design; Tangible interaction; CAD surface modelling; Design communication

1. Introduction

Distributed collaborative design is playing an important role in global manufacturing. Designers often discuss their design ideas with their distributed collaborators via various audio and video communication tools over the Internet. However, these tools are less well able to support 3D physical model-based communication because making physical models sharable is far from ease.

For 3D form design, designers (stylists) prefer to directly develop 3D soft models because current computer aided design (CAD) systems are less intuitive due to requiring accurate 3D input for well-structured curves. Soft models with clay, wax, gypsum, polyurethane (PU) forms and so forth are used in a similar way to 2D sketches [1] to quickly communicate and record ideas. Based on a full range of physical feedback and direct sensorial perceptions of the object's characteristics, i.e., tangible interaction, the designers can develop physical models very intuitively by sculpting.

The use of soft prototypes not only makes the 3D form design easier, but also enhances design communication. Note that the soft-model development process is iterative and incremental, and designers often discuss and present their ideas during the model development. Working physical prototypes at different stages and details frequently need to be communicated with design colleagues for quick feedback. This kind of communication can be performed very well via face-to-face discussion when physical models and their real world feedback are available.

However, without corresponding CAD models, it is inconvenient for designers to discuss their 3D form design in progress with geographically distributed colleagues. For instance, sending physical models form one site to another takes long time and costs more, whereas sending a CAD model or a 2D image of the physical model through an email is more convenient and efficient. The CAD model can also be easily transferred back to 3D physical model via Rapid Prototyping (RP) machines. Furthermore, the CAD model can be rendered with different materials, textures and lightings to provide virtual design visualisation. This will enhance both local and distributed design communication.

Some research in the virtual design [2] has been carried out to directly model 3D virtual objects. For example, SensAble's FreeForm modelling system [3] uses PHANTOM touch technology to allow sculptors and designers to model on the computer using their sense of touch. It is an interesting technology but it cannot provide a full range of physical world feedback during the form design process. Design creativity may be affected from the limited sensorial perceptions.

Thus, it is desirable in industry for a novel 3D form design and CAD modelling approach to simultaneously support

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intuitive physical model development such as 3D sculpting, and CAD surface modelling for effective design communication, evaluation and collaboration. The research problem is that how the physical 3D objects can be captured, modelled and transferred in 3D very easily. Although the reverse engineering (RE) technique has been developed for creating new products starting from the shape of already existing physical objects [4,5], and used for rapid product development [6] and aesthetic form design [7], there are some limitations when applied to an iterative form design process. A physical model after 3D scanning can be converted into a 3D CAD model with some commercial software systems such as RapidForm [8]. However, various 3D digitizers generate an enormous amount of point data (10^4 to 10^8 points). This leads to a huge file size that requires a large execution time and makes difficult to transfer it from a site to another. In addition, surface operation on these point data takes a great deal of time and skill and becomes a bottleneck [9]. Furthermore, the resultant surface still needs to be modified by engineering designers in order to make it suitable for production, no matter how accurate and precise the surface reconstruction has been. The modified surface needs to be submitted to the stylist for the validation of its shape based on such as cross-sectional curves [7]. Moreover, after a local modification of the physical model, the corresponding RE model needs to be updated completely (not locally) because RE techniques have been considered effectively as one-off operations. As a result, this will change the CAD model for unchanged regions. It is undesirable.

In order to drastically reduce the point cloud data, and make surface modelling and transfer easy, a novel form design and CAD modelling approach has been proposed and developed. It makes use of a LCD projector to create 2D patterns on a working physical model on a rotary platform, and a single digital camera (or web camera) to capture perspective images of the physical model with patterns. Instead of computing thousands and thousands of 3D points from the images as in RE [10], our approach only reconstructs much less points on cross-sections corresponding to pattern line projections. This method can construct a CAD model from a set of cross-sections of a working physical model. It supports intuitive physical model development such as 3D sculpting, and CAD surface modelling for effective design communication. It can easily transfer a physical model to a CAD model. When a designer makes local changes to the physical model, the corresponding 2D perspective images of the sculpted physical prototype can be rapidly reconstructed to update the 3D CAD model locally and then the resulting CAD model can be easily distributed to colleagues for evaluation. Because this approach utilises only cross-sections to capture the physical object and represents the corresponding CAD model, it is also easy for the stylist to validate its shape based on cross-sectional curves [7].

In this paper, we present the novel design approach. The utilised techniques being less time consuming, make communication richer, impose less computational burden and are easier to use. The rest of this paper is organised as follows. The new design method is introduced in Section 2. Some experimental tests are given in Section 3. Finally, conclusions are drawn in Section 4.

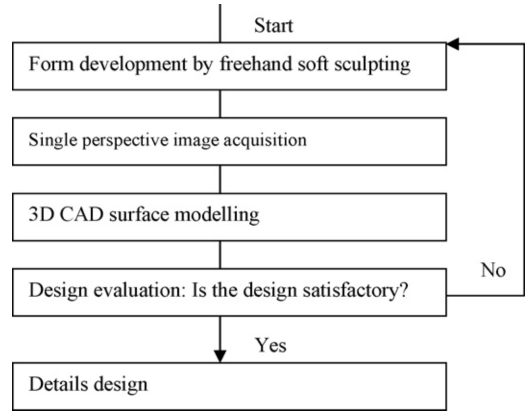

Fig. 1. The form design process.

2. New method

The new method supports a novel form design process starting with form design and development by freehand sculpting. The resultant working physical model can be positioned on a design desktop system to obtain an image from a web or digital camera. This image is further computed to gain the corresponding 3D CAD surface model for design communication. The physical model and the corresponding CAD surface model can be effectively used for collaborative design evaluation. If the working physical model is satisfactory, the corresponding CAD model can be passed to the next design and manufacturing applications such as details design. If not, the designers can continue their sculpting activities through both adding and removing soft materials. The novel design process is shown in Fig. 1.

This form of design and development method is especially useful for conceptual design. By using soft prototypes made from easily carved materials form design in 3D can be developed very intuitively because physical models and tangible interaction are available. At this conceptual stage, making aesthetically pleasing proportions and combinations of various design forms is very important, rather than accurate geometry. In other words, designers focus more on the overall shape design rather than manufacturing details.

The CAD model can be used as a backup model because physical modelling processes are not good at the undo operation. When designers decide to go back several steps, it is difficult to restore a previous model by the opposite physical operations of adding or removing materials. If a backup model is available, another soft model can be reproduced by Rapid Prototyping. On the other hand, the backup model can serve as a preserved master model to support a concurrent modelling process. That means that multiple designers can try different form developments simultaneously from the same starting model. Thus, the use of updated CAD models can not only save lead-to-market time, but also provide more freedom for the design process.

2.1. Principles of surface reconstruction

The surface reconstruction depends on transferring 2D projection points back to their corresponding 3D coordinates