

INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN

ICED 03 STOKHOLM, AUGUST 19-21, 2003

## A NOVEL UPDATING MODELLING METHODOLOGY FOR FREE-FORM SURFACE MODIFICATIONS IN EARLY STAGES OF DESIGN

P.A.Prieto, D.K.Wright and S.F.Qin

### Abstract

The paper describes the first implementation of a method in which an initial CAD model is updated from a physical model. The method is based on image-mapping in which an initial CAD model is updated from images of a soft rapid prototype model (RPM) which has been sculpted in order to carry out formal developments. The RP model is made by a 3Dimensional-colour printer, has a built-in contrasting grid composed by parallel planes in the X, Y and/or Z co-ordinates and has special consistency allowing it to be easily sculpted with hand modifications. During the sculpting process changes on the surface affect the lines on the RPM, which are the external presence of the internal grid planes and are corresponding to the initial CAD construction lines. These lines (profiles) then are visually contrasted by making use of identical perspective transformations and viewpoints for the virtual model and the RP model image. The initial CAD model is then updated by modifying the surface's construction lines to match the lines on the RP image by moving control points, such as in the Z direction.

*Keywords: Computer aided design (CAD), Reverse Engineering (RE) updating modelling and Rapid Prototyping (RP).*

### 1. Introduction

Currently early formal developments of products are usually carried out without computer tools, free nature developments are more easily carried out by hands instead computer CAD tools. Sketching directly on paper or sculpting over a foam model are the most used methods to carrying out formal development because compared with CAD design tools, they have simpler interfaces and can provide visual and tactile real time feedback.

However modern manufacturing techniques like CNC and RP are supported by CAD along the design process and applied at early stages advance the solution of the future problems on product development making the cycle shorter and efficient. Therefore formal developments carried out off the CAD have to be inserted into CAD systems for continuing the entire product development efficiently.

The current process to insert early formal development into CAD uses RE techniques. 3D scanners or 3D coordinate-measuring devices are used to obtain the geometry of developments carried out over physical model. The obtained surface data is then proceeded in order to rebuild a new surface in CAD format. However, existing techniques are mainly

applied to reproduce 3D products or parts and there is little work done to apply it into early stages of design, when the shape is still under development. In addition they are currently prohibitively expensive and inappropriate for the rapidity required in early stages which need a quick feedback.

In early stages of the design process computer tools currently available for designers and modellers have still difficulties to be included in early stages of design. Computer modelling tools have been improved considerably over the last few years. Research focused on sketch and CAD modelling [1-3], images as reference in CAD environment [4-5] and NURBS surfaces focused on free-form surfaces modelling [6] have been carried out in order to allow designers develop ideas in a user-friendly way inside CAD environment. New commercial CAD packages have powerful tools capable of building virtual products, looking at them from different points, transforming them, changing their colours, displaying them and even making a physical representation through the RP technology link. However the modelling process is still hard in early stages because the shape to be modelled is in this stage under developed and several modifications usually of free form nature are carried out away of computer environment.

Our work is focused on developing a new method to update initial CAD models in the early stages without uses of traditional RE techniques via 3D scanners or measurement devices. The new approach is an image-mapping based method in which a CAD model is updated from images of a soft rapid prototype model (RPM) that has been sculpted in order to carry out formal developments. The CAD model is updated by matching the differences between the initial CAD model and the modified RPM by making use of identical perspective transformations and viewpoints for the initial CAD model and a RPM.

## 2. The current method

Currently formal design attempts are first carried out off computer. These design intents are usually carried out by hand sculpting soft materials or sketching using paper and pencil; this allows a fluent formal development without computer restrictions e.g. two-dimensional screen. The resulting design is then inserted in CAD by modelling it directly or using RE techniques.

The process of obtaining digital models from an existing physical model by acquiring surface information using scanning or measurement devices is usually called reverse engineering. The traditional RE have the following different steps [7]:

- Point data acquisition.
- Noise filtering
- Data reduction
- Segmentation
- Curve/surface fitting
- 3D surface model generation

Modelling free-form shapes directly on CAD packages is extremely difficult. Free-form surfaces have not clear key modelling shapes such as a circle modelling a cylinder; in other words there are no primitives for free-form shapes. Reverse Engineering (RE) techniques could then be used to support three-dimensional CAD modelling from a physical model. A

3D scanner or a coordinate-measuring machine obtains the surface information. The output from the scanning process is point cloud data that is processed and fitted with 3D surfaces in a CAD package.

When a CAD model is available Rapid Prototype Models then can be used in the early stages to check fitting, ergonomics and aesthetic issues, to share the model with other members of the company and even carry out physic modifications over them. The most used system is 3D printing because it is the cheapest and its characteristics such as accuracy, consistence, high building speed and building colour capability are suitable for early models. Modifications can be carried out directly on the surface and converted into a CAD model by applying Reverse Engineering techniques. Usually the method is recurrent and several physical models may be needed to create a final CAD model of a satisfactory solution.

Rapid prototyping is a process by means of which a physical representation of a virtual model can be made directly from a computer (Figure 1). The model is made layer by layer and can be complicated three-dimensional shapes. Key aspects of accuracy and material properties have been improved dramatically over past years and new applications have been developed.

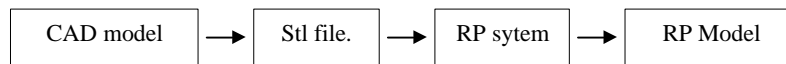


Figure 1. The figure shows a simplified diagram to make a RP model.

The 3D-printer technology has an important distinctive characteristic, which is the ability to build models in full colours. The standard input file for RP t is STL but for printing in colours the model must be painted in special package or modelled in colour and exported as a VRML file, which is a standard import file used by the Zcorp 3Dprinter to print colour models.

The drawback of current design methodology shown in figure 2 is that it highly dependent on RE techniques for updating the models. In the past few years the accuracy and time consuming for the capturing surface data have been improved significantly. However, the output is cloud data, which must be specially processed with software functions.

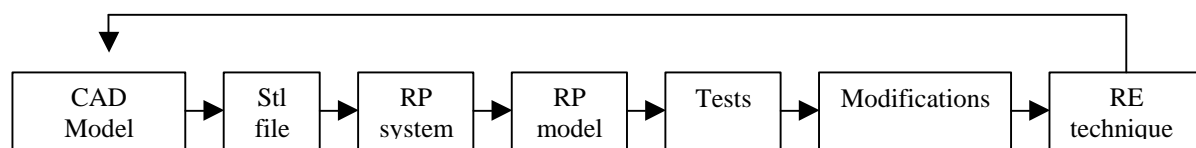


Figure 2. The figure shows a current design methodology using RP and traditional reverse engineering.

### 3. The new method

In order to update an initial CAD model in the early stages of design, we have developed an image-mapping based method in which a CAD model is updated from images of a soft rapid prototype model (RPM) which has been sculpted in order to carry out formal developments. The RPM has a built-in contrasting 3-dimensional grid composed by parallel planes in the X, Y and/or Z co-ordinates. The initial CAD model is modelled by skinning NURBS surface across cross-section curves. This technique is widely used to modelling free-forms surfaces because of its high flexibility. The RP model is made by a 3Dimensional-colour printer and

has special consistency allowing it to be easily sculpted and formal developed with hand modifications. A single image for each modified area is then obtained, e.g., by mean of a digital camera is used. The image has to be taken from a convenient point of view in order to capture the sculpted area of the RPM clearly. During the sculpting process changes on the surface affect the lines on the RPM, which are the external presence of the internal grid planes. These lines correspond with the construction curves (NURBS) of the initial CAD model. Therefore, the differences between the initial CAD model and the modified RP model can be easily detected by making use of identical perspective transformations and viewpoints for the CAD window view and the corresponding RPM image. The initial CAD model is then updated by modifying the surface's construction lines to match the lines on the RP image by moving control points, such as in the Z direction. As a result the CAD model has now been refined by the new formal development carried out on the RPM.

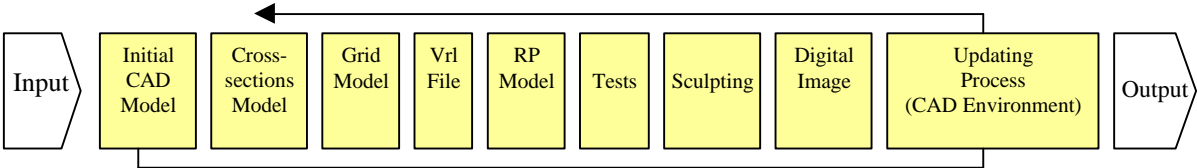


Figure 3 shows the involved steps for the new method

### 3.1 The first implementation

The method has been evaluated using a 402c 3D-colour printer by Zcorp to produce the RPM and the environment was based on Studio from Alias Wavefront. Several examples were carried out. Initially a cube was modified on one face with a small depression, and its corresponding CAD representation was then updated with the new geometric information. Volumes with free-form surfaces, representing a more difficult problem for updating CAD models were then used. Free-form shapes are difficult to reproduce in CAD packages because primitives do not model them and small free formal developments carried out on physical models are particularly difficult to detect and gauge for reinsertion into a CAD model without using RE techniques.

### 3.2 The input

The initial CAD models (Fig. 4.a) were modelled in Alias using standard surface modelling tools and were then rebuilt by skinning cross-sections (Fig. 4.b). The reason for rebuilding the surfaces was that it could reorganise the model construction lines in a standard and correspondent structure as the internal contrasting grid. The colour grid and the construction lines (Fig. 4.c) are then correspondent and placed in the same scale and position to enable later comparison between the RPM pictures and the Virtual Model's view.

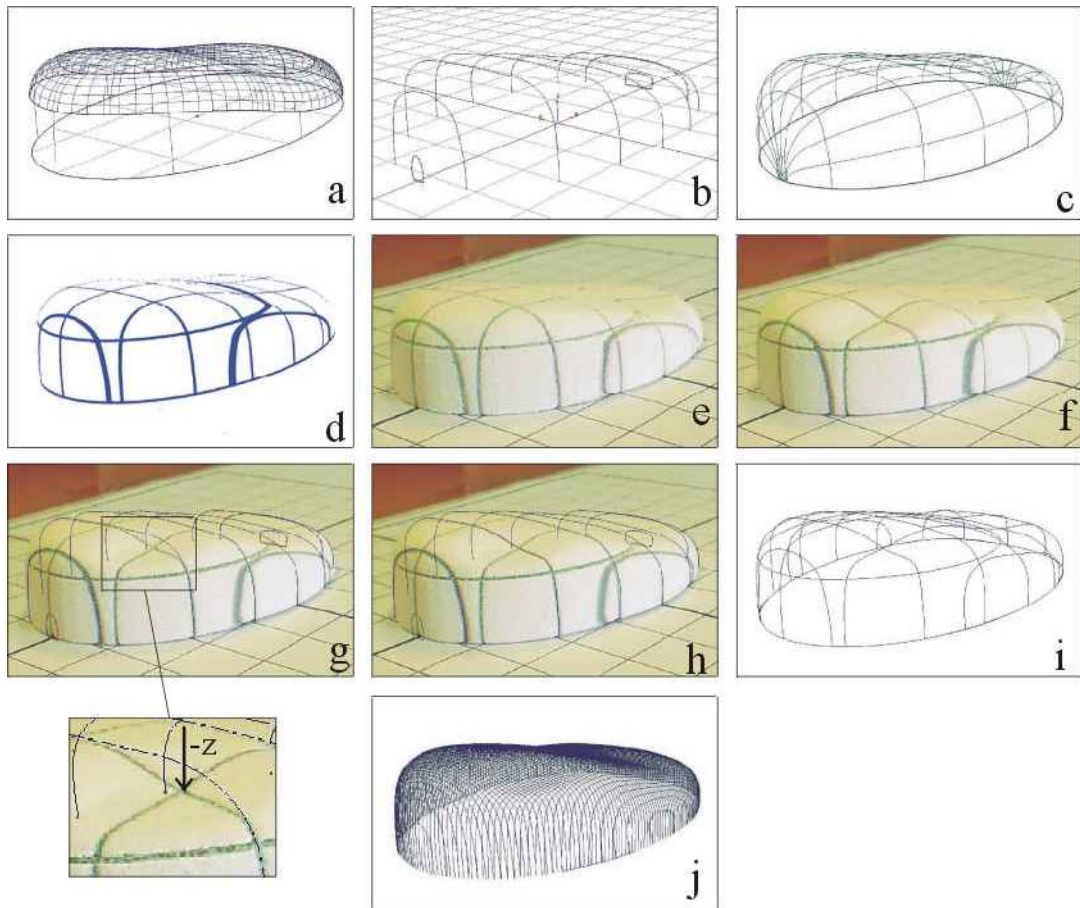


Figure 4. The figure shows an initial CAD model (a); The cross sections model (b); The rebuilt reference surface model by the cross sections (c); The grid CAD model (d); The RP model modelled in colour Grid (e); The sculpted RPM (f); The differences between the initial CAD model and the sculpted RPM (g); The modified cross sections (h); The new updated surface (i) and a cross section representation of the updated surface (j).

### 3.3 Grid Modelling

The current commercial Zcorp 3d printers print a colour shell on the model, therefore the colour is printed only on the surface model, the inside model is built without colour and every closed space is assumed to be solid. This points problems in the generation of an interior grid. By using Boolean operations a colour grid can be integrated in a shape combining two different models. These two different models consist of a colour grid and the solid model volume split into cubes (figure 5).

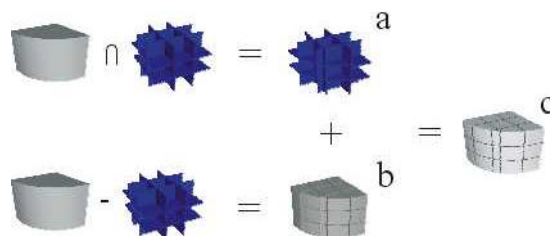


Figure 5. The scheme shows the main boolean operations for modelling the 3d printer input shape in colour grid. The figure (A) shows the grid colour, the figure (B) the volume model split in cubes and (C) shows the final grid model.

In the grid modelling process some little considerations must be taken. A little gap must exist between them, grid and cubes. Small holes must go through the grid, opening every closed space. Thus the 3D printer can recognise different objects: one inside another with different colours instead of a close space. The gap between grid and cubes is accomplished through scaling all the cubes from its own central pivot points (origin). The thickness of gap has to be not more than two layers of the 3D printer slicing so as to keeping the model integrity. Finally a CAD grid model with a three-dimensional colour grid is modelled and exported as VRML file to the 3D printer (Fig. 4.d).

### 3.4 3D Printing

A three-dimensional colour printer was used to print out the RPM (Fig. 4.e). The consistency of the 3d-printed model, without any infiltration, allows modifications easily by hand. This is a tremendous advantage for sculpting models in our proposed method. Other strong point of 3D printing technology is the colour printing capability that allows prints out full colour surfaces models.

The three-dimensional printers have two principal parameters to control the surface accuracy and model consistence. The thickness layer has a direct relation with the surface resolution, if the thickness is high the steps between the layers are more noticeable on the surface model. The second parameter is saturation that depends on the quantity of binder liquid sprayed on each layer; if the saturation is high the model is stronger.

Specials set up were used to facilitate the model as sculpting material. Through changing parameters as saturation and thickness layers, it is possible to find an appropriate model consistency. The parameters were modified from the default value in order to find a balance between resolution and an adequate model consistence and the grid resolution in order to facilitate the sculpting process and the grid visibility. In our implementation the chosen saturation is 0.8 and (the default value is 1) and the layer thickness was 0.008 inch. (The default value is 0.004). Figure 6 shows the traditional RPM and the RPM built in colour grid

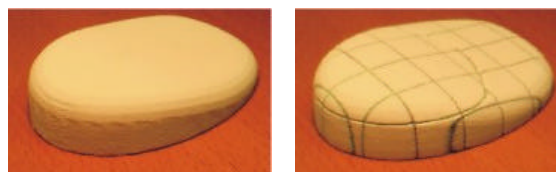


Figure 6. The picture shows the traditional RPM and the RPM built in colour grid.

### 3.5 The modifications

When the RPM in colour grid with built, form fitting, ergonomic and/or aesthetic tests are carried out. During this process, modifications are carried out directly on the model surface (Fig. 4.f), which change the grid information shown on the RPM surface.

### 3.6 Comparison & updating

A single picture is located on the CAD package background and visually compared with the virtual model (Fig. 4.g). The chosen point of view has to show clearly the modified area. Model cross sections have been located in the same place with the RP model. It is important to make use of identical perspective transformations and viewpoints for the initial CAD model and the corresponding RPM.

To fit the CAD model to the RPM picture some basic geometric characteristics must be considered. The X and Y co-ordinates are the same because the cross sections (construction surface lines) and the correspondent line on the RPM surface are in the same cross plane. Therefore, the surface is fitted to the RP picture by moving control points of the cross sections only along the Z-axis. When the cross sections are fitted to its correspondent picture section (Fig.4.h and 4.i), a new surface is rebuilt automatically (Fig.4.j).

Finally the new modified CAD model can be received and if necessary it can be used as initial input for next recurrent design cycle.

## 4. Results & Discussion

Compared with typical reverse engineering processes, our approach is simpler and easier. It is not necessary to use 3D scanning or coordinate measuring devices for updating existent initial geometrical CAD models with data obtained from modified physical models. Moreover, there is in addition no substantial modification to the mathematical design of surface model.

The method bridges gaps between different techniques and technologies involved in early stages. Gaps between RP and sculpting, sculpting and Virtual Modelling and virtual modelling and RPT are connected through an understandable method. In this way the approach gives to designers a more integrated, natural and intuitive way to work the early stages of design process using the advantages of the current technologies.

The approach has been demonstrated as a new interface to improve the interaction in early design environments. It provides a more interactive and natural way to work through the design process, especially in the early stages. Our method improves the interaction between computer and designer through increasing the tactile and visual fed-back, taking advantage of basic motor and perceptual designer's skills.

## 5. Future work

The method has proved to be a good routine for early stages of design and the focus will be on developing a supporting tool capable to update the a CAD model from the RP images in automatic way. This tool should improve the method considerably because the user will be focused in the creative process instead of computer interface problems.

Another work being considered is using laser devices to create lines (profiles) on big surfaces for some applications as in car industry were big RP models are not possible or too expensive.

### **Acknowledgements**

The authors are grateful to the Interaction Design Group for valuables discussions especially to Matthew Benham and Paul Gammans.

This work is partially supported by the EPSRC Research Council Grant (GR/S01702/01). Pablo Prieto would also like to thank the Chilean government for financial support.

## References

- [1] Casper G.C and Amnon A.C., “Sketch input for conceptual surface design”, Computers in Industry, Vol. 34, 1997, pp. 125-137.
- [2] Lynn Eggli, Chiang-yao Hsu, Beat D Brüderlin and Gershon Elber., “Inferring 3D models from freehand sketches and constraints”, Computer-Aided Design, Vol. 29, 1996, pp. 101-112.
- [3] S.F.Qin, D.K.Wright and I.N.Jordanov., “From on-line sketching to 2D and 3D geometry: a system based on fuzzy knowledge”, Computer-Aided Design, Vol. 32, 2000, pp. 851-866.
- [4] Henri Veldhuis and George Vosselman., “The 3D reconstruction of straight and curved pipes using digital line photogrammetry”, Photogrammetry & Remote sensing, Vol 53, 1998, pp. 6-16.
- [5] A.R François and G.G. Medioni., “Interactive 3D model extraction from a single image”, Image and Vision Computing, Vol. 19, 2001, pp. 317-328.
- [6] E. Dimas and d. Briassoulis., “ 3D geometric modelling based on NURBS: a review”, Advances in Engineering Software, Vol. 30, 1999, pp. 741-751.
- [7] Tamás Várally, Ralph R. Martin and Jordan Cox., “Reverse engineering of geometric models, an introduction”, Computer-Aided Design, Vol. 29, 1997, pp. 255-268.