Generating CAD Models from Sketches

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Abstract: The ultimate goal of the application described in this paper is the conversion of two-dimensional sketches into three-dimensional CAD curves and surfaces. The first creative step of planning and outlining a conceptual idea often is realised in so-called scribbles (conceptual sketches). Normally, they are scribbled with pencils on sheets and thus only can be used for background information to develop the virtual three-dimensional shape.
A new method enables the conceptual designer to scan paper scribbles and afterwards convert them into a virtual sketch model. The virtual sketch model includes all the 'fuzziness' of the scribble and the therein expressed conceptual steps but is automatically represented in a sequence of real B-Spline curves. The conceptual designer can develop it into the final concept and into the three-dimensional CAD elements.

Key words: Conceptual design, conceptual sketches, computer aided design, virtual modelling, Fuzzy-Spline curves, wireframe modeller, surface modeller

1. INTRODUCTION

1.1 New Information Processing Concepts

Within the product development process and its individual steps a new trend is rapidly emerging: a shift towards the virtual reality. Thus, information processing concepts like the Digital Master, Digital Mock-Up or Product Living Data are created which integrate new information as well as manufacturing technologies to enhance the processing steps. Based on this, new processing steps arise which more and more require a global, continuous information management. Therefore the virtual product model in its different stages is an essential prerequisite for the virtual modelling of processes.

As a result we observe the increasing individualisation of products with an accompanying high complexity of their configuration. The styling of the products is also granted more leeway - this furthermore involves an increasing influence on the development and the characteristics of innovative products.

Within these new information processing concepts, the CAD package is assigned the role of an 'engineering backbone', the fundamental function in information management (Dankwort 2000).

Nowadays, the 3D-CAD package (e.g. CATIA, ProEngineer, AutoCAD, SolidWorks) is the most commonly used tool for product development. It primarily supports the engineering design work which is based on precise and scaled product data applied to preserving the shape of the final product (e.g. full-scale details).

1.2 Integrating the Early Stages of Conceptual Design in Computer Aided Design and Modelling

However, product design already starts with conceptual design including all the concepts for shape and function. The transfers between the basic steps of planning, concept, outline and elaboration are smooth and the creative process is characterised by a high extent of individuality and is not stringent. The conceptual designer works on 'fuzzy' product data applied to shape creating (e.g. proportions).

'Fuzziness' means different aspects: the shape of the future product is interpreted in a couple of scribbles which are partly coloured, handmade patterns, verbal descriptions, photographs and montages etc., which define the appearance and the function of the product. Thus, the product firstly is abstracted as a 'subject' which will be translated intuitively into a multifaceted 'vocabulary' of curves and shapes (von Lohr 2000).

CAD technology provides but insufficient support for this intuitive work. Therefore, the conceptual designer uses design modeller packages (e.g. StudioTools, Maya, 3DStudio) to create computerised, virtual models as well as sheet sketches and handmade models to stimulate his imagination while forming curves and shapes and verifying the function and ergonomics of these conceptual models. Thus even the early conceptual stages comprise different coexisting model types, e.g. virtual and physical models. In a certain way, these models are different and independent of one another because they cannot, or can only with great difficulty be derived from one another or transformed into each other. This means that the concept modelling has to be carried out separately in each stage and cannot be executed iteratively.

This will be the crucial question for future strategies of product development. The additional development of intuitive virtual design tools should support the conceptual design in the same way as with CAD or CAM.

1.3 The Project 'DeCign'

The most important factor in this regard is the enhancement of these virtual tools with fuzziness and spontaneity (the design engineer may say: inaccuracy). It shall be possible to transfer an arbitrary sketch, scribbled on a sheet and representing more a 'frozen movement' than an object itself, into a design modeller package. Individual design curves and shape characteristics which form the basis of typical CAD wireframe models shall be extracted and visualised without losing the fuzziness of their appearance.

This was the major task of the research project 'DeCign'. The aim was to develop a continuous information processing chain supporting product development. This was to be realised with a so-called 'Hybrid Workstation for the Conceptual Designer and the Design Engineer'. The workstation was not conceived as a real, single computer workstation but as both the optimisation of the different tools of conceptual designer and design engineer and the development of new styling and assessing tools which make creative use of virtual modelling strategies (Roth-Koch 1998). The main focus was set on the early stages of design work. At these stages of conception and shaping, the sketches and physical shape models carry the shape information.

This paper presents a semi-automatic method of transferring conceptual sketches into fuzzy virtual sketches as a basis for the CAD modelling that follows. Initial (two-dimensional) virtual sketches can be completed to drawings which imply design requirements (like continuity). Thus the conceptual designer still can work with his sketch-pad while virtual modelling offers him new options like the computer-aided assessment and verification of his concept from an engineering point of view or the adequate presentation of his concept. Moreover, the research work has shown that there is a strong requirement for new conceptual-design-related modelling strategies, e.g. a semi-automatic proceeding which is combined with intuitive tools.

2. THE BASICS

2.1 What Conceptual Design Means

The traditional design process comprises the development of a product beginning from the idea, continuing through the outline right up to the construction plans or, under some circumstances, up to the finished product (von Lohr 2000). This process can hardly be regarded in general terms since it depends on numerous objective factors - such as the developmental environment, as well as numerous subjective factors - such as the individuality of the designer.

All the phases of the design process entail the use of traditional-real aids which are supposed to rouse the imagination and provide inspiration. The sketches are often supplemented with texts or suitable photographs and are explained so as to breathe as much life as possible into the underlying idea. Eventually, outlines are produced which, as a final step, are elaborated into three-dimensional, physical models – the shape models.

This ultimately means that the extent of detail in the sketches continually increases and that special details can be specified in individual sketches while the rest of the sketch may remain vague. Inaccuracies are therefore accepted. Several formal realisations of the pursued concept are thus produced and adapted to the conceptual idea in an iterative process, the goal being a rapid production of alternatives. The degree of elaboration increases as concept and outline merge. Shape and curve characteristics are determined, for example. Presentation sketches of the shape defined in this manner are now prepared (e.g. for the customer).

Various sketching techniques are employed. Space and three-dimensional objects are depicted using perspective, for example. Perspectives, on the other hand, may be created with the help of several sketching methods, but they can never really be drawn true to scale. One can furthermore distinguish between line and surface sketches or combinations of both. Often individual styles and/or preferences for certain drawing instruments are also important.

The manually prepared initial models (shape models) therefore allow the only truly three-dimensional assessment of the outline and the laying down of the conceptual statement in its entirety.

Initial models may also be line models (wireframe models) or surface models. It is also possible, to some extent, to work with volumes (e.g. foam blocks) or to transfer particular shapes onto simple basic structures (Roth-Koch 2000).

The transfer of the sketches or the initial models into virtual models for the purposes of design development and verification is not carried out in practice. One either draws sketches directly using the design modelling package – thereby reducing the shaping opportunities described above, since the modelling strategies demand that an analytically constructive approach be adopted for further model construction immediately after the freehand input of curves – or one directly proceeds to construct a CAD model. The virtual sketch models thus generated are based on the same geometrical elements as the CAD models, e.g. the free-form curves are always defined as B-Spline curves or as NURBS curves and therefore embody a comparatively 'tangible' shape representation. Their "scribble" nature is thus lost.

2.2 Required Steps for Computer Aided Design and Modelling

The further development of virtual conceptual design models into CAD models demands that several conditions be met. Surface-oriented 3D CAD packages and design modeller packages utilise the same basic geometrical functions for the description of regular and free-form geometry. Their incorporation into a system-specific data model is, however, carried out in different ways. In particular, the incorporation of the generated curve features or surface features into topological models (i.e. their attachment to the object surface) takes different forms. This variety definitely makes sense since the computed models all represent different stages of outlining and development.

In order to incorporate the outlining phase into the virtual development of the product, these differing models must be integrated and transferred into one another. Either sketches or the conceptual designer's handmade initial model are the starting point. Both kinds of product outlines still exhibit certain inaccuracies, however. Therefore a transfer into a computed, virtual model cannot result in a 1:1 copy which accurately preserves the established shape, but is merely supposed, for example, to precisely depict a few essential forming lines while schematically visualising the "remaining geometry".

If the conceptual designer's 2D sketches are used as pattern, then two-dimensional computerised contours have to be extracted from the fuzzy description of forming lines (e.g. multiple pencilled contours) after the sketches have been scanned. From this a 3D wireframe model must then be constructed. Since the only available perspective views are indistinct and therefore not to be automatically evaluated, the conceptual designer must visually monitor and manually influence the process of contour specification. The wireframe model initially interprets the product's form as consisting of edges (wires) which are either forming lines, the object's genuine edges or surface borders with adjoining conditions, depending on the extent of detailing.

Building on such a wireframe model, one must now generate surfaces for the further completion of the virtual initial model. These surfaces should be based on CAD modelling strategies from the start in order to avoid future transformations which always lead to loss of information. At present, two major types of surface model are available: parametric surfaces and faceted surfaces. Parametric surfaces represent the exact CAD model description (with regular shapes) or the approximate CAD model description arrived at through the use of polynomial functions (with free-form shapes). Faceted surfaces are produced via the triangulation of individual points (e.g. digitising points) and also provide an approximate surface description. They are mostly used for visualisation purposes and for calculating the control parameters for conventional manufacturing (e.g. milling) or for Rapid Prototyping (e.g. stereolithography).

3. HOW TO DIGITIZE A SKETCH AND CREATE A VIRTUAL COUNTERPART

Methods for integrating the early stages of product design into the CAD/CAM process must take into account the fact that current CAD developments tend to become process-oriented multi-component systems which manage a specialised, object-oriented data structure. The methodical basis described in this paper uses the methodical and geometrical kernel of the development toolkit CASCADE (since January 2000 OpenCASCADE / www.openCASCADE.com) by Matra Datavision which deals with a (STEP compatible) non-manifold geometric description. Thus, the implemented software modules can be used as both independent modules and enhanced functions of CAD packages. The data exchange can be executed by standardised interface structures or via the transfer of b-rep models.

The primary aim of the digitising of physical models (like sketches, scribbles etc.) is the conversion of shape-based, physical information into formal information, i.e. into virtual models. The essential information of the sketch has to be analysed in this context because it is not relevant to gaining a 1:1-reproduction without any context preservation.

Normal flatbed scanners are used to digitise sketches rapidly. The result is a grey-level image or colour image where neither geometrical properties nor features (curves, edges, profiles, forming lines etc.) can be read directly.

Further problems to be considered are the fuzziness and 'incompleteness' of the sketches. The fuzziness of the sketch means different amounts of thickness of lines, multiple lines, shadings, open contours etc.. That is why only selected forming/shaping elements or features (shaping curves, light reflection curves etc.) are to be transferred.

The definite identification of such forming/shaping elements in grey-level images as a prerequisite to detecting geometrical data is generally the task of image processing techniques. Conventional image processing strategies (clustering, regions of interest, texture analysis) normally use specifiable information from given geometric shapes. This kind of information cannot be obtained from sketches at first glance. The 'fuzzy' elements of a sketch must be identified by iterative analysis and/or user interaction.

First of all we had to investigate search methods driven by user targets for regions and contours of fuzzy or ambiguous objects. We have found a rich field of solutions in the geo-sciences. The implemented procedures can be expanded to other applications dealing with ambiguous objects (e.g. reflecting objects).

The elaborated strategies allow the definition, partly by automatic extraction, of the relevant regions of geometrical basis elements in scanned sketches. Furthermore, the conceptual designer can define relevant regions where he imagines the object's contour by interaction.

Using this information, a virtual model is built which fits the sketch visually (with a few omissions and simplifications) and is modelled in a CAD style (with B-Spline curves). This makes the conversion into the initial CAD wireframe model of selected model curves possible after its further development within a design modeller package. This wireframe model and some additional surface points are normally the informational basis for CAD modelling.

3.1 What is the Gist of Sketches?

The pictured perspective plays no essential role from the point of view of geometrical evaluation in preparing the exact geometrical model (CAD model) because it is not possible to extract three-dimensional information automatically.

But it is important for the further development of the virtual model. Furthermore, conceptual sketches comprise elements which have no relevance to the geometrical shape, like coloured markings, background shadings etc. These would falsify the evaluation result and have to be removed. Since they are mostly typical expressions of the designer's personal style, they must to be removed by the designer himself before starting the feature extraction. This can be done with the usual image handling software (Photoshop, CorelDraw etc.) and is accepted by the designer.

3.2 What is the Gist of the Virtual Model ?

The preserved but still fuzzy contours, which may possibly be in warped perspective, should be transferred into a design modelling package to develop them into a real three-dimensional model.

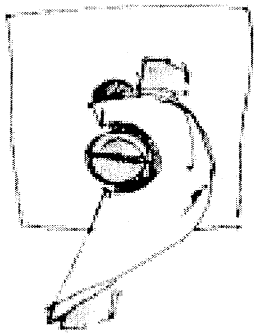

Figure 1. Conceptual sketch

The character of the sketch, i.e. the visualisation of fuzzy contours should be preserved in the initial virtual mapping. On the other hand, the visualised curves should be defined as geometrical elements for using usual modelling procedures. Our method of resolution fulfils these demands by implementing an array of curves which represents the fuzzy contour of the object. The individual curves in this array can be manipulated with parameters derived from the manner of representation in the sketch - for example: a kind of 'importance' may be assigned to contour areas near thick lines or a cluster of tightly packed lines.

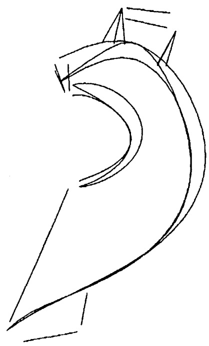

Figure 2. Evaluation of the sketch and virtual modelling

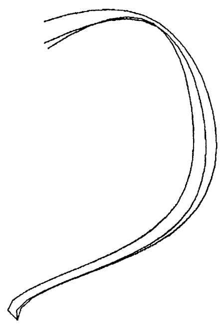

Figure 3. Description of individual fuzzy contours

4. METHOD OF RESOLUTION

The implementation method is based on the OpenCASCADE development toolkit. Additional algorithms (for image processing) are implemented and their results converted into an OpenCASCADE data model after the evaluation is complete for the purpose of enabling the use of OpenCASCADE functions (Stotz 2001).

4.1 Configuration of Functions and Interaction

1. User interaction

   The conceptual designer scans the sketch with an appropriate resolution, and clears it of elements not belonging to the object's shape (markings etc.) with the aid of an image-processing program.

2. Image pre-processing / image decoding

   The conceptual designer scans the sketch with an appropriate resolution, and clears it of elements not belonging to the object's shape (markings etc.) with the aid of an image-processing program.

3. Contour and edge analysis

   In order to be able to gather information from the bitmap with regard to the development of the sketched lines, areas from which sketched lines should be taken must first be specified by the user to be incorporated into a CAD drawing (design features). This is done by fixing so-called guiding polygons, along which the bitmap is scanned for lines nearby.

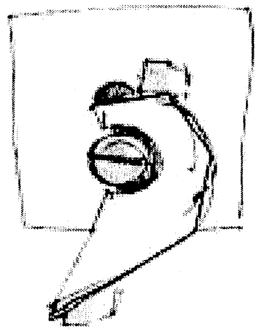

Figure 4. Guiding polygon

In simple sketches, it is also possible to extract so-called skeleton lines automatically from the binary image. If a sufficient number of thick, connecting lines are present in the sketch, the skeleton lines will also be adequately connected. Their final selection is performed by clicking on the line to be incorporated into the design model. The skeleton lines are then vectored. In this way, guiding polygons are also created here.

4. Parameterisation and definition of fuzzy points

From the guiding polygon, a chordal parameterisation is calculated for the fuzzy spline curve to be formed. Profiles are formed orthogonal to the guiding polygons. By matching grey-level values, a fuzzy point is then calculated on the profiles at each fixed segment. The fuzzy point reflects the blurred definition of a point and thus reproduces the most probable position of a point on an assumed, real contour being looked for (near to dark or clustered lines).

Firstly, extreme values x_i of grey-level distribution are determined orthogonal to the guiding polygon lines within of a tube of flexible width.

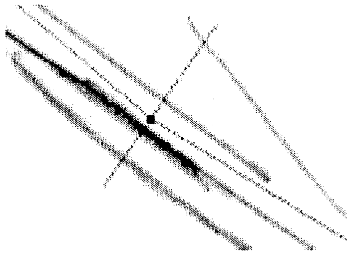

Figure 5. Determination of the extreme values of grey-level distribution

The computation of the fuzzy member function then adds all distances of the extreme values among each other:

$$F(x) = \sum_{i=0}^{n} e^{-k_i (x-c_i)^2} \quad \text{with} \tag{1}$$

$$c_i = x_i + |x_i - x_{i+1}| / 2, \qquad k_i = 6\,|x_i - x_{i+1}| / |x_0 - x_n| \tag{2}$$

where factor 6 (‘weight’) has been found by trying.

5. Constructing a fuzzy spline to form the basis of a wireframe

Fuzzy splines are approximated using these points. This can be represented as a range of spline curves, which reproduces the blurred definition of the original sketch, so that the user is not committed to any clear curves right at the beginning (see figure 6).

Furthermore, by altering parameters, the conceptual designer is able to change the position and the form of the B-Splines:

– modifying the ‘weight’ parameter displaying one discrete curve,

- changing the width of the considered region around the 'guiding polygon',
- displaying of individual levels of the Fuzzy-Splines.

In this way, various forms can be experimented with before deciding on a final contour. The selected curves may further be processed in design modeller packages or in CAD packages after having been stored as a DXF data file. A further development of the geometrical shape to be created in the sketch is thus possible. Since the virtual sketch model is not three-dimensional, for any spatial development a spatial shape structure must first and foremost be defined.

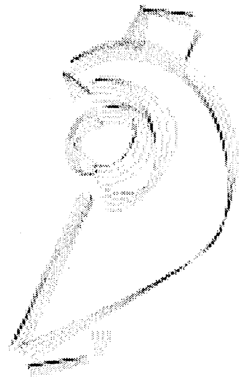

Figure 6. Virtual sketch model

An alternative procedure can be proposed in principle. First, the two-dimensional wireframe model can be generated from the disjointed array of B-Spline curves in the sketch, which is then impressed or 'slipped onto' the defined spatial shape structure. On the other hand, further project ideas exist for deriving three-dimensional virtual sketches directly from the scanned paper sketches by using, for example, the shading of the perspective view.

The concept of the two-dimensional wireframe model out of B-Spline curves was implemented using the development toolkit OpenCASCADE with regard to the generally valid case of the three-dimensional wireframe.

5. CONCLUSION

The methods described for the transfer of outline sketches drawn on paper into virtual models are the first step towards integrating the traditional working methods of the conceptual designer with the virtual product development process. The conceptual designer can scan his pencilled scribble and 'transfer' the included fuzzy shape description into the Fuzzy-Spline curves of a virtual model. At a very early stage the conceptual designer is thus presented with entirely new tools for developing and verifying his outline without relinquishing the shape outlines (e.g. pencil sketches or wooden initial models) that are so important for creative work. At the same time, virtual product development is supplemented with the outlining stage, for which iterative model construction leading to the complete product data model is now also possible.

These are, of course, only a few preliminary steps. The fuzziness of the sketch is preserved in the virtual sketch model and the conceptual designer is able to digitise his first stylistic idea without having to specify individual geometrical features. The next crucial steps shall consist of methods for developing the two-dimensional sketch model, which may possibly contain perspective, into a three-dimensional model using virtual tools, a suitable means for the conceptual designer. The experience gained by the conceptual designer working with virtual sketches is to supply the basis for the drafting and implementation of such methods. Ways to take advantage of shading in order to specify a spatial direction (Rockwood 1997) or to "slip" the sketch over a pre-modelled basic structure are currently under consideration.

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