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3D geometry reconstruction from orthographic views: A method based on 3D image processing and data fitting

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A B S T R A C T

Industrial esthetic designers typically produce hand-drawn sketches in the form of orthographic projections. A subsequent translation from 2D-drawings to 3D-models is usually necessary. This involves a considerably time consuming process, so that some automation is advisable.

Common approaches to this "reconstruction problem" start directly from "exact" 2D vector representations or try to vectorize 2D raster images prior to the reconstruction phase. These approaches, however, typically fail to deal with free form geometries like the ones commonly found in esthetic industrial design.

This work presents a new methodology suitable for free form geometries, comprising the generation and processing of a 3D voxel image obtained from a hand drawing, the creation of a set of 3D curves fitting the voxel image and the automatic generation of surface patches on the resulting curve network.

Several case studies are also presented in order to emphasize and discuss strengths and weaknesses of the proposed method.

1. Introduction

Computer Aided Design systems are deemed to be essential for all the phases characterizing the design and the development of a new industrial product. However, especially for products characterized by a strong stylistic content, handmade drawings are often preferred to CAD software packages.

In the early stage of the development of a new product, esthetic designers typically produce a rich set of sketches (usually in the form of orthographic projections) to develop and communicate their ideas. Product-managers often have to select stylistic alternatives based on a set of hand-drawings depicting possible solutions. However, it is much more effective to base the selection on a virtual 3D model which conveys far more information. In fact, some hand-drawn alternatives are even "translated" into 3D models (and possibly rendered models) capable to provide a more realistic view of the object and to allow a deeper analysis of the design intent.

The translation process, involving a close interaction of esthetic designers and CAD operators in order to produce a CAD model carefully representing the designer's intent, is known to be considerably time consuming. Accordingly, the design alternatives available in the form of three-dimensional models result to be a very small subset of those developed by the designers (usually one or, at most, two).

The common methodology (Fig. 1) used to turn a set of orthographic projections into a 3D model starts from arranging the scanned images of the hand-drawn views on the correspondent orthogonal planes in a CAD software environment. Using such images, the CAD operator (often assisted by the designer) manually redraws the style lines in order to obtain the 3D wireframe model which is, eventually, used as a support frame for the definition of the final surfaces.

The automation of this process, i.e. the 3D retrieval from 2D drawings (known as "reconstruction problem"), is a key target for commercial software houses as well as a vigorous focus from an academic outlook.

Recently a set of software tools have been released by major software houses, like Dassault Systemes®, Autodesk® and PTC®, which support the CAD operators in some of the reconstruction process phases. These tools, however, entail a strong user interaction and only marginally speed up the process. In addition, most of them require as an input an "exact" set of 2D vector drawings (e.g. DXF or IGES files).

From the academic point of view, a number of works have been proposed since the first '70s, providing a series of methodologies for solving the reconstruction problem starting from an "exact" set

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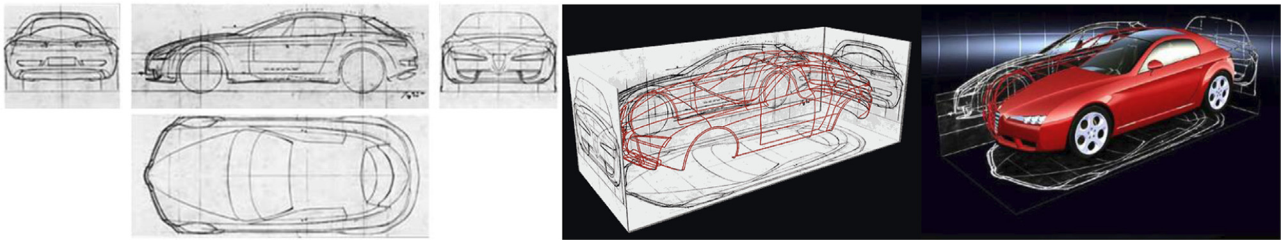

Fig. 1. Typical 2D to 3D "translation" process.
courtesy of Italdesign-Giugiaro

of 2D vector drawings. A dramatic boost to the research on this topic was provided by Wesley and Markowsky in their studies [1,2] which are probably the best known works among the researchers working on 3D reconstruction. Wesley and Markowsky provided a comprehensive set of guidelines for reconstructing 3D CAD model starting from orthographic projections. Their procedure is, still today, a milestone for almost every reconstruction study. Moving from these guidelines, many works have been developed, particularly referring to the 3D reconstruction from technical (industrial and/or architectural) vector drawings. Most of them have been conceived for retrieving 3D models starting from 2D straight edges, arcs or, at most, conics [3–7].

In addition, a few approaches have been developed dealing with the reconstruction problem based either on a set of 3D features which can be possibly found in a technical drawing (e.g. revolutions and extrusions) or on information coming from additional views, like cross-sections. The works which confront the reconstruction problem for curvilinear objects, however, usually present quite "tricky" approaches, generally involving a considerable amount of user interaction [8,9].

The most significant limitation to the approaches cited so far is that, as already mentioned, in all the cases the reconstruction is based on "exact" vector drawings and is limited to specific kinds of geometries.

Moving from these considerations, this work is meant to discuss a methodology to perform a quasi-automatic "translation" starting from a 2D scanned image of hand-drawn orthographic views.

Though this work and the ones mentioned above share the same goal (3D reconstruction from planar views), the starting point is completely different, since it consists of raster data from inherently inexact drawings like the ones, mentioned at the beginning of this section, coming from the initial design phases. Moreover, as detailed in the methodology description, the presented approach is applicable regardless of the typologies of geometries represented in the starting drawings, and is particularly well suited for free form geometries like the ones commonly found in esthetic industrial design.

The paper is organized as follows.

In Section 2 the reconstruction methodology is presented with reference to an exemplificative case study; in Section 3 additional reconstruction examples are presented in order to demonstrate the robustness of the proposed method; strengths and weaknesses of the presented approach depending on possible usage scenarios are also discussed; in Section 4 a few concluding considerations are drawn and possible options for future developments are briefly hinted at.

2. Methodology

As mentioned in Section 1, the proposed methodology is based on the processing of a single 2D raster image (e.g. bmp or jpg file) depicting the orthographic views of the object whose 3D geometry is to be retrieved.

The method is structured according to a set of phases which can be summarized in the following list.

1. Building a wireframe-like voxel cloud (3D image) representing a raster model of the original object.
2. Separating branches (3D labeling) of the resulting 3D image by means of approximate intersection detection.
3. Obtaining a 3D wireframe model made of spline curves starting from each labeled entity of 3D image and, successively, refining the obtained curves in the intersection zones.
4. Building a surface representation of the object by using surface patches attached to the spline curve network.

Each of these main phases will be detailed in the rest of this section, with reference to an exemplificative case study, by splitting them in procedural steps.

2.1. Building a wireframe-like voxel cloud (3D image) representing a raster model of the original object

Step 1 – The Image of the hand-drawn sheet depicting the orthographic views is acquired by means of a flatbed scanner (grayscale – 8 bit). The scanning resolution needs to be selected so that separate lines in the drawing remain separate in the resulting digital image (Fig. 2). In practice, this requires to have at least 3–4 "white" pixels separating each drawing line. Typically, an indicative resolution value can be 150 dpi for a line thickness drawing in the range 0.5/1.0 mm.

Step 2 – The orthographic views in the resulting image are identified and the sheet orientation is automatically compensated. In this step, it is assumed that the views are correctly arranged in the original drawing (according either to the first-angle or to the third-angle projection rule) and separated by means of continuous lines representing the mutual intersections of the planes on which the views are projected.

The sheet orientation is compensated by identifying the two orthogonal lines in the image characterized by maximum length (reference lines). This is done applying the well-known Hough transform to the thresholded image, where the threshold value t_s must be manually selected in order to obtain a clear binary representation of the drawing. First, a slope range of $\pm 10^{\circ}$ (0.1° step) with respect to the horizontal direction is selected and the best scoring line is considered (slope α_{h}); secondarily the best scoring line with a slope in the range $\alpha_{\nu^*} \pm 5^{\circ}$, where $\alpha_{\nu^*} = \alpha_{\mathrm{h}} + 90^{\circ}$. The slope of this new line is labeled as α_{ν}. The intersection point of the two lines is identified and is considered to be the origin O of the set of orthographic views (Fig. 3). Finally, the original grayscale image is rotated around O using bi-cubic resampling, so that the line characterized by the highest overall score results to be horizontal (either α_{h} or α_{v} is set to zero).

Afterwards, the separate views in the rotated image are identified by isolating the four quadrants delimited by the horizontal line and the origin O.