20

Reverse Engineering in combination with digital photogrammetry (ICEM SURF/ICEM PHOTO)

P. Bonitz
Kuesterstr. 8
ICEM Systems GmbH
D - 30 519 Hannover
Germany
Phone:(+49)511-9848-833
Fax: (+49)511-9848-810
e-mail: pb@icem.de

P. Krzystek
Smaragdweg 1
INPHO GmbH
D - 70 174 Stuttgart
Germany
Phone: (+49)711-2288-120
Fax: (+49)711-2288-111
e-mail: peter@inpho.de

Abstract

An online procedure which includes both the digitization of a physical model by means of a photogrammetric measurement system and the CAD based surface description, will be introduced. The CAD system creates class A quality surfaces.

Keywords

Reverse Engineering, digital photogrammetry, computer aided car body design, class A surfaces

M. J. Pratt et al. (eds.), *Product Modeling for Computer Integrated Design and Manufacture*

1 INTRODUCTION

The digitizing of a physical model is supported by ICEM PHOTO (a digital photogrammetric system) which provides measured data of the physical model. The result of digitizing the physical model with ICEM PHOTO is not huge masses of digitized points, but exactly the information needed by the designer to design the CAD surfaces. The digitizing can either be automatically applied along desired sections or manually along distinctive lines (character lines) depending on the curvature. This data is directly read in to ICEM SURF, a free-form surface modeler for class-A surfaces, where the measured data will be transformed into a mathematical (CAD) description of surfaces with accurate skin lines. Accurate skin lines are a criterion for highest surface quality in surfaces which have to meet aesthetic requirements, e. g. the exterior surfaces of car bodies. These car body surfaces are verified within CAD systems using curvature diagnosis, reflection lines, and other diagnostic functions. Considering the time it takes to create a perfect class A shape of the whole body, one can understand the wish of designers to keep as much of that detailed geometry description as possible when stylists make subsequent shape modifications. The designers want to adapt the existing surface description to the new digitizing data, which are often measured along profiles. The reverse engineering function of ICEM SURF offers exactly this possibility, if the shape modifications are relatively small in the range of millimeters (as compared to a part of the car body, e. g. a hood). During this adaptation the original surface structure and parametrization will remain (almost) unchanged.

2 DIGITAL PHOTOGRAMMETRY

2.1 General Remarks

Photogrammetry for a long time used to be well-known as an advantageous measuring technique in various industrial application fields. The first successful application of digital photogrammetry to the measurement of design car bodies was achieved by the InduSURF system
(Schewe 1987, Sorgatz 1988) This system is today still used successfully at VW and AUDI. However, the time-consuming development of the analog

photos and the mainly interactive measuring processes reduced the applicability and the acceptance. Since digital images became available by scanners and digital cameras, new industrial application fields have been opened because of the great potential of process automization. Image processing techniques can semi-automate or even fully automate measuring processes which have been slow so far because of the human operator. Furthermore, the instantaneous availability of digital images has also reduced the processing times significantly, so that even real time applications have become feasible. Digital cameras with large CCD sensors became available only some years ago. Recently, the still video camera DCS460 from Kodak were equipped with a large CCD sensor with 3000 x 2000 pixel at a pixel resolution of 9 μm. In the measurement of design cars, so far an accuracy of ± 0.10 mm has usually been required. These very tough requirements are mainly influenced by a traditional design philosophy which needs very accurate raw data from the physical model. However, design strategies are changing towards reduced accuracy requirements in the order of 0.5 mm or even 1.0 mm on the full scale model. In this case the design work is shifted to a modern CAD system using visualization tools. (Refer also to section 3.3.2.)

2.2 System Approach

The key idea of the system approach of ICEM PHOTO is to capture several digital images of the object of interest which sufficiently overlap the object (see Figure 1, left). The hardware of the system comprises two digital still video cameras DCS460 from Kodak which are mounted on a stereo base. A texture projector is installed between the two cameras to provide a random pattern by using a texture slide. The artificial texture is needed to successfully apply correlation methods in case the object of interest has no natural texture.

2.3 Operational Steps

The operational steps are basically the following:

The **camera calibration** (1) comprises parameters for lense distortion (radial and tangential), focal length and principal point. These parameters are derived in a highly redundant bundle adjustment using several images

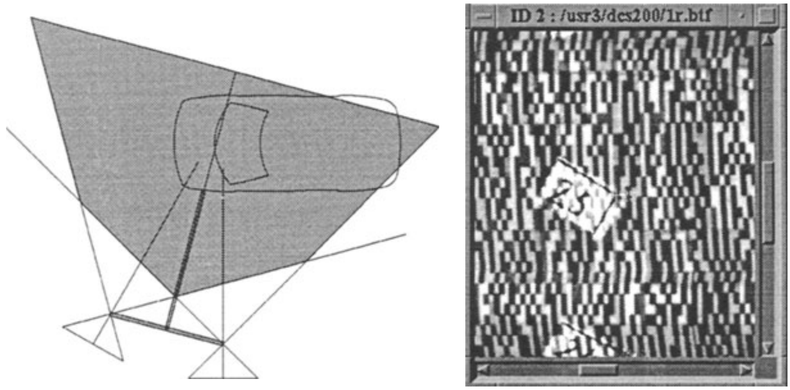

Figure 1: Left: Principle of stereo photogrammetry. Right: Texture and reference point.

which are taken from a flat calibration point field. The points are defined by black circular dots which can be automatically detected and precisely measured by means of least squares matching. The calibration procedure is highly automated and needs only initial interactive input. Once the calibration parameters have been determined they can be used for some time. It is recommended to check them periodically within a reasonable time frame of several weeks. The **preparation of the object** (2) comprises mainly the fixation of tags for reference points and tie points on the object. The 3D coordinates of the reference points have to be measured with a suitable 3D measurement system (e.g. CMM). These points provide the scale and the referencing with respect to the model coordinate system. The tie points are to be measured only in step (5) in the images. They are necessary to accurately tie up the images in the overlapping areas (Gruendig/Buehler 1985). Eventually, the surface of the object must be tarnished by using for instance an appropriate dulling spray in order to avoid critical reflections in case of shiny object surface. The subsequent **image capture** (3) is operationally quite easy because of the simplicity of the camera handle. The images are transferred via Laptop (**Data transfer** (4)), connected to the SCSI port of the cameras, to the SGI workstation for final processing. In the **photo triangulation** (5) the reference points and tie points are manually measured in the digital images. The result of the photo triangulation provides orientation parameters of the cameras (position and attitude) which are necessary

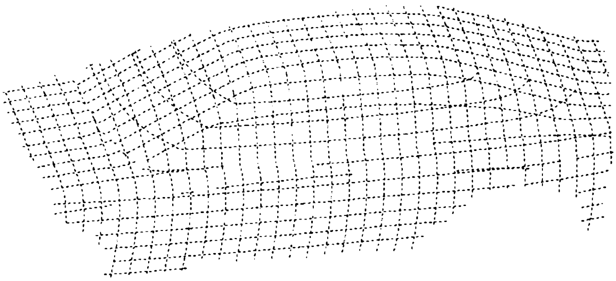

Figure 2: Raw data point sets, input for ICEM SURF.

to intersect any surface point from at least two image rays.

The photo triangulation (5) is followed by the automatic **surface measurement** (6) which only needs some interactive input for preparation. (For instance, some starting points, measurement areas and exclusion areas are to be defined.) After this preparatory part the automatic surface measurement can be initiated. All individual surface measurements (covering parts of the object to be measured) resulting from the individual stereo pairs can be linked to one consistent raw data set which describes the object surface. It can be **output** (7) in any **CAD exchange format** like VDAFS or DXF. Examplarily, we show profile raw data of a car body (Figure 2).

2.4 Accuracy Aspects

For a short accuracy consideration, let us presume a typical stereo camera configuration with a camera-to-object distance d = 1.3 m and a base-to-height ratio b/d of 1/2 (see Figure 1). The camera in use should be a DCS460 digital camera with a focal length of 24 mm. In this case and because of the used feature based matching techniques and applied least squares methods the standard deviation σ of a derived single profile point lays in the range of 0.1 through 0.3 mm. For detailed information please see (Krzystek 1991).

2.5 System Performance

The following table shows the time needed for the complete measurement of e. g. half a full scale design model. Half such an object could be covered by about 15 - 20 stereo models (= 30 - 40 images) presuming a camera-to-object distance of about 1.3 m and a base-to-height ratio of 1/2.

Step	time required
Object preparation	2 h
Image capture	2 h
Data transfer	1/4 h
Photo triangulation	4 h
Surface measurement	6 h
Total:	14 h

2.6 Benefits

- ICEM PHOTO is a handy and easily transportable measurement system.
- By using ICEM PHOTO the design model is only occupied for the short period of taking the images.
- The digital images document each step in the design process. Particular areas of the design model can be re-measured by ICEM PHOTO without using the design model.
- The cameras can be flexibly arranged in any position. Thus, certain areas of the design model can be digitized for special purpose.

3 REVERSE ENGINEERING

3.1 Terms and Phrases

Reverse Engineering means that a CAD model description is derived from a digitized physical model. We distinguish two tasks: *Surface description*

with and without a CAD reference model. The so-called *Suction Method* has been designed in ICEM SURF specifically for task 1 (raw data with a CAD reference model). Task 2 (raw data without a CAD reference model) is quite an ordinary job in ICEM SURF. However, the user can also apply the *Suction Method* in case of task 2. It is an additional tool for creating spatial shapes.

3.2 CAD Reference Model Exists

As an example we want to look at the outer surface of a door.
See Figures 3 to 4.

3.2.1 Task

The CAD model and the measured data of the geometric object are given. The sample points have been derived from the modified physical model. They have already been adjusted to the CAD model, see Figure 3. The crowning of the outer surface of the door was enforced. The newly digitized data is measured along x = const. profiles. It is displayed as dashed lines. The second picture in Figure 3 shows the x = const. sections as well as the digitized data having the same x-values. The deviations between the sections of the original surface and the newly digitized data are shown with a scaling factor of 10 in the third picture of Figure 3. The adapted CAD model is requested. The CAD model is to be adapted to the new raw data, preserving the surface structure as far as possible.

3.2.2 Solution: Difference Surface

Suction Method

Figure 4 shows the deviations after the door has been modified by the reverse engineering function using the same scaling factor.

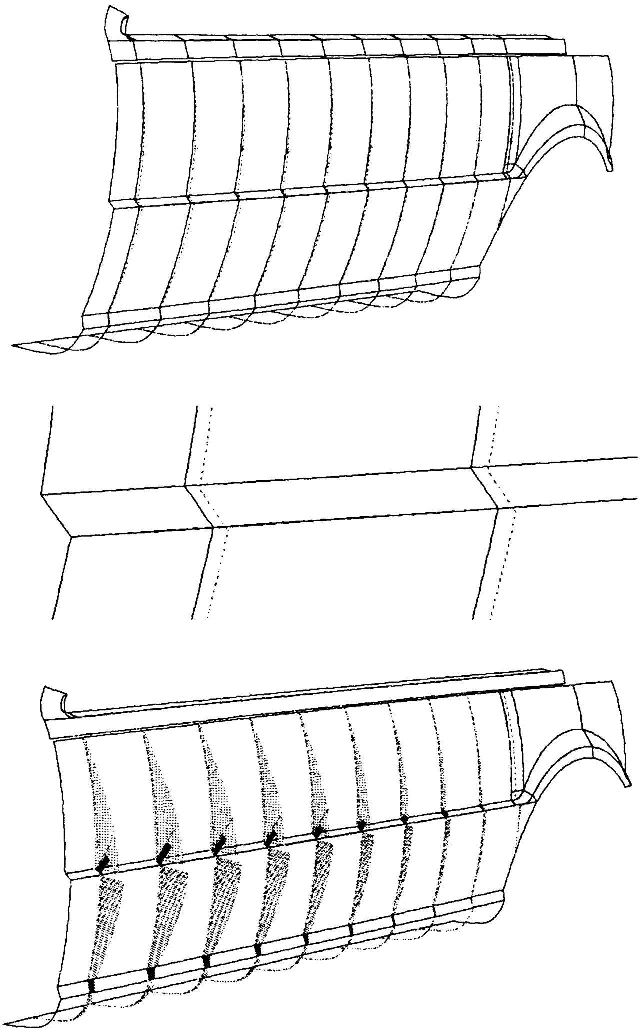

Figure 3: CAD model, original patches to be modified, and new raw data. State before using the reverse engineering function.

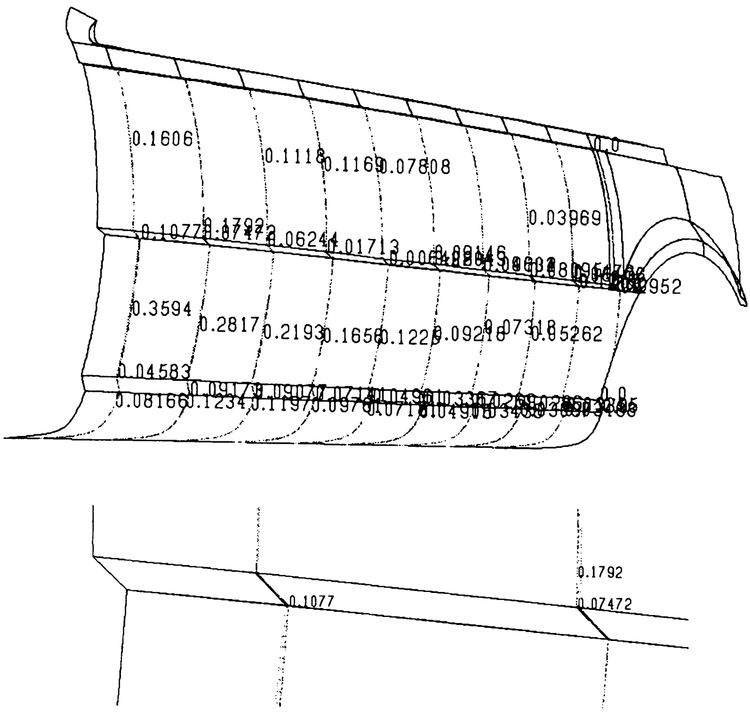

Figure 4: Diagnosis of the deviations. State after using the reverse engineering function.

The original patches are ***sucked*** to the digitized data, preserving the surface structure as far as possible. The ***suction principle*** is very simple. Patch by patch the given CAD model and the digitized data determine a difference surface. The difference surfaces DS will be added to the original surfaces OS. Thus, the resulting surfaces RS will be created: RS = OS + DS.

The resulting surfaces RS will be computed such that the parametrization of the original surface is preserved as far as possible. A satisfying result will be obtained only if the differences are relatively small and if the newly digitized data is distributed almost regularly across the original patches. If the original surface is composed of Bezier patches with continuous transitions (G^1 or G^2 transitions), the addition may violate the conditions. However, provided that the differences are small, the violations will be nearly invisible. If necessary, the continuous transitions can be restored using the appropriate functions of ICEM SURF. Nevertheless, adding the difference surfaces also works with large differences. It will, however, require manual corrections to close the resulting gaps and to restore continuity at the transitions. If you transform the Bezier patches into a B-Spline surface in advance, the continuous transitions will be preserved.

3.3 CAD Reference Model does not Exist

3.3.1 Task

Only the measured data of the geometric object is given. The CAD surface description is requested.

3.3.2 Ordinary Solution: Interactive Associative Surface Approximation or Construction

In the following we will describe the quite normal daily work of an ICEM SURF user. He is familiar with raw data and the errors they usually include. Randomly occuring errors do not seriously influence the surface description process. It is not important to create an exact interpolation through each measured point, but to recognize the global trend of the curvature within user-defined areas. As trend surfaces we usually use Bezier patches of the lowest possible order. These patches can be created by approximation (least square fit) of the point cloud after the user specified the edge curves. The algorithm used also takes into account the measured erroneous data between the four edges. Experienced users, however, prefer the interactive bending of initially planar patches to the mentioned approximation. The bending interactions for creating the desired spatial shape comprise definite movements of single or groups of connected control points with degree elevation.

The *Deviation Diagnosis* between patches and measured data will visualize a *random noise* of the measured data of approximately 0.1 to 0.3 mm, if you use the camera type mentioned above and a similar camera setup mentioned above in section 2.4. The process of describing a surface based on raw data point sequences with ICEM SURF will be successful if you keep in mind the following rules and principles: Please create a minimum number of patches having the lowest possible order and a segmentation which is exactly suited to the curvature characteristics of the whole geometry. This means that the patches should be as large as possible, and every patch in itself should have rather constant curvature values. Please create patch boundaries, if the curvature changes from flat (low curvature) to bent (high curvature). Please make use of all associative diagnostic functions to evaluate the shape of the created patches and the geometry as a whole. The process of creating surfaces from raw data with ICEM SURF avoids the time-consuming and difficult iterative process of creating curves from raw data and surfaces from curves. Using ICEM SURF you may directly create patches from raw data. These patches can be modified using the control point modification functions and evaluated by the just mentioned diagnostic functions, leading to the initially mentioned accurate skin lines.

3.3.3 Additional Solution: Difference Surfaces

The principle of adding a difference surface can also be used for a mathematical description without having the CAD reference model. First, planar patches need to be designed in a suitable plane. The experienced designer will recognize the most suitable subdivision of the surface according to the rules presented in section 3.3.2. He will only determine the planar edge curves of the patches. Creating the planar patches from these edge curves is a routine task which can be performed automatically. The distances between the single points of the raw data point sequences (digitized data) and the planar patches in the direction of the plane normal will be computed to a total difference surface. Then we can use the suction method.

4 REFERENCES

Gruendig, L., Buehler, W. (1985) Zur Naeherungswertbestimmung und Buendelausgleichung von Konvergentaufnahmen. *Bildmessung und Luftbildwesen* **53** (6)

Krzystek, P. (1991) Fully automatic measurement of digital elevation models, *Proceedings of the 43rd Photogrammetric Week*, Stuttgart, 203 - 214.

Krzystek, P., Petran, F., Schewe, H.(1995) Automatic Reconstruction of Concept Models by using a Digital Photogrammetric Measurement System, *IAPRS*, **30**, Part 5W1, ISPRS Intercommission Workshop, From Pixels to Sequences, Zurich, March 22-24.

Schewe, H. (1987) Automatic Photogrammetric Car-Body Measurement. *Proceedings of the 41st Photogrammetric Week*, Stuttgart, 47 - 56.

Sorgatz, U.(1988) Das Geometriedatenerfassungssystem VWSCAN im CAE-Konzept, *VDI-Z* **7**, 38-46.