INTERNATIONAL DESIGN CONFERENCE - DESIGN 2004
Dubrovnik, May 17 - 21, 2004.

DESIGN 2004

CHEAP PHOTOGRAMMETRY VERSUS EXPENSIVE REVERSE ENGINEERING TECHNIQUES IN 3D MODEL ACQUISITION AND SHAPE RECONSTRUCTION

S. Gerbino, M. Martorelli, F. Renno and D. Speranza

Keywords: reverse engineering, photogrammetry, scanner 3D, digital camera

1. Introduction

This paper aims at verifying a procedure both for the acquisition and the reconstruction of 3D CAD models by combining Photogrammetry and Reverse Engineering techniques. This procedure makes use of a passive optical system and a photogrammetry-based software. Reverse Engineering techniques allow to get the digital duplication of a real object starting from a point cloud acquired with a 3D scanner from a point cloud by means of CMM (Coordinates Measure Machine) or optical systems. The use of CMM can ensure results very accurate (≈ 1μm), but shows two drawbacks: 1) the digitizing phase is very slow, and due to the high number of points a powerful computer is needed, 2) the high cost of the CMM.

Today, optical systems, like laser scanner 3D, are often used in RE applications. They allow to realize very fast acquisition with an acceptable smaller accuracy. Optical systems though less expensive than CMM, remains however too expensive. For this, the main target of the authors is to search a cheaper acquisition and 3D reconstruction process to get good results similar to results obtainable by means of common RE systems. The Photogrammetry methods allow to get the dimensions and the shape of a real object by means of three or more photos. In the literature there are very few studies on the applications of photogrammetry in industrial field, especially in the acquisition of small size parts of mechanical components. So, the innovative aspect of this paper is the analysis of the results obtainable in industrial applications (close-range photogrammetry of small components) by using cheaper technological resources, like a digital camera, and a software based on photogrammetry.
This work moves along four steps: first, there is a view of the photogrammetry and its applications, the system used and the analysis of a particular case study are presented. Last, results and conclusions on the procedure used are outlined.

2. Photogrammetry

Photogrammetry is the measuring technique of real objects by means of photographs. It is a non-contact measurement based on the principle of triangulation. So, it is possible to produce 3-D point measurements by taking photographs from at least two different positions. Photogrammetry was used for the first time in 1851 by the French officer Aime Laussedat (who developed the first photogrammetrical devices and methods, he is seen as the initiator of photogrammetry). Today, photogrammetry techniques are used in many fields like [Doneus 1996]:

- *Topography* (GIS, Map production)
- *Civil Engineering* (Building CAD Model reconstruction)
- *Architectural & Historical Preservation* (Sufficient data can be extracted from images of a historic object or building to completely reconstruct it in a 3D CAD environment for preservation or restoration purposes).
- *Quality Control* (Photogrammetry can also be used as a quality control tool for piping manufacturers. Any shape variations in the product can be handled at the manufacturer's shop where the work is performed at a more effectively cost).
- *Aerospace* (Tooling inspection, Reverse Engineering of parts by aftermarket fabricators).
- *Automotive* (Photogrammetry can be useful in measuring the effect of crash-tests),
- *Shipbuilding & Repair* (represents one of the main industrial application photogrammetry in the US. Most shipyards have adopted an advanced measurement technology in an effort to contain costs and further cut down the production cycle).

The photogrammetry techniques can be used in the manufacturing process in-line or off-line. They can be applied in the process of development of a product (research and development) [Sciammarella 2000]. Some companies use photogrammetry methods to generate a high accurate reference coordinate system especially for the measurement of very large objects. Steinbichler, a German company specialized in optical measurements uses the Aicon photogrammetry system, based on coded targets to be applied on the object or all around it, which guarantees very accurate measurements and offers high freedom when digitizing large and complex objects (e.g. 1:1 car model with an overall accuracy of 0.15 mm) [Steinbichler 2003]. The output of a photogrammetric process can be: 3D points coordinates, topographical maps, rectified photographs (*orthophoto*).

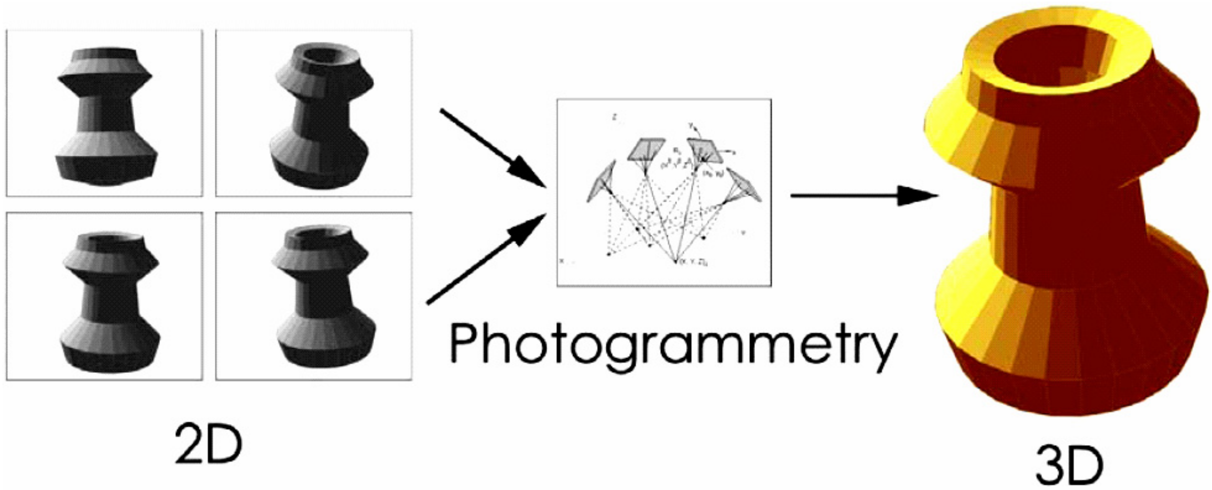

Figure 1. [Geodetic 2000] – Representation of a photogrammetry process

Photogrammetry techniques can be classified as follows (Figure 2):

Far-range photogrammetry (areas of m^2) is used to produce topographical maps, to reconstruct the shape of buildings, and so on.

Close-range and *very close-range* techniques are preferred for the industrial applications technique [Leifer 2003]. In this case the dimensions of the physical object and of its features can vary between 1 cm^2 and 1 mm^2. In this paper, a particular case study is examined by means of a close-range photogrammetry.

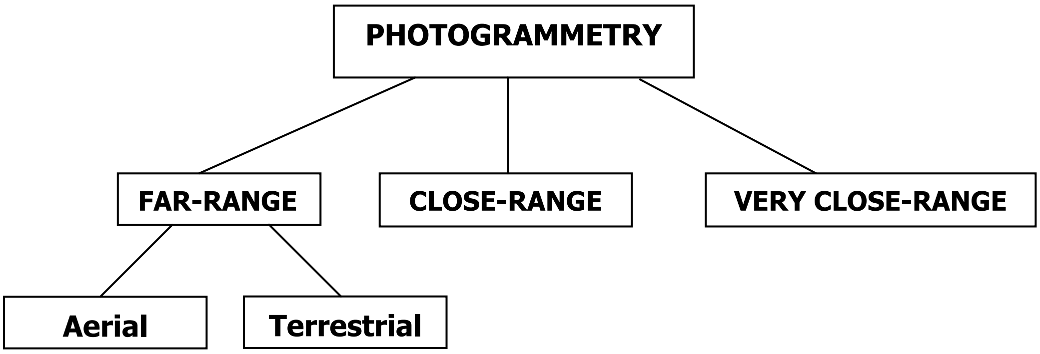

Figure 2. Classification of Photogrammetry techniques

2.1 System and software

Passive image-based methods (e.g. photogrammetry or computer vision) acquire 3D measurements from single images, they use projective geometry and they are very portable [Remondino 2003]. The system used is based on a digital camera (4 Megapixel resolution), a Photogrammetry-based software (*Photomodeler*), and a post-processing CAD software (*Raindrop Geomagic Studio*). Particular attention is to be used setting the process. The camera is to be placed on a tripod. The environment must be fairly light. The quality of the images utilized for the reconstruction is a basic requirement to get the best results with the photogrammetry technique. The better the photo the better the results. So, high resolution pictures are needed (min 1200x1900 *pixels*). Photogrammetry works well if some tricks are adopted such as white background, coded target on the object, pictures taken at every 30-40 degrees.

2.2 Camera calibration

It is very important for the reliability of the whole project [Tangelder 2003] that the lens focal length and the lens distortion, can be obtained by calibrating the camera by using the calibration pattern provided with Photomodeler.

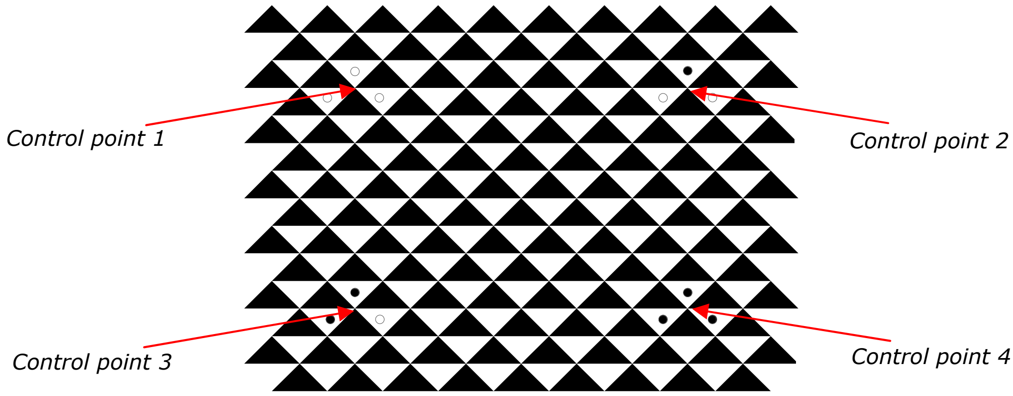

Figure 3. [Photomodeler 2002] - Calibration pattern

The calibration process works if six or more pictures are taken from different angles of a dense point grid. The Camera Calibrator needs the distance between control points 1 and 4 on the projected or printed pattern (scaling phase). It is important to highlight that the pattern should fill as much of the photograph as possible [Photomodeler 2002]. The user should be careful to include in each picture all the control points.

2.3 Accuracy

The photogrammetry approach is commonly considered not very precise. With CMM systems it is possible to obtain measure points with accuracy near μm. Instead, by using a Photogrammetry-based approach it is quite normal to get accuracy lower than 1mm, but special tricks might be adopted to acquire points with higher accuracy. So, a close-range technique may be a suitable solution for a model measurement and/or reconstruction, if a very high precision isn't required. Photomodeler offers the possibility to get accuracy of the object size till 1:2000 or higher so that for an object with a 10m longest dimension, and can produce 3D coordinates with 5mm accuracy at 95%. If other factors are taken care of good geometry, good camera calibration, it is possible to achieve 1:25.000 or higher accuracy in a project that is all or substantially all done with particular tricks.

3. Case Study

To evaluate the adaptability of the photogrammetry in the industrial field a test on some components of a car seat skeleton has been done. Figure 4 shows on the left the whole car seat skeleton analyzed whereas on the right the component tested is depicted. This component was firstly acquired by a laser scanner with high accuracy (Vivid Minolta 900) and reconstructed by Geomagic Studio 4 software dedicated for Reverse Engineering applications.

(a)

(b)

Figure 4. Whole car seat skeleton (a) and the tested component (b)

The CAD model of that object (figure 5) is the master model used to test the goodness of the photogrammetry acquisition.

This kind of physical object represents a difficult case study due to its curvatures and its features. So, a complete CAD model reconstruction it is hard to obtain in Photomodeler environment, but it is possible to use photogrammetry methods as digitizing and measures tools.

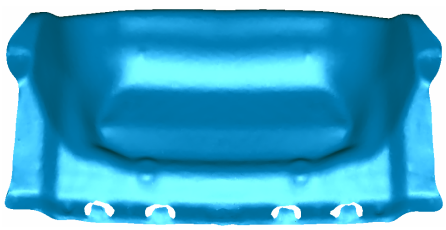

Figure 5. Seat CAD model

Figure 6. Seat with targets

Some targets (∅10 mm stickers) have been used to make easier the acquisition of specific points on the main geometric features of the object [Uffenkamp 1993].

4. Results

The output of this Photomodeler procedure is a point cloud (160 points). The several tests made show an average error of ± 0,58 mm. The maximum error is 2,2 mm (red point in the figure 7). In particular, the value of the average error is good. The maximum error (red point in the figure 7) is located in the highest part of the seat. The "cyan" and the "yellow" points show a typical error caused by the high curvature of the seat in those points. By taking some optimized additional photos of the seat it will be possible to optimize the error values.

So, these results are going to be improved by means of other trials and some tricks. In particular, will be possible to obtain better results improving the quality of the photos and using Photomodeler Sub-pixel Target Marker tool. It allows to mark with higher accuracy the centre of a target improving the measuring process. During the 3D Processing, points with "sub-pixel" characteristics have a tighter precision set (smaller standard deviation errors). These enhancements will produce an error reduction that will be analyzed in next publications.

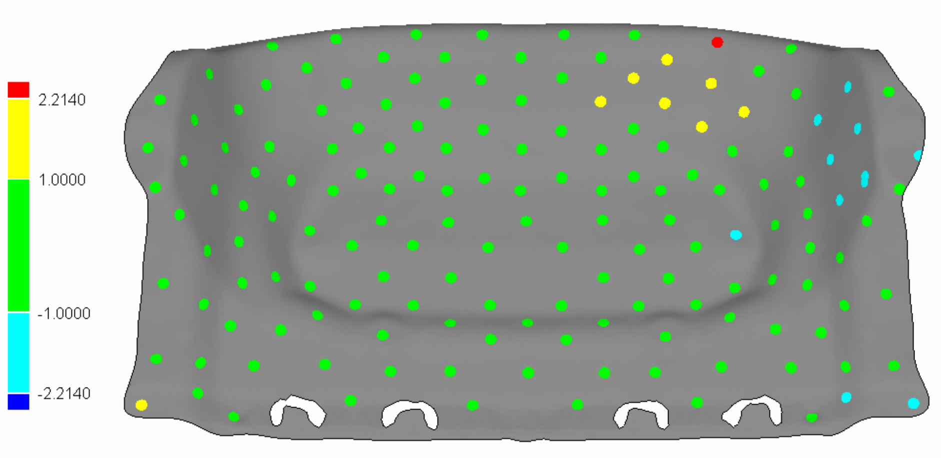

Figure 7. Comparison between CAD model and Photomodeler Point cloud

5. Conclusions

The results obtained are encouraging referring to the whole process simplicity and rapidity. The typical RE process, often, involve an expensive and slow process for the 3D model acquisition and the shape reconstruction. By means of a photogrammetric process, instead, the errors can be very small by means of cheap tools in industrial applications on mechanical components. The Photogrammetry methods can be powerful alternative techniques in the CAD model reconstruction of small real objects. At present, it is possible to get interesting results in many fields and applications, even in the industrial sector. In a short time, the accuracy of photogrammetry tools and methods will be improved and will allow the analysis of any features to be conducted obtaining reliable and accurate data.

Acknowledgements

The authors want to thank Ing. Stefano Papa for his contribution, his technical ability especially for providing skilled advice.

References

Doneus, M. , "Aerial archive", http://www.univie.ac.at/Luftbildarchiv , 1996

Geodetic Services. Inc., "Basics of Photogrammetry", http://www.geodetic.com, 2000

Leifer, J., "A close-range photogrammetry laboratory activity for mechanical engineering undergraduates", 33rd ASEE/IEEE Frontiers in Education Conference, November 5-8,2003, Boulder, Co.

Photomodeler Guide, Eos Systems, Vancouver, BC, Canada. http://www.photomodeler.com, 2002

Remondino, F., "From Point Cloud To Surface: The Modeling And Visualization Problem", International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV-5/W10, 2003

Sciammarella, C. A., "Industrial Applications of Optical Techniques that Measure Displacements", http://www.sciammarella.com.
Steinbichler, H., "Optical 3D Scanning and Industrial Applications", Atti del IV Seminario Italo-Spagnolo "Reverse Engineering Techniques and Applications", June 3 2003, 3-14
Tangelder, J.W.H., Ermes P., Vosselmann G., van den Heuvel F.A., "CAD-Based photogrammetry for Reverse Engineering of Industrial Applications", Computer-Aided Civil and Infrastructure Engineering 18 (2003) 264-274
Uffenkamp, V., "State Of The Art Of High Precision Industrial Photogrammetry", Proceedings of the Third International Workshop on Accelerator Alignment, Annecy, France, October 1993.

Fabrizio Renno, Ph.D. Student
University of Naples, Federico II
Department of Progettazione e Gestione Industriale
P.le Tecchio, 80 – 80125 Naples, Italy
Telephone: +39 081 7682457, *Telefax: +39 081 7682466*
E-mail: fabrenno@unina.it