TOWARDS CAD/CAM SYSTEMS: 3D MODELLING THROUGH CLOSE RANGE PHOTOGRAMMETRY AND SOFTWARE APPLICATION DEVELOPMENT FOR PLANAR PATTERNS COMPUTATION

P. Arias [1], J. Armesto [2], J. Vallejo [3], H. Lorenzo [4]

1. P. Arias, Department of Natural Resources Engineering and Environment, University of Vigo, 36208 Vigo, Spain; e-mail: parias@uvigo.es
2. Dep. Natural Resources Engineering and Environment, University of Vigo, 36208 Spain; e-mail: julia@uvigo.es
3. Dep. Expresión Gráfica y Proyectos, University of País Vasco, Spain; e-mail: eppvamaj@bi.ehu.es
4. Dep. Natural Resources Engineering and Environment, University of Vigo, 36208 Spain; e-mail: hlorenzo@uvigo.es

ABSTRACT

This paper shows a semi-automated methodology to obtain 3D CAD models of objects with doubly curved surfaces and a custom application is developed that compute the corresponding planar profiles which are needed in CNC manufacturing systems. The 3D modelling is performed by close range digital Photogrammetric techniques; several methodological considerations are presented that allow obtaining high accuracy results and minimize processing time. Furthermore, the computation of the planar patterns is based on the solution of an optimization problem that takes into consideration the geodesic curvature of the surface of the isoparametric curves. Through this application an optimized planar pattern is obtained automatically.

Keywords: 3D modelling, Digital Photogrammetry, complex surfaces, cutting profiles.

1 INTRODUCTION

In several industrial applications, the manufacturing of curved shell structures by forming shaped pieces of thin sheets of flat material is needed and CNC machining together with CAD/CAM systems are becoming one of the largest areas of expansion and renovation in this kind of manufacturing systems [2] [3]. But the implementation of CNC cutting systems in manufacturing processes from flat sheet material becomes a non-trivial task when complex geometries are accomplished, since difficulties arise from the definition of the most adequate shape of the planar profiles, which are essential to plan the corresponding cutting trajectories. Further a prior stage might be carried out consisting of digital recording and modelling, in order to get an accurate knowledge of the prototype geometry. Either the accurate 3D modelling or the development into planar profiles procedures are key tasks for the automation and the reliability of this kind of manufacturing process concerning complex curved surfaces.

In recent years, research efforts involving digital modelling of complex shaped objects in the industrial manufacturing field have been aimed at terrestrial laser scanning technology. However, surface reconstruction from random scanned data usually requires a complex time-consuming reconstruction process and significant amount of computation [5]. These considerations have leaded this paper to focus on the feasibility assessment of Close Range Digital Photogrammetry in the 3D modelling of objects with a complex topology and to develop an automated procedure for computation of the corresponding 2D profiles. A digital monoscopic photogrammetric system has been considered preferable for testing since factors such as cost of equipment, flexibility, simplicity and time needed for data processing are important enough to consider these systems more feasible in industrial applications in terms of cost-efficiency balance than stereo vision techniques or single image processing procedures. A custom application is developed that implements an efficient algorithm for the planar development of the obtained CAD model. It automatically outputs a CAD neutral file, which includes the definition of the optimum cutting profiles of the curved surfaces. This procedure is tested on a wooden sculpture which has either simple developable surfaces or doubly curved surfaces.

2 METHOD

2.1 3D modelling: photogrammetric procedure

A digital calibrated camera, Canon EOS 10D, 6,291,456 pixels CCD resolution is used. The sculpture is placed on a supported base covered by a 10 cm plan grid. A grid of dots set 5cm apart from one another is also projected over the doubly curved surfaces. Photograms are taken all around the object from a distance of 1 metre, keeping the convergence of rays at 40º to 90º. A convergent bundle adjustment is applied to the whole network (see [8] for details). The vertices of the linear edges of the object and the dots projected over the doubly curved surfaces are manually restituted in order to achieve the maximum accuracy. Non-Uniform Rational B-Spline curves (NURBS) are used to describe non-straight edges. A Delaunay triangulation is performed for the boundary vertices and the inner points which were obtained by restitution of the projected dots. The triangular meshes are then smoothed in order to get a better fitting with the original surface.

The accuracy of the resulting 3D model is difficult to know when the real shape of the object is unknown, a common circumstance when a part or prototype needs to be modelled. But when the camera is precisely calibrated, as in this case, errors can be considered to be caused exclusively by the orientation and restitution processes. So errors derived from the final bundle adjustment are taken as an indicator of the accuracy of the resulting model.

2.2 Surface flattening method

The procedure implemented here is based on the Azariadis and Aspragathos method [12].

Mesh definition

The mesh development procedure that is applied in the second stage is based on the flattening of one of the families of isoparametric curves. Therefore, the surface is accurately approximated by a set of plane triangular elements that are homogeneously distributed. This means that their vertices are placed at the intersection of a u-isoparametric curve and a v-isoparametric curve of the x = f(u, v) surface. Each strip of triangles is defined between two u- or v-isoparametric curves that are approximated by the set of triangle sides with vertices on the same curve.

Isometric mapping of a surface curve with geodesic curvature preservation

The second stage consists of an initial estimation of the mesh development. One set of isoparametric curves is developed preserving the length of the curve between each two points (isometric map) and the geodesic curvature. This criterion is essential because it guarantees the uniqueness of the resulting planar curve. The flattening procedure of a curve C lying on a surface requires the approximation by a finite set of points C_i taken on the curve. The tangent plane T_i and the normal vector N_i to the surface has to be known at each of these points. The curve C is isometricly mapped onto a planar curve C* making the chord lengths of C* the same as the distance between the corresponding points of C. Geodesic curvature of C is preserved at each intermediate point C_i if we keep the angle $?_i$ between two successive chords (C_{i-1}^* , C_i^* , C_{i+1}^*) of the planar curve C* the same as the angle defined by the projections onto the tangent plane T_i of the segments (C_{i-1} , C_i , C_{i+1}).

In the triangular mesh of the surface, the sides of the triangles that join the vertices lying on these curves approximate the u- and v-isoparametric curves. The first estimation of the developed mesh is obtained applying an isometric map to these lines with geodesic curvature preservation. By carrying out this procedure, developable surfaces are flattened without distortions, while a distorted flattened mesh is obtained in the case of doubly curved surfaces.

Reduction of the distortions using an energy based method.

The flattening of the surface approximated triangulation may be expressed by the same procedure applied to the mapping of one curve. Isometric mapping requires the preservation of the distances between pairs of nodes measured on the 3D mesh. The fact that each node of the triangulation lies on the crossing point of two u- and v-isoparametric curves of the surface has to be taken into account. Preservation of the geodesic curvature at each node of the mesh requires the angle to be preserved between the projected segments of each one of the isoparametric curves and also the relative angle between them.

If the surface is doubly curved, it is not possible to preserve the geodesic curvatures and the isometric mapping, therefore the planar development of the mesh will contain an error. To estimate this error an energy function is proposed. This function combines two main error components. The first error term estimates the error caused by the difference of distances between the nodes in the 3D mesh and the corresponding nodes in the planar development. The second term estimates angular distortion between the isoparametric curves at each node.

3 RESULTS

3.1 3D modelling: photogrammetric procedure

The employment of a plan grid as support base for the object simplifies the processing stage, since identification of points on a 2D surface is significantly less affected by visual perception errors than the identification of 3D vertices. The generation of the 3D surface model through digital monoscopic photogrammetry has shown to be a straightforward, fast and reliable method when developable surfaces are surveyed. In the case of complex curved surfaces, the employment of the projected grid of dots has shown to be a simple and affordable system that provides high accuracy results (see table 1). Nevertheless it might be pointed out that the effectiveness of this system is highly dependant on the size of the object, since the larger it is, the further away the dots might be projected from, involving larger projected dots within the surface, and consequently, higher errors in the restitution stage.

Table 1. 3D model accuracy assessment: vertices position error (95% confidence) in X,Y, and Z axes, Root Mean Square (RMS) error and Maximum Residual error.

	X (mm)	Y (mm)	Z (mm)	RMS residual (pixel)	Residual.max. (pixel)
Average	0,2	0,2	0,2	3,6	5,4
Maximum	0,3	0,4	0,4	13,8	16,5

2.2 Surface flattening method

A custom application has been described and implemented that obtains the planar development of surfaces with a double curvature. Starting from the CAD definition of the surface, the application generates a CAD neutral file with the shape of the cutting profile that is needed for the machining processes of the metal sheet. Table 2, showing the evolution of the relative value of distance deformations and angular distortions in successive iterations, illustrates the effectiveness of the implemented method.

Table 2. Results obtained during the error minimization process of the flattening method applied to a doubly curved surface.

Iteration	Distance deformations (%)		Angular distortions (%)		Total error
	Medium	Maximum	Medium	Maximum	
Initial value	1.2535	33.4477	0.0994	1.8206	1.3529
1	0.1688	2.9025	0.159	2.0219	0.3278
2	0.0881	0.6932	0.0772	0.4116	0.1653
3	0.0831	0.5025	0.0663	0.3744	0.1494
4	0.0827	0.529	0.0645	0.339	0.1473

4 CONCLUSIONS

An approach to the planar cutting profiles optimization and computation, involving objects with complex surfaces, is presented in this paper. Firstly, a 3D CAD model is obtained through digital monoscopic photogrammetry. Some methodological and computational considerations have been made to optimize the reliability of results. Secondly, a surface flattening method, based on isometric mapping and geodesic curvature preservation, is implemented. Finally, an iterative energy based optimization procedure is applied that minimises distortions in the final planar profiles.

Two main contributions should be highlighted. Firstly, digital photogrammetry has shown to be a feasible and affordable tool in the accurate 3D model generation of complex objects; note that both of the aspects of feasibility and affordability are decisive factors in the accomplishment of automated manufacturing processes. In second place, the proposed surface flattening and optimization methods have been proven to be effective and highly efficient in the case study.

REFERENCES

[3] K.P. Karunakaran, S. Agrawal, P. D. Vengurlekar, O. S. Sahasrabudhe, V. Pushpa, R. Ely, Segmented object manufacturing, *IEE Transactions*, Vol. 39 (2005) 291-302.

[5] H.T. Yau, R. K. Lee, C. M. Chuang, C. Y. Hsu, NC Tool-Path Generation Based on Surfel Models Constructed from Random Scanned Data, *Computer-Aided Design & Applications*, Vol. 2, Nos. 1-4 (2005) 567-576.

[7] P. Benko, R. R. Martin, T. Varady, Algorithms for Reverse Engineering Boundary Representation Models. *Computer Aided Design* Vol. 33, nº 11 (2001) 839-851.

[8] M. Cooper and S. Robson, Theory of Close Range Photogrammetry, In: Atkinson, K. B. *Close Range Photogrammetry And Machine Vision,* Whittles Publishing, Caithness, Scotland, UK. (2001) 9-51.

[12] P. Azariadis, N. Aspragathos, Geodesic curvature preservation in surface flattening through constrained global optimization, *Computer-Aided Design*, Vol. 33 (2001) 581-591.