Proceedings of

ODIMAP III

3rd Topical Meeting on *Optoelectronic Distance/Displacement Measurements and Applications*

University of Pavia, Italy, Sept. 20-22, 2001

Promoted by:

LASERS AND ELECTRO OPTICS SOCIETY

IEEE-LEOS, Italian Chapter

Organized by:

University of Pavia
Department of Electronics

AEI

Associazione Elettrotecnica ed Elettronica Italiana

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Combination of Optical and Mechanical Digitisers for use in Reverse Engineering of CAD Models

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Abstract - This paper describes a methodology for the reverse engineering of free-form surfaces, based on the integration of the measurement information from an optical digitiser and a co-ordinate measuring machine (CMM). The aim is to reconstruct the CAD model of objects of complex geometry with high accuracy and at the same time rapidly, exploiting the advantages deriving from the use of the optical and the mechanical sensors, with a minimum of human intervention. In the paper, the combined system is described, and an interesting application is shown.

1 INTRODUCTION

The reverse engineering (RE) process can be defined as the process of taking a physical model and creating a virtual computer model for downstream CAD/CAM applications. The goal is to retrieve the geometric form of physical objects, and to update the CAD models or replace a worn, broken or obsolete part that is no longer available from the original manufacturer. At any stage of the development phase, the designer can modify the physical prototype and draw back the engineering changes to the CAD model by digitising the surfaces, which had been re-designed. If this task is performed manually, it involves a great amount of time and is also prone to errors.

A common problem of those RE approaches using mechanical probes is the time-consuming and non-reliable manual digitisation process. The reconstructed CAD model depends on the knowledge and experience of the operator, and the final result depends on the first decisions in the digitising process [1].

Using vision systems, different problems need to be resolved, as the lack of precise control in the reconstructed surface CAD model and the difficulty of managing huge data sets especially with complex surfaces. These digitisers may be characterised by a redundant amount of data, often unsuitable for specific applications in RE [2]. In fact, most CAD/CAM systems are unable map and process such data files into surface models, especially when the 3D data are unstructured and the density of the acquired points does not meet the surface trend.

Methodologies for RE have received extensive attention in the last years and several works have been presented [3, 4]. In spite of several encouraging partial results in particular areas, a fully automated solution is still a goal. Thus, the development of integrated systems to reconstruct the mathematical model in commercial available formats and to save the overall modelling time using a minimum number of significant points, is still a critical issue for the success of RE process.

This paper describes an integrated reverse engineering method, which uses co-operative sensor integration between a vision system, and a CMM equipped with a touch probe [5]. Appropriate software has been developed. It is an intelligent interface between the digitising systems and the CAD environment, where complex surface forms can be easily reconstructed invoking the appropriate surface modelling routines. The whole approach enables to construct the functional curves in an intuitive and interactive way and to produce the final mathematical model reducing drastically the process time.

2 OVERVIEW OF THE METHOD

Two digitizers are integrated in the process. These are (i) an optical digitiser, specifically developed to perform fast acquisition of even large surfaces with accuracy within 100 micron; (ii) a co-ordinate measuring machine having a scanning contact probe. It is equipped with a software package dedicated to digitise and measure free-form surfaces.

The starting point is the acquisition of a number of clouds of points using the 3D optical system. Each one provides initial dimensional information of the object. They are then pre-processed by means of suitably developed procedures for the ordering and the adaptive sampling of the point clouds, in dependence of the surface curvature. Curves and surfaces are defined over the point clouds, by using specialised tools of the CAD system. A 'rough' CAD model of the surface is determined, to be used as start point for the digitisation step in the CMM environment. The a-priori knowledge of a 'rough' surface model allows an efficient programming of the scanning and digitising path of the CMM mechanical probe, with a reduction of the number of touch points and of the iterations needed to achieve the complete digitisation of the object. Then, the measured data are imported back to the CAD environment and used to produce the final, accurate CAD model.

A commercially available 3D CAD system (PRO/Engineer by PTC), equipped with a specific module for the reverse engineering process is exploited to merge the measurement information from the two digitisers.

3 THE OPTICAL DIGITISATION

Figure 1 shows the optical digitiser. A LCD projector projects suitable patterns of structured light on the target object, these are acquired, along a different direction with respect to that of projection, by a video camera. The deformation induced on the patterns by the object shape allows suitable light coding; high range and high resolution are achieved by using the combination of the Gray Code and the Phase Shift methods [6].

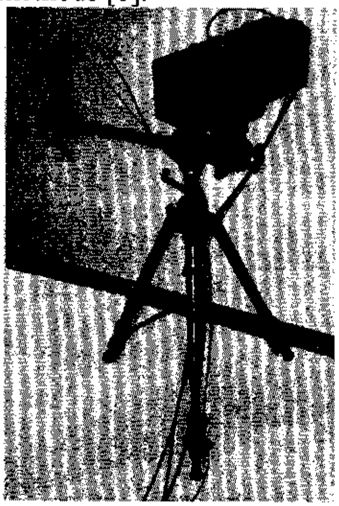

Figure 1. The optical digitiser

The measurement procedure allows the achievement of dense point clouds, expressed in the video camera internal reference system. Single views, ranging from (50 X 50 mm^2) to (350 X 400 mm^2) are acquired in 2 seconds. The point clouds can then be edited, visualized and merged to reconstruct the whole shape.

As an example, the range acquisition of the prototype of a turbine blade (60X20X30 mm^3) is shown. Figure 2 represents the effect of the fringe deformation induced by the object on one of the light patterns used to retrieve the shape information. Two views are sufficient to reconstruct the whole object shape. The resulting point clouds are then aligned in a common reference, as shown in Figure 3.

4 THE ROUGH CAD MODEL

The point clouds are then *massaged* and converted into organised data before being imported in CAD environment. In fact, a common problem in the reconstruction of surfaces is that some CAD algorithms need ordered point sets to reconstruct scan curves. Suitable software, called *Visual Point*, has been developed for the ordering of the points. It divides the clouds in a set of bands. In this way, the data from the optical system are automatically assigned to bands and ordered along different directions. This allows us to decrease the human intervention in the curves reconstruction. Figure 4 shows the scan curves in the y-direction automatically created by Visual Point. The organised points are then imported in the CAD system and used for reconstructing the functional surfaces. 'Style Curves' and 'Style Surface' options are selected.

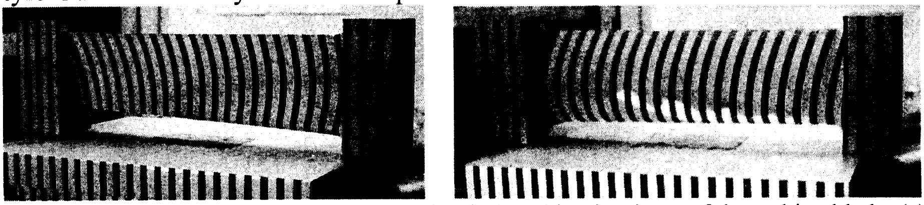

Figure 2. The effect of the fringe deformation induced by the shape of the turbine blade. (a) view at 0°; (b) view at 180°.

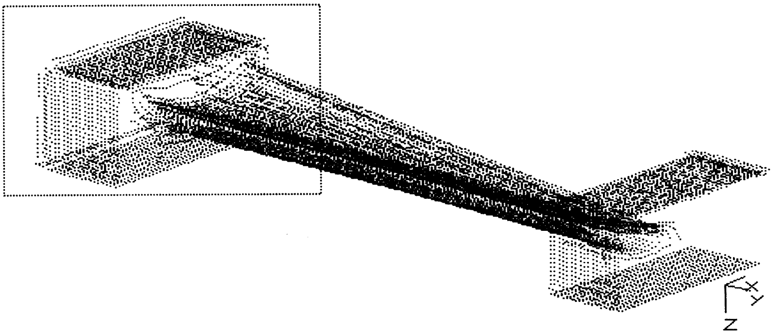

Figure 3. Alignment of the point clouds.

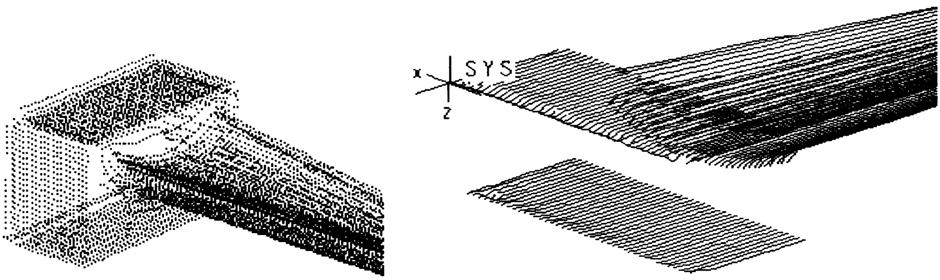

Figure 4. Reconstruction of scan curves. (a): zoom of the point cloud framed in Figure 3; (b) scan curves correspondingly determined.

The parametric surfaces are created by blending the curves along the chosen ordering direction. The surface information available in the rough CAD model is used to split the object in surfaces that are composed of patches on the basis of curvature changes. The usually long time spent to define small patches is not required, because the optimisation in the next step by means of the CMM does not need high accuracy in the rough model. In fact, it is more important that surfaces are not distorted, than they interpolate many curves.

5 CONTACT DIGITISATION AND FINAL CAD MODEL

The functional surfaces are digitised using the scanning area function of the CMM environment. The inspection process, which includes the definition of the measurement sequence, of the number of measurement points, of the number of probes and their configuration, is planned using predefined inspection plan functions available in the CMM software. By specifying the grid of points or the parameters of the scanning area, it translates the user command into the detailed steps necessary to drive the CMM in a grid-structured cycle. Surfaces are then digitised using the mechanical probe and the measurements are carried out until the fixed target tolerance is obtained. After the first initial digitisation, Bezier surfaces are automatically created in the CMM software using the acquired points. By analysing the deviations between nominal points (those on the reconstructed surface) and actual points (those acquired by the CMM), further refinement of the CAD model can be performed in order to obtain the required reconstruction accuracy. With a scanning step of 0.5 mm and a speed of 8mm s^{-1} the measurement cycle for each functional surface of the turbine blade was performed in less than 20 min. Figure 5 shows the CAD model of the turbine blade after one digitisation cycle. For the concave functional surface of the object, after one mechanical digitisation (1270 points), a maximum digitising error of 0.155 mm and an average error deviation of 0.025 mm were found. On the convex surface 1245 points were used and a maximum digitising error of 0.658 mm and an average error deviation of 0.019 mm were found. The resulting final CAD model is shown in Figure 6.

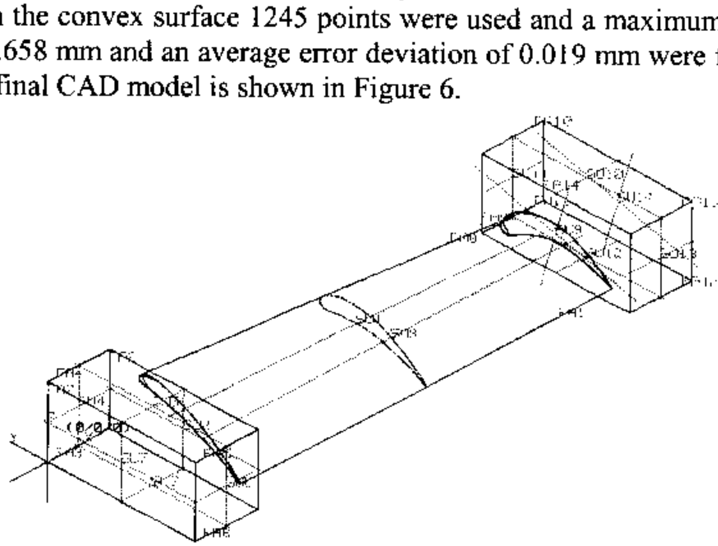

Figure 5. Partial reconstruction of the functional surfaces

6 CONCLUSIONS

Capturing shape and translating it into a mathematical model is a difficult task in the reverse engineering process, particularly when complex surfaces are involved.

The proposed method integrates the vision system and the CMM at the level of intelligent aggregation of the information. The absence of the physical integration of the two sensors is a strength of the methodology, as it results into a good level of flexibility of the optical head, and increases the typology of measurable objects. Moreover, the measurement characteristics of the CMM are not modified by the integration of the vision system, and, in principle, the use of a single vision system in conjunction with different CMMs is realistic, provided that the sensor has the characteristics of portability and easy calibration.

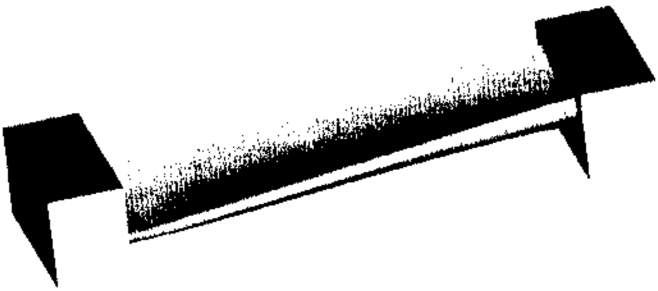

Figure 6. The accurate CAD model

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