MODERN DIMENSIONAL MEASURING TECHNIQUES BASED ON OPTICAL PRINCIPLES

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Abstract: Measurement systems based on optical principles, laser scanning and CCD cameras are able to acquire dimensional data in a non contact and very fast manner. This paper covers the individual measuring principles, the measuring result and their use in industrial applications (case studies) of the ATOS digitizing system and the TRITOP photogrammetry system.
Keywords: Optical Measurement Systems, Digitizing, Reverse Engineering

1   INTRODUCTION

The development of measuring systems based on CCD cameras for industrial use started ten years ago. At that time, Holographic Interferometry was established in research. This technique produces images of the object with fringe patterns representing the deformation of the object under load. Looking at these fringe patterns allows engineers to understand the behavior of the object under test. To achieve quantitative results in addition, CCD cameras interfaced to computers were used.

The same software modules developed for Interferometry could also be applied to fringe projection and Moiré experiments. Using these techniques, full frame digitizing was possible.

2   FULL FRAME DIGITIZING

The early digitizers used a fringe projector unit and a camera in a triangulation set up. From these images, the fringes are traced and a numbering information is allocated to each fringe. Then a starting point is selected and the position of the points on the traced fringe are calculated using triangulation routines. To obtain data for each picture element of the CCD camera (pixels), 4 images have to be projected with slightly shifted fringes (90 degree phase shift). Then from the 4 images, a phase value can be calculated for each pixel using a fast calculation routine.

To define the order of the fringes, additional images are needed. One possible technique is the "Gray coding", projecting a series of fringe pattern with doubled fringe width for subsequent projections.

In Interferometry, the interference fringes are considered equidistant as almost parallel rays are used and the deformation is very small compared to the observation distance. Using these assumptions, the triangulation equation is very simple. To compensate for errors due to central projection used in the fringe projector and the viewing camera, a calibration method has to be applied to derive a correction matrix.

These early digitizing systems proved to be useful for small and flat objects. If multiple views had to be added to digitize an object, the integration of the individual views was manual work. To overcome this limitation, the optical measuring units were attached to mechanical coordinate measuring (CMM) systems.

The calibration of this combined system turned out to be difficult and the accuracy could not be maintained. Thus the flexibility and the ease of use which came along with the optical digitizers was lost again.

2.1   Requirements for the Measurement System

Traditionally models were scanned on CMM systems, with tactile probes producing section data. This measurement data were gathered with good accuracy, but the set up and the measurement process was time consuming and cumbersome and only low density data were gathered.

A good and efficient method for scanning models with limited size is given by laser point scanners like the the system CyLan 3D with rotating the object and moving the laser beam step by step producing a set of section data describing the whole model. With the laser scanning method high

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density data with good accuracy are created. The limitations of the laser scanning method are in the size of the scanned model and the flexibility and mobility of the measuring system.

The requirements for an efficient digitizing system are therefore:

- high data accuracy
- high data density if necessary
- short measuring time
- flexibility and mobility

2.2 The Measuring Principle of the 3D Laser Scanning System CyLan

The distance measuring-principle of the laser scanning system CyLan 3D is shown in Figure 1.
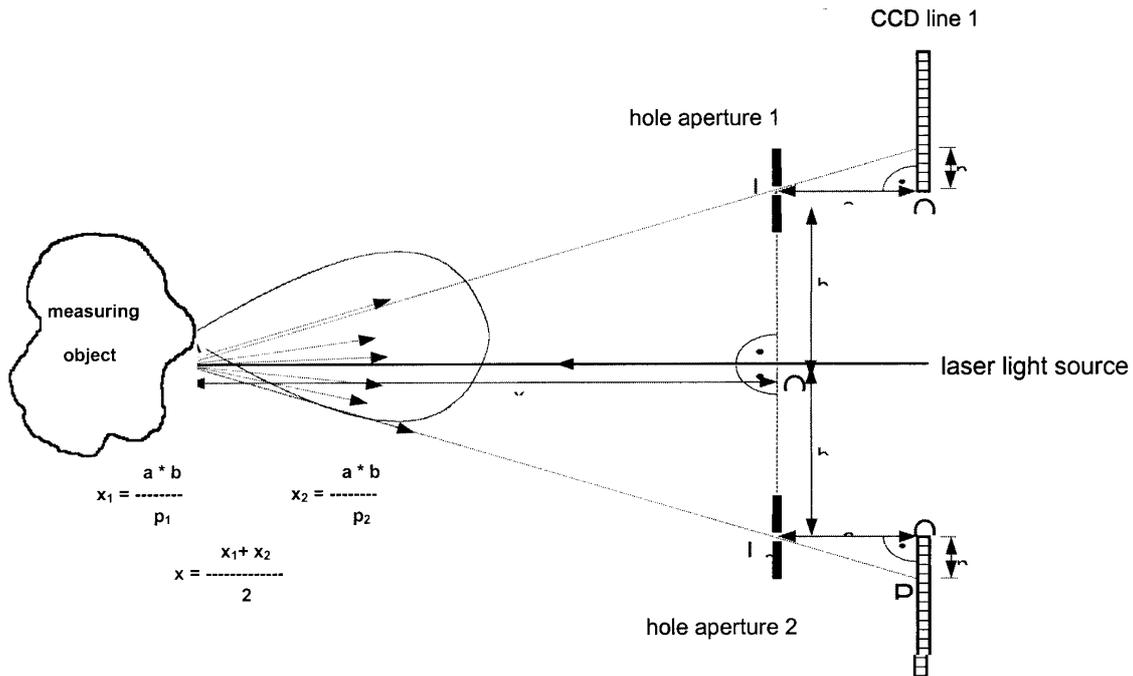

Figure 1. Distance measuring principle of the double point by point laser triangulation

The Object which should be scanned is rotating while the laser scan unit is moving step by step along the object. High speed measurement with 4000 measuring points per second is done with point by point laser triangulation and intelligent selection. With two symmetrical arranged receivers and average calculation it is possible to get high accuracy.

Figure 2. Three-dimensional Laser Scanner CyLan 3D
(a complete 4-axis device for objects up to 375 mm height and 350 mm diameter)

With the lager three dimensional laser scanner CyLan 700 it is today possible to scan objects within a diameter of 1200 mm and a height of 1400 mm.

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2.3 The Measuring Principle of the Optical 3D Digitizing System ATOS

The fringe projection sensor ATOS is based on triangulation: different fringe patterns using the phase shift- and the "Gray code" technique are projected onto the object and observed with two cameras.

Using efficient calibration methods, the digitizer is calibrated in 10 minutes. Then, during the measurement, the 3D-coordinates for each of the 1.300.000 camera pixels are automatically determined with high precision based on this actual calibration.
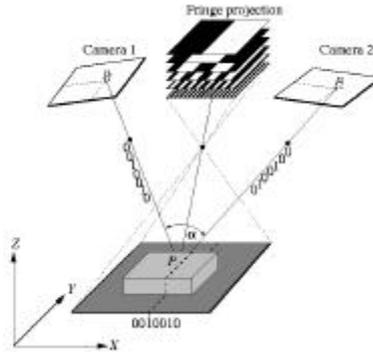

Figure 3. Principle setup of the fringe projection sensor

2.4 ATOS Sensor Heads and Measurement Ranges

A projection unit and two CCD-cameras are integrated in the ATOS sensor heads. Two versions are available from the shelf:

- The standard sensor (Figure 4, left) covers measurement areas from 100 x 80 x 80 mm^3 up to 350 x 280 x 280 mm^3 in one single view.
- The ATOS HR (Figure 4, right) covers volumes from 100 x 80x 80 mm^3 up to 800 x 640 x 640 mm^3 in one single view.

Figure 4. ATOS and ATOS HR

2.5 The Measurement process

The ATOS digitizer is positioned on a tripod in the free-hand mode (Figure 5) and a single view is recorded. For a complete measurement of a 3D object, multiple views have to be integrated into one set of data. To allow an automated transformation of the digitized data, reference markers are attached to the object and/or to its support. The ATOS digitizer detects these markers in their exact positions, together with the digitized data. Additional views are taken and automatically integrated into the existing set of digitized data and detected markers, if a minimum of three markers is previously defined. The measurement time for a single view with the ATOS HR sensor, capturing 1.3 million data points is approx. 15 seconds (ATOS: 440'000 data points in approx. 5 s).

Figure 5. ATOS HR Sensor in use

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The progress of the measurement is displayed on the monitor view by view. Details which are not captured can be digitized in a next shot.

The measurement volume can individually be adapted to the user's needs. The ATOS HR system can be set up to digitize e.g. in one view 600 x 480 x 480 mm^3 with 2 data points per mm and after changing the optics and a new calibration, (typically 15 minutes), digitize a measuring volume of 100 x 80 x 80 mm^3, with 12.8 data points per mm (325 dpi).

3   PHOTOGRAMMETRIC DETERMINATION OF THE REFERENCE MARKERS USING TRITOP

For big or complex objects, the integration of additional views into the existing set of data based only on the defined data is not accurate enough. For these parts, the position of the markers has to be defined accurately using TRITOP, the XL part of the ATOS XL system, before the digitizing starts.

Figure 6. Complete photogrammetric measurement system TRITOP

Figure 7. Image from a car with retroreflective markers, taken with the digital camera
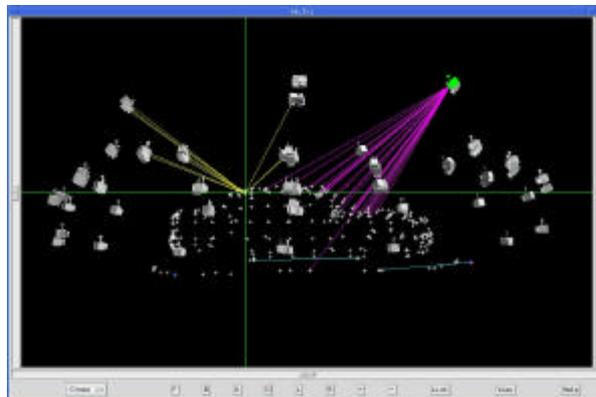

Figure 8. Complete photogrammetric evaluation, display of the camera positions and the marker position in a 3D viewing window using TRITOP

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The markers are applied onto the object to be digitized and some coded markers and a scale bar are placed in addition onto the object. Then the digital camera supplied with TRITOP is used to acquire images of the object from different viewing directions. After the images are taken, the data are downloaded to the computer and an automatic calculation of the object coordinates is started. First all markers are identified in their image positions and then their 3D positions are calculated very precisely using photo- grammetric methods. The marker positions are viewed in a 3D window and listed in a file. After this, the coordinate system of the marker data is defined to match the coordinate system of the object and the data are stored to be used in the ATOS digitizing process later. Figure 6 shows a complete TRITOP system with camera, reference targets, adapters, scale bars and computer.

4   APPLICATIONS

4.1   Surface Modeling

If a model is built to show the design intend, low quality data can be used as input into surface modeling. Then the design is re-defined in the CAD system. If good quality models and high quality digitizers are used, which produce ample data points and feature lines, then Reverse Engineering can be much more efficient. At present software modules are ready which are able to do an automated "fast Reverse Engineering" based on high quality input data. The goal is to get the time for Reverse Engineering down to the time which is required to scan the part. This fast generated surfaces will not be Class A, but it will allow a fast and efficient work in: Model Development, Quality Control, Packaging and Assembly studies, Engineering Verification and the Preparation of the Production. In addition these data can be imported in standard CAD systems. This will make digitizing and Reverse Engineering of a car body possible as a one day job and shorten the time to market drastically. Then, if the final part is defined, the Class A surfaces can be generated, based on the digitized data.
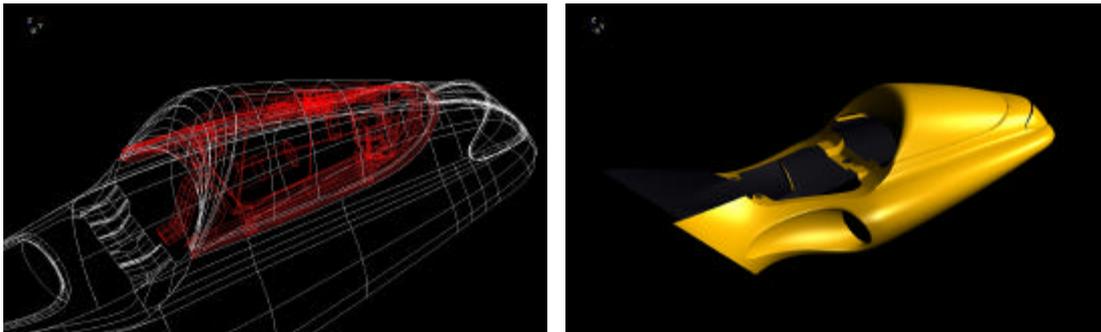

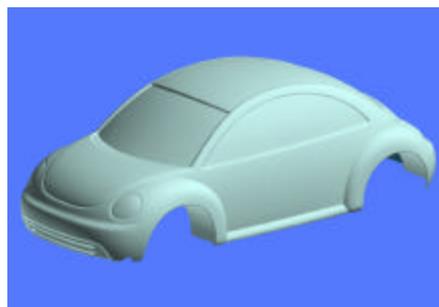
Figure 9. CAD-patch and shaded view

Figure 10. Digitization of a design study of the VW-Beetle (1:4) in shaded display mode

4.2   Quality Control

Quality Control based on digitized data and CAD data is simple. The main problem for this application is the availability of scanner data with high accuracy for a consistent Quality Control process. Usually the digitized data is best fit to the corresponding CAD or STL data and the deviation is calculated and displayed in a color coded scaling.

Figure 11 shows the mold of a fender digitized with ATOS. A comparison of the point cloud with the CAD data identifies the manually modified areas during the prototyping process. The digitized data is then used to modify the CAD data to represent the actual shape of the part.
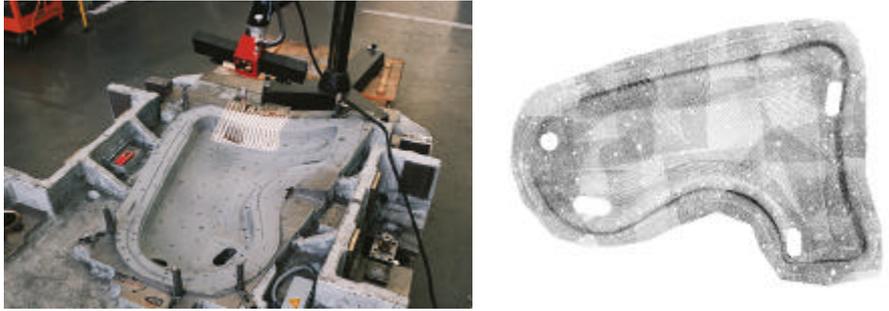
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Figure 11. Digitization of a fender mold and the corresponding point cloud

4.3   Rapid Prototyping

To input the digitized data into Rapid Prototyping systems, e.g. FDM, Stereo-lithography or Laser Sintering, polygon-meshes in STL-format are required. ATOS can post-process the digitized data into a surface STL format. Figure 12 shows the digitized Beetle (Figure 10) as copy created by LOM. This model can be used for reproduction by casting methods or to speed up the model development, the production or the marketing process.

Figure 12. A copy of the Beetle model using LOM-Technique

4.4   Milling on Scanned Data

For the model development, for visualisation and for verification, model have to be created. Using digitizers, different materials can be milled, based directly on the scan data of the ATOS digitizer (preprocessed point cloud or STL data). State of the art CAM-systems create milling trajectories for a three to five axis set-up. The result (Figure 13, right), however, does not reach the surface quality achieved with milling on CAD data, due to small imperfections in the scan data. In future, special Reverse Engineering software will preprocess the scanner data, extract the features and generate a fast CAD model which will have very good surface quality.
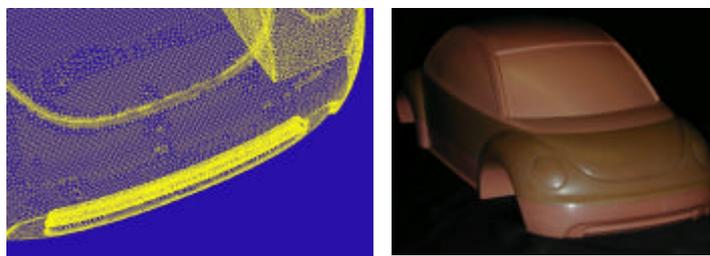

Figure 13. Polygonized triangle-mesh (left) and a copy milled out of clay (right) from a design model, digitized with ATOS

4.5   Animation and Virtual Reality

There is a big need in Virtual Reality to create very detailed digital models. For display, polygonized meshes which can be simply derived from good quality scan data is a good solution. For digital models which need animation, a CAD model is required. Today, this CAD request is the limiting factor for the use of digitizers in animation and Virtual Reality applications.

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Figure 14. Digitized toy figure

5   CONCLUSION

Efficient optical measuring systems and laser point scanners are established in automotive and aircraft industry, in consumer product design and manufacturing and in animation and Virtual Reality. First, digitizing was used in the design process, as an input to generate CAD data. Today, the biggest need comes from Quality Control. Production has to be consistent and the CAD data has to be up to date and available. Especially companies working with physical master models and in stamping, are using production tools with no exact CAD data available. In animation and in Virtual Reality, the need is to create objects fast and have them available for full 3D view and animation.

For all these needs, digitized data acquired at high speed and in good quality is the key to success. Since laser scanning and optical measuring techniques with post processing of the digitized data is established, Quality Control, RP and milling applications will have the highest benefit. In the near future, some new products will be available on the market which will have fast transition of scan data into CAD models available. This will make surface modeling and animation based on digitized data a very efficient tool.

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