NEW CONCEPT OF A PHOTOGRAMMETRY SYSTEM WITH ADAPTED “INTELLIGENT“ ILLUMINATION FOR 3D-SHAPE CAPTURE USING COMPUTERGENERATED HOLOGRAMMS

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Abstract: A non-contact measurement system, based on the principle of photogrammetry, developed at the Fraunhofer IPT, permits a highly exact 3D-shape-measurement of objects. Because of the limited depth focus of the projection lens used, the axial measurement range is reduced to only a few centimetres. In order to digitize the 3D-shape of technical objects of various dimensions, the structured illumination on the object surface must be in focus for each axial depth. The principle of holographic projection offers a crucial benefit, in order to project a sharp pattern in any plane. By applying computer generated holograms for projection of patterns, further depth information can be encoded. Only this allows the measuring of 3D-shapes in one step.

Keywords: photogrammetry, optical 3D-measurement, holography, structured illumination

1 INTRODUCTION

Today many enterprises try to integrate non-contact measuring systems directly into the manufacturing process in order to obtain information on manufactured product quality as soon as possible. Thereby, such highly automated measurement systems have to be applicable for a component spectrum as broad as possible with the guarantee to achieve a large measuring volume combined with high measuring accuracy for two- and three-dimensional features. Today the existing optical measuring systems fulfill the expected measuring rate and the measuring uncertainty in an insufficient way. Therefore they are only used in low scope.

In the following, a new technology for 3D-shape measurements is described. It is based on the combination of photogrammetry and holography. Crucial benefits concerning the enlargement of the measuring volume as well as shorter gate times can be achieved in this type.

Figure 1 shows the experimental setup:

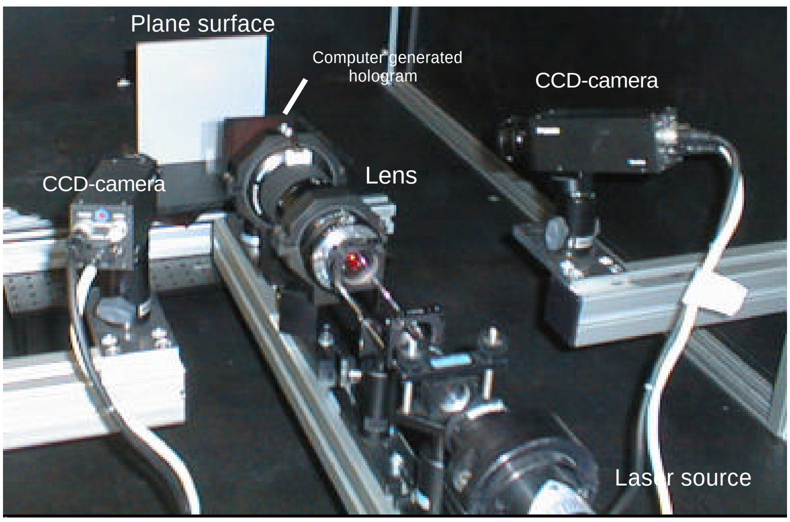

Figure 1. Experimental setup

2 PHOTOGRAMMETRIC MEASUREMENT PRINCIPLE

With active multi-picture photogrammetry, points of the object surface are signaled by the projection of patterns. They are observed with cameras from different orientations. After the camera positions and orientations have been calibrated [Sch96], the 3D-coordinates of the object points can be calculated by means of point triangulation. With the method presented here, feature-based patterns are projected on the object surface so that the measuring system is independent of the presence of a surface texture [Sch96], [Bey93]. Such feature-based pattern are for example ellipses or cross grids (figure 2).

The benefits to project these feature-based patterns holographically are as follows.

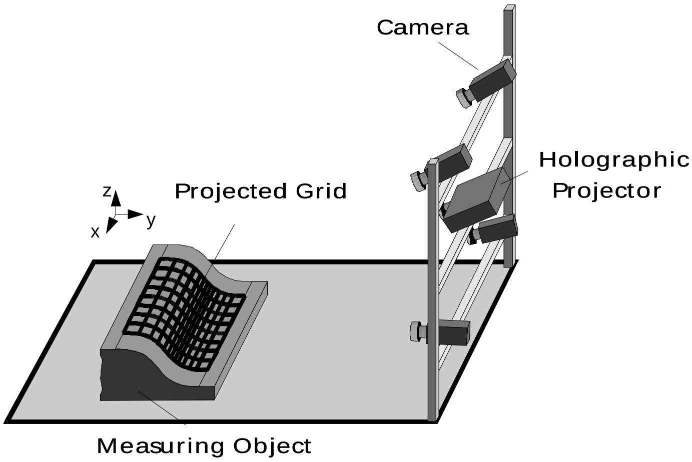

Figure 2. Principle of active multi-picture photogrammetry by means of holographic pattern projection.

Each crossing point is detected by the different cameras. For a correct measurement, a lot of surface points have to be detected with the camera sensors. In this context the central problem is how to find the corresponding points in the different camera views as necessary for calculating the 3D-points using triangulation. This problem is solved through epipolar-lines. The measurement accuracy of a conventional photogrammetry system is typically 50µm in a measuring field of 200 mm.

To calculate the crossing points the cross grid detected by the cameras has to be processed with a digital filter. The digital filters reduce background noise an dilate the bright structures of the grid. The result of detailed analysis was that the cross point calculation is much more stable after processing the pictures as shown in figure 3, 4.

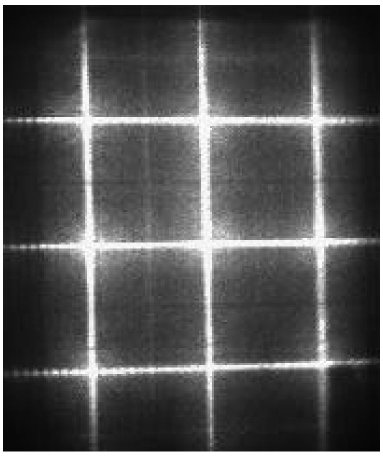

Figure 3. Holographically projected cross grid on a plane surface.

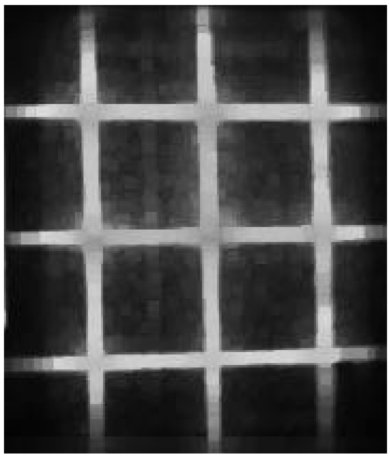

Figure 4. Projected cross grid after subsequent treatment with digital filters.

3 CGH - COMPUTER GENERATED HOLOGRAMS

Problems arising from the relative low depth focus of a projection lens can be avoided by applying a holographic projector. The advantage of holographic projection is its capability of projecting sharply focused three-dimensional patterns in any desired plane. Thus, the axial measuring range can be increased almost without limits [Dre96],[Les92]. By this means even large components can be measured using photogrammetry, which is not possible with the present projection units. The holograms used for projection of the test patterns can be calculated and produced on the basis of CAD data. This offers the possibility to project test patterns only to specific interesting areas of the component. Thus, measurement time can be shortened leading to a considerable speed benefit, which is an essential requirement for online inspection of moving objects.

The recording process for synthetic holograms is simulated with computers. This offers the advantage to be independent of real existing objects during the hologram production. As synthetic holograms are calculated numerically, light structures can be realized, which are not possible with the conventional recording technology. For instance, several points can be projected along one axis with synthetic holograms. This cannot be achieved by conventional holograms, since the points would cover each other. Thus, with synthetic holograms, feature-based test patterns can be provided, substantially increasing measuring accuracy and speed. A further benefit of holographic projection is the large flexibility and compactness of the assembly. For the measurement of a new object only the hologram needs to be exchanged.

With regard to time and costs, binary amplitude holograms were employed for pattern projection during the early stages of this work. The reconstruction of the hologram generates an equally spaced grid at a predefined distance (focal plane) behind the CGH. The holograms used for the generation of these patterns are Fresnel holograms. The distribution of the complex electric vector E in the hologram plane for the reconstruction of a single line parallel to the x-axis can be calculated according to (see also figure 5)

$$E(x_{holo}, y_{holo}) \propto \frac{i}{\sqrt{2 l z}} e^{ikz} e^{i\frac{k}{2z}(y_{holo}-y_{line})^2} \int_{x_1}^{x_2} e^{i\frac{p}{2}x^2} dx \qquad (1)$$

with

$$x_{1,2} = \sqrt{\frac{k}{p\,z}} \left(\mp \frac{L}{2} + x_{line} - x_{holo} \right) \qquad (2)$$

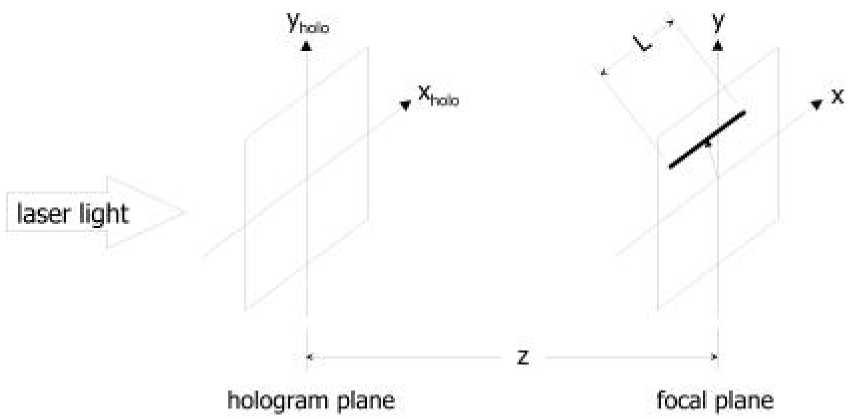

Figure 5. Principle of the holographic projection.

In eq. (1) x_{line} and y_{line} are the coordinates of the center of the line that is reconstructed in the focal plane, k ist the wave number of the used laser beam with the wavelength l. For the output of the CGH on a laserprinter the calculated gray-scaled hologram pattern has to be binarized. Examination showed, that the ‘Floyd and Steinberg error diffusion algorithm‘ [Flo76] produces the best results. Figure 6 shows a magnified part of the hologram before and after binarization with error diffusion.

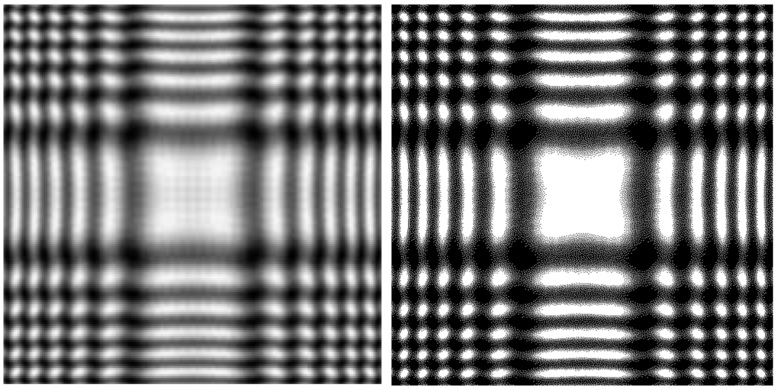

Figure 6. Magnified part of a CGH before and after binarization.

4 CONCLUSION AND OUTLOOK

In this paper a new concept and first results concerning a photogrammetry system with a holographic structured illumination for 3D measurements was introduced. A laser source illuminates a computer generated hologram to project a cross grid structure on the object surface. The projected cross points mark points on the object which are detected by at least two CCD-cameras. Three-dimensional coordinates from the object surface can be calculated using triangulation methods.

First results show a holographic projected cross grid structure on a plane surface (figure 2). The benefits of holographic projection are discribed in this paper.

The next step in our aim is to develop a photogrammetry system with a holographic projection unit to maximize the number of projected lines by computer generated phase holograms. Further, it is important to generate holograms which project sharp patterns in different focal planes in order to increase the measurement range and the focal depth.

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