High speed 3-D digitizer for CAD-CAM in industrial and dental applications

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Introduction

The use of optical 3-D measurement techniques in industry is strongly increasing in a variety of applications, such as quality control, rapid prototyping and in dentistry for production of crowns, bridges and inlays.
Starting from previous developments we employed the principle of uniform scale representation and full hemisphere measurement for 3-D data acquisition recording /1, 2/ and developed a concept for high speed and high resolution measurement.
For this purpose we developed a new optical, mechanical and electronic design of the 3-D digitizer while introducing / adapting high end components like:

– High resolution digital CCD-camera;
– Pixel addressing LCoS projection chip;
– Mechanical system for object handling.

3-D digitizer – system set-up for high speed fringe projection

Our measurement based on the fringe projection technique in a special kind. Its principle is the following one /1, 2/: The measurement is characterized by the exclusive use of phase-measurement values for coordinate calculation. At least three linearly independent phase-measurement values are needed for each object point to calculate the coordinates of this point. To obtain the phase-measurement values, the object under test is successively illuminated by a periodic grating structure (applying Gray-code in conjunction with four 90 degs phase-shifts) from at least three different directions using a telecentric projection system. A CCD camera records the intensity distribution of the fringes intersected by the object. The sample and the CCD camera are both mounted on a large rotation table turning both of them with respect to the fringe projector. The rotation axis has a constant angle with respect to the projection direction. By rotating the object and the camera simultaneously, we can adjust the projection direction.
The system was expanded by including a second rotation axis, that rotates the object with respect to the camera. This second rotation axis is tilted by 40 degs with respect to the first rotation axis. By this way, the object can be view from different viewing directions. Altogether, a whole-body 3-D measurement of the object is possible through using different projection and viewing angles. The pictures in Fig. 1 shows the set-up of the system.

New system components

The main task of work was the selection and integration of new components and algorithm into our system. The high speed fringe projection system is realized by using a non-mechanical projection technique basing upon a pixel addressing reflecting LCoS (Liquid Crystal on Silicon) chip. LCoS and DMD projection elements are novel and effective units for digital fringe projection /3/. They are characterized by the following advantages:

– high resolution,
– short response time for new picture (fringe pattern) generation,
– high contrast,
– simple digital electronic controlling via VGA-signal from the PC.

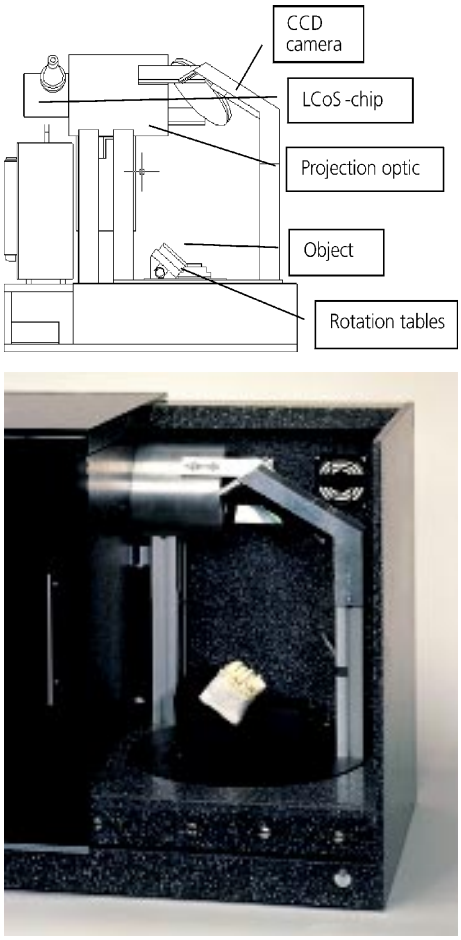

Fig. 1:
(Schematic picture + photo) 3-D digitizer HSDIG.

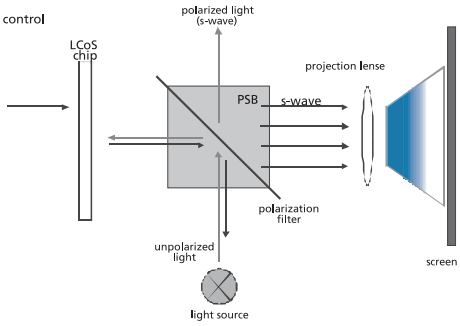

Fig. 2:
Principle of LCoS.

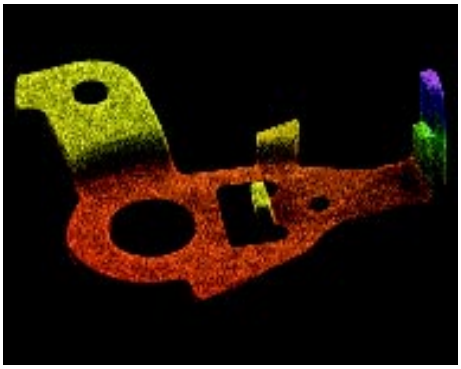

Fig. 3:
Point cloud of a metallic probe, colour indicate height.

The pixels of a LCoS-chip are electronically controlled by the PC and change the polarisation of the incoming light (see Fig. 2). Each Pixel can be addressed separately. Hence, we are able to generate well known Gray-code and phase shift fringe projection technique for phase measurement. Furthermore, a high-resolution digital camera is used as image capturing system. The advantages are:

– Digital data transfer without additional noise from the cables,
– External shutter control for easy adjustment of the light intensity,
– Increase of the point density.

The shutter control offers the possibility to adjust the exposure time to the requirements of different surfaces simply by changing the illumination time directly via the PC without mechanical action in the system (aperture changing). In conclusion, the realized system is characterized by the following parameters:

Parameter of LCoS-Chips:		
	min	max
pixel size	7 µm	20 µm
Pixel number	800 x 600	2048 x 2048
Contrast	70:1/200:1	1000:1
chip size	0,7“	1,5“

Tab. 1:
Parameter of LCoS-chips.

Measurement time	30 sec .. 4 min
Number of views	8 .. 16
Number of points	typical 3.000.000 maximum 16.000.000
Measuring field	∅ 90 mm height 25 mm
Typical accuracy (σ)	< 16 µm

Tab. 2:
Parameter of the digitizing system.

Applications

The system is designed for use in industry and dental labs. For industrial applications the shape measurement of highly complex objects is possible and a CAD-compare process can be realized. Some results are shown in Fig. 3, 4.
Furthermore, in dental application the task is to realize measurements of single tooth as well as the full tooth arc, see Fig. 5, /4/. The measured point cloud is used as an input for an optimised CAD / CAM process for the production of crowns, bridges and caps using different kind of materials like titanium or ceramic (aluminium oxide or zircon oxide) /5/.

Conclusions

The developed high-speed digitizer highly increases the working efficiency of 3-D scanning. The data quality is enhanced by an intelligent consistence check and adapted to the request of dental works. It is straightforward to use the digitizing system in different technical applications, like non-destructive evaluation, quality control or CAD-compare. The concept for high speed and high resolution measurement for industrial and dental purposes is a new step in using the optical 3-D measurement principle in real applications.

References

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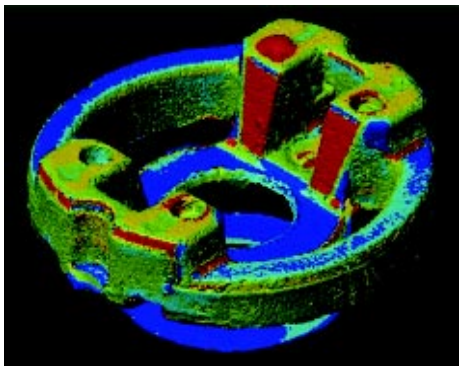
/3/ Notni, G.: 360-deg shape measurement with fringe projection – calibration and application; Fringe 2001, ELSEVIER, (Eds. W. Jüptner, W. Osten), (2001), 311–323

/4/ Kuehmstedt P., Notni G., Hintersehr J., Gerber J.; CAD-CAM-System for Dental Purpose – an Industrial Application; Fringe 2001, ELSEVIER, (Eds. W. Jüptner, W. Osten), (2001), 667–672

/5/ www.hintel.com



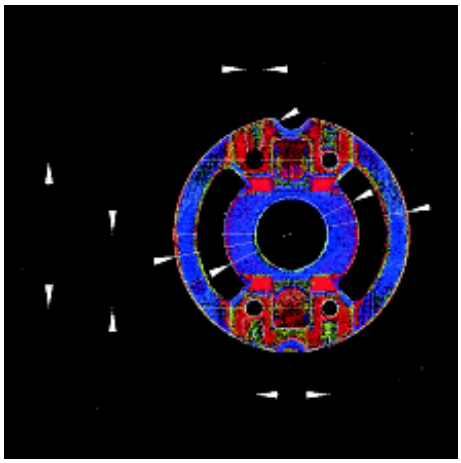


Fig. 4:
3-D-CAD-comparison of a micromechanic part
object size: 8 mm, colour indicate deviation

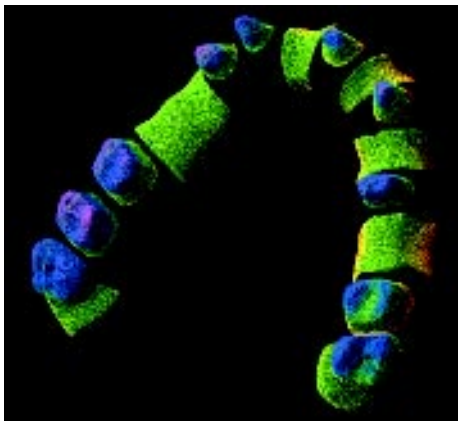


Fig. 5:
Point-cloud of a complete tooth – arc.