XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

3D SURFACE INSPECTION WITH A DMD BASED SENSOR

F. Bitte [1], H. Mischo [1], T. Pfeifer [1] and G. Frankowski [2]
[1] Fraunhofer Institute of Production Technology IPT
Metrology and Quality Management
Steinbachstraße 17, D-52074 Aachen, Germany
[2] Gottfried Frankowski Messtechnik GmbH
Warthestraße 21, D-14413 Teltow, Germany

Abstract: In this paper a method for non-contact scanning of small structures is presented similar to that of confocal microscopy but using the technology of Digital Micromirror Devices (DMD) instead of ordinary pinholes. It offers parallel scanning of various specimen following to a principle, where a DMD is used for illumination and a selective CCD for detection. The fundamental concepts concerning system layout and system performance as well as measurement results with a first experimental demonstrator are presented.

Keywords: metrology, surface inspection, confocal microscope, digital micromirror device, DMD, micro-systems technology

1 INTRODUCTION

Since the upcoming market for micro-systems technology (MST) must be regarded as tremendous [1], the field of this future key-technology is currently in the state of extensive research. Accordingly, with the re-scaling of the dimensions in MST, the demands concerning shape and surface-quality of future products will increase steadily.

Currently, a prototype of a scanning 3D-measurement system is being developed at the Fraunhofer IPT. Its fundamental technology is based on the Digital Micromirror Device (DMD) developed by Texas Instruments. The DMD used in this setup consists of 1024 x 768 programmable micromirrors. Each of these micromirrors has dimensions of about 16 x 16 μm^2 and can be switched to an angle of -10° or +10°. **Figure 1** shows images of a DMD magnified by a scanning electron microscope (SEM).

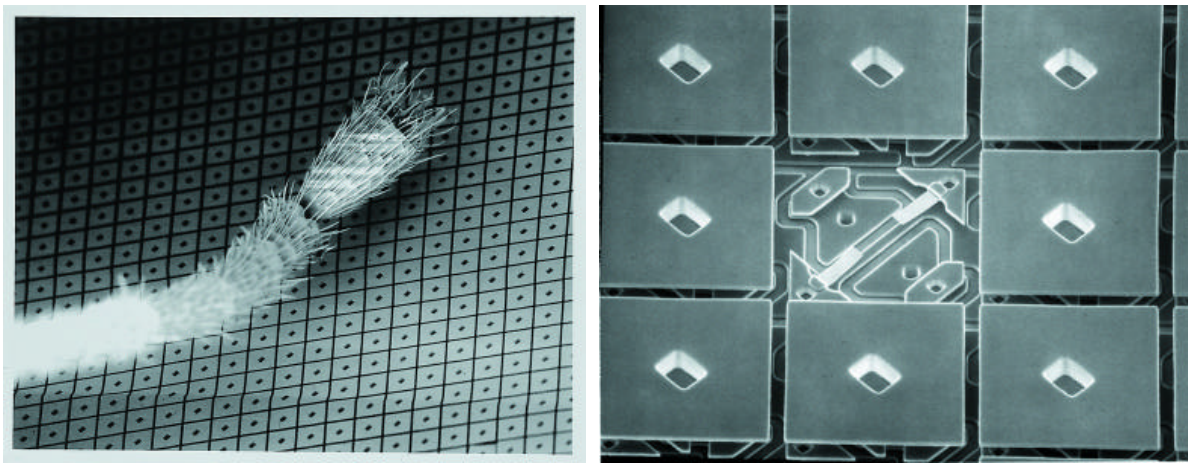

Figure 1. Magnified images of a DMD © Texas Instruments Inc.

Being illuminated, the DMD allows much more than simple reflection of light and projection of various patterns as done in typical applications such as digital video- and image projection. Since every mirror-element can also function as a pinhole, this technology provides a completely new means for confocal 3D-scanning [2,3,5]. Since several confocal systems can operate in parallel when the whole aperture of a single DMD is used, the measurement time can be significantly reduced without losing accuracy and without using expensive mechanical scanning mechanisms. Accordingly, the scanners currently used in conventional confocal microscopes may eventually be substituted by a device from the consumer market.

2 PRINCIPAL OF THE DMD BASED CONFOCAL MICROSCOPE

The measurement system in some issues resembles a confocal microscope [2] shown in **figure 2** (left). However, the lateral scanning-technique of regular confocal microscope is typically based on either a rotating Nipkow disk with pinholes [2], mechanical laser scanning mirrors [3,5] or microlens-arrays [7,8]. Dislike these ordinary approaches no pinholes for illumination and detection, no mechanical scanners for lateral scanning nor microlens-arrays are used. The basic principle of the modified confocal microscope which is related to a patent owned by GF Messtechnik GmbH (patent no. EP0943950A1) is shown in **figure 2** (right).

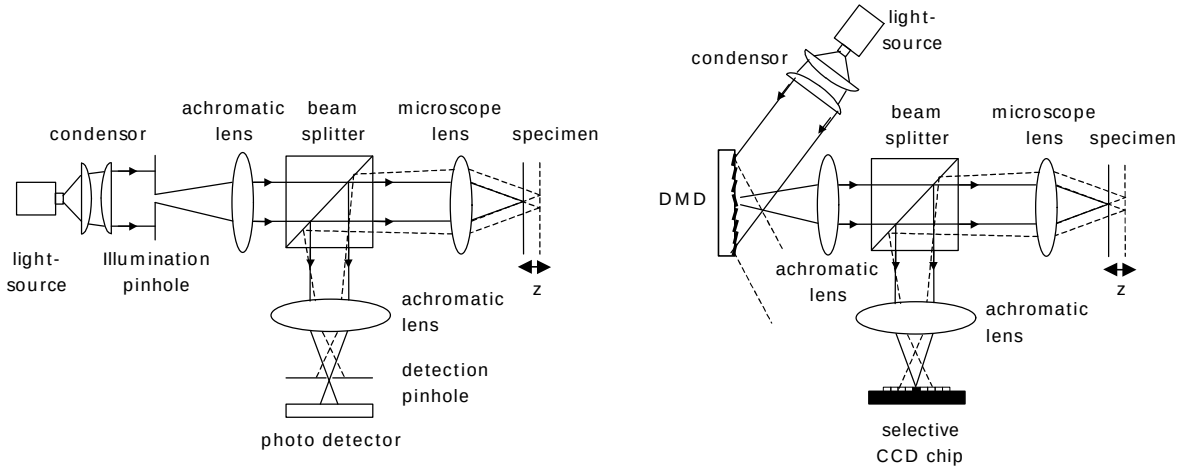

Figure 2: Schematics of a standard (left) and DMD based confocal microscope (right)

In the modified measurement system the *detection pinhole* is substituted by considering only certain regions of interest (r.o.i.) on the CCD chip for evaluation (selective CCD). In order to compare the behaviours of these two approaches the measured depth response curves (i.e. the intensity measured by the photo detector or CCD chip respectively, vs. the displacement of the specimen [3]) for both the pinhole and the selective CCD chip are shown in **figure 3**.

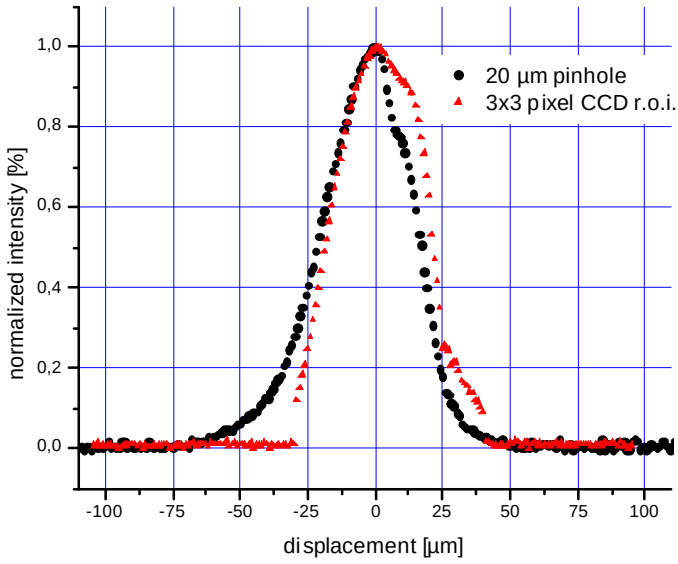

Figure 3. Comparison of the depth response using (a) a 20 µm detection pinhole and (b) a 3x3 superpixel on the CCD chip

Both curves were taken with a 20x/0.4 microscope lens and a 20 µm illumination pinhole. The results show that the full width at half maximum (FWHM) of the two curves are approximately 40 µm for the CCD and approximately 39 µm with the pinhole. The difference is less than 3%, indicating that the achievable depth resolution should be similar as well.

Further, the *illumination pinhole* is replaced by the DMD which is illuminated in reflection. The depth response curves with a 100 µm illumination pinhole and a 6x6 DMD superpixel (size: 101 µm) were taken with a 63x/0.85 microscope lens and the selective CCD chip for detection. The result is shown in **figure 4.**

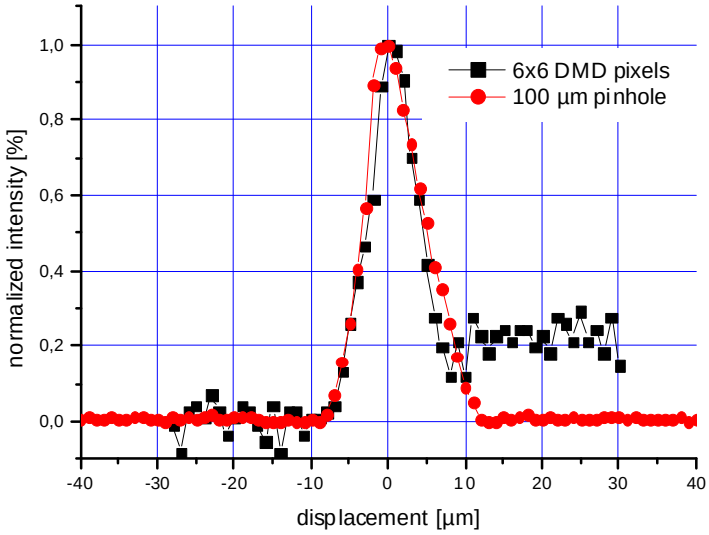

Figure 4. Comparison of the depth response using (a) a 100 µm illumination pinhole and (b) a 6x6 superpixel of the DMD

By omitting illumination- and detector-pinhole without losing their effect as aperture-stops, advantages occur from the possibility of flexible programming of shape and size of the pinhole geometry (i.e. superpixel geometry) on DMD and CCD chip to fit various applicational requirements. Thus, for example, lateral sampling rates and pinhole sizes can be adjusted online, according to the current surface structure under measurement.

3 SYSTEM DESIGN AND OPERATION

The entire optical field is scanned laterally in x- and y-direction, by sweeping all the parallel operating DMD superpixels (i.e. pixels forming small solid circles or rectangles that function as pinholes of a confocal microscope) over the DMD following a specified pattern and step size. The scanning schematics are illustrated in **figure 5**.

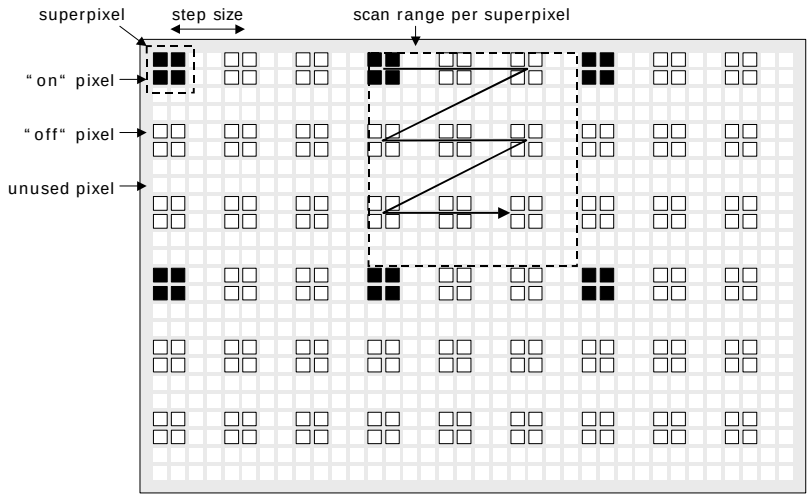

Figure 5. Scanning schematic on the DMD chip for lateral surface sampling

Each DMD superpixel is imaged on the surface of the specimen and back onto the CCD detector. The images on the CCD have their maximum intensity and minimum size when the corresponding spot on the specimen is in the confocal plane. The images get blurry, bigger and loose intensity when the specimen is behind or in front of the confocal plane. **Figure 6** illustrates the images on the DMD and CCD when a tilted plane is considered the measurement object. While the specified pinhole patterns are produced on the DMD chip, a corresponding pattern on the CCD chip is considered simultaneously and only these pixels of the CCD chip are regarded as region of interest for evaluation. The small and bright spots at the right hand side of the CCD chip indicate that the surface is in the confocal plane at these points.

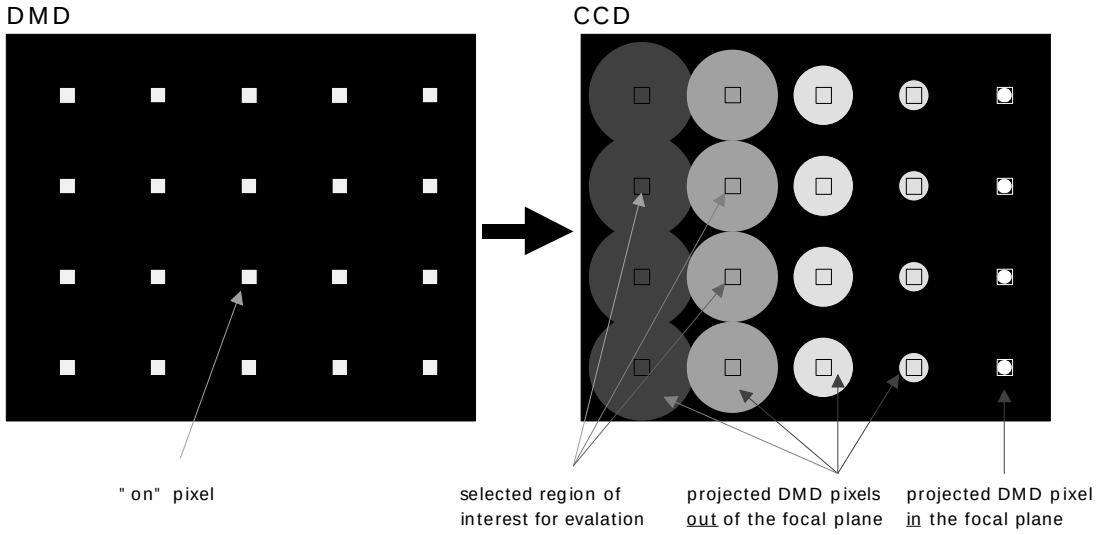

Figure 6. Images projected by the DMD and obtained by the CCD chip (measurement object: tilted plane)

The intensity in each considered pixel or superpixel on the CCD chip depends on the displacement of the object surface from the confocal plane and follows a known depth response curve [2,5]. Hence, by measuring the different intensities of all considered superpixels on the CCD chip, and finding its maximum while the specimen is moved through the confocal plane, information about the height-profile of the object surface can be obtained.
Since the size of the imaged DMD superpixels increases when the surface of the specimen is not in the focal plane, the measurement of steps may become difficult. In this case it may occur that while one DMD superpixel is imaged to maximum intensity and minimum size, the superpixel next to it may be that big that the two images interfere, hence, the measured intensity may not be reliable and it may be difficult to interpolate the maximum. Thus, the number of superpixels used simultaneously is limited and must be in accordance with the maximum step height on the surface of the specimen.

The course of measurement is as follows: First a specified pattern of DMD superpixels is produced and the CCD image is evaluated at the corresponding regions of interest. Then the DMD superpixels and CCD regions of interest are moved and evaluation is carried out again at different positions on the specimen. These steps are repeated until the surface is completely scanned in x- and y- direction. Afterwards, the specimen is moved in z-direction and the lateral scan restarts. After the depth-scan is completed, the interpolated intensity maximum is calculated for each superpixel. The intensity maximum is linked to the motor position allowing the 3D surface topography to be obtained. The course of measurement is summarised in **figure 7**.

The optical layout has to be specifically designed in order to meet two requirements concerning the most distant DMD pixel from the optical axis, the corner pixel:

- Every pixel, including the corner pixel of the DMD must be imaged onto the CCD chip and
- also the corner pixel must be able to pass through the rather small aperture of the microscope lens.

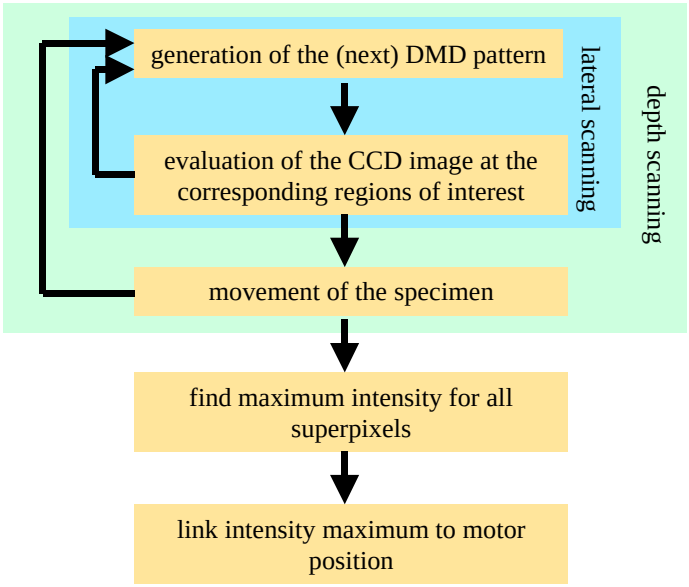

Figure 7. Course of measurement

The beam path of the system is shown in **figure 8** (compare to **figure 2**). Note that the beam path to the right of the specimen in **figure 8** is mirrored and light source and beam splitter are omitted.

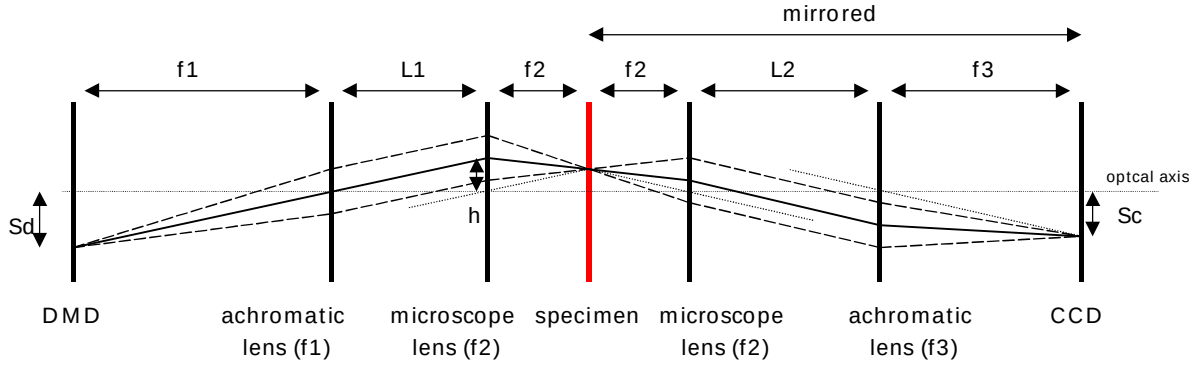

Figure 8. Beam path of the DMD based confocal microscope

Following the principals of geometrical optics [4], the equations for the image size can be derived to

$$s_C = s_D \frac{f_3}{f_1}, \tag{1}$$

where s_C is the distance between the optical axis and the corner pixel of the CCD chip, s_D is the distance between the optical axis and the corner pixel of the DMD and f_1 and f_3 represent the focal lengths of the two achromatic lenses used. The second condition yields

$$h = s_D \frac{L_1}{f_1}, \tag{2}$$

where h represents the radius of the microscope lens and L_1 the distance between the achromatic lens and the microscope lens. With eq. (1) and (2) the required focal lengths f_1 and f_3 can be obtained. L_1 should be chosen as small as possible in order to get a compact system.

Typically, s_C and s_D are roughly the same size and h is merely 1-2 mm, hence, it is necessary to choose f_1 and f_3 somewhere in the range of 300-400 mm resulting in a rather big setup. Alternatively, additional optical components may be added to appropriately reduce the image size right before the microscope lens.

4 ACKNOWLEDGEMENTS

This work is supported by the European Commission (Craft project, contract no. SMT4-CT98-5525) and carried out by AXXICON Moulds Helmond BV, Eindhoven University of Technology, Fraunhofer Institute of Production Technology IPT, GF Messtechnik GmbH, Ing. Gottfried Gruber, Nanofocus Messtechnik GmbH, NMI (Nederlands Meet Instituut) and Procornea Nederland BV.

REFERENCES

[1] VDE e.V.: dialog, Nr. 2, März / April 1998
[2] T. Wilson: “Confocal Microscopy”. Academic Press, (1990) London
[3] T.R. Corle, G.S. Kino: “Confocal Scanning Optical Microscopy and related Imaging Systems”. Academic Press, (1996) San Diego, USA
[4] H.S. Lipson, S.G. Lipson, D.S. Tannhauser: “Optik”. Springer Verlag, (1997) Berlin
[5] T. Wilson, C. Sheppard: “Theory and Practice of Scanning Optical Microscopy”. Academic Press, (1984) London
[7] H.J. Tiziani, H. M. Uhde: Three-dimensional analysis by a microlens-array confocal arrangement, Applied Optics 33, p. 567, (1994)
[8] H.J. Tiziani, H. M. Uhde: Three-dimensional image sensing by chromatic confocal microscopy arrangement, Applied Optics 33, p. 1838, (1994)

AUTHORS: Fraunhofer Institute of Production Technology IPT, Metrology and Quality Management, Steinbachstraße 17, D-52074 Aachen, Germany, Phone +49 (0) 24 1/89 04-2 59, Fax +49 (0) 24 1/89 04-1 98, E-mail: bitte@ipt.fhg.de, Internet: http://www.ipt.fhg.de
Gottfried Frankowski Messtechnik GmbH, Warthestraße 21, D-14413 Teltow, Germany, Phone +49 (0) 33 28 / 305 185, Fax: +49 (0) 33 28 / 305 188, E-mail: info@gf-messtechnik.de, Internet: http://www.gf-messtechnik.de