A telecentric line scanning system: requirements in the macroscopic and microscopic regime

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Last year (lecture A28 - 115th DGaO annual meeting), we presented the concept of a compact and modular telecentric line scanning system, capable of measuring large surfaces, e.g. for deformation and scratch detection of aluminium rolled sheets. In this particular construction, a circular scan curve is imaged onto one line.

1 Introduction

This telecentric line scanning system consists of a torus mirror, an imaging system and a line scan camera [1]. The imaging system maps a circular scan curve to a line scan camera. The magnification of this imaging should be independent from the distance between the object and the scanning system. Therefore, the telecentric condition must be satisfied. To be applicable either in macroscopic or microscopic regime, single components as well as the complete system have to be configured accordingly. Due to the modular and simple design of the system, and the fact that it generates a long scan line along the surface, the scanner can easily be applied in an inline process.

2 Design

A torus mirror with a hyperbolic conic section creates virtual intermediate image points, which was described in detail in [2]. Those points define an intermediate object field, which is to be imaged onto a line scan camera by a preferably simple lens system. For an undistorted image of this curved object field on the plane detector, the imaging system has to satisfy the Petzval condition (1).

$$\frac{1}{\mathrm{r_p}} = \sum_{\mathrm{i}} \frac{1}{\mathrm{r_i}} \left(\frac{1}{\mathrm{n_{i-1}}} - \frac{1}{\mathrm{n_i}} \right) \qquad (1)$$

$\mathrm{r_p}$ describes the radius of the Petzval surface, r the radii of the different surfaces of the imaging system, labeled by the index i, as well as $\mathrm{n_{i-1}}$ and $\mathrm{n_i}$ the refractive indices of the homogeneous materials in front of and behind surface i, respectively. With the given parameters of the mirror, the imaging system requires a value of the Petzval sum of approx. $0.003\ \mathrm{mm^{-1}}$. Furthermore, because of the fixed mirror design and the paraxial imaging conditions of the entire setup, the lens system has to obey a specific focal length. Design and simulation of the imaging system as well as the entire setup is based on raytracing methods.

3 Macroscopic regime

For the macroscopic system, the object sided lateral resolution $\Delta\mathrm{x}$ is demanded to be $40\ \mu\mathrm{m}$. The depth of field (at a given wavelength λ of $620\ \mathrm{nm}$ and a numerical apperture ($\mathrm{NA} = 0.61\lambda/\Delta\mathrm{x}$) of 0.009), according to Lord Rayleigh, is therefore approx. $13.9\ \mathrm{mm}$. In this project, two designs for the imaging system in the macroscopic regime were simulated. Note that, in combination with the hyperbolic mirror, the entrance pupil of the imaging system coincides with the telecentricity stop of the entire system.

3.1 Triplet

This approach is based on a standard triplet [3], which was adapted to the desired parameters by optimization using raytracing algorithms. Fig.1 shows the torus mirror, the triplet design of the imaging system, and the detector (row camera).

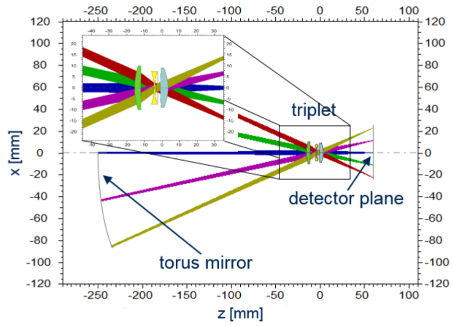

Figure 1: *top view of the simulated telecentric scanning system with torus mirror, triplet, and detector plane.*

3.2 Planar

This initial design is based on a planar [4] (the denotation "planar" is being used and kept for concise distinction). The original design by Paul Rudolph was developed to reduce many wave aberrations and especially for the correction of astigmatism and field curvature. Fig.2 shows the torus mirror, the design of the lens system based on the planar, and the detector.

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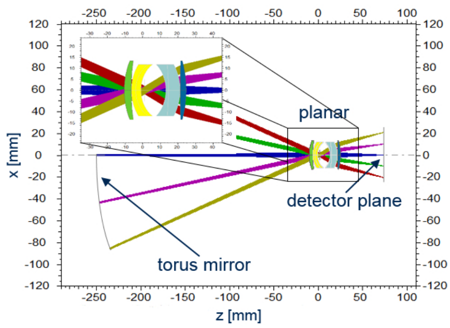

***Figure 2:** top view of the simulated telecentric scanning system with torus mirror, planar, and detector plane.*

3.3 Comparison

To compare the two designs of the lens system, the field curvature (FC) was simulated, both for a plane and a curved intermediate object field, respectively (fig.3). Usually, larger field angles effectuate larger distances between the image points and the detector plane. Here, for a curved object field, the maximal distance of the FC is approx. $50\ \mu\mathrm{m}$ for both systems.

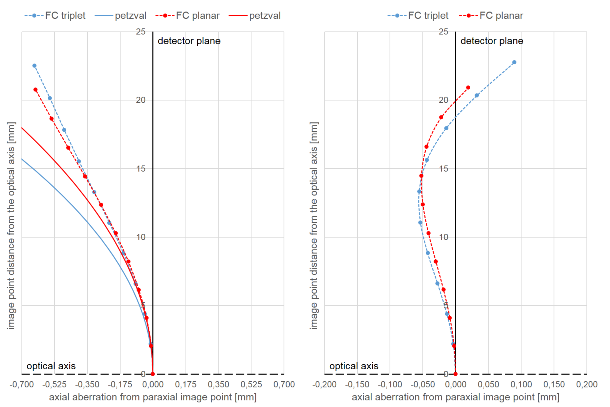

***Figure 3:** field curvature (FC) of a plane (left) and a curved (right) object plane for triplet and planar designs.*

In case of the triplet system, the Strehl ratio decreases for larger field angles, whereas, for the planar design, it remains constant over the entire image field (fig.4).

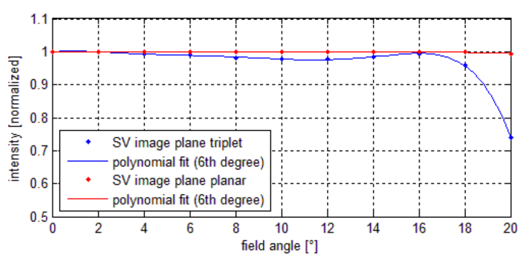

***Figure 4:** Strehl ratio (simulation values - SV) of the PSF in the detector plane for different field angles.*

The wave aberrations (WAs) for each image point are very low over the whole image field. But for the triplet system the WAs rise more sharply to the edges of the field as for the planar system.

4 Microscopic regime

The micro system is designed for microscopic applications. Therefore, an object sided lateral resolution of $4\ \mu\mathrm{m}$, resulting in a depth of field of approx. $139\ \mu\mathrm{m}$, were determined. The dimensions of the hyperbola segment are ten times smaller than the dimensions in the macroscopic regime. But that implys for the required resolution above an increase of the NA to ten times respectively the wave aberrations of the torus mirror. Therefore a redesign of the imaging system (planar) must be done. Fig.5 shows the complete design of the microscopic imaging system.

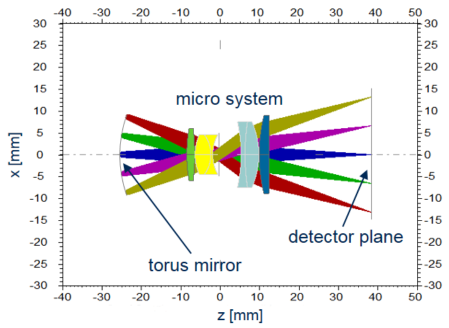

***Figure 5:** top view of the simulated telecentric scanning system with torus mirror, micro system, and det. plane.*

5 Summary

In this proceeding, the description of a telecentric scanning system was presented. In the macroscopic regime the planar has its advantages, especially for larger field angles. In the microscopic system the aberrations are critical (due to higher NA for higher lateral resolution on the measured surface), but the point spread functions (PSFs) in the detector plane are still sufficient for imaging.

6 Bibliography

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