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Influence of camera temperature on MTF measurements with finite image distance

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Abstract. Line Spread Function (LSF) based Modulation Transfer Function (MTF) measurements with finite image distance are sensitive to displacement errors in axial direction. Axial displacements between the sample and camera detector cause defocusing and thus, a MTF error proportional to the axial gradient of the sample's MTF. This article demonstrates the influence of the camera temperature on the focus position in the MTF reference setup at PTB.

1 Introduction

The MTF is a commonly employed key performance imaging parameter to asses the quality of optical lenses [1, 2]. It is a metric specifically defined for optical systems with linear transfer behaviour with respect to the electric field or intensity. The MTF is linked to the spatial resolution of the imaging system and describes the systems amplitude transfer characteristic for input signals of different spatial frequencies. The PTB employs a LSF based MTF measurement system with a slit object at infinity and finite image distance to the sample as proposed in ISO 9335 [3]. A sketch of the measurement setup is depicted in Fig. 1.

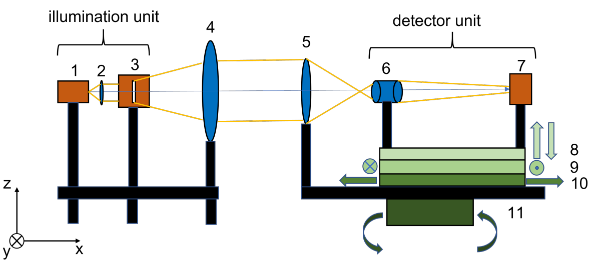

Figure 1. Schematic depiction of the MTF measuring setup [4]: 1) Fibre coupled led light source (Schott KL 2500), 2) optical system comprising a diffusor, condensor and wavelength filter ($\lambda \approx 546$ nm), 3) object slit, 4) optical collimator $D_c = 110$ mm, $f = 1100$ mm, 5) sample mount, 6) microscope objective for finite imaging, 7) camera detector, 8) z-positioner, 9) y-positioner, 10) x-positioner, 11) rotation axis to assign different field angles.

A thin slit object (3), which is unresolvable by the optical system, is imaged through the combination of a collimating lens (4) and the sample under test (5). The sample employed here is a calibration objective with infinite to finite imaging, a focus distance of $f_s = 50$ mm and a f-number $a_s = 4$. The image produced by the sample under test is magnified employing a relay microscope objective (6) and finally recorded by the camera detector (7). In the imaging plane the sharp rectangular slit object will appear as a blurred LSF. The form of the LSF encodes the characteristic transfer behaviour of the optical system, which is analysed in the frequency domain by its corresponding MTF. For more information about the setup at PTB the reader is referred to [4, 5]. MTF measurement systems are sensitive to defocus effects [2, 3]. Therefore, it is important to analyse the influence of thermal defocus as part of the measurement uncertainty contributions.

2 Experiment and Results

A characteristic datum point of the sample under test is its on axis focus position P_f. To determine the focus position the focal criterion as described in [3] (5.1.5 Focusing a)) is employed. By this focal criterion, the test specimen is focused on-axis, if the MTF value at a given spatial frequency ν_0 reaches its maximum. The influence of camera temperature on MTF measurement with finite image distance is determined by measuring the shift in the focus datum point $\Delta P_f(t, \tau)$, while the camera is heating up. For this purpose the MTF measurement setup is shut down for multiple hours until a thermal equilibrium at room temperature is established. The setup is then turned on ($t_0 = 0$ min) and the required settings for a repeated focus scan measurement are applied. This takes approximately $t_1 = 3$ min, during this time the camera already heats up. The detector unit scans the focal region of the sample under test M times, measuring the MTF at discrete positions $x_n \forall n \in [1, \cdots, N]$. This results in M through focus curves of the MTF evaluated at the frequency ν_0, which describe the changes in the MTF when the sample gets defocused. The maximum of the through focus curve indicates the focus position ac-

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cording to the focal criterion [3] (5.1.5 Focusing a)) described above $P_f = x|\max_x(\mathrm{MTF}(x, \nu_0))$. Fig. 2 shows the through focus curves of a measurement at camera temperature $\tau_1 = 39.55\,°\mathrm{C}$ at time $t_1 \approx 3\,\mathrm{min}$ in comparison to the stationary camera temperature $\tau_M = 48.44\,°\mathrm{C}$ at time $t_M \approx 193\,\mathrm{min}$ at the end of the recording. It is visible that the focus position has changed by $\approx 3\,\mu\mathrm{m}$, which causes a high deviation $\max(|\Delta\mathrm{MTF}|) \approx 0.05$ between the recorded MTF curves. This is in good agreement with the defocusing tolerances for a lens with f-number $a_s = 4$ at $\lambda = 500\,\mathrm{nm}$ and $\nu_0 = 100\,\mathrm{lp/mm}$ given in table 1 of ISO 9335 [3]. Fig. 3 shows the shift of the focus position $\Delta P_f(t, \tau)$, with respect to the focus position observed in the first measurement, in comparison to the camera temperature. It appears, that the shift of the focus position follows the temperature. It is likely, that the observed shift in the focus position is caused by the thermal expansion of the camera and thus, the thermal displacement of the camera chip. The camera temperature is measured at the camera core board inside the housing. The camera model is the a2A5320-23umBAS from Basler, the housing is a combination of zinc diecasting mount ($\alpha_{\mathrm{Zn}} \approx 30.2\cdot10^{-6}\,\mathrm{K}^{-1}$) and a steel sheet ($\alpha_{\mathrm{Steel}} \in [11, 13]\,10^{-6}\,\mathrm{K}^{-1}$) with dimensions of $42.8\,\mathrm{mm} \times 29\,\mathrm{mm} \times 29\,\mathrm{mm}$. Assuming that the housing temperature will converge to a stationary temperature that is lower than the core board temperature, the shift in focus position of $\Delta P_f \approx 3\,\mu\mathrm{m}$, which occurs for a core board temperature change of $\Delta\tau \approx 9\,°\mathrm{C}$ may reasonably be assigned to a shift of the image sensor caused by the thermal expansion of the housing. The ambience room temperature was recorded during the experiment and showed a peak to valley deviation of $\mathrm{PV}_{\tau_{\mathrm{amb}}} = 0.38\,°\mathrm{C}$, thus its influence on the measurement is considered to be negligible.

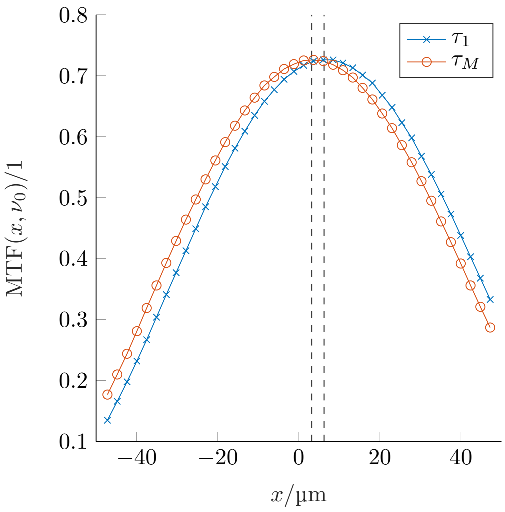

Figure 2. Comparison of the recorded MTF through focus curves evaluated at the spatial freuqency $\nu_0 = 100\,\mathrm{lp/mm}$ at temperature $\tau_1 = 39.55\,°\mathrm{C}$ at time $t_1 \approx 3\,\mathrm{min}$ (blue crosses) and the stationary camera temperature $\tau_M = 48.44\,°\mathrm{C}$ at time $t_M = 193\,\mathrm{min}$ (red circles). The black dashed lines indicate the position of the maximum of the MTF through focus curves, which coincide with the focus position P_{f1}, P_{fM} respectively.

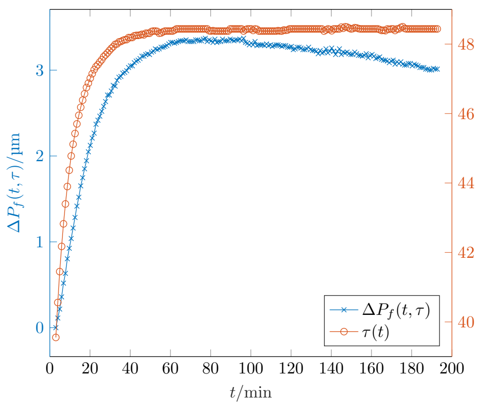

Figure 3. Shift of the focus position $\Delta P_f(t, \tau)$ with respect to the focus position observed in the first measurement (blue crosses). Camera temperature $\tau(t)$ over time t (orange circles).

3 Conclusion

The presented results demonstrate, that the heating of the camera sensor may cause large deviations in the measured MTF. The MTF deviations are dependent on the specimen specific MTF gradient and the axial displacement of the camera chip. The measurement should not be started before the system has reached a stationary temperature.

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