Tuning Imaging Resolution through Mirror Tilt in Mach–Zehnder Interferometric Microscopy: An Experimental and Numerical Study

Ferhat Hanife[1,2,*] and Yashar Azizian-Kalandaragh[2,3]

[1]Department of Photonics Science and Engineering, Graduate School of Natural and Applied Sciences, Gazi University, 06560 Ankara, Türkiye
[2]Photonics Application and Research Center, Gazi University, 06500 Ankara, Türkiye - [3]Department of Photonics, Faculty of Applied Sciences, Gazi University, 06500 Ankara, Türkiye

ABSTRACT

In Mach–Zehnder interferometric microscopy, the angle between the two beams can affect the interference pattern and imaging performance. In this study, we investigated how changing the M2 mirror angle affects spatial resolution. The M2 angle was varied while all other experimental conditions were kept constant. Image resolution was evaluated using the FWHM of the point spread function (PSF). The same angle range was also modeled in Zemax OpticStudio to examine the angle-dependent behavior numerically. Experimental and Zemax images were analyzed using the same MATLAB method so that the results could be directly compared.

***Aim*: To investigate the effect of M2 mirror angle on PSF-based imaging resolution.**

THEORETICAL *BASIS*

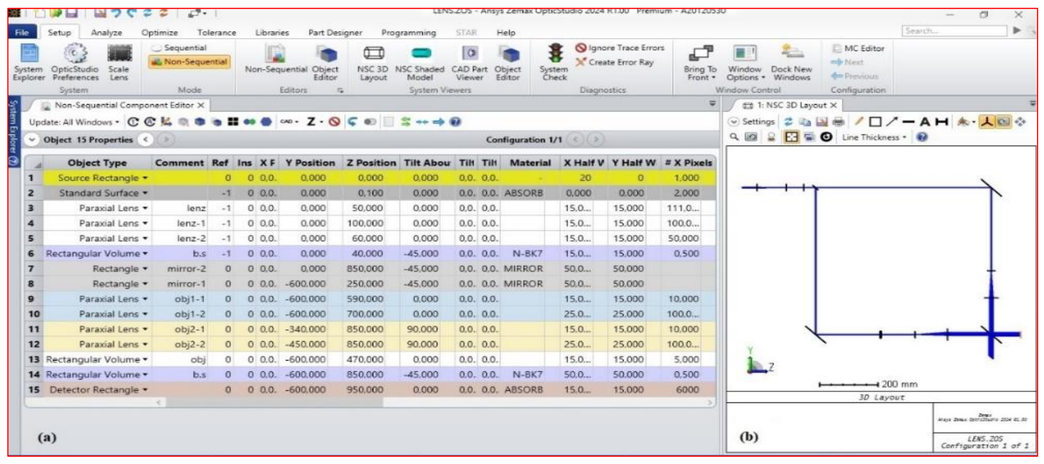
$$I(r) = I_1 + I_2 + 2\sqrt{(I_1 I_2)}\cos[(k_1 - k_2)\cdot r + \Delta\varphi]$$

Tilting M2 changes the relative wave-vector difference $\Delta k = k_1 - k_2$ between the coherent beams, modifying the spatial frequency and geometry of the interference pattern at the detector. This change influences the measured point-source PSF and its FWHM.

M2 tilt → Δk changes → interference pattern changes → measured PSF/FWHM changes

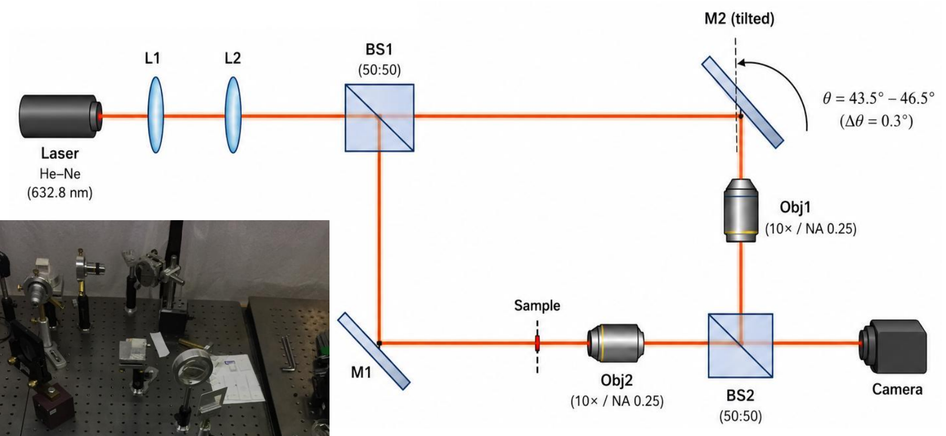
A narrower PSF (lower FWHM) indicates a more localized point response and is used here to compare imaging performance.

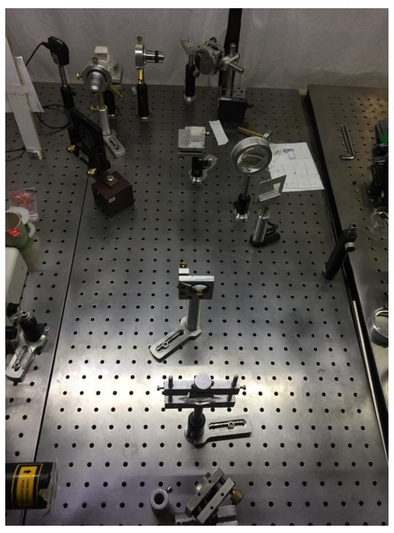
ZEMAX NUMERICAL MODEL



The experimental Mach–Zehnder system was modeled in Zemax OpticStudio using a non-sequential approach. As in the experiment, only the M2 mirror angle was varied, while all other system parameters were kept constant. This allowed the effect of M2 angle on the system response to be studied numerically.

EXPERIMENTAL SETAP

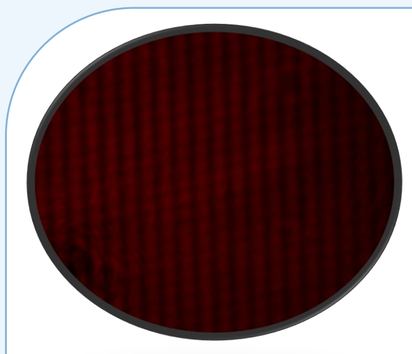




A Mach–Zehnder interferometric microscope was built using a 632.8 nm He–Ne laser, two lenses (L1 and L2), two 50:50 beam splitters (BS1 and BS2), mirrors M1 and M2, and 10×/NA 0.25 microscope objectives.

During the measurements, only the M2 mirror angle was changed from 43.5° to 46.5° in 0.3° steps. All other experimental conditions were kept constant. Point-source images were recorded at each angle and used for PSF/FWHM analysis.

DETECTOR IMAGES



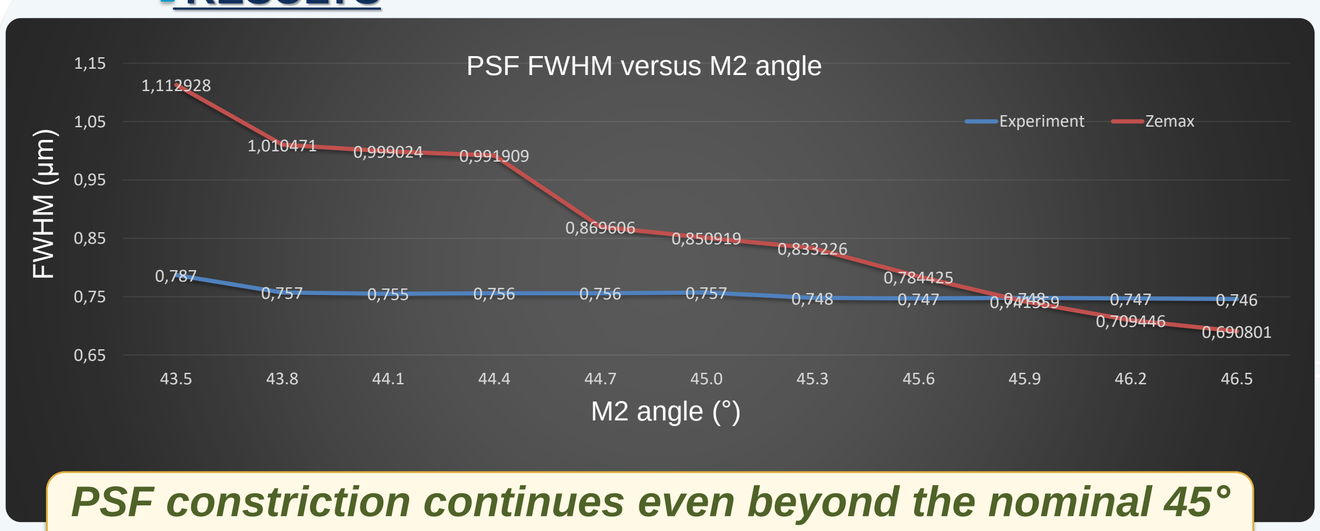
Experimental (45°)



Simulation (45°)

Experimental and Zemax detector images were obtained at each M2 angle. Both image sets were processed using the same MATLAB analysis method, and the FWHM of the point-source PSF was calculated. This allowed a direct comparison of the experimental and numerical results under the same analysis conditions.

RESULTS



PSF constriction continues even beyond the nominal 45° mirror orientation

Both the experimental and Zemax results show a decrease in PSF FWHM as the M2 angle increases. In the experimental data, the decrease is more pronounced up to 45° and becomes smaller above 45°. The Zemax results show the same overall trend, but with a stronger dependence on the M2 angle. Within the tested range, the lowest FWHM in both datasets is observed at 46.5°.

CONCLUSION

The M2 mirror angle clearly affects the PSF/FWHM response of the Mach–Zehnder system. The experimental and Zemax results show a similar decreasing trend over the tested angle range, although the amount of change is different. The nominal 45° position does not give the minimum FWHM, and PSF narrowing continues above 45°. This shows that the M2 mirror angle is an important parameter for interferometric imaging performance.

The similar trend observed in both experiment and simulation also shows that the angle-dependent behavior can be predicted with the Zemax model. This approach may be useful for selecting suitable operating conditions and optimizing interferometric systems.

Acknowledgement: *This study was supported by the Gazi University Scientific Research Projects Coordination Unit (BAP) under Project No. FDK-2024-9503, titled "Enhancement of Super-Resolution in Microscopy Using Structured Light."*

We gratefully acknowledge the Gazi University Scientific Research Projects Coordination Unit (BAP) for their support.

***Contact**: ferhathanife64@gmail.com*

REFERENCES

[1] Ansys Zemax. *OpticStudio User Manual.* Ansys Zemax LLC; 2024.

[2] Rubio-Oliver R, Micó V, Zalevsky Z, García J, Picazo-Bueno JA. *Quantitative phase imaging by automated Cepstrum-based interferometric microscopy (CIM).* **Opt Laser Technol.** 2024;177:111121. doi:10.1016/j.optlastec.2024.111121.