

Lens-free Microscope for Portable Pollen Grains Imaging System

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Summary:

The developed lens-free microscope is a compact, portable system capable of real-time, high-resolution pollen imaging. It accurately reconstructs pollen morphology comparable to a conventional lens-based microscope, while offering a larger field of view and simplified design. With its small size and fast processing, it holds strong potential as a ubiquitous microscopy platform in diverse environment.

Keywords: Holography, Lens-free microscope, Image reconstruction, Pollen, Real-time measurement

Background

Pollen allergies tend to peak during the flowering season, often leading to significant health concerns. Recent estimates suggest that between 1% and 40% of the European population is affected by allergic rhinitis, with a gradual upward trend being observed [1]. Although pollen monitoring and counting systems are widely used, they still face challenges in accurately distinguishing pollen grains from other similarly sized particles. Therefore, imaging-based approaches using microscopes remain essential for reliable identification and improved detection accuracy.

Different approaches—such as laser-based systems with lens-focused beams[2], imaging using inverted microscopes[3], and setups employing three-wavelength laser illumination[4]—have been developed for pollen imaging system. However, these methods convey particular complexities like relying heavily on laser-based illumination and multiple optical lenses in their configurations. This limits their massive applicability in harsh or outdoor environments, where compact, robust and low-cost setups are required.

In this work, we present the development of a compact, lightweight, and portable lens-free microscope for pollen imaging system. By eliminating traditional lenses, the system significantly reduces complexity and costs, while enhancing performance.

Material and Method

The lens-free microscope used in this study is based on the principle of in-line holography. The system consists of only three main components:

a light source, a CMOS image sensor, and a sample placed between them. The light source is specifically designed to possess an optimal level of coherence, which is critical for generating clear interference patterns.

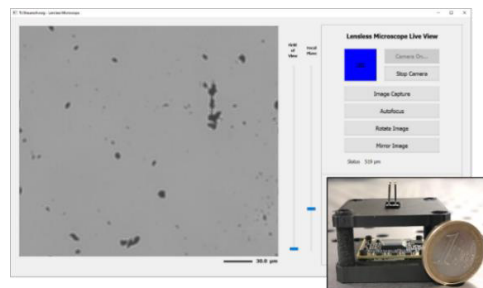


Fig. 1. Graphical user interface of the lens-free apps. Inset: 4 cm × 4 cm × 3 cm the lens-free microscope setup

To meet these requirements, a custom-fabricated 10 μm GaN-based micro-LED with a peak wavelength of 450 nm was developed in our cleanroom facility. The use of a micro-LED in this setup not only enhances spatial coherence and energy efficiency, but also simplifies the system design and minimizes the risk of damage to both the sample and the sensor. For image acquisition, a 5-megapixel MT9P031 CMOS sensor is used to record the light intensity across the sensing surface. To facilitate system control and real-time image capture, a custom graphical user interface (GUI) application was developed in-house. This software enables users to perform live image acquisition and provides cloud connectivity, allowing remote monitoring and data access from virtually any location. Fig. 1 shows a screenshot of the GUI and an image of the microscope prototype fabricated.

Due to the high spatial coherency of the micro-LED illumination, this simple design is effective in generating distinct interference patterns forming a raw image, from which 3D image information with higher spatial resolution can be extracted. For this, a reconstruction algorithm based on the Fourier Transform has been integrated into the system. The reconstruction process works by back propagating the pattern in the frequency domain to reconstruct the optical field in the object plane. The reconstruction process implemented in this system is mathematically represented by the equation below:

$$U(x, y, z_{target}) = \frac{1}{N_x N_y} \sum_{n_x=0}^{N_x-1} \sum_{n_y=0}^{N_y-1} f(n_x, n_y) e^{ik_z z} e^{2\pi i \frac{x n_x}{N_x}} e^{2\pi i \frac{y n_y}{N_y}}$$

Results and discussion

We tested the system using pollen grains collected directly from flower samples. The sample is prepared by applying a droplet containing pollen onto a glass slide, followed by direct observation using the lens-free microscope. For comparison, the same samples are also examined using a conventional Leica DM2700 M lens-based microscope.

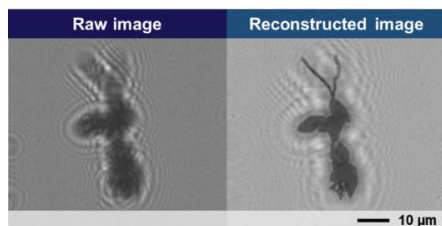


Fig. 2. The comparison between the raw and reconstructed images generated by lens-free microscope.

The initial test involved live image acquisition and reconstruction of pollen images using the lens-free microscope. The results demonstrated that the system is capable of accurately reconstructing images with high resolution and sharpness (Fig. 2). Moreover, the reconstruction algorithm is completed in under one second, enabling real-time image processing. The reconstructed images were then compared to those captured with the lens-based microscope (Fig. 3). The comparison showed that the lens-free microscope could reconstruct pollen morphology with a quality comparable to the images produced by the conventional much more complex and much more expensive system.

These results confirm that our lens-free microscope can achieve a resolution high enough for analyzing pollen. Additionally, the wide active area of the CMOS sensor (5.7 mm × 4.28 mm) allows the system to capture images with a large field of view while maintaining high resolution—an achievement that is challenging for traditional

lens-based microscopes. With a resolution of down to 700 nm, this system opens the door to further developments, such as pattern recognition for shape classification and spectral analysis, for identifying unique characteristics of various pollen types and enabling more precise and comprehensive analysis.

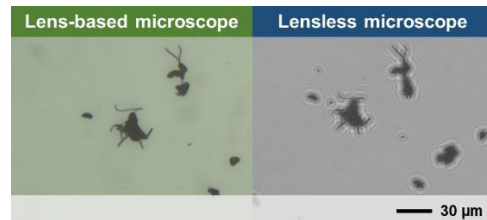


Fig. 3. The evaluation of the images captured by lens-based microscope and lens-free microscope.

With compact dimensions of just 4 cm × 4 cm × 3 cm (Fig. 1 inset), the lens-free microscope not only serves as an effective tool for pollen imaging, but also demonstrates strong potential as a point-of-care device and a ubiquitous microscopy platform, facilitating on-demand observations in diverse environment. Moreover, its compact and lightweight design enables to be used in extreme conditions, such as outer space.

References

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