Smartphone-based microscope rapidly reconstructs 3D holograms

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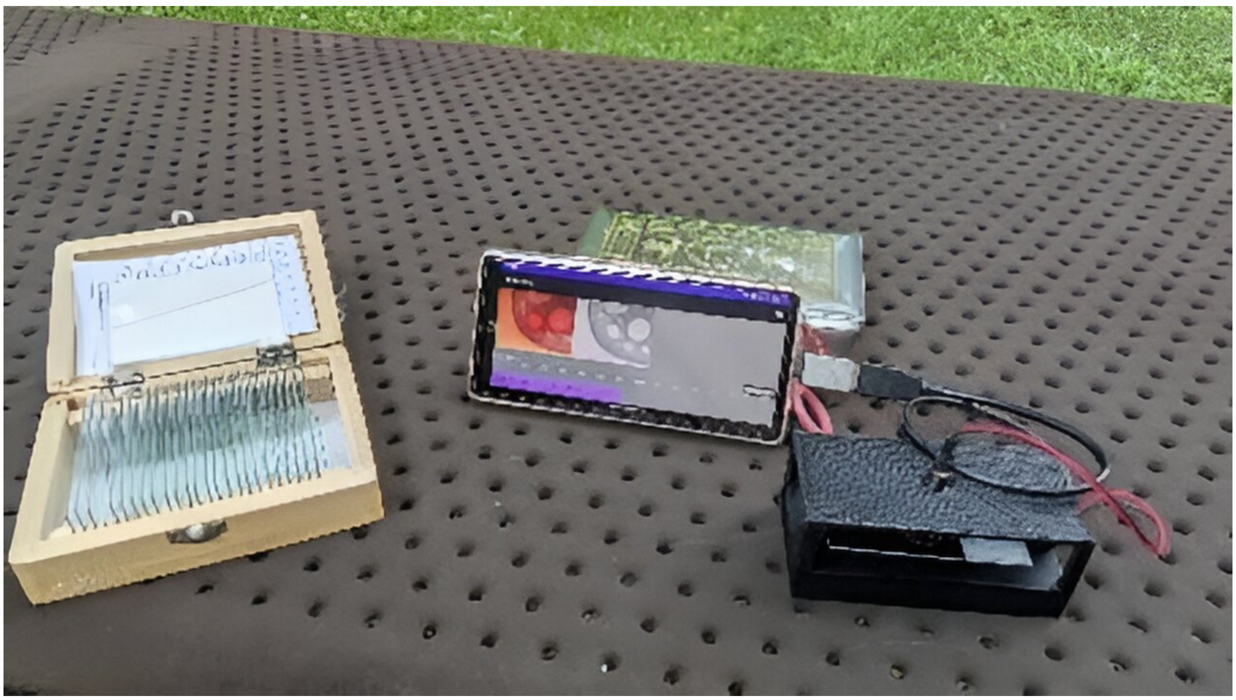


The new inexpensive smartphone-based digital holographic microscope provides a portable way to perform 3D measurements. Credit: Yuki Nagahama, Tokyo University of Agriculture and Technology

Researchers have developed a new smartphone-based digital holographic microscope that enables precision 3D measurements. The highly portable and inexpensive microscope could help bring 3D measurement capabilities to a broader range of applications, including educational uses and point-of-care diagnostics in resource-limited settings.

Holographic microscopes digitally reconstruct holograms to extract detailed 3D information about a sample, enabling precise measurements of the sample's surface and internal structures. However, existing digital holographic microscopes typically require complex optical systems and a personal computer for calculations, making them difficult to transport or use outdoors.

"Our digital holographic microscope uses a simple optical system created with a 3D printer and a calculation system based on a smartphone," said research team leader Yuki Nagahama from the Tokyo University of Agriculture and Technology. "This makes it inexpensive, portable and useful for a variety of applications and settings."

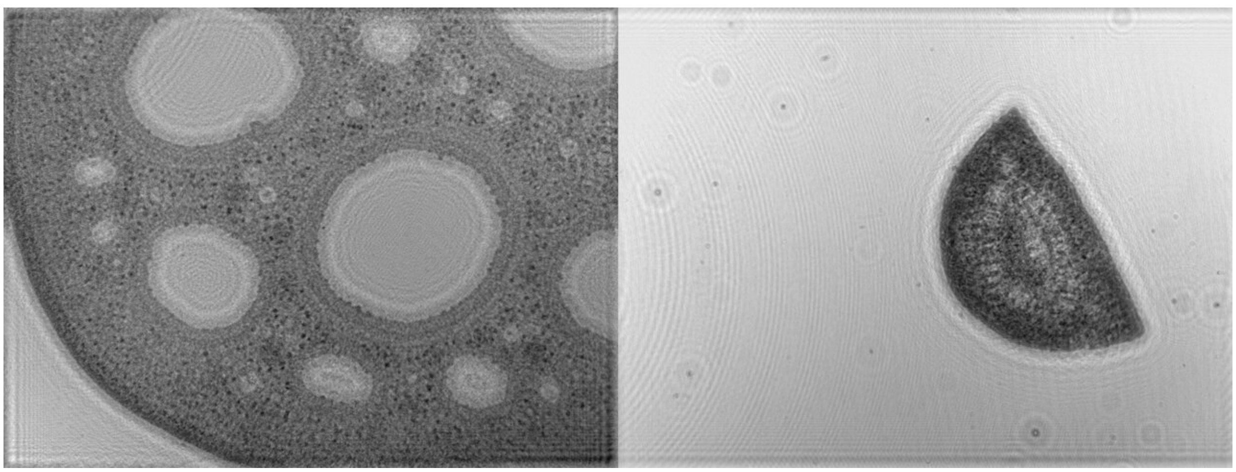
In the journal *Applied Optics,* the researchers demonstrate the smartphone-based digital holographic microscope's ability to capture, reconstruct and display holograms in almost real time. The user can even use a pinch gesture on the smartphone screen to zoom in on the reconstructed hologram image.

"Since our holographic microscope system can be built inexpensively, it could potentially be useful for medical applications, such as diagnosing sickle cell disease in developing countries," said Nagahama. "It could also be used for research in various field environments or in education by allowing students to observe living organisms at school and at home."

Fast smartphone-based reconstruction

Digital holographic microscopes work by capturing the interference pattern between a reference beam and light scattered from the sample. The hologram is then digitally reconstructed, which generates 3D information that can be used to measure the sample's features, even those below the surface.

Although smartphone-based digital holography microscopes have been developed previously, available technologies either reconstruct the holograms on a separate device or lack real-time reconstruction. This limitation arises from the restricted computing and memory capacity of most smartphones.



Researchers developed a smartphone-based digital holographic microscope that can capture, reconstruct and display holograms in almost real time. They used the microscope to acquire cross-sectional images of a Nymphaea plant stem (left) and a pine needle (right). Credit: Yuki Nagahama, Tokyo University of Agriculture and Technology

To achieve fast reconstruction on a smartphone, the researchers used an approach called band-limited double-step Fresnel diffraction to calculate the diffraction patterns. This method reduces the number of data points, enabling faster computational image reconstruction from holograms.

"When I was a student, I worked on portable digital holographic microscopes, which initially used laptops as the computing system," said Nagahama. "With the rise of smartphones, I began exploring their potential as computing systems for broader applications and considered leveraging them for tasks like removing artifacts from observed images, which ultimately shaped the development of this microscope."

To help with portability, the researchers created a lightweight housing for the optical system using a 3D printer. They also developed an Android-based application to reconstruct the holograms acquired by the optical system.

The microscope generates a reconstructed image of the hologram on the image sensor of a USB camera built into the optical system. This hologram can be observed by the Android smartphone, which provides computational image reconstruction in real time. The reconstructed hologram is then displayed on the smartphone, where users can interact with it via the touchscreen.

Near real-time reconstruction

The researchers evaluated their new microscopy system by using a prepared object with a known pattern and then testing whether the pattern on the object could be accurately observed with the microscope. They were able to successfully observe the pattern on the test target and also used the microscope to image other samples such as a cross section of a pine needle.

The researchers showed that when using band-limited double-step Fresnel diffraction, holograms could be reconstructed at a frame rate of up to 1.92 frames per second. This enabled images to be displayed in almost real time when observing stationary objects.

Next, they plan to use deep learning to improve the quality of the images generated with the smartphone-based microscope. Digital holographic microscopes often generate second unintended images during hologram reconstruction, and the researchers are exploring how deep learning could be used to remove these unwanted images.

More information: Yuki Nagahama, Interactive zoom display in a smartphone-based digital holographic microscope for 3D imaging, *Applied Optics* (2024). DOI: 10.1364/AO.532972

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