

Lensless white light interferometry for technical surfaces

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Lensless white light interferometry (WLI) based on digital holography enables lightweight and compact measurement systems. Compared to conventional WLI, it allows larger fields of views, reduces the number of images required and thus measurement time and sensitivity to vibration. The method allows in-process applications with interferometric axial resolution.

1 Introduction

Lens-based WLI relies on mechanical scanning of complex Mirau objectives to generate images and interference. Its ability to achieve single-digit nanometer height resolution makes it a powerful measurement technique for the topographical characterization of surfaces. Furthermore, it has become a well-established optical measurement technique in applications such as optical quality assurance. The use of lenses and mechanical scanning however makes such systems large and expensive, sensitive to vibrations, and cause a long measurement time.

The new lensless WLI approach based on digital holography, allows similar performance at a higher speed and less sensitivity to vibrations, which we will demonstrate in the following sections.

2 Lensless white light interferometry

Digital holography, the bases for lensless WLI, enables the determination of the phase and amplitude of a complex optical wave field. By capturing the interference of the scattered wave field $u(\vec{x})$ of the object and a known reference wave $r(\vec{x})$, with a digital sensor, and using e.g. temporal phase shifting the mutual coherence function $\Gamma(\vec{x}) = u(\vec{x}) \cdot r^*(\vec{x})$ can be extracted. Lensless WLI combines the coherence functions of multiple different wavelengths to create a custom tailored coherence function, which allows the simulation of short temporal coherence necessary for use in WLI [1].

By propagating the individual coherence functions a virtual scan of the reference mirror can be performed. This simulates the scan of the Mirau objective in the conventional lens-based WLI design, i.e. simulates a coherence scan. The surface profile can be determined by finding the maximum of the combined coherence function [1].

3 Measurement results

3.1 Field of View

Figure 1a) shows a schematic of a reflection holographic setup for temporal phase shifting and collimated illumination, while b) shows a prototype based on that design. The prototype highlights the compactness ($9\text{ cm} \times 3.2\text{ cm} \times 3.7\text{ cm}$) and light weight design ($\sim 150\text{ g}$) of such a lensless WLI.

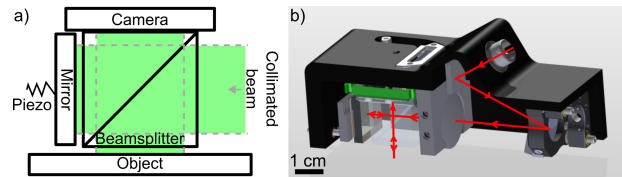


Fig. 1 a) Schematic of a reflection holographic setup employing temporal phase shifting using a piezo and collimated illumination. b) Lensless WLI prototype of size $9\text{ cm} \times 3.2\text{ cm} \times 3.7\text{ cm}$ and weight $\approx 150\text{ g}$ with beam path indicated by the red arrows. Taken from [2].

Figure 2 demonstrates a lensless WLI measurement using an EPROM-Chip. The setup uses a Sony IMX541 sensor with $4512 \times 4512\text{ px}$ and a pixel pitch of $2.74\text{ }\mu\text{m}$. This results in a field of view of $12 \times 12\text{ mm}^2$ and space band width product (SBP) of 20.36 million, which is only limited by the size of the camera sensor. The heightmap is cropped to the topography of the EPROM-chip. The zoomed section shows that the lateral resolution of $2.74\text{ }\mu\text{m}$ is sufficient to resolve most of the structures, except for the smallest ones. Switching to larger camera sensors like the Sony IMX411 with a SBP of 151 million would allow a further increase of the field of view. To put these numbers into context, high end microscope objectives such as Thorlabs TL10X-2P, are limited to an SBP of $\approx 16\text{--}20$ million, hence a smaller field of view. So, by forgoing lenses and scaling the sensor size, larger field of views can be achieved. Instead of stitching multiple smaller lens-based measurements together, each requiring a full mechani-

cal scan, a single scan using a large sensor is sufficient. Therefore, the speed advantage of the lensless WLI approach lies not only in a faster individual scan speed, but also in the fact that just one instead of multiple measurements are needed, thus drastically multiplying the speed. At the moment such a lensless measurement only requires 90 intensity images, which is at least a tenfold reduction in images compared to a conventional WLI.

For illumination 15 wavelengths between 510.0 nm and 590.2 nm with equal frequency spacing were used. These are created using an NKT supercontinuum laser in combination with an NKT SuperK SE-LECT filter.

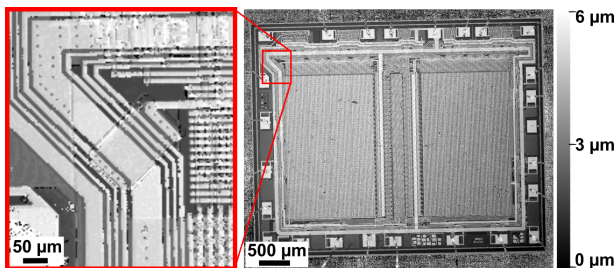


Fig. 2 Demonstration of the field of view offered by the lensless WLI approach using an EPROM-Chip M2716 by SGS-Thomson. The region is cropped from $12 \times 12 \text{ mm}^2$ to the size of the chip. The lateral resolution is $2.74 \mu\text{m}$.

3.2 Lateral resolution

To overcome the limitation of the resolution determined by the pixel pitch, the lensless WLI approach can be combined with the lensless microscopy approach provided in [3] resulting in a higher resolution over a smaller field of view since the SBP of the image sensor cannot be exceeded. Figure 3a) illustrates the achievement of a lateral resolution of $\approx 1 \mu\text{m}$, using an USAF-Chart (Group 9, Element 1) and a wavelength of 532 nm, while b) shows the setup where the collimated illumination is replaced by a convergent one.

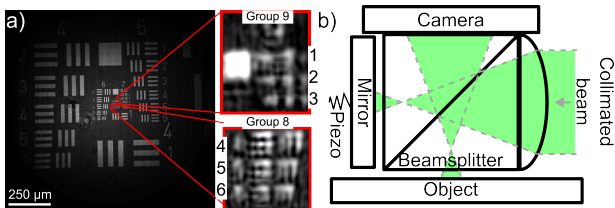


Fig. 3 a) Demonstration of $\approx 1 \mu\text{m}$ lateral resolution by resolving Group 9, Element 1 of an USAF-Chart with a wavelength of 532 nm. b) Schematic of the altered setup compared to Fig. 1 using a convergent illumination.

Combining lensless microscopy and lensless WLI results in a high resolution measurement as shown in Fig. 4. A lateral resolution of $\approx 1 \mu\text{m}$ is achieved, while the field of view has a diameter of roughly

1.2 mm. The limiting factor is the NA of the lens used for beam forming. Based on resolution and SBP of the camera a field of view of $4.4 \times 4.4 \text{ mm}^2$ should be possible. The wavelengths were the same as for the collimated illumination.

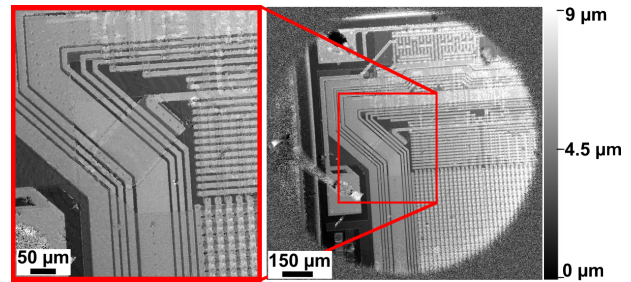


Fig. 4 High resolution surface height measurement with $\approx 1 \mu\text{m}$ lateral resolution achieved by combining lensless WLI and lensless microscopy.

4 Conclusion

In this work we have shown, that lensless WLI is a viable alternative to lens-based WLI. Not only does it offer faster measurement, it also offers larger field of view, reducing the amount of measurements required. Furthermore, it enables a compact and lightweight design as well as robustness against vibration, allowing for in-process applications.

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