Topography of hidden objects revealed using THz digital holography

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Abstract. We describe a setup for digital off-axis holography based on a high-power far infrared gas laser and a high-resolution uncooled micro-bolometer array detector. Amplitude and phase of the diffraction pattern of test objects in reflection are obtained from phase-stepped digital holograms. The object topography is reconstructed using numerical Fourier transform algorithms. A lateral resolution of around 0.2 mm and a relative phase sensitivity of about λ/10 are estimated. We apply holographic surface topography to the measurement of a fingertip imprint behind a plate and compare the results to white-light fringe projection measurements.

Introduction

Terahertz (THz) radiation is part of the far infrared spectrum at wavelengths between λ = 30 µm (10 THz) and 3 mm (0.1 THz). It penetrates many non-conductive materials that would absorb visible light completely, but is reflected by e.g. metals [1]. We are interested in the interaction of skin and other materials, e.g. textiles, which can cause skin irritations, inflammations or bedsores. The mechanical interaction is influenced by the properties at the interface, e.g. the texture of the skin surface and the textile, the real contact area, and the presence of interfacial liquids.

While imaging methods based on time-of-flight and beam or object scanning have been around for many years, imaging using coherent THz radiation is gaining ground only recently. Recent work on THz imaging and THz holography made use of micro-bolometer array detectors. Like Golay cells and pyroelectric devices bolometers are thermal detectors and typically optimized for the longwave infrared band between 8 – 12 µm. It was, however, shown that they can perform surprisingly well for THz radiation [2]. When a sufficiently strong THz source is available, array detectors allow for dynamic measurements, in contrast to the scanning methods. Interferometric methods such as digital off-axis holography take advantage of the phase and amplitude information of the scattered THz beam to assess the topography of the object of interest with a resolution well below λ. While a disadvantage of the long wavelength is the reduced lateral resolution, the advantage is its robustness against ambient vibrations and surface roughness. THz topography in reflection with sub-mm resolution was demonstrated on metallic targets [3,4], while topography in transmission is equivalent to a thickness measurement. We have demonstrated THz topography in transmission on a fingertip replica achieving a lateral resolution of 200 µm, which was enough to resolve the skin furrows [5]. In this contribution, we demonstrate the capabilities of our technique to profiling an object, hidden behind a plate, in reflection. Results are compared to an established topography technique: white-light fringe projection.

Experimental

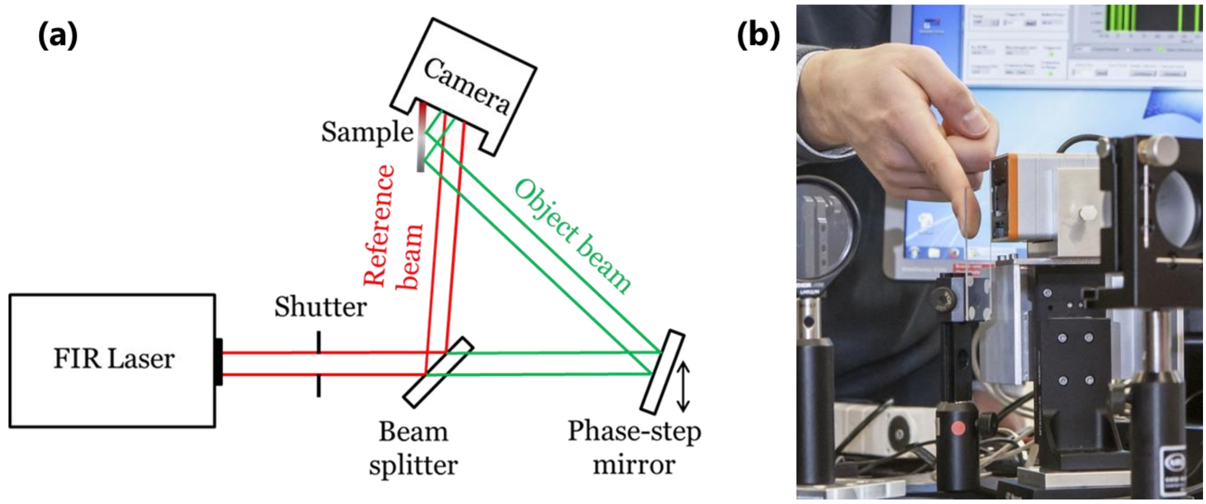

Figure 1: Schematics of the THz off-axis digital holography set-up in reflection (a) and a close up of an object behind a plate (b).

Fig. 1 shows a schematic of the experiment. The source of THz radiation was a far infrared gas laser (Edinburgh Instruments, Livingston, Scotland), The reference beam is split off by a plate and directed towards the detector, while the object beam travels to the object surface via a mirror which can be used as a phase stepper. An uncooled micro-bolometer a-Si array served as detector with 640×480 pixels on a 17 µm pitch (Xenics, Leuven, Belgium). Note that the sample makes an angle of around 45° to the detector plane.

Results

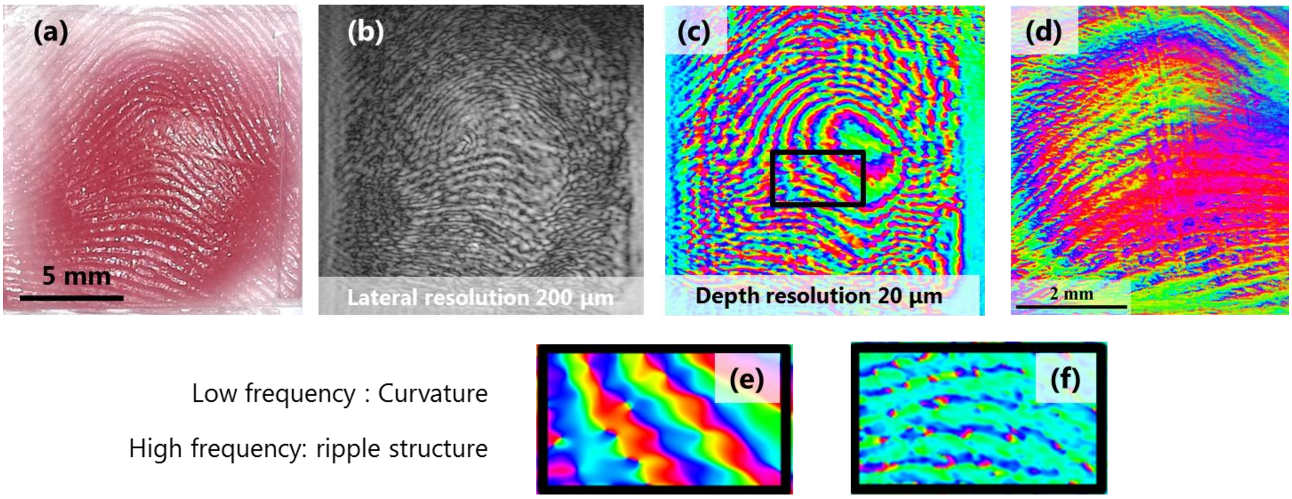

Figure 2: The object (a), the reconstructed intensity (b) and reconstructed phase map (c). The phase map contains information on both the overall curvature (e) and ripple structure (f). For comparison, a fringe projection measurement through the plate is given in (d).

Fig. 2 shows a result of the experiment. The fingertip imprint in wax was measured in reflection. No plate was used in this illustration for the THz holography measurement. Phase was obtained with a phase-stepping method, and resolution was improved using a Synthetic Aperture method based on shifting the detector. While a quartz plate was inserted to allow for comparison with the topography measured using white-light fringe projection, Fig. 2d.

For the numerical reconstruction of the object from the recorded hologram, both the distance and angle to the detector plane had to be appropriately set. In general, plate reflections can be comparable to the scattered object intensity. Then neither a phase stepping nor a Fourier plane separation of object and plate contributions is possible, as both the plate and the object are illuminated by the same object beam and are oriented in the same direction. We resort to a procedure based on difference measurements which allows for an individual determination of all contributions to the hologram and to single out the object intensity and phase in the detector plane before reconstruction [6].

Conclusion

We have implemented a digital holography set-up for high-resolution THz topography of hidden objects in reflection. The depth resolution of the profiles is around $\lambda/10$ and thus comparable to white-light profiling in reflection using projected fringes. The use of digital off-axis holography, high power THz source and an array camera paves the way for dynamic measurements of the interface.

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References

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