ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/242198443

Infrared digital holographic imaging

Article

CITATION
1

READS
60

6 authors, including:

Pietro Ferraro
Italian National Research Council
781 PUBLICATIONS **10,477** CITATIONS

SEE PROFILE

Lisa Miccio
Institute of Applied Sciences and Intelligent Systems - ISASI
185 PUBLICATIONS **2,645** CITATIONS

SEE PROFILE

Simonetta Grilli
Italian National Research Council
236 PUBLICATIONS **4,113** CITATIONS

SEE PROFILE

Riccardo Meucci
INO - Istituto Nazionale di Ottica
114 PUBLICATIONS **2,541** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project LAN ON A CHIP FOR BIOMEDICAL SCIENCE BY CHORENT MICROSCOPY IN DIGITAL HOLOGRAPHY MODALITY View project

Project Holographic interferometry View project

All content following this page was uploaded by Pietro Ferraro on 01 June 2014.

The user has requested enhancement of the downloaded file.

SPIE Newsroom

10.1117/2.1200802.0991

Infrared digital holographic imaging

Pietro Ferraro, Lisa Miccio, Simonetta Grilli, Riccardo Meucci, Sergio De Nicola, and Paul Buah-Bassuah

A digital holographic technique has an extended measurement range and improved resolution at infrared wavelengths.

Long-wave interferometers have been widely used in many applications, including infrared (IR) optics, IR transmitting materials, and high-reflective multilayer dielectric coatings for high-power laser systems.[1–3] In the field of metrology, researchers have focused on longer wavelengths because they greatly extend the measurement range of interferometric techniques. However, one significant drawback of longer wavelengths is that they decrease resolution, and existing technologies for IR interferometers, such as pyrocam arrays, are limited by low spatial resolution.

Other methods to extend the measurement distance employ longer synthetic wavelengths[4] (the beat wavelengths between two different wavelengths). In these methods, several holograms are recorded at multiple color wavelengths. These techniques present some practical difficulties. In general, digital holograms recorded with different wavelengths produce images of different sizes. In addition, color digital holographic display requires simultaneous reconstruction of images recorded at each color wavelength, and the resulting reconstructed images must be perfectly superimposed to get a correct color display. Finally, the images require a proper resizing operation[5] at the end of the reconstruction process.

We have developed a new approach that results in improved resolution, a large measurement range, and does not require a complicated reconstruction process. By using classical digital holographic microscopy (DHM) at IR wavelengths[6], combined with a zero padding operation for improving the spatial resolution, we have shown that long-wave interferometry may be a viable method for quantitative phase imaging.

DHM is similar to traditional microscopy, but relies on a laser for its light source. The experimental setup, shown in Figure 1(a), uses a Mach-Zehnder interferometer, a pyrocam array detector,

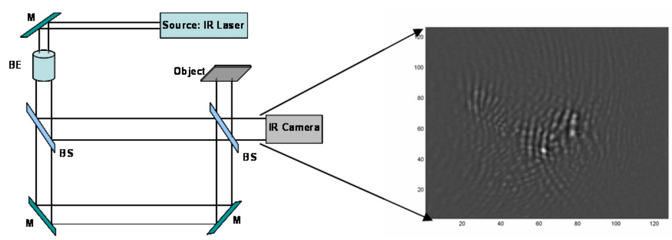

Figure 1. *(a) A beam expander expands light from the IR source, then a beam splitter separates the beam into the reference and object beam. After reflecting off of two mirrors, the object beam hits the sample. (b) The light reflected by the object interferes with the reference beam on the IR detector, which records an interference pattern. BE: beam expander; BS: beam splitter; M: mirror; IR: infrared.*

and a 10.6μm wavelength CO_2 laser to image samples that are reflective at infrared wavelengths. DHM involves two steps. First, the IR detector is placed out of focus and records the interference pattern, shown in Figure 1(b). Second, the image is numerically reconstructed based on phase and amplitude information of the wavefront reflected from the object.

Figure 2(a) shows the amplitude contrast image of the first object, a 20mm $\times$ 35mm opaque aluminum block with the

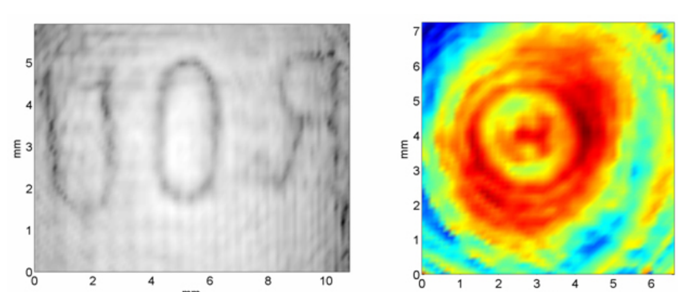

Figure 2. *(a) Amplitude image of the letters ROU inscribed on an aluminum block. (b) The phase image of an aluminium disc inscribed with concentric circular tracks.*

Continued on next page

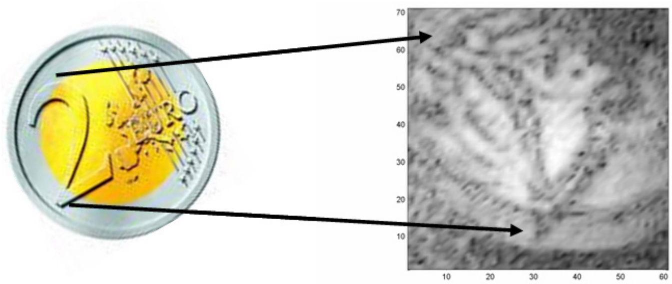

Figure 3. *An amplitude contrast image (right) of a two euro coin (left).*

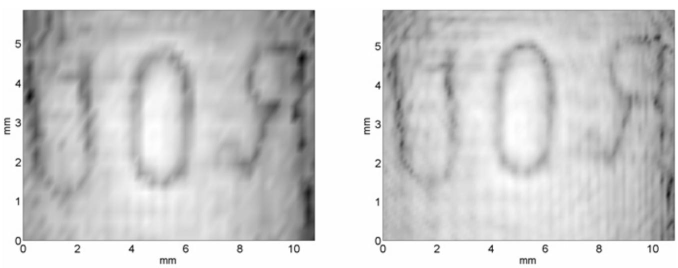

Figure 4. *(a) Amplitude contrast image of the aluminum block before padding. (b) After the zero padding operation, the image shows noticeable improvement in spatial resolution.*

3mm×4mm letters UOR inscribed on it. Figure 2(b) shows the phase contrast image of a 25.4mm radius disc inscribed with a set of concentric circular tracks. Both images are able to capture the defining features of each sample. The amplitude image of a two euro coin (Figure 3) also displays some of the 3-dimensional features on the surface of the coin.

In the experiments, the object plane was a distance *d*= 250mm from the recording plane. To compensate for the loss of resolution with increasing reconstruction distance *d*, we used a zero padding operation . Before the padding, the $85\mu m \times 85\mu m$ pixels yielded an image plane pixel size of $\Delta x \times \Delta y = 213\mu m \times 213\mu m$. Figure 4(a) shows the amplitude contrast image of the aluminum block without zero padding. The digitized hologram, which is a matrix of *NxN* pixels (*NxN*=124x124), was then padded with a value of zero to achieve a larger array of $N * \times N* = 256 \times 256$ points. The resulting array has a reconstruction pixel of size $\Delta x \times \Delta$ y=103μ m $\times$ $103\mu m$. The amplitude contrast image of the block after the padding operation, shown in Figure 4(b), exhibits a noticeable improvement in spatial resolution.

The results demonstrate that digital holography can be a viable method to obtain phase and amplitude reconstructions, even at long wavelengths. The method proposed for improving the accuracy of the reconstruction, based on a zero padding operation, compensates for the loss of resolution at longer wavelengths and the low spatial resolution of the pyroelectric camera array. Improvements in spatial resolution in digital holography in the mid-infrared regime[7,8] may enable advances in cell and tissues analysis, where electric potential or light-induced phase changes are expected to play a significant role in the characterization of complex biological structures.

Author Information

Pietro Ferraro, Lisa Miccio, and Simonetta Grilli
Istituto Nazionale di Ottica Applicata (INOA) del CNR
Pozzuoli, Napoli, Italy

Dr. Pietro Ferraro received his PhD in physics, summa cum laude, from the University of Napoli Federico II, Italy, in 1987. Soon after he joined Aeritalia-Alenia Aeronautics to develop applied research in optical nondestructive testing of carbon fiber materials. In 1993 he joined Consiglio Nazionale delle Ricerche (CNR) Institute of Cybernetics as an Associate Researcher to develop interferometric and holographic methods. He joined the INOA as senior research scientist in 2003.

Lisa Miccio obtained her physics degree, cum laude, from the University of Naples Federico II, Italy, in 2006, and has worked at INOA-CNR ever since. Her main research focus is optics. She is currently a PhD student at Florence University, where she studies optical techniques to determine material properties.

Simonetta Grilli received her PhD from the Royal Institute of Technology in Stockholm and is now a research scientist at the INOA-CNR. Current interests include non-invasive investigation of reversed ferroelectric domains and fabrication of sub-micron structures. She is the co-author of more than 25 international journal articles and more than 40 conference papers.

Riccardo Meucci
Istituto Nazionale di Ottica Applicata (INOA) del CNR
Firenze, Italy

Sergio De Nicola
Istituto di Cibernetica E. Caianiello del CNR
Pozzuoli, Napoli, Italy

Sergio De Nicola received his BS in physics from University of Naples Federico II, Italy in 1982. From 1983 to 1987, he was a system analyst with Elettronica SpA and Alenia SpA, Naples.

Continued on next page

10.1117/2.1200802.0991 Page 3/3

Since 1988, he has been on the staff of the Institute of Cybernetics, E Caianiello, of the National Council of Research, Italy, where he is currently a senior researcher. He has contributed to about 200 papers in international journals and conferences.

Paul Buah-Bassuah
Physics Dept. University of Cape Coast
Cape Coast, Ghana
Istituto Nazionale di Ottica Applicata (INOA) del CNR
Firenze, Italy

References

1. R. J. Mahon, J. A. Murphy, and W. Lanigan, *Digital holography at millimetre wavelengths*, **Opt. Commun. 260**, pp. 469–473, 2006.
2. N. Miyamoto, S. Nisiyama, S. Tomioka, and T. Enoto, *Application of the nitroanisole as an infrared detector used in middle infrared interferometer*, **Opt. Commun. 260**, pp. 25–29, 2006.
3. K. Creath, *Step height measurement using 2-wavelength phase-shifting interferometry*, **Appl. Opt. 26**, pp. 2810–2816, 1987.
4. P. Ferraro, S. Grilli, L. Miccio, P. K. Buah-Bassuah, R. Meucci, S. De Nicola, and F. T. Arecchi, *Imaging and phase measurement of 3D object at 10.6 micron by digital holography*, **Proc. SPIE 6736**, p. 673612, 2007. doi:10.1117/12.746239
5. P. Ferraro, L. Miccio, S. Grilli, M. Paturzo, S. De Nicola, A. Finizio, R. Osellame, and P. Laporta, *Quantitative Phase Microscopy of microstructures with extended measurement range and correction of chromatic abberations by multiwavelength digital holography*, **Opt. Express 15**, pp. 14591–14600, 2007. http://www.opticsinfobase.org/abstract.cfm?URI=oe-15-22-14591
6. K. N. Prettyjohns, S. DeVore, E. Dereniak, and J. C. Wyant, *Direct phase measurement interferometer working at 3.8 μm*, **Appl. Opt. 24**, p. 2211, 1985.
7. E. Allaria, S. Brugioni, S. DeNicola, P. Ferraro, S. Grilli, and R. Meucci, *Digital holography at 10.6 μm*, **Opt. Commun. 215**, p. 257, 2003.
8. N. George, K. Khare, and W. Chi, *Infrared holography using a microbolometer array*, **Appl. Opt. 47**, pp. A7–A12, 2008.

© 2008 SPIE