



HAL
open science

Long Wave Infrared Wavefront Reconstruction Through Complex Media

Anwesh Bhattacharya, Pascal Berto, Valentina Krachmalnicoff, Ignacio Izeddin, Gilles Tessier, Yannick De Wilde

► **To cite this version:**

Anwesh Bhattacharya, Pascal Berto, Valentina Krachmalnicoff, Ignacio Izeddin, Gilles Tessier, et al.. Long Wave Infrared Wavefront Reconstruction Through Complex Media. Conference on Lasers and Electro-Optics CLEO: Applications and Technology 2022, May 2022, San Jose, United States. pp.JF2A.2, 10.1364/CLEO_AT.2022.JF2A.2 . hal-03861336

HAL Id: hal-03861336

<https://hal.science/hal-03861336>

Submitted on 19 Nov 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Long Wave Infrared Wavefront Reconstruction Through Complex Media

Anwesh Bhattacharya¹, Pascal Berto^{2,3}, Valentina Krachmalnicoff¹, Ignacio Izeddin¹, Gilles Tessier³, Yannick De Wilde¹

¹ Institut Langevin, ESPCI Paris, Université PSL, CNRS, 1 Rue Jussieu, 75005 Paris, France

² Université de Paris, 45 Rue des Saints Pères, 75006 Paris, France

³ Sorbonne Université, CNRS UMR7210, INSERM UMRS968, Institut de la Vision, Paris, France

anwesh@espci.fr

Abstract: A novel broadband infrared (IR) speckle imaging system with a thin scatterer and an uncooled microbolometric camera is employed to encode wavefront phase variations as local speckle deformations. The phase reconstruction from speckle shifts using a fast diffeomorphic algorithm ultimately demonstrates IR wavefront reconstruction through complex media. © 2021 The Author(s)

1. Introduction

Long wave infrared (LWIR) radiation ($\lambda = 8\text{-}14\ \mu\text{m}$) enables illumination-less passive thermal imaging, and precise chemical identification, besides atmospheric sensing, fault detection, and medical testing. Investigating far-field thermal emission from IR nano-antennas [1], and reconstructing thermal wavefronts from tunable free-form planar optics [2] has motivated our development of a novel broadband thermal wavefront sensing technique. Speckle imaging is widely used for intensity or phase imaging with broadband sources through complex inhomogeneous media at visible wavelengths [3], and recently in the infrared [4]. Visible speckle imaging has demonstrated the ability to encode the wavefront information in an intensity pattern [5], with the ability to reconstruct wavefronts by comparing a reference speckle to a deformed speckle [3]. We demonstrate LWIR wavefront reconstruction using a broadband speckle imaging setup comprising a thin scattering medium in front of an uncooled microbolometric camera. Our technique promises future imaging applications through visually opaque samples like semiconductor chips, solid-state nanoelectronics, and infrared optics, for defect characterization.

2. Speckle Imaging

Upon transmission through complex scattering media, a wavefront produces a unique speckle pattern. A local wavefront tilt produces a corresponding local deformation in the speckle pattern, which facilitates precise wavefront sensing as the speckle is a unique fingerprint of the incident wavefront. Assuming that θ , the tilt angle of the incident wavefront is small, the optical path difference δ and the tilt angle are related as $\theta \simeq \tan\theta \simeq \sin\theta = \|\nabla_{\perp}\delta\|$. The local displacement vector field of the speckle grains, \mathbf{s} , is proportional to the gradient of the optical path difference (δ) encountered by the beam:

$$\nabla_{\perp}\delta = \frac{\nabla_{\perp}\varphi}{k_0} \simeq \frac{\mathbf{s}}{d}, \quad (1)$$

where, d is the distance between the scatterer and the speckle imaging plane, φ is the phase of the wavefront, and $k_0 = \frac{2\pi}{\lambda}$ is the wavenumber. This equation gives access to the phase of the wavefront by computing the displacement \mathbf{s} over the entire field between the reference speckle and sample speckle image. The displacement map is estimated using the fast non-rigid diffeomorphic Demon's algorithm for image registration. [6] The gradient of this displacement vector field is integrated in 2-D to finally obtain the reconstructed wavefront.

3. Experimental Setup and Results

Our far-field LWIR speckle imaging setup consists of a Silicon carbide global blackbody source which is imaged using a Zinc Selenide (ZnSe) lens (7-12 μm) in a Köhler illumination scheme onto an iris for spatial filtering. The iris image then becomes a secondary source, which is collimated using another lens. This plane wavefront is incident on the complex medium, where it undergoes surface scattering. The transmitted light forms a reference speckle due to the inhomogeneous surface roughness of the scattering medium's exit surface. With a phase object, the plane wavefront is distorted and this produces a deformed sample speckle. The speckles formed 1mm away

from the scattering medium are imaged using a close-up lens of focal length $f = 62$ mm and magnification $M = 0.69$ onto the sensor of a FLIR A655sc uncooled microbolometric LWIR camera. Our imaging setup is therefore a broadband uncooled thermal speckle imaging system. To test the feasibility of LWIR wavefront reconstruction using speckle imaging, we use a ZnSe lens of focal length, $f = 1$ m, as a known phase object. This sample lens distorts the plane wavefront and produces a converging wavefront with a focus 1 m along the propagation axis. The local speckle grain shifts between the reference speckle and the sample speckle are computed using the rapid non-rigid image matching technique of diffeomorphic Demon's algorithm, which minimizes the mean squared difference function between the two images. The computed displacement vector field is then integrated in 2D in the Fourier domain to obtain the reconstructed wavefront. As evident from Figure 2, the reconstructed wavefront matches the phase values and the spherical profile of the ideal expected wavefront, which opens up the path towards precise quantitative LWIR wavefront reconstruction.

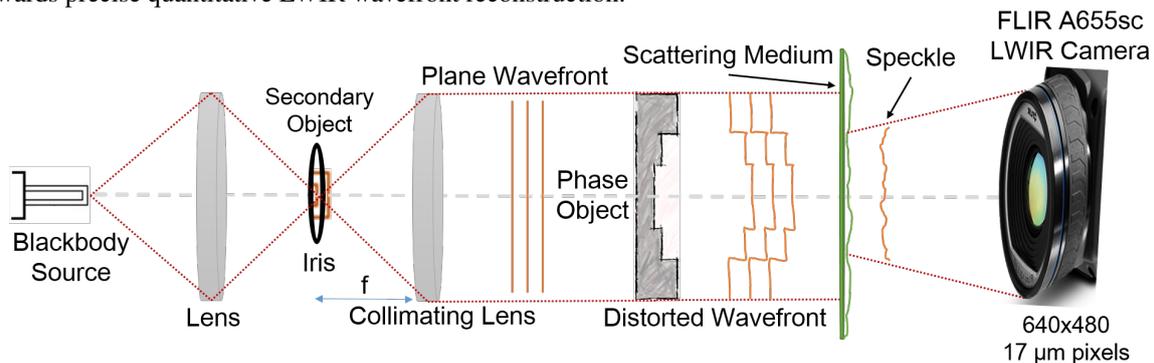


Fig. 1: Experimental Setup for LWIR Speckle Imaging

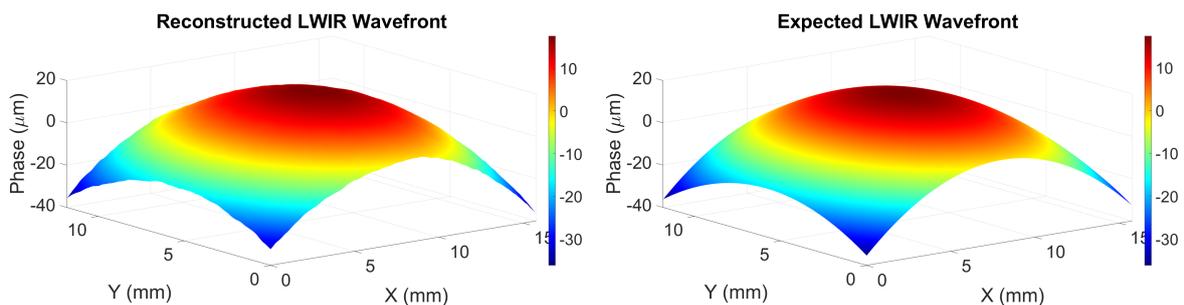


Fig. 2: LWIR Wavefront Reconstruction. Experimentally reconstructed (left) & ideal expected (right) wavefronts when a Zinc Selenide lens of $f = 1$ m is placed as a phase sample in the setup shown in Figure 1.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 754387. This research is also supported by LABEX WIFI (Laboratory of Excellence within the French Program "Investments for the Future") under references ANR-10-LABX-24 and ANR-10-IDEX-0001-02 PSL.

References

1. L. Abou-Hamdan, C. Li, R. Haidar, V. Krachmalnicoff, P. Bouchon, and Y. D. Wilde, "Hybrid modes in a single thermally excited asymmetric dimer antenna," *Opt. Lett.* **46**, 981–984 (2021).
2. P. Berto, L. Philippet, J. Osmond, C. F. Liu, A. Afridi, M. Montagut Marques, B. Molero Agudo, G. Tessier, and R. Quidant, "Tunable and free-form planar optics," *Nat. Photonics* **13**, 649–656 (2019).
3. P. Berto, H. Rigneault, and M. Guillon, "Wavefront sensing with a thin diffuser," *Opt. Lett.* **42**, 5117 (2017).
4. S. Divitt, D. F. Gardner, and A. T. Watnik, "Imaging around corners in the mid-infrared using speckle correlations," *Opt. Express* **28**, 11051 (2020).
5. O. Katz, P. Heidmann, M. Fink, and S. Gigan, "Non-invasive single-shot imaging through scattering layers and around corners via speckle correlations," *Nat. Photonics* **8**, 784–790 (2014).
6. T. Vercauteren, X. Pennec, A. Perchant, and N. Ayache, "Diffeomorphic demons: Efficient non-parametric image registration," *NeuroImage* **45**, S61–72 (2009).