Method for increasing the view field of THz holograms

To cite this article: A T Turov et al 2018 J. Phys.: Conf. Ser. 1096 012128

View the article online for updates and enhancements.
Method for increasing the view field of THz holograms

A T Turov¹, N S Balbekin¹, M S Kulya¹ and N V Petrov¹

¹ITMO University, Kronverkskiy prospect 49, St. Petersburg, Russia, 197101

e-mail: artemtur442@gmail.com, nbalbekin@niuitmo.ru, mskulya@corp.ifmo.ru

Abstract. In this paper we demonstrate the method of widefield amplitude-phase object images reconstruction from the spatially-limited broadband terahertz wavefield spectral components distributions in the Fresnel diffraction zone, based on the wave propagation equations iterative solution algorithm. Using of this method allows one to overpass the spatial resolution limit of an object image, reconstructed from the digital pulse terahertz hologram in low-frequency components of the THz radiation, used in the research. In its turn the created software allows to simulate the process of holograms registration in case of limited detector aperture and to reconstruct the full images of an object.

1. Introduction

Terahertz (THz) spectrum of electromagnetic radiation is represented by the frequencies between 0.3 and 3 THz and, consequently, by the sub millimeter wavelengths range between 1 and 0.1 mm. Though a great research has been made since it was discovered, it still remains unexplored enough, despite being interesting to scientists all over the world because of lots of its potential practical uses. Terahertz waves are perfectly suitable for nondestructive testing [1, 2], including quality control [3], biomedical and chemical research and diagnostics [4, 5], other imaging purposes [6, 7], including security applications [8, 9]. This is possible due to the ability of THz waves to provide high resolution and penetration depth, get the spectroscopic information of an object, which features are covered by this range, for example, explosives [10], polymers, organic molecules. Because of such big wavelength, comparing with visible light, it is diffracted by much more huge objects. Finally, THz radiation applications often don’t require optics, meaning that the optical aberrations will be minimal. But, howbeit, most of the technologies and methods, used nowadays to implement the THz radiation practical applications, mentioned above, suffer from low signal-to-noise ratio[11] and inability to be used in all the variety of THz frequencies. So do one of the most common and universal of them - THz pulse time domain holography (PTDH) [12, 13]. Trying to at least partially overcome the mentioned problems we have carried out series of experiments.

2. Previous experiment

2.1. Preparations

Simulating the real conditions we added a noise of radiation source and detector to the created clean THz impulse. As an initial amplitude object a mask imitating the two closely placed pinholes was used. Initial phase distribution was provided by “flat phase”. Then the field distribution in the resultant hologram plane was calculated in all frequency components, also with the use of THz PTDH principles (Fig. 1).
2.2. Multi-wavelength iterative self-extrapolation algorithm

To increase the resolution and suppress the noise a multi-wavelength self-extrapolation algorithm (MWSEA), developed for one frequency [14] and adopted by us for a broadband THz spectrum, was used. The algorithm includes four steps (Fig. 2): (i) Hologram plane input complex field formation for the THz frequencies array. Array dimension increasing by a factor of 2 for each frequency. (ii) Back propagation to the object plane and image reconstruction. (iii) Filling in the object plane value of the field, outside central part, with zeros. (iv) Hologram recording from the obtained field in the plane of the object and replacement of the central region on the field from the hologram plane of the original input data array. Repeating the cycle according to the desirable number of iterations.

2.3. Intermediate results

As a result of the first experiment we obtained the best noise suppression and resolution increasing on some low frequencies at the fifth iteration. But the question still remained with no answer due to the minimal variations of amplitude masks used: what are the limits for the applied algorithm – a distance between the pinholes, their diameter, a number of iterations for each variation? To get an answer we have carried out the second experiment.

3. The second experiment

3.1 Preparation and carrying out

In the second experiment we used the same methods for noise addition and its suppression and resolution increasing, but used 100 amplitude masks like one described before, step-by-step varying the distance between pinholes (L) and their diameter (D) from 14 and 2 to 32 and 11 pixels respectively (Fig. 3).

Figure 1. a) Amplitude mask “2 pinholes”. b) “flat phase distribution”. c) 3D data array of amplitude distribution via frequency in hologram plane.

Figure 2. The algorithm 4 steps for each iteration.

Figure 3. Some amplitude masks used: a) D = 2px, L = 14px. b) D = 6px, L = 22px. c) D = 11px, L = 32px.
One pixel is equal to 0.6 mm$^2$, meaning that each of its sides has a length of 0.78 mm. As an initial phase distribution we took a white 64x64 pixels square. As a result after implementation of noise addition and MWSEA with 6 iterations we obtained 600 amplitude pictures of an object on each THz frequency used.

3.2 Results
We noticed that the maximum number of iterations for each object remained equal to 5 and the algorithm is workable in all the range of distances and diameters used. We achieved noise suppression and resolution increasing in about X THz for $L = 14$ and $D = 2$ and Y THz for $L = 32$ and $D = 11$. It is clearly demonstrated on the Fig. 4 below.

4. Conclusion
We have shown that the MWSEA is workable in a wide range of distances and diameters. It allows increasing the resolution on low frequencies for lots of objects of different sizes and using of THz PTDH methods in a wider range of frequencies and samples. In its turn use of lower frequencies makes possible to apply THz radiation features more efficiently, because lower frequencies are scattered less. With all the potential applications of THz PTDH and other THz radiation methods it can increase the depth of penetration for signal, leading to more efficient, productive, accurate scanning for security reasons, quality control, non-destructive testing, chemical and biological researching and diagnostics.

Figure 4. Amplitude images of an object for each frequency, D, L and number of iterations.
5. References

[1] Balbekin N S, Novoselov E V, Pavlov P V, Bespalov V G and Petrov N V 2014 Nondestructive monitoring of aircraft composites using terahertz radiation *Proc. SPIE* 9448 94482D

[2] Antsipov V E 2016 Automatic target recognition for low-count terahertz images *Computer Optics* 40(5) 746-751 DOI: 10.18287/2412-6179-2016-40-5-746-751

[3] Ah K and Anwar M 2016 Advanced terahertz techniques for quality control and counterfeit detection *Proc. SPIE* 9856 98560G

[4] Zeitler J A, Taday P F, Newnham D A, Pepper M, Gordon K C and Rades T 2007 Terahertz pulsed spectroscopy and imaging in the pharmaceutical setting - a review *J. Pharm. Pharmacol* 59(2) 209-223

[5] Massaouti M, Daskalaki C, Gorodetsky A, Koulouklidis A D and Tzortzakis S 2013 Detection of Harmful Residues in Honey Using Terahertz Time-Domain Spectroscopy *Appl. Spectrosc* 67(11) 1264-1269

[6] Shiraga K, Ogawa Y, Suzuki T, Kondo N, Irisawa A and Imamura M 2014 Characterization of Dielectric Responses of Human Cancer Cells in the Terahertz Region *J. Infrared Millim* 35(5) 493-502

[7] Smirmov S V, Grachev Ya V, Tsypkin A N and Bespalov V G 2014 Experimental studies of the possibilities of diagnosing caries in the solid tissues of a tooth by means of terahertz radiation *J. Opt. Technol.* 81 464-467

[8] Zimdars D and White J S 2004 Terahertz reflection imaging for package and personnel inspection *Proc. SPIE* 5411 79-83

[9] Federici J F, Schulkin B, Huang F, Gary D, Barat R, Olivera F and Zimdars D 2005 THz imaging and sensing for security applications – explosives, weapons and drugs *Semiconductor Science and Technology* 20(7) S266

[10] Shen Y C, Lo T, Taday P F, Cole B E, Tribe W R and Kemp M C 2005 Detection and identification of explosives using terahertz pulsed spectroscopic imaging *Applied Physics Letters* 86(24) 241116

[11] Balbekin N S, Kulya M S and Petrov N V 2017 Terahertz pulse time-domain holography in dispersive media *Computer Optics* 41(3) 348-355 DOI: 10.18287/2412-6179-2017-41-3-348-355

[12] Petrov N V, Kulya M S, Tsypkin A N, Bespalov V G and Gorodetsky A 2016 Application of Terahertz Pulse Time-Domain Holography for Phase Imaging *IEEE Trans. Terahertz Sci. Technol.* 6 464-472

[13] Balbekin N S, Kulya M S, Rogov P Y and Petrov N V 2015 The modeling peculiarities of diffractive propagation of the broadband terahertz two-dimensional field *Physics Procedia* 73 49-53

[14] Latychevskaya T and Fink H W 2013 Resolution enhancement in digital holography by self-extrapolation of holograms *Opt. Express* 21 7726-7733