Theoretical limits and perspectives of the digital holographic technology in bio-detection related on-field decision making

János Pálhalmi (CA),[1] Béla Mihalik[2], Francesca Pennati[3], Alessandro Molani[3], Andrea Aliverti[3], Abhinav Sharma[4], Paul Claassen[4], Thijs Withaar[4], Anna Mező[1], Mariana L. Ferrari[5], Rémy Artus[5], Györgyi Bela[2], Michel Zayet[6], Marcin Niemcewicz[7] (co-CA)

[1]DataSenseLabs Ltd., Budapest, Hungary;
[2]Ideas Science Ltd., Budapest, Hungary;
[3]Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Milan, Italy;
[4]Sioux Technologies B.V, Eindhoven, Netherlands;
[5]Institut Pasteur, Biological Resource Center - ICAReB, Paris, France;
[6]DMI – End Users, Communication & Training, Lyon, France;
[7]Biohazard Prevention Centre, Faculty of Biology and Environmental Protection, University of Lodz, Lodz Poland

Corresponding author: janos.palhalmi@datasenselabs.net, marcin.niemcewicz@biol.uni.lodz.pl

Introduction. Concerns of biological terror events and the appearance of new pathogens have generated an intensive demand for rapid, on-site applicable bio-detection methods which can be integrated into either the preventive or the intervention related decision-making process of CBRNE first responders [1]. The combination of optical and digital holographic detection methods contains the possibility of overcoming the problem of rapid response time and connectivity with other existing sub-systems.
Methods and Results. In the dimensional range of bacterial objects, the “Mie” simulation method [2] was used to investigate the performance of single object detection in the function of particle diameter between 50 nm and 2 µm. Refractive indexes (RI) of particles were optimized for bacteria (RI=1.4) in water-based solution (RI=1.33). Simulations were validated against measurements for various experimental configurations (laser line wavelengths: 405 - 840 nm). The amplitude and half-width of holographic intensity and phase representation were analyzed, and a pixel-to-pixel correlation method was developed to quantify the difference between the center and surrounding regions of the images. Pixelwise Pearson’s correlation coefficients (R) and p-values (p) showed no significant difference ($R<0.8$, $p>0.05$) between the center and center-surrounded regions of the simulated images in the particle diameter range of 2 – 0.250 µm. This indicates a prominent difference regarding the detectability of peaks under and above 0.250 µm.
Conclusions. According to the results, even a single particle of 50 nm diameter can be detected under ideal conditions. On the other hand, it must be noted, that the half-width of both the phase and the intensity plane is almost comparable to a 512x512 pixel wide detector area in the case of 200 nm pixel size. Above 0.250 µm particle range, the phase and intensity plane characteristic are optimal to improve detection performance, which makes object detection and classification possible within the dimensional range of bacteria.

References

[1] M. Saito, et al, “Field-deployable rapid multiple biosensing system for detection of chemical and biological warfare agents”, *Microsystems & Nanoengineering*, vol. 4, no. 1, 2018.
[2] W. Chen, et al, “Empirical concentration bounds for compressive holographic bubble imaging based on a Mie scattering model”, *Optics Express*, vol. 23, no. 4, 2015.
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