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

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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. The combination of optical and digital holographic (DH) detection methods offers the possibility of overcoming the problem of rapid response time and connectivity with other existing sub-systems.

In the present study, results of single frame simulations carried out under ideal conditions were used to define the theoretical limit of detection in the case of in-line, point source digital holography. Regarding data analytical comparisons, fundamental statistical methods were used to describe the properties of the raw datasets without the application of any signal processing to uncover the potential of the system as a direct measurement method.

Conclusion

Detectability of homogenous particles in the 1-2 µm range is within the 95% coverage probability under ideal conditions. This establishes the possibility of detecting changes with high confidence in the distribution of airborne particle diameter within the dimension of bacteria.

Analysis of the periodicity within the intensity profiles of simulated particles indicates that the reliable limit of detection is within the submicron range (above 125 nm) which provides the possibility of nanoparticle detection as well, by applying the appropriate signal processing, digital and optical filtering methods.

Based on the current results, the DH measurement methodology is capable of quick detection of changes in the distribution of airborne nano- and micro-particles, which enables the integration of DH technology by the first-responders on-site, for quick decision making.

Holographic Representation of Individual Particles

Fig.1.

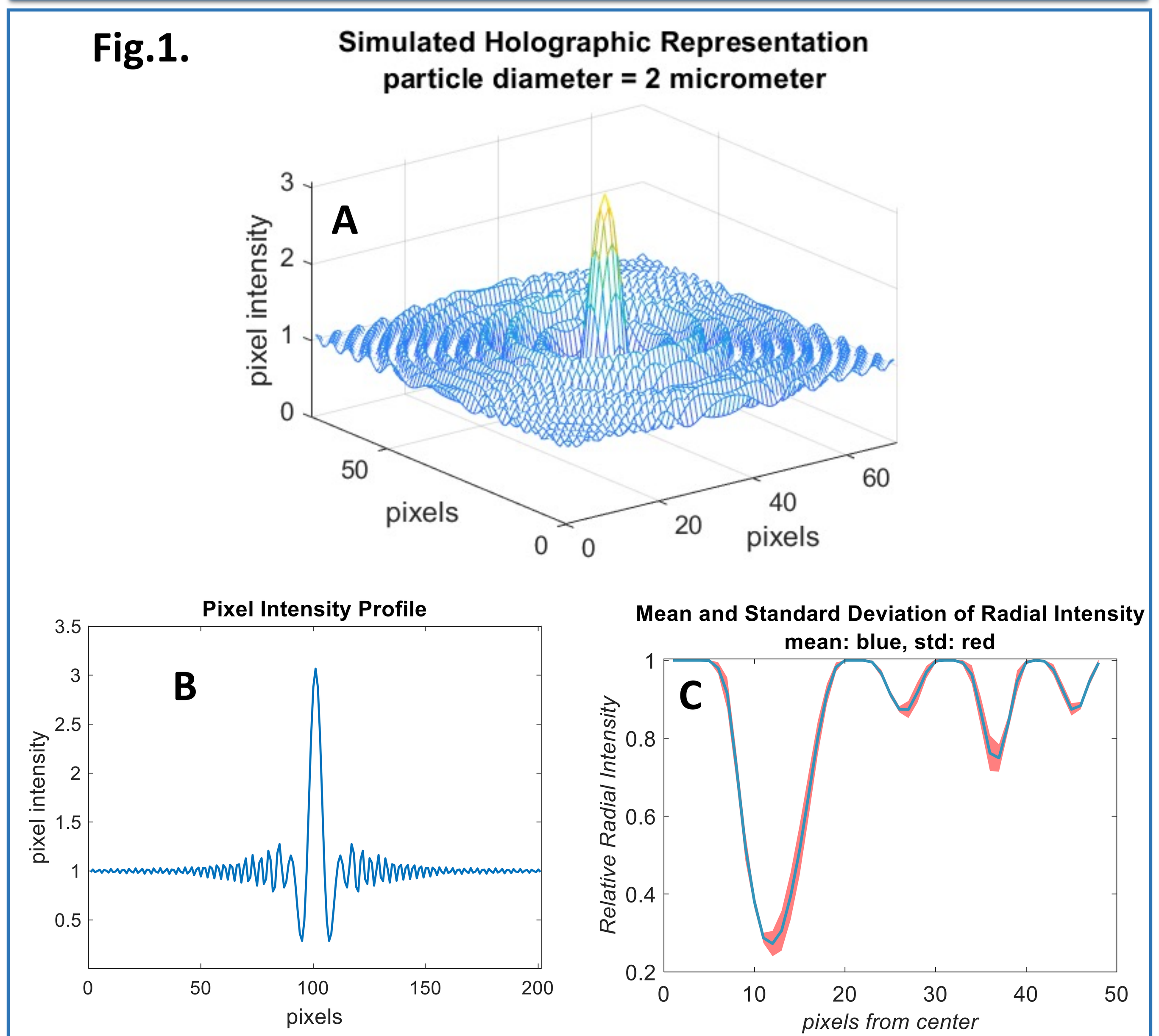

Fig.2.

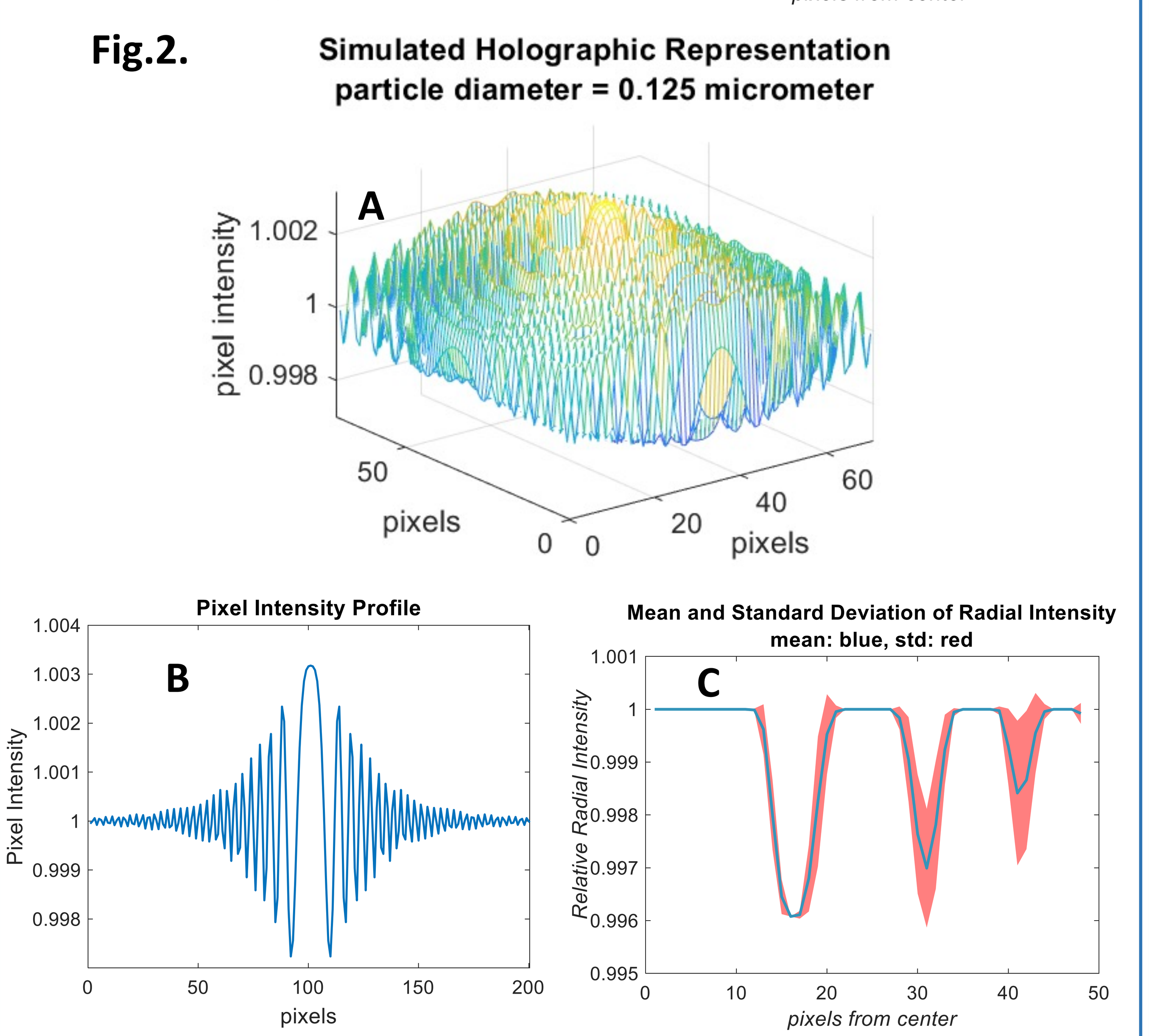

Fig. 1. and 2. A, B, C.
Representation of the holographic raw data output of in-line, point source Simulation according to the 'Mie' model.
Fig.1.A.: 3D plot of a particle with 2 µm diameter. **Fig.1.B.:** Pixel intensity profile of the same particle with 2 µm diameter. **Fig.1.C.:** Mean and standard deviation of the polar coordinate representation of same particle with 2 µm diameter.
Fig.2.A, B, C.: Representation of the holographic raw data in the case of a particle with 0.125 µm diameter respectively.

Influence of Wavelength and Sample Background on Detection Limit

Fig.3.

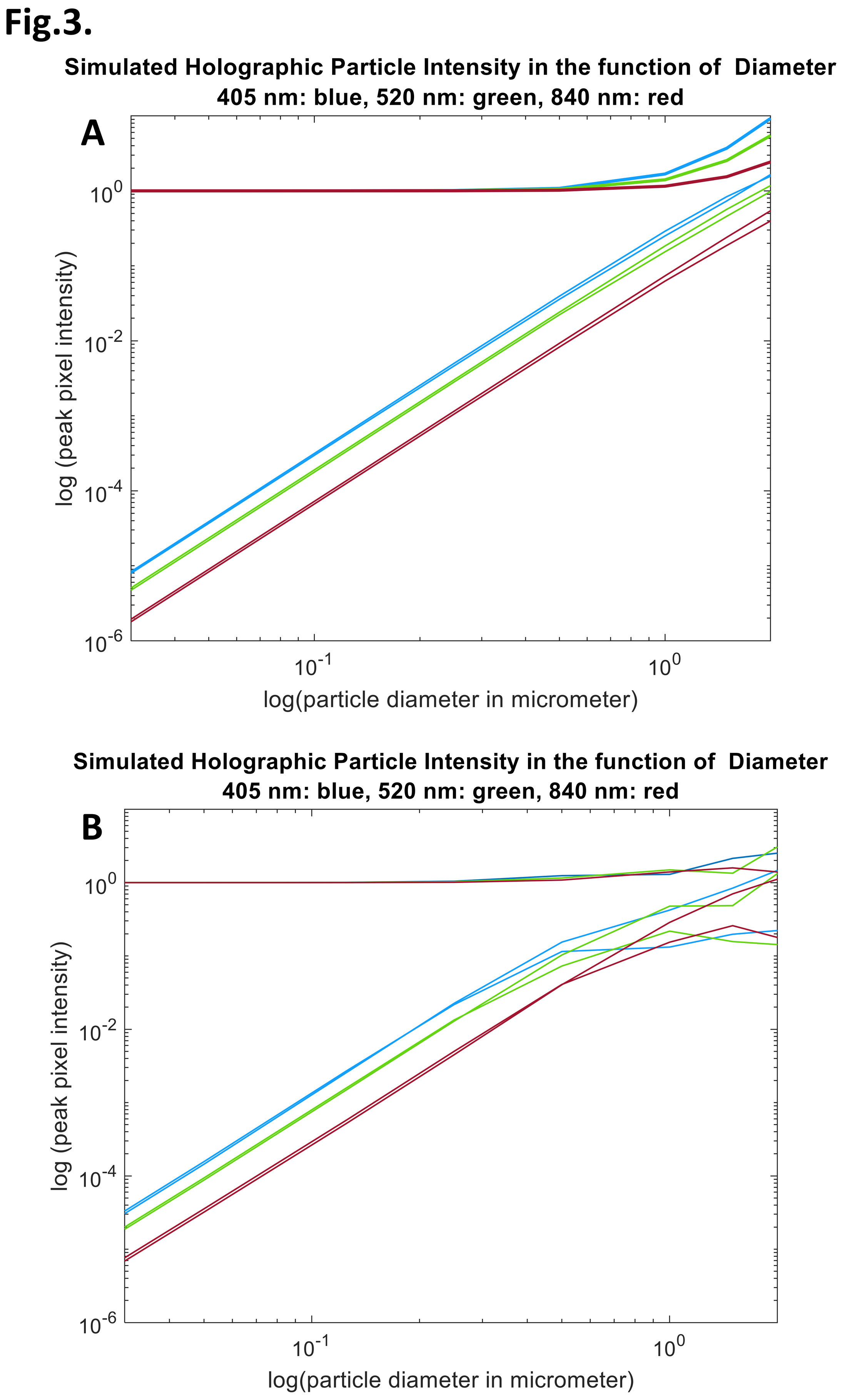

Fig. 3. A, B.
Peak value of the pixel intensity profile of the holographic raw data and the calculated phase and intensity representations are plotted against the particle diameter. Colours indicate the wavelength of coherent laser illumination as referred to in the figures. Simulations were carried out according to the 'Mie' scattering model. Distance of the particle from the detector plane was 6 µm to establish comparable conditions with lens-supported simulations within the focus-plane.
A. Summarizes the results of simulations in water-based environment.

B. Summarizes the results of simulations under air background

Please note the simulated limit of detection is remarkably lower in the case of air background.

Statistical View of Detection Limit

Fig.4.

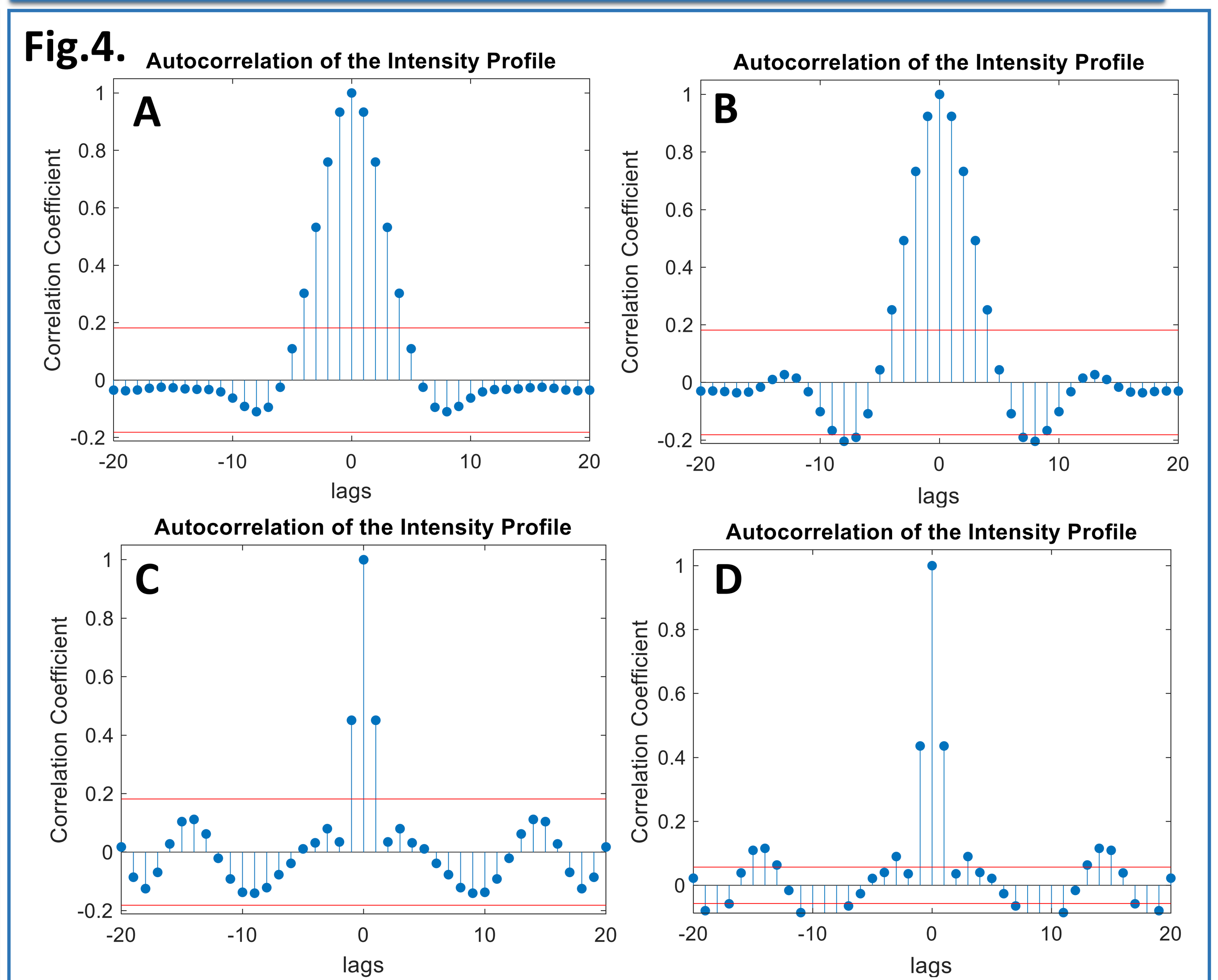

Fig. 4. A, B, C, D.
Autocorrelation coefficient of simulated pixel intensity profiles plotted against 'lags'. Particle diameter d = 2 µm **(A)**; d = 1.5 µm **(B)**; d = 0.125 µm **(C)**; d = 0.05 µm **(D)**.
95% confidence interval (red line) indicates that the intensity profiles are hardly different from a random process under 0.125 µm diameter of particles. The intensity profiles are distinguishable under 95% coverage probability within the range of 1 – 2 µm of particle diameter.

Standard Deviation Gradient Ratio

d =	2 µm	1.5 µm	1 µm	0.5 µm	0.25 µm	0.125 µm	0.05 µm
520 nm - air	4445	84	200	191	51	33	30
520 nm - water	2552	1317	467	154	53	28	24

Table 1.
Standard deviation gradient (STDG) ratio of the simulated images was calculated by comparing the STDG values of the pixel intensity profiles of the center line and the periphery. The STDG ratio is proportional to the prominence of the signal compared to the background. Please note the hardly observable difference between the particles of 0.125 µm and 0.05 µm diameter.

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