Micro endoscope-integrated holographic, through scattering media imager, realized by tunable projection of 2D spots array

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Objective of the technology

The objective of this research includes integration of high-resolution imaging through scattering medium, such as blood, into a disposable micro-endoscope. A fiber laser integrated into the micro-endoscope as part of its illumination channel, allows to project a tunable array of spots of light onto an object, that is located behind the scattering medium. If the distance between the projected spots is larger than the imaging resolution, then by applying localization microscopy algorithms together with scanning of the position of the spots in the array, will yield a high-resolution reconstruction of the inspected object.

Description of the technology

We have a laser fiber as part of the illumination channel of a disposable micro-endoscope. By using proper optics, we convert the temporal modulation of the laser into spatial distribution. Thus, the result is generation of spatial spots when using a pulsed laser. The detection channel is a holographic recording of the collected back scattered light, that allows extraction of the electrical field. By time integrating the field we obtain the realization of the spatial array of illumination spots formed on top of the inspected object and behind the scattering medium. By changing the temporal modulation of the illumination laser (changing its temporal photonic signals), we can tune the positions of the spots in the illumination array. Since the distance of the spots in the array is larger than the imaging resolution, by applying localization algorithms and scanning with the array of spots, high 2D resolution reconstruction of the inspected object is obtained.

Research narrative

Previously we significantly improved the SNR of an image when imaging through scattering medium as blood. However, the operation principle required having an object being composed from discrete array of points because the imaging was done through special diffractive optical element (DOE) composed as an array of micro-lenses like structures. Every micro-lens in the array was “treating” a single point in the input object. In order to realize this requirement, in this paper we present an approach that illuminates the object though the scattering medium but generates an array of discrete illuminating spots such that the proposed SNR enhancement approach could handle.

Mathematical derivation

$$\int a(t)s(x-vt)dt$$

Where a(t) denotes the time changing amplitude of the illuminating laser. s(x) is the speckle pattern generated behind the scattering medium when illuminated by the laser spot.

The illumination spot is shifted with velocity v and the projected electric field is time integrated.

$$P(x)=\int\left(\int a(t)s(x'-vt)dt\right)exp\left(\frac{-2\pi i x'x}{\lambda Z}\right)dx'$$

$P(x)$- Fourier transform of the pattern that is projected on the object (far field assumption)

Z is the distance between the scattering medium and the object, λ is the wavelength. After computing:

$$P(x)=S\left(\frac{x}{\lambda Z}\right)\left(\int a(t)exp\left(\frac{-2\pi i v t x}{\lambda Z}\right)dt\right)$$

We will assume:

$$a(t)=\sum_n \delta(t-n\Delta t)$$

where Δt pulse’s time, n- natural number

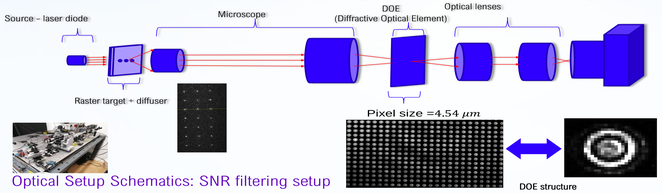
This yields:

$$\int a(t)exp\left(\frac{-2\pi i v t x}{\lambda Z}\right)dt=\sum_n \delta\left(\frac{xv}{\lambda Z}-\frac{n}{\Delta t}\right)=\sum_n \delta\left(x-n\frac{\lambda Z}{v\Delta t}\right)$$

Resulting with the Fourier of the speckle pattern multiplied with an array of spots which is actually a projected array of spots:

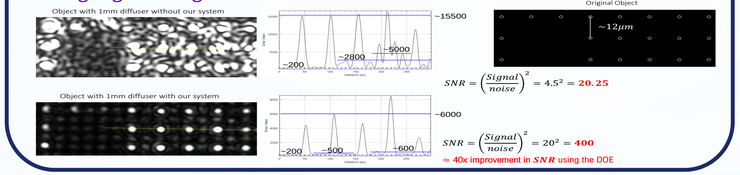
$$P(x)=S\left(\frac{x}{\lambda Z}\right)\sum_n \delta\left(\frac{x}{\lambda Z}-\frac{n}{v\Delta t}\right)$$

Previous results (for object being a discrete array of points



Optical Setup Schematics: SNR filtering setup

Imaging through few mm of blood



Preliminary results

We will now present an experimental lab demonstration for our novel design and demonstrate the generation of the projected array of spots being formed on top of the object and behind the scattering medium (where it is being positioned).

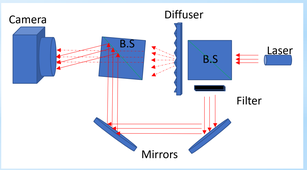
A holographic recoding setup is needed because as mathematically shown, the formation of the illuminating array of spots on the object is obtained when in the camera a time-integration of the electrical field (and not intensity) is performed.



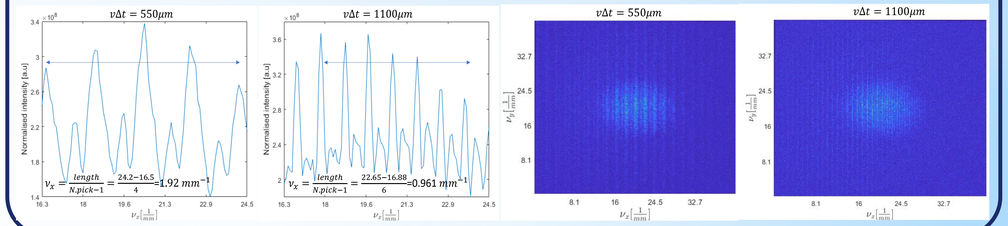
$v\Delta t(\mu m)$	$v_x\ (mm^{-1})$	$\frac{1}{v\Delta t}\ (mm^{-1})$	$x_{exp}(\mu m)$
550*1 (Initial)	1.92	1.8	0.21
550*2=1100	0.96	0.9	0.10
550*3=1650	0.64	0.6	0.07
550*4=2200	0.49	0.45	0.05
550*5=2750	0.38	0.36	0.04
550*6=3300	0.32	0.33	0.03

Setup for projection of an array of discrete points.





Great agreement between the theoretical calculation and experiment ($v_x = 1/v\Delta t$)



Conclusions

We present a time multiplexing super resolving novel holography related imaging concept that is integrated into a disposable micro-endoscope allowing to obtain a high-resolution imaging of objects though scattering medium such as blood. We theoretically and experimentally demonstrate the discussed operation principle and show its potential as a modality in medical endoscopic procedures.