Enhancing imaging contrast of absorptive object using a backscattering matrix

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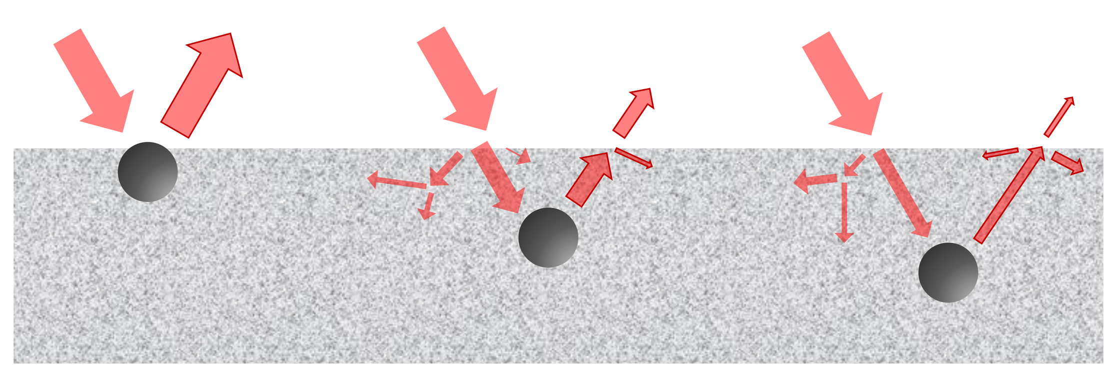
Introduction

Multiple scattering events restricts the range of imaging depth



Eigenchannels differentiates objects depending on their absorptivity

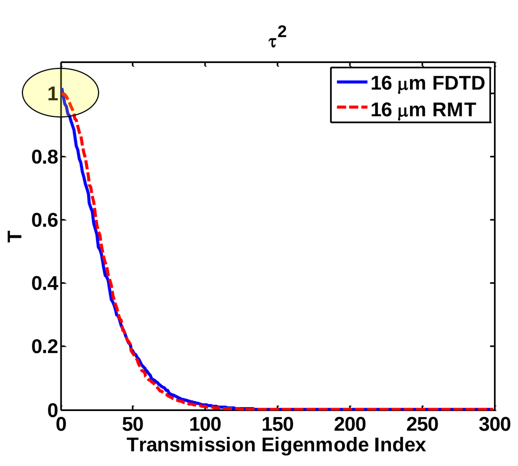
- Random matrix theory predicts perfect reflection
- Singular value decomposition of the backscattering matrix

$$t = U \tau V^{\dagger}$$

V : Unitary matrix connecting input waves into eigenchannels

U : Unitary matrix connecting eigenchannels into output channels

τ : Real non-negative diagonal matrix



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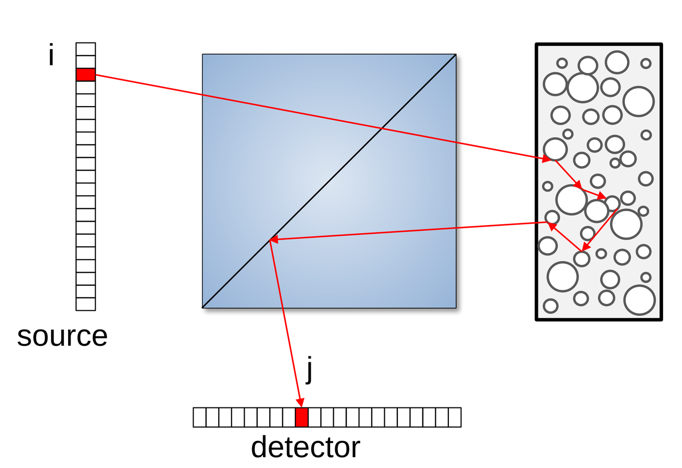
Choi, W. et al. *Phys. Rev. B* **83**, 134207 (2011).

- Each eigenchannel takes proper spatial distribution depending on the absorptivity distribution of the scattering medium

Materials and method

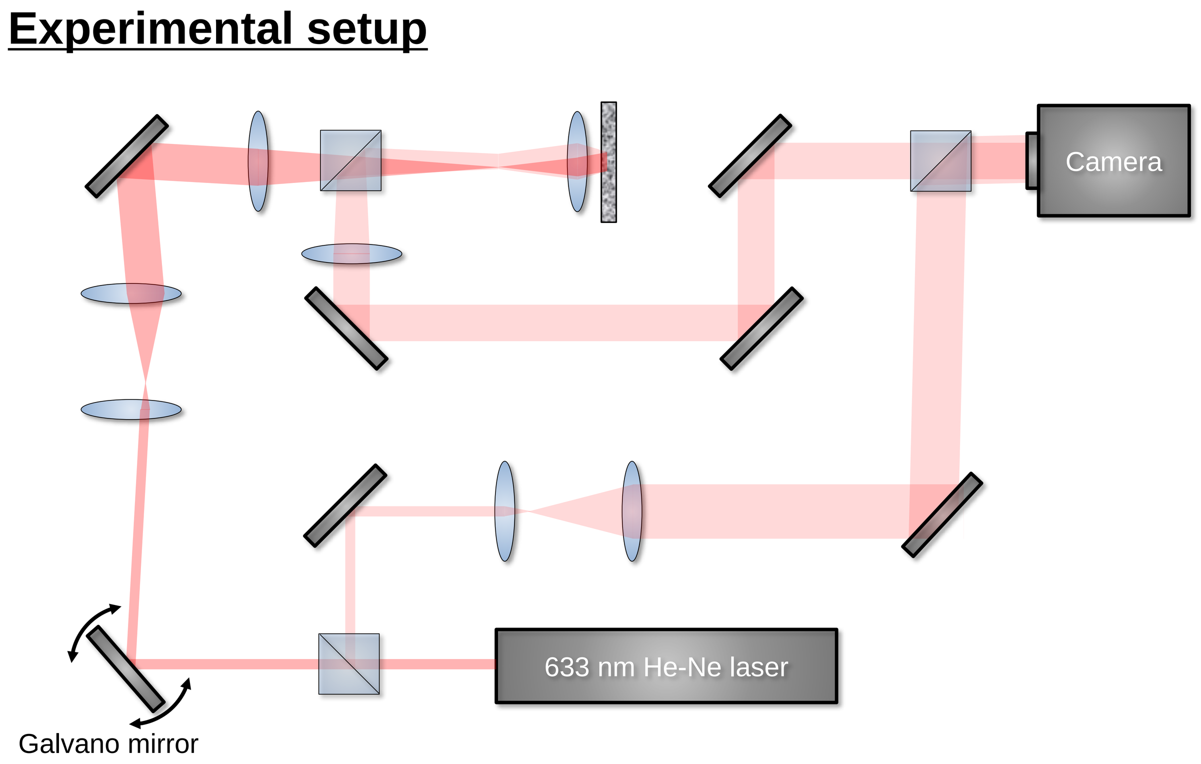
Definition of backscattering matrix



$$E_j^{(out)} = \sum_i r_{ji} E_i^{(in)}$$

$$\vec{E}^{(out)} = r \vec{E}^{(in)}$$

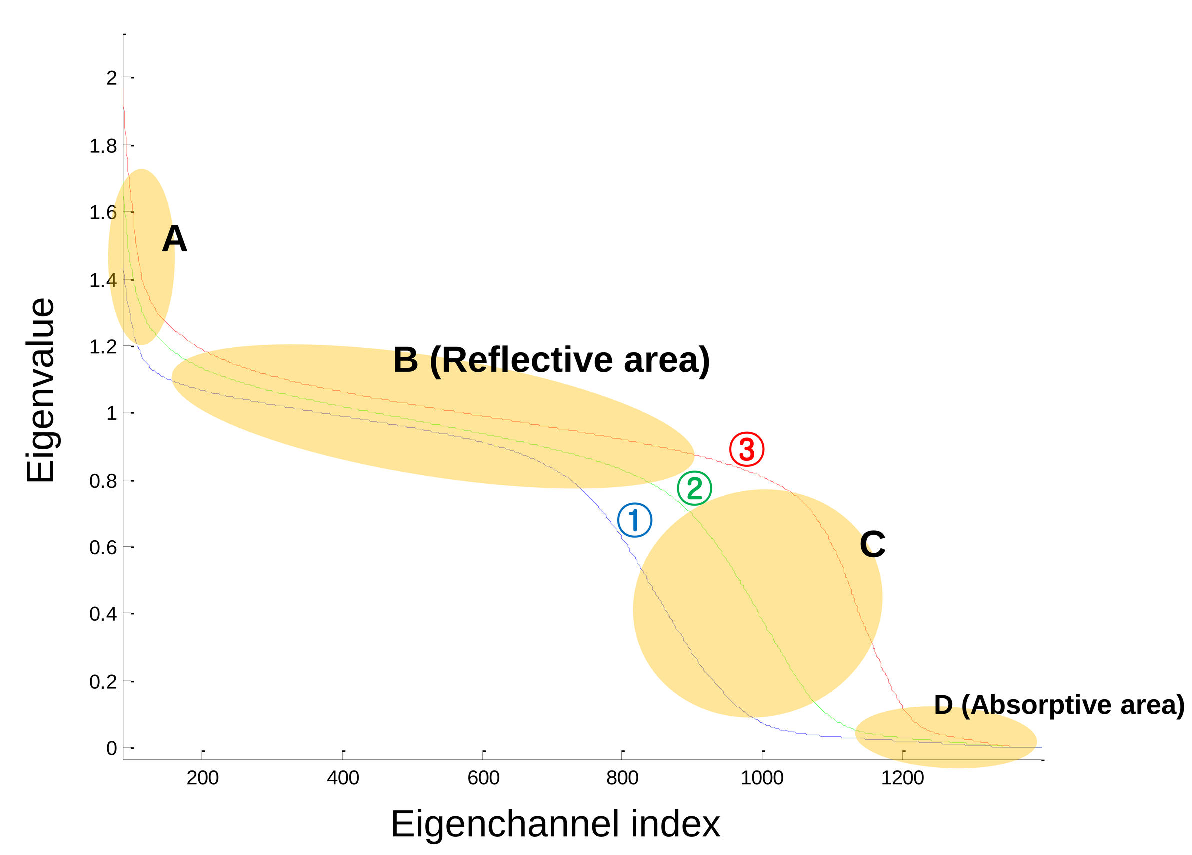
Experimental setup

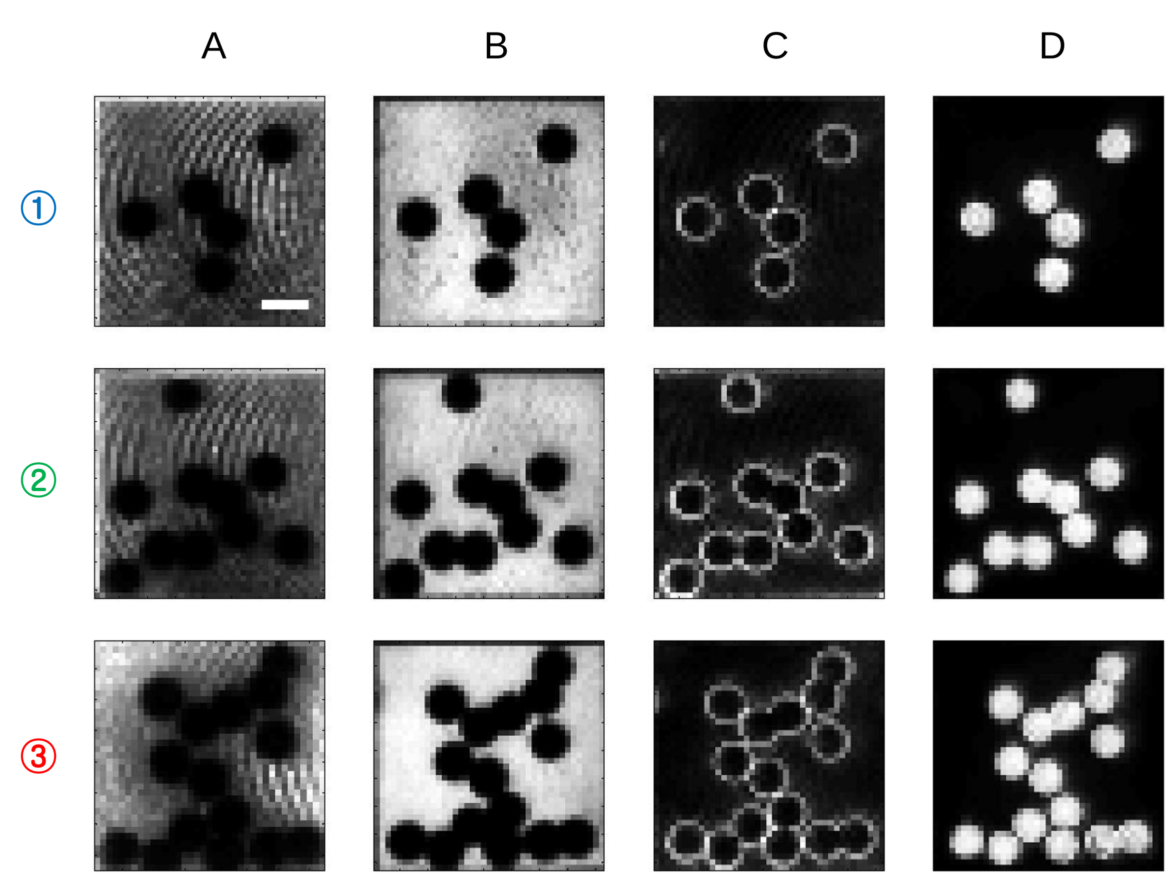


- 633 nm He-Ne laser
- Scattering medium: Mixture of PDMS and ZnO powder
- Absorptive target: 3 um & 10 um blue microsphere
- Experimental condition
  - Illumination area: 21.6 x 21.6 ㎛
  - Illumination NA: 0.6
  - Recording NA: 0.6
  - Recorded image: 1800

Results

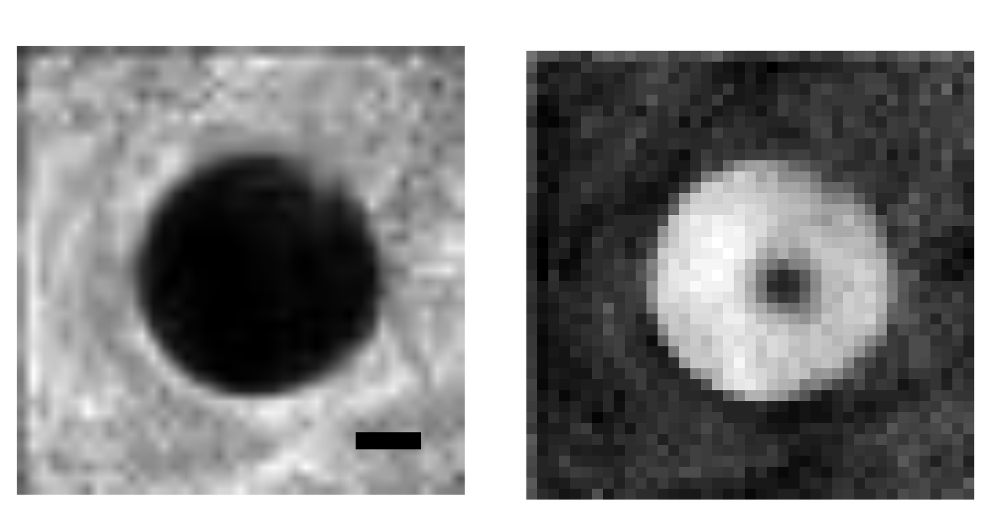
Absorptive area on reflective mirror surface





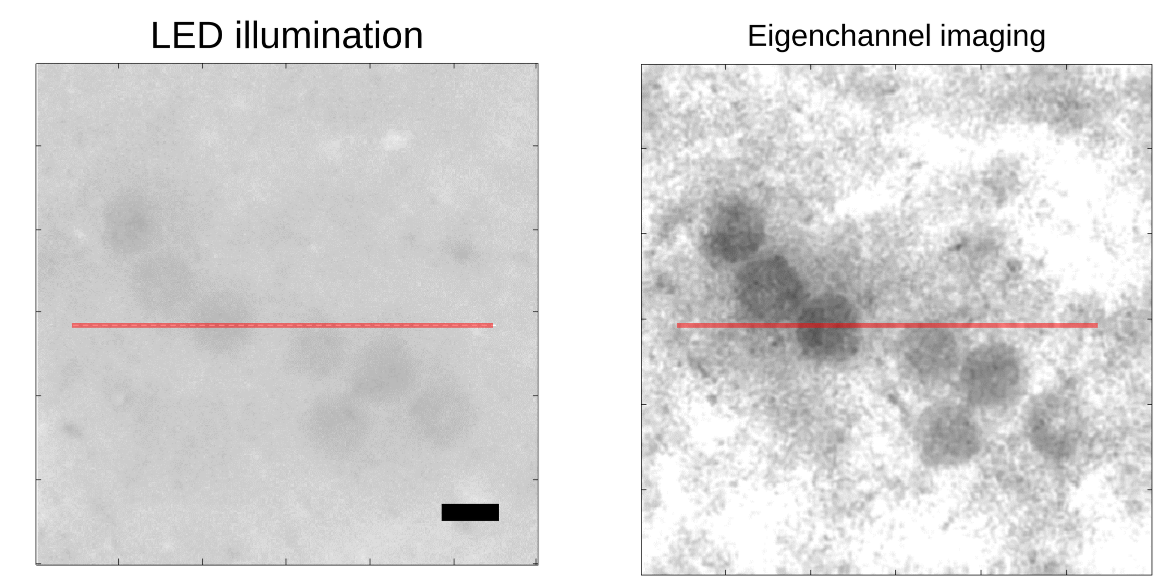
- From the eigenvalue curve, reflective area (B) and absorptive area can be identified
- We could selectively image the area with specific absorptivity, by selectively summing the eigenchannel images identified from the eigenvalue curve
- Scale bar 3 um

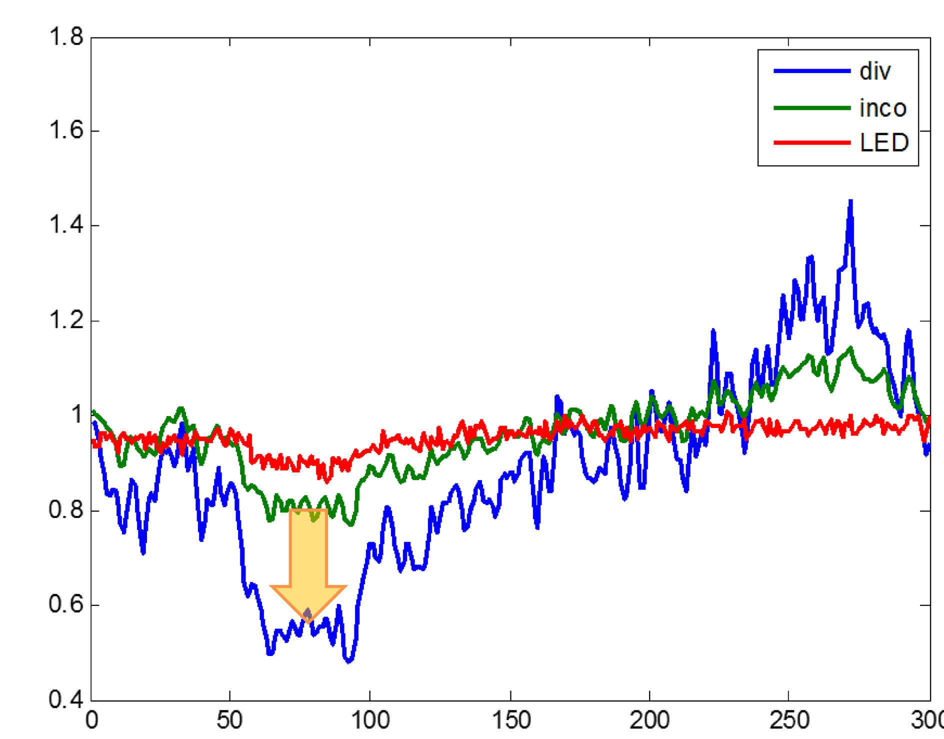
Absorptive area on scattering medium



- Mixture of PDMS and Zinc oxide was used as a scattering medium
- We also could selectively image the reflective area (scattering medium) and the absorptive area
- Open eigenchannel tends to illuminates the scattering medium to make high reflectivity
- Closed eigenchannel tends to illuminates the scattering medium to make low reflectivity
- Scale bar 3 um

Comparison with incoherent illumination imaging





- We divided open eigenchannel image by closed eigenchannel (div)
- By this, we improved the imaging contrast of absorptive objects by ~20 % in comparison with the conventional incoherent illumination imaging

Conclusion

- We recorded the backscattering matrix of a scattering medium with absorptive targets
- We identified reflection eigenchannels of the scattering medium
- Eigenchannels identified from the singular value decomposition of the backscattering matrix differentiated objects depending on their absorptivity
- By using the property, we improved the imaging contrast of absorptive objects by ~20 % in comparison with the conventional incoherent illumination imaging

Reference

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[2] Moonseok Kim, Wonjun Choi, Changhyeong Yoon, Guang Hoon Kim, Seunghyun Kim, Gi-Ra Yi, Q-Han Park, and Wonshik Choi, “Exploring anti-reflection modes in disordered media," Optics express, 23, 12740-12749 (6 May 2015)

[3] Wonjun Choi, Allard P. Mosk, Q-Han Park and Wonshik Choi, "Transmission eigenchannels in a disordered medium," Physical ReviewB 83, 134207 (2011)

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