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Effect of the Exposure Time in Laser Speckle Imaging for Improving Blood Vessels Localization: a Wavelet Approach

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Hello!

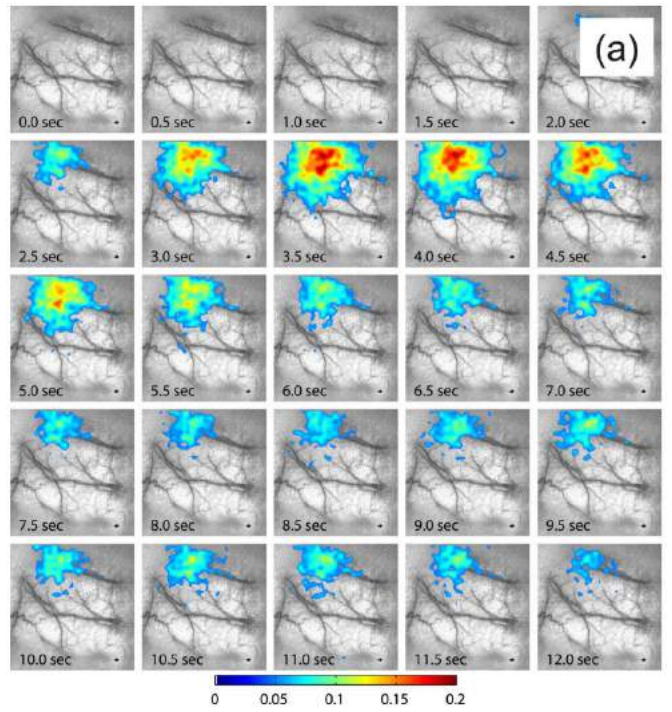
This is the index :)

- First a short introduction
  - Speckle, Exposure time, Contrast and Wavelets
- Then, ours methodology
  - The wavelet approach!
- Then, ours experiments and results
  - Nice results
- Finally, the conclusions :)

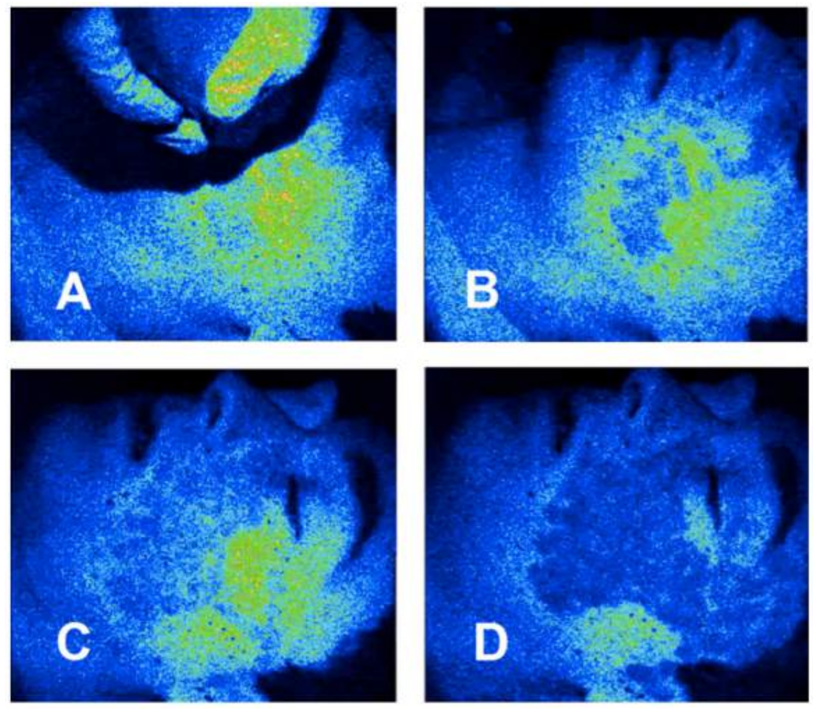
Introduction

Visualization and localization

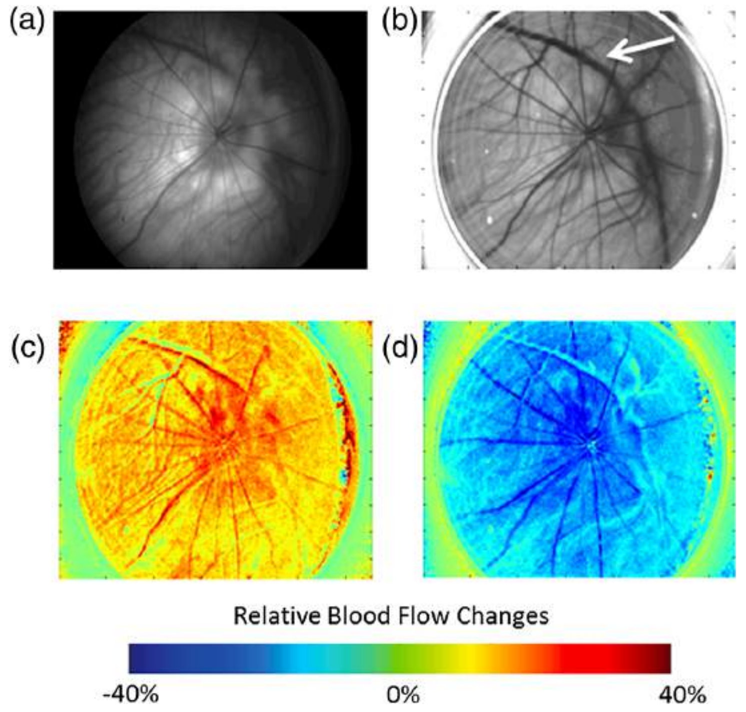
- **Visualization and localization of blood vessels (VLBV)** is important for different biomedical applications, such as neuroscience, dermatology and ophthalmology[1].



(a) Brain activation and blood flow changes in the brain[1].



(b) Assessment of photodynamic therapy in Port Wine Stains[2].



(c) Visual stimulation and blood flow analysis in the retina[3].

- **Laser Speckle Imaging (LSI)** is the most widely used non-invasive technique for measuring blood flow and is based on the speckle phenomenon[4].

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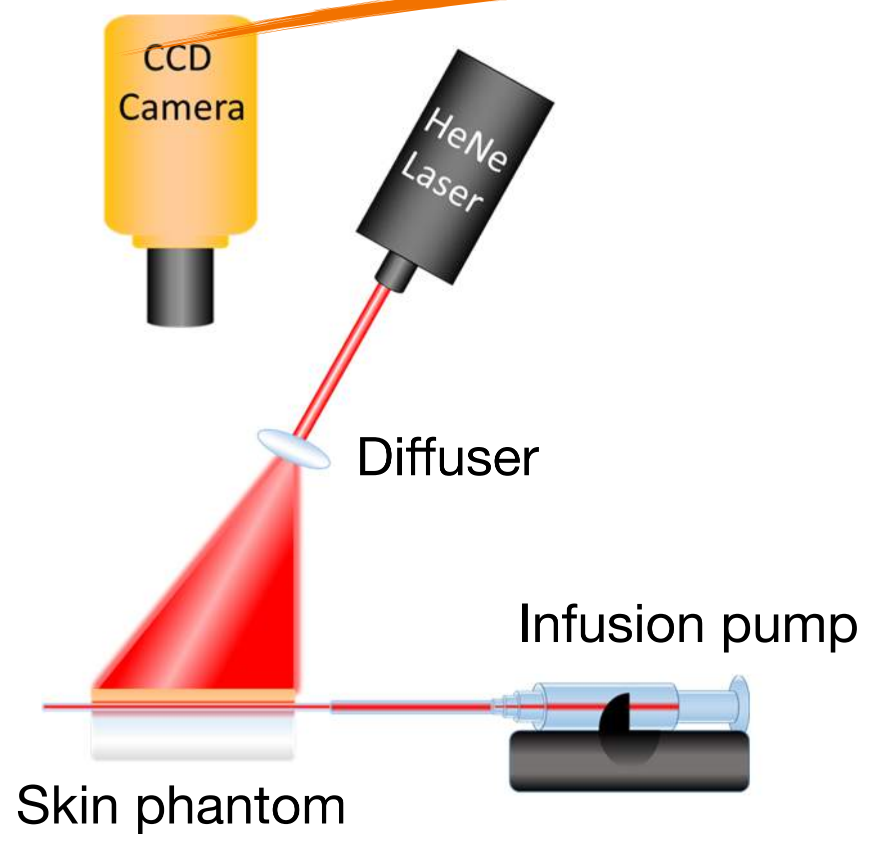
[1][Boas et al., 2010]. *"Laser speckle contrast imaging in biomedical optics"*. Journal of biomedical optics.
[2][Choi et al., 2016]. *"The role of laser speckle imaging in port-wine stain research: Recent advances and opportunities"*. IEEE Journal of Selected Topics in Quantum Electronics.
[3][Ponticorvo et al., 2013]. "*Laser speckle contrast imaging of blood flow in rat retinas using an endoscope"*. Journal of biomedical optics.
[4][Briers, et al., 2013]. *"Laser speckle contrast imaging: theoretical and practical limitations"*. Journal of biomedical optics.

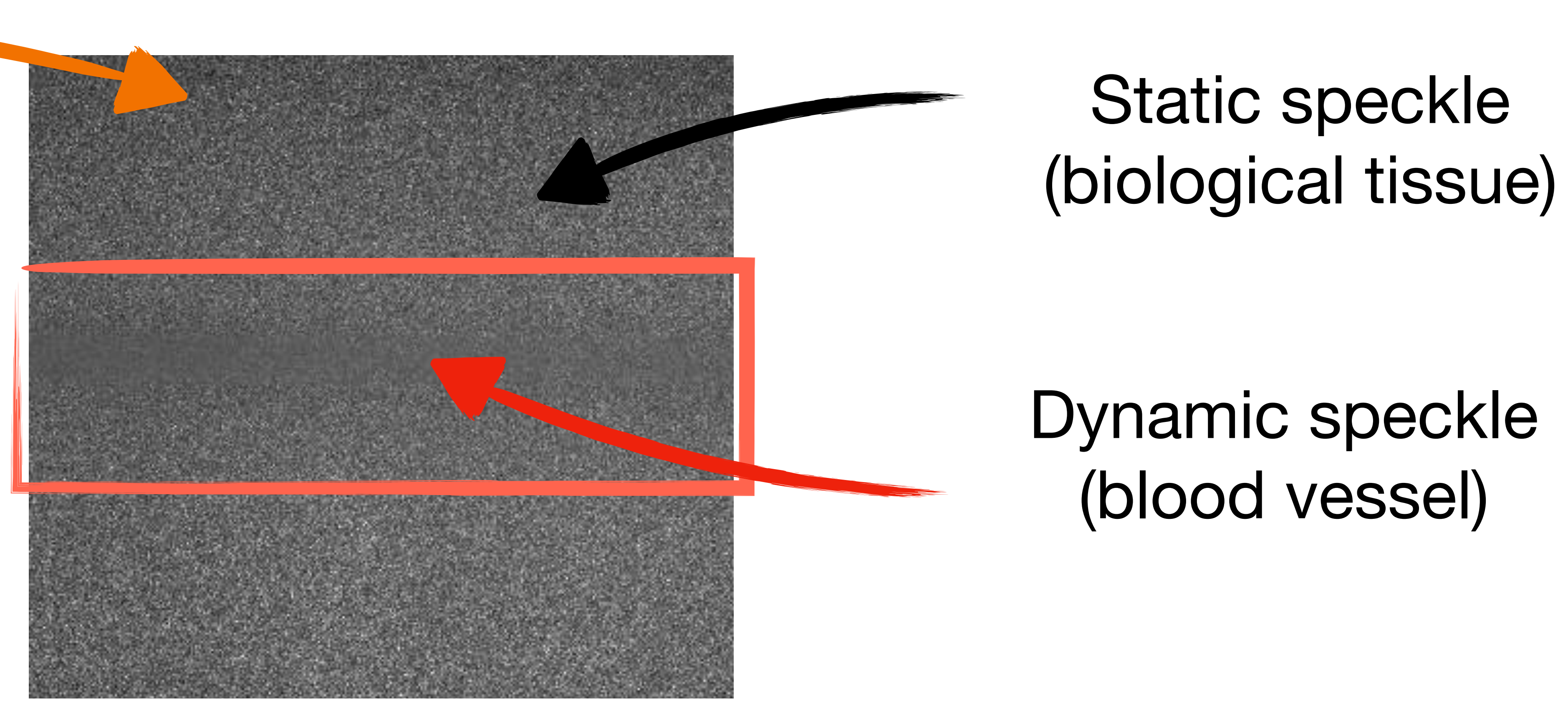
Introduction

Laser Speckle Imaging (LSI)

- Speckle is a scattering phenomenon. It appears by interaction between photons, of a coherent light laser, and a rough surface such as biological tissue[5].



(a) Experimental setup



ρ = 0μm (superficial)

(b) Speckle image

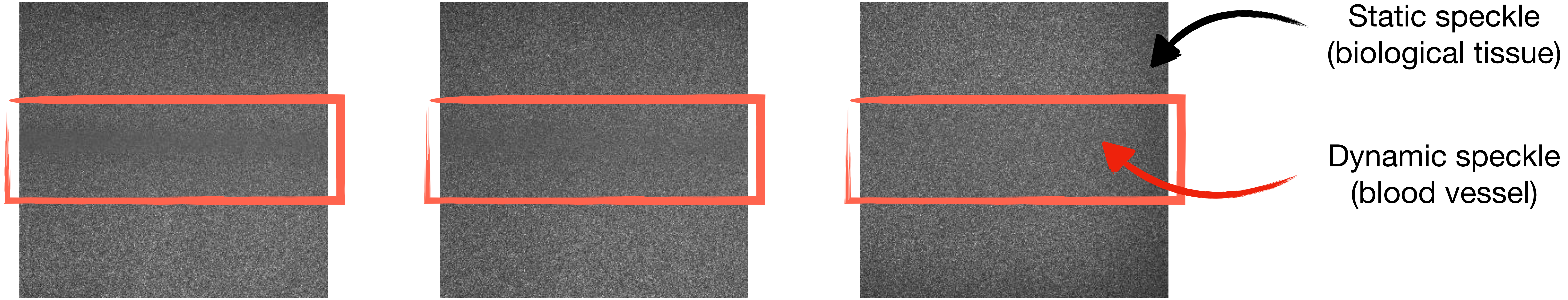
- The movement of particles (i.e. blood cells) inside a rough surface generates a **blurring effect (BE)**. LSI technique is used to analyze the **BE**[6].

[5][Aizu and Asakura, 1991]. *"Bio-speckle phenomena and their application to the evaluation of blood flow"*. Optics & Laser Technology.
[6][Draijer et al., 2009]. "*Review of laser speckle contrast techniques for visualizing tissue perfusion"*. Lasers in medical science.

Introduction

Laser Speckle Imaging (LSI)

- The main limitation of **LSI** is related to **VLBV**. Speckle images noise increases when the depth of the blood vessels (ρ), inside the skin, is higher. It is due to strongly scattering of static structures[7].



(a) ρ = *0µm (superficial)* (b) ρ = *310µm (deep)* (c) ρ = *1000µm (the deepest)*

Visualization of straight in-vitro blood vessels in a speckle image to different depths (ρ).

[7][Vaz et al., 2016]. *"Laser speckle imaging to monitor microvascular blood flow: a review"*. IEEE reviews in biomedical engineering.

Introduction

State of the art

Visualization and localization of blood vessels

Physical methods

Exposure time
Non-invasive

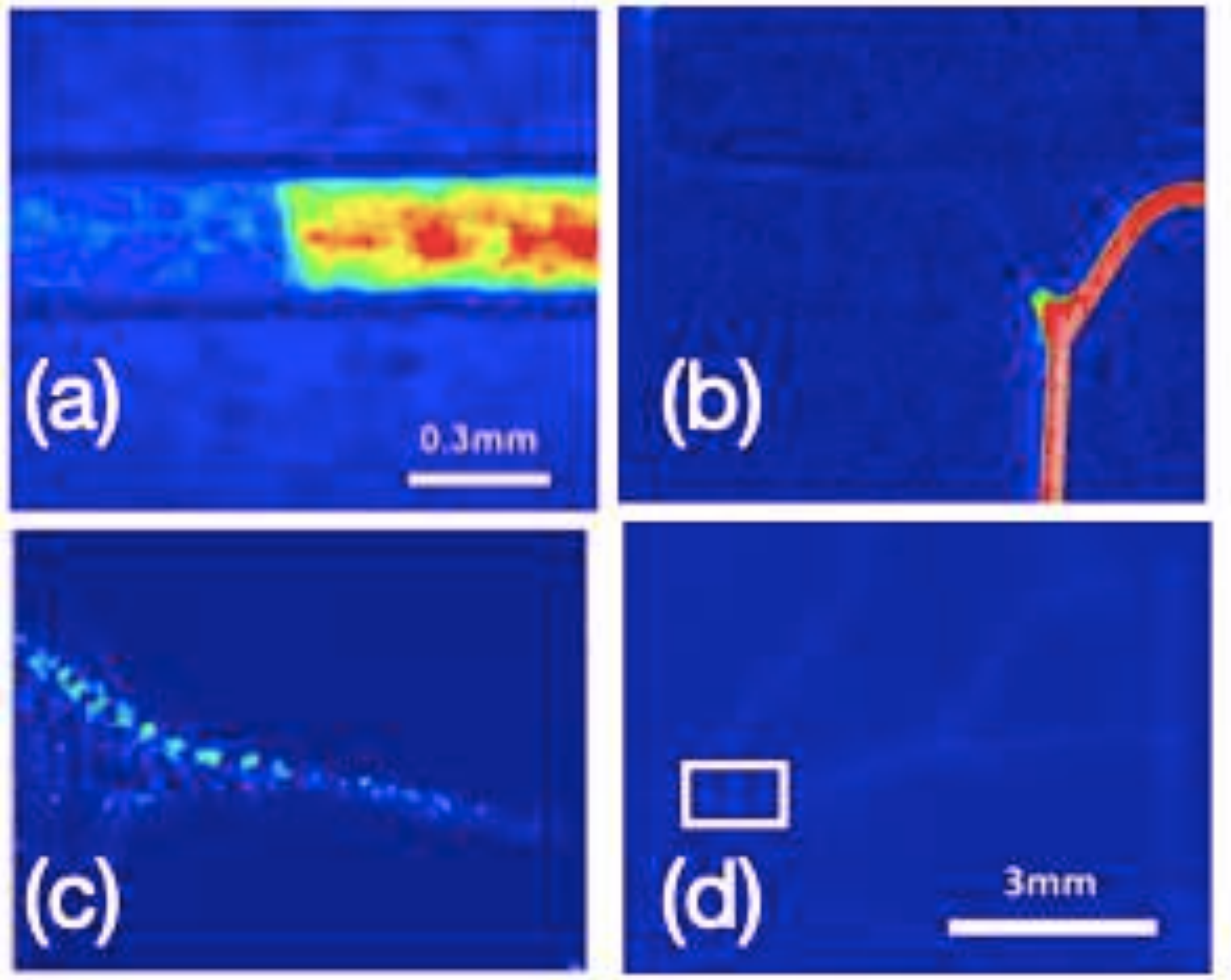
External agents
Invasive

Computational methods

Slow dynamics

Fast dynamics

Contrast
Non-invasive



Physical improvements: (a) exposure time calibration[8], (b) substances on the skin, (c) particles in the blood[10], and (d) heat[11].

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[8][Wang et al., 2017]. *"Improving the estimation of flow speed for laser speckle imaging with single exposure time"*. Optics letters.
[9][Son et al., 2013]. *"Contrast enhancement of laser speckle contrast image in deep vasculature by reduction of tissue scattering"*. Journal of the Optical Society of Korea.
[10][Kim et al., 2010]. *"Magnetomotive laser speckle imaging"*. Journal of biomedical optics.
[11][Regan et al., 2014]. *"Photothermal laser speckle imaging"*. Optics letters.

Introduction

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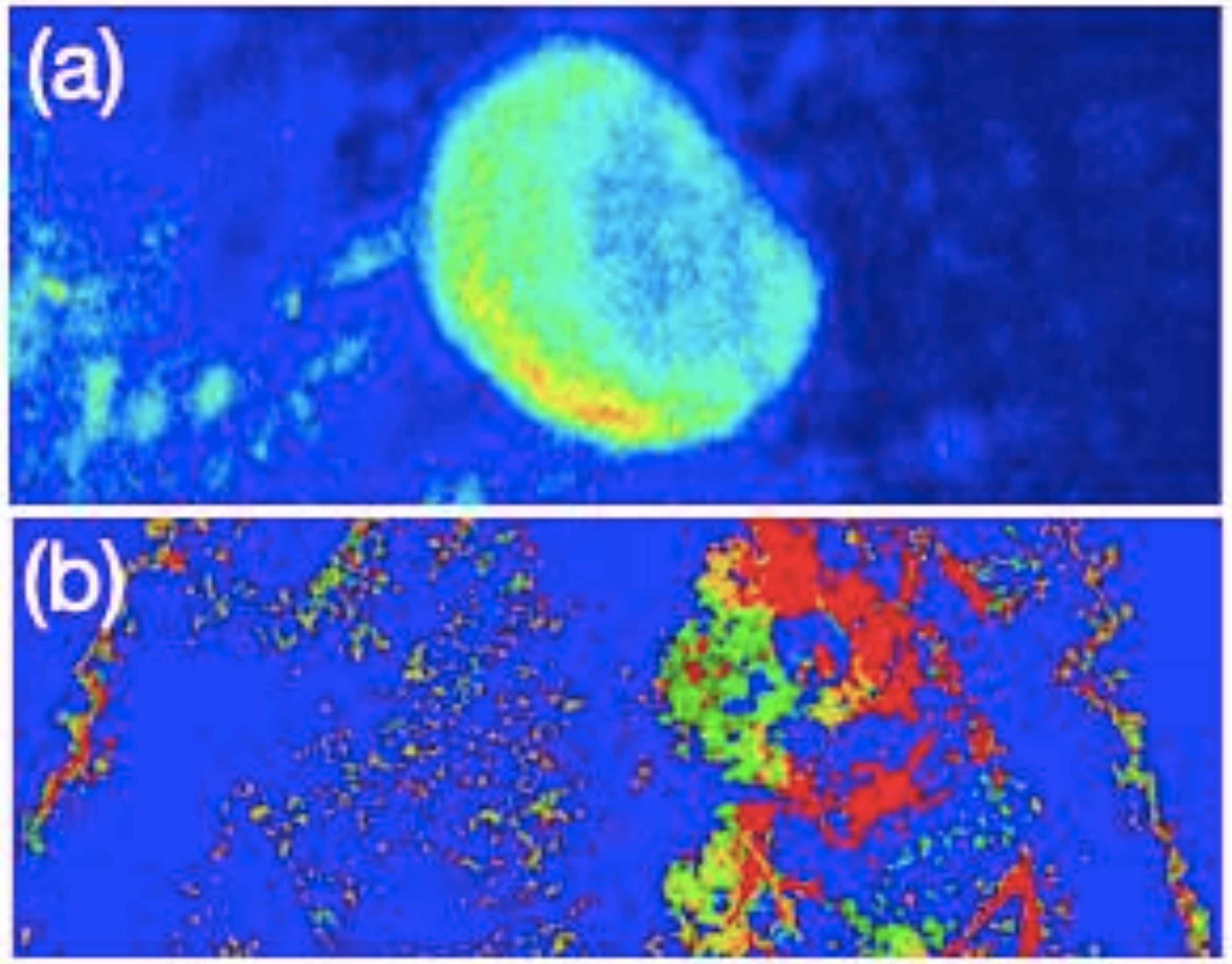

Computational methods. Slow dynamics such as (a) Motion History Image[12], and (b) Generalized Differences[13].

[12][Godinho et al., 2012]. "*Online biospeckle assessment without loss of definition and resolution by motion history image*". Optics and Lasers in Engineering.
[13][Arizaga et al., 2002]. *"Display of local activity using dynamical speckle patterns"*. Optical Engineering.

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Visualization and localization of blood vessels

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Non-invasive

External agents
Invasive

Computational methods

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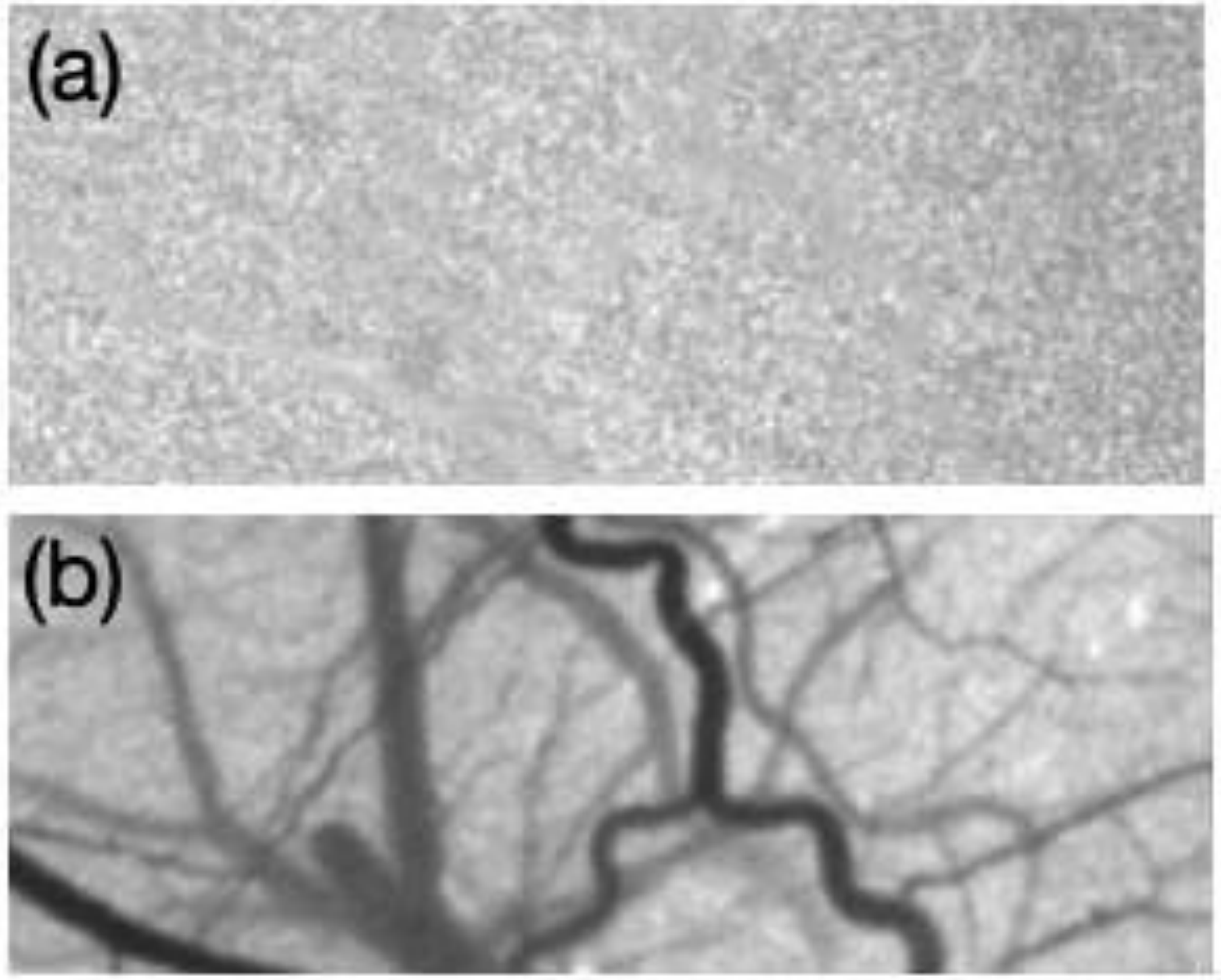
Fast dynamics

Contrast
Non-invasive



Computational methods[7].
Fast dynamics with contrast representation.
(a) speckle image, and (b) contrast image.

[7][Vaz et al., 2016]. *"Laser speckle imaging to monitor microvascular blood flow: a review"*. IEEE reviews in biomedical engineering.

Introduction

Exposure time to improve VLBV

- In physical methods, exposure time calibration[8] is a non-invasive method to improve blurring effect (BE).

- **BE** in the speckle image depends on:

  1. The depth of the blood vessels (ρ) inside the biological tissue.

  2. The exposure time (T) of the charge-coupled device camera.

  3. The speed-flow (v) in the blood vessel.

- Visualization is limited for superficial blood vessels (up to *100µm*), therefore the boundaries between dynamic and static speckle are difficult to establish (localization)[7].

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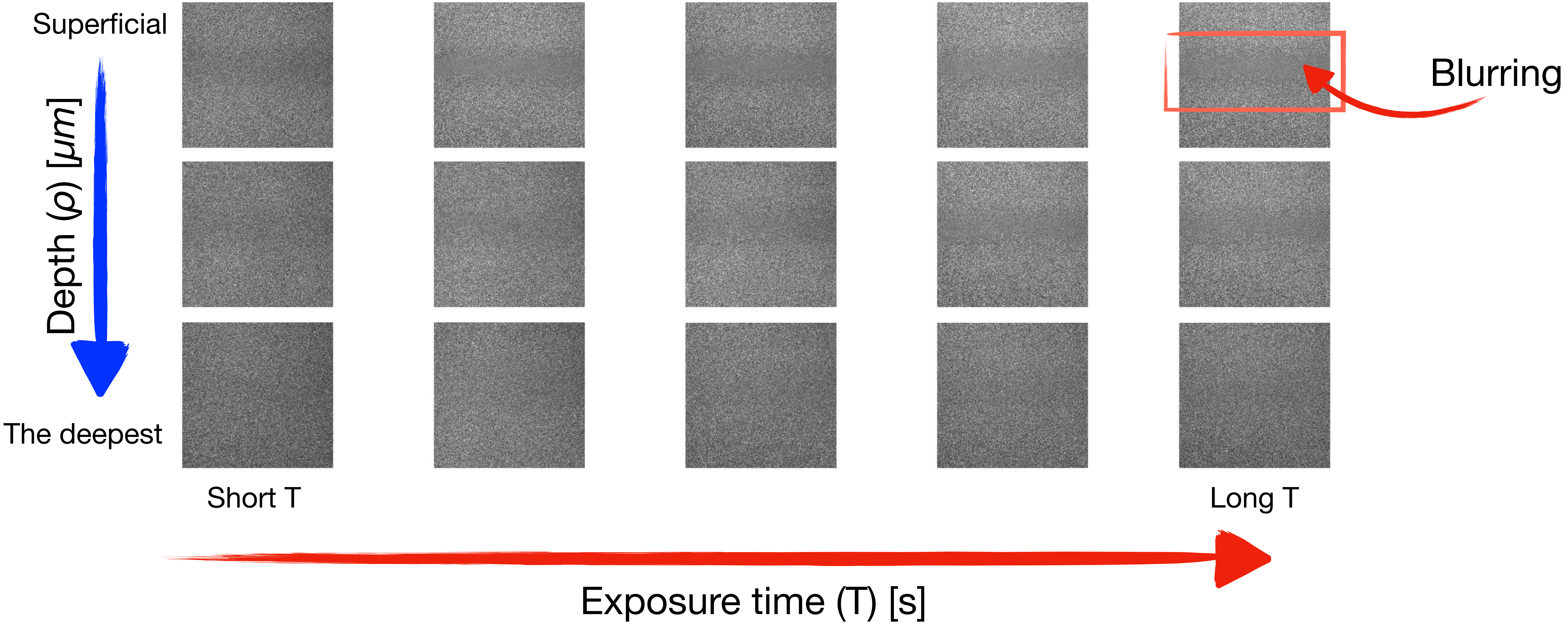
[7][Vaz et al., 2016]. *"Laser speckle imaging to monitor microvascular blood flow: a review"*. IEEE reviews in biomedical engineering.
[8][Wang et al., 2017]. *"Improving the estimation of flow speed for laser speckle imaging with single exposure time"*. Optics letters.

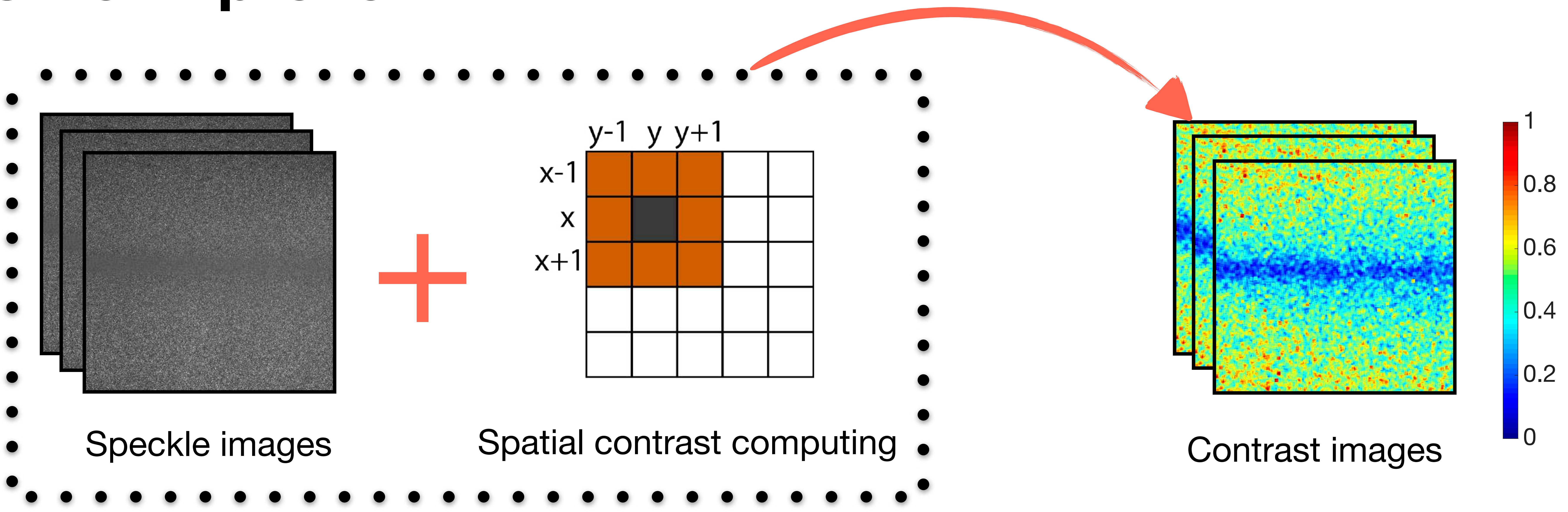
Introduction

Exposure time to improve VLBV



Introduction

Contrast to improve VLBV



- Contrast (K) in speckle images can be calculated using traditional methods, such as spatial contrast (sK)[7].

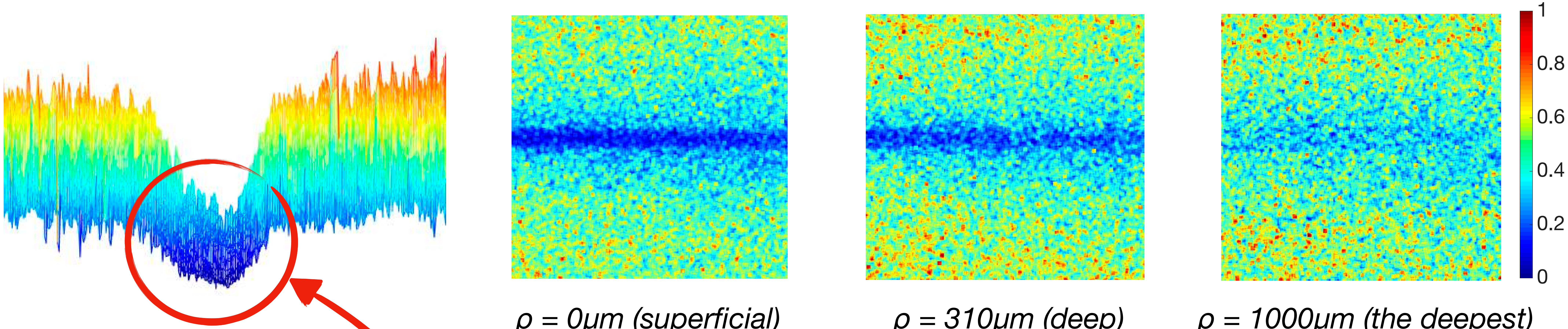
- K is the ratio between standard deviation and the average intensity, σ(W) and I(W), respectively, in a dxd analysis window.

[7][Vaz et al., 2016]. *"Laser speckle imaging to monitor microvascular blood flow: a review"*. IEEE reviews in biomedical engineering.

Introduction

Contrast to improve VLBV

- Information fusion due to noise, between static and dynamic speckle, is present in contrast images.



ρ = 0μm (superficial) *ρ = 310μm (deep)* *ρ = 1000μm (the deepest)*

Visualization of straight in-vitro blood vessels in a contrast images to different depths (*ρ*).

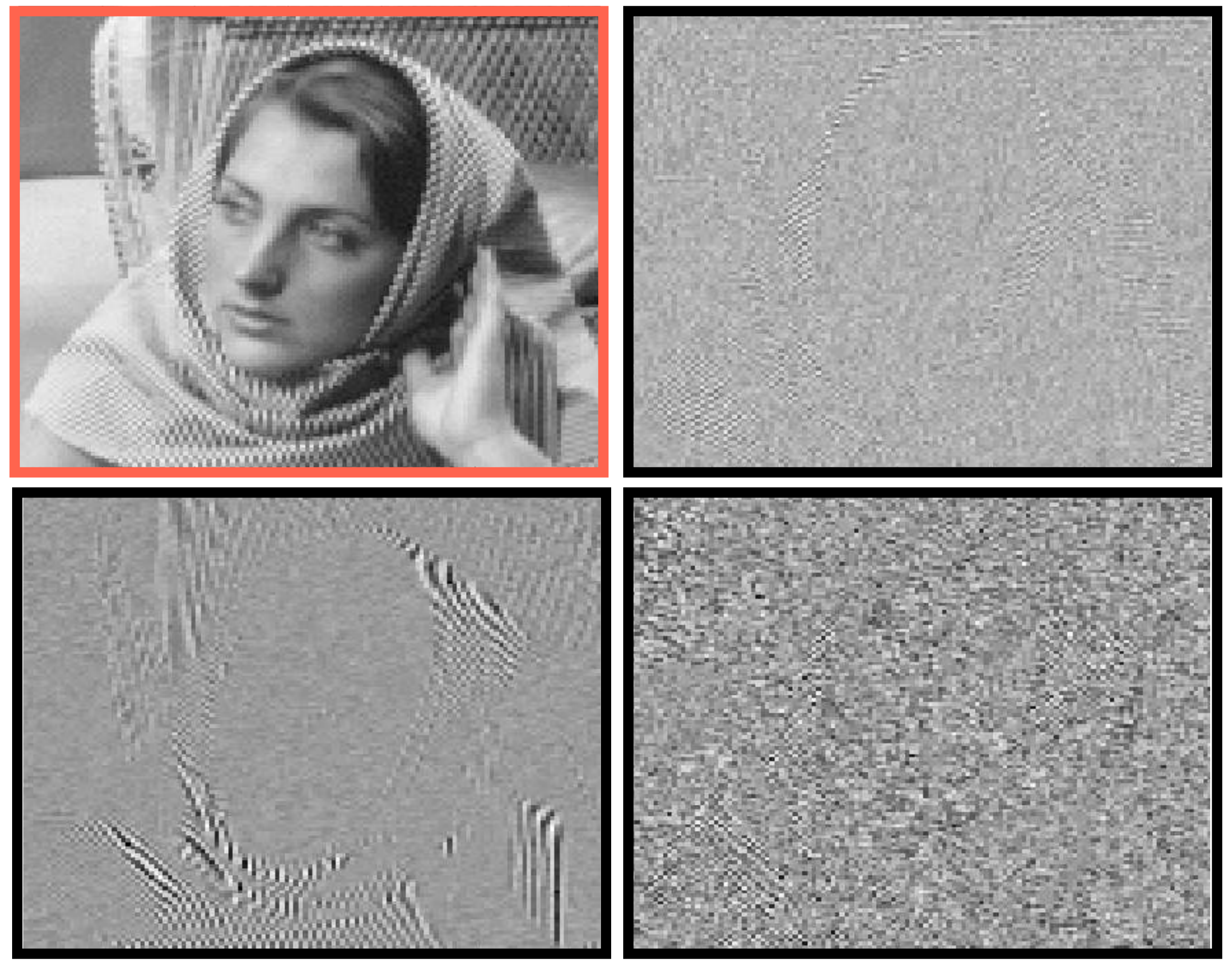
- To avoid information fusion, the noise in the blood vessel region must be attenuated to improve VLBV.

Introduction

Wavelet Transform

- Wavelet Transform (WT) is a technique to noise's attenuation. It provides a better spatial resolution in images compared to other techniques such as Fourier Transform[14,15].

(a) **Input image** with salt and pepper noise.



(b) First filtering level coefficients (approximation and detail).

(c) **Output image attenuated.**

[14][Kimlyk et al., 2018]. "*Image denoising using discrete wavelet transform and edge information*". In 57 Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), IEEE.

[15][Mallat et al., 2008]. *"A wavelet tour of signal processing".* Third edition: The sparse way.

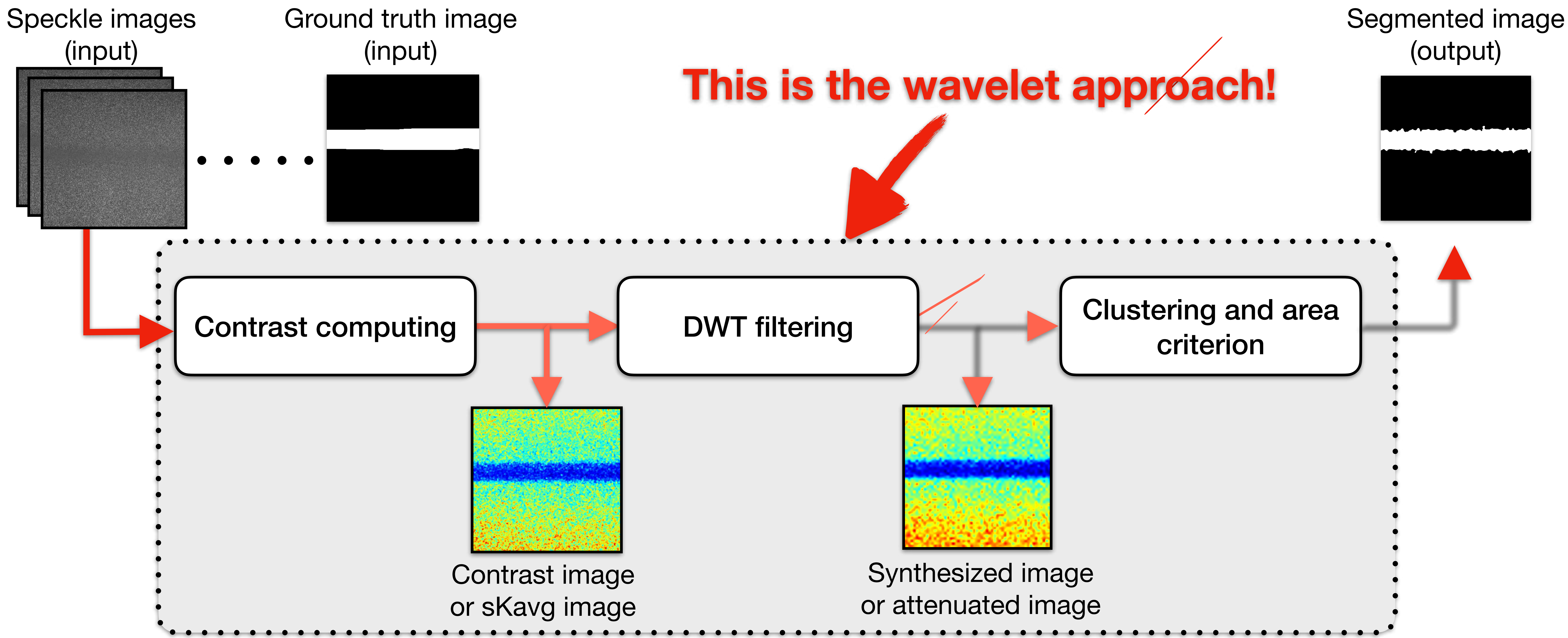
This work

- The proposed methodology works two aspects:

  1. An approach based on the wavelet transform (called wavelet approach!) to improve the visualization and localization of blood vessels, and

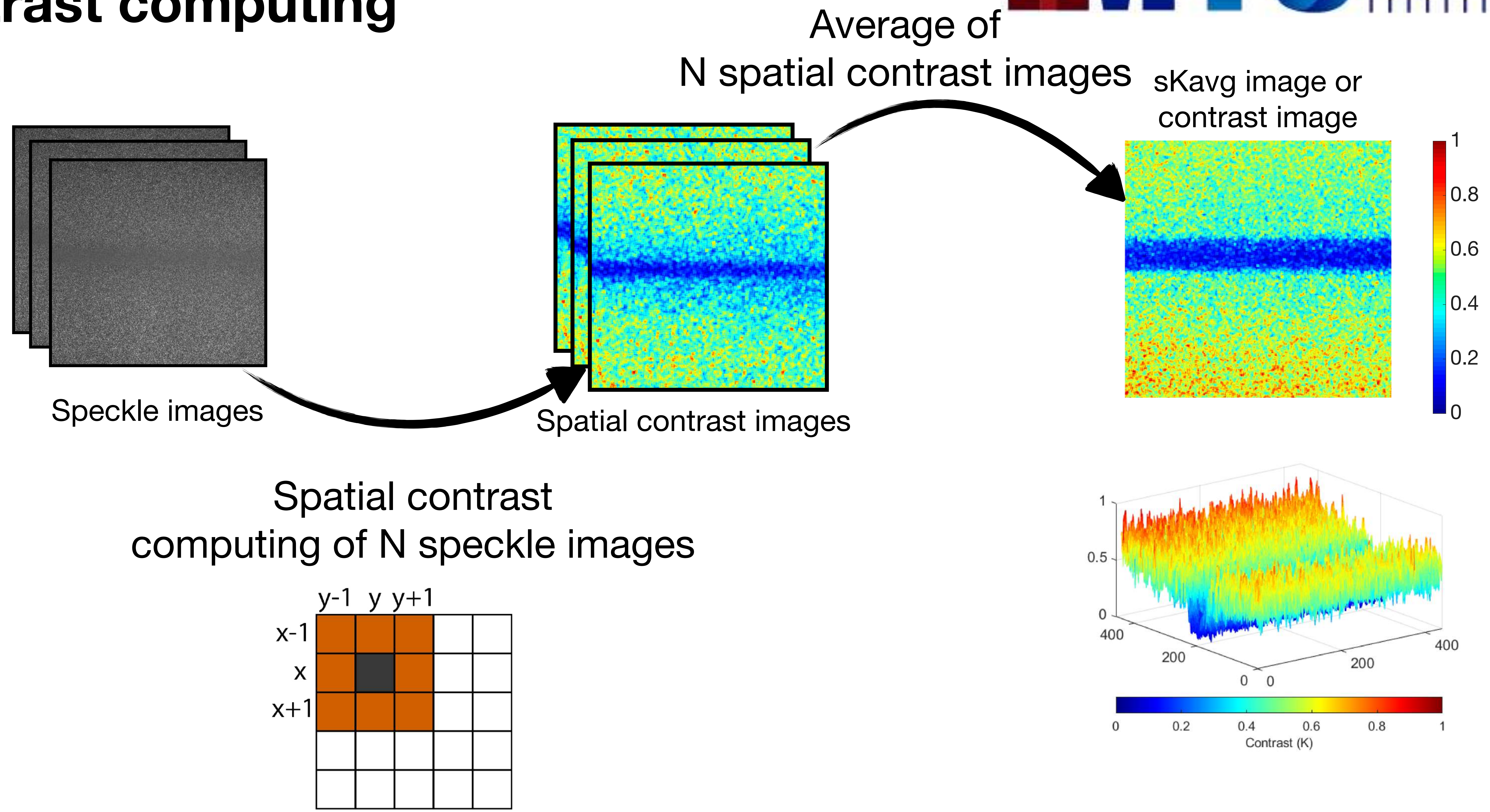
  2. The blurring effect analysis, due to exposure time, in contrast images.

This work
Methodology



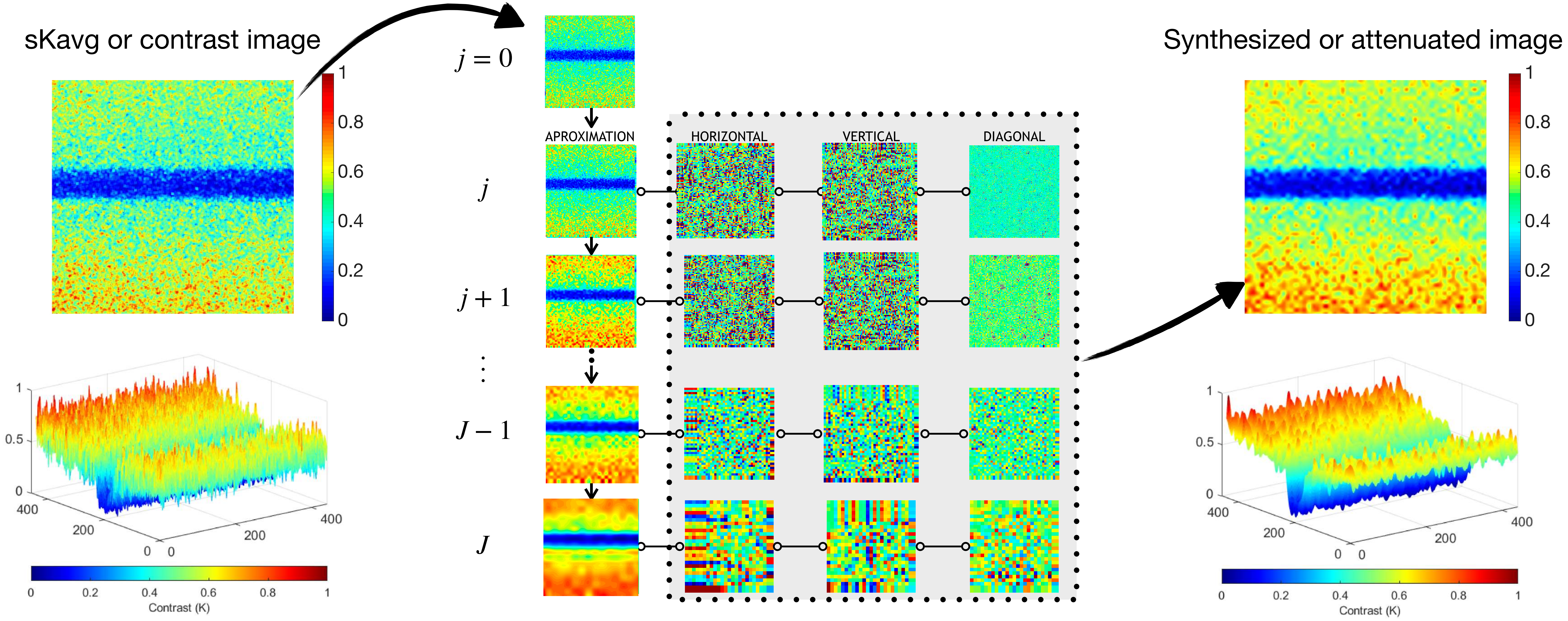
This work

Contrast computing



This work

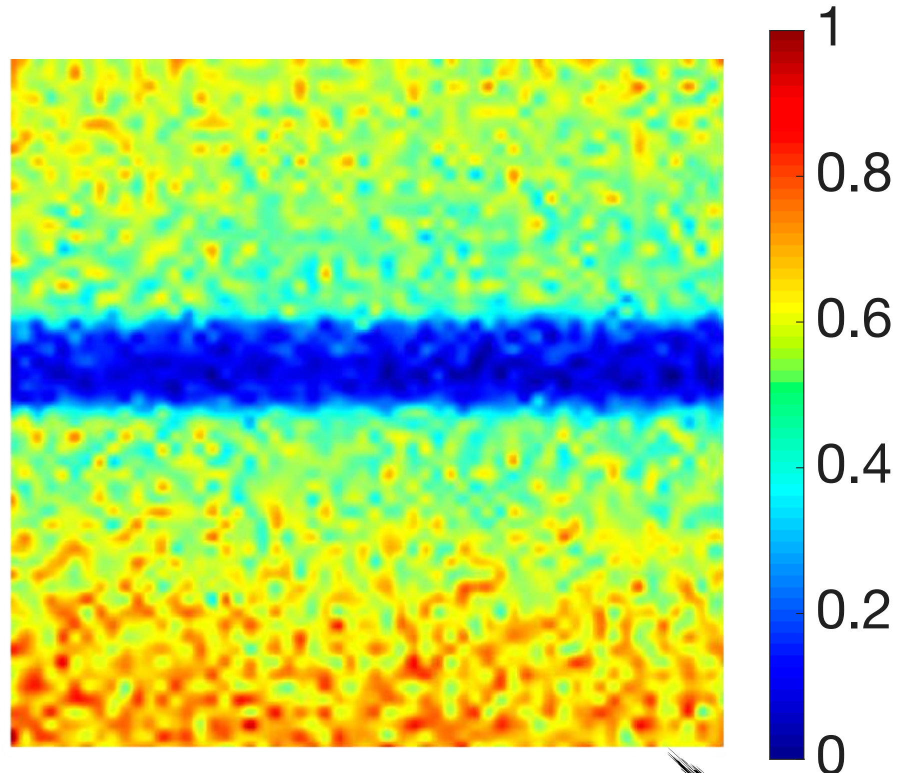
WT filtering



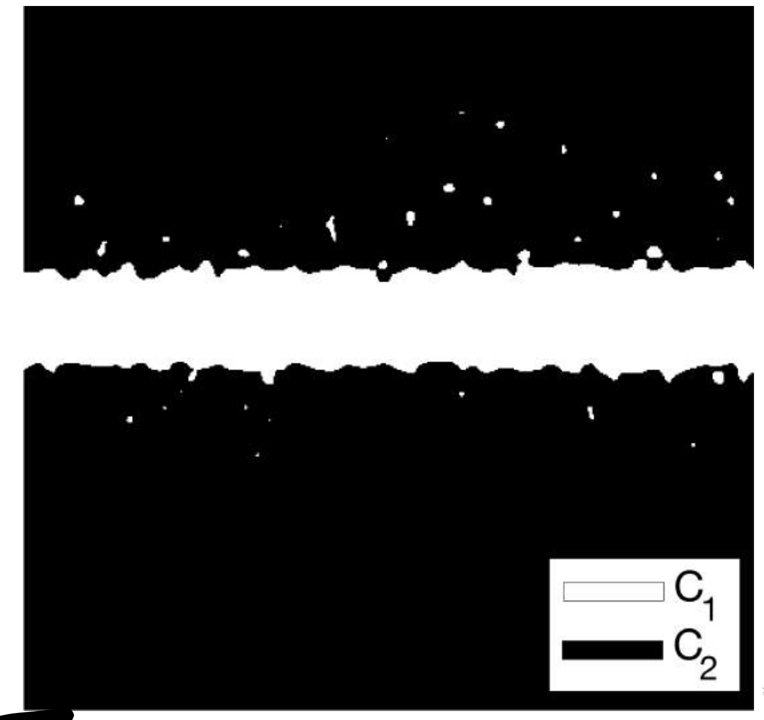
This work

Clustering and area criterion

Synthesized or attenuated image



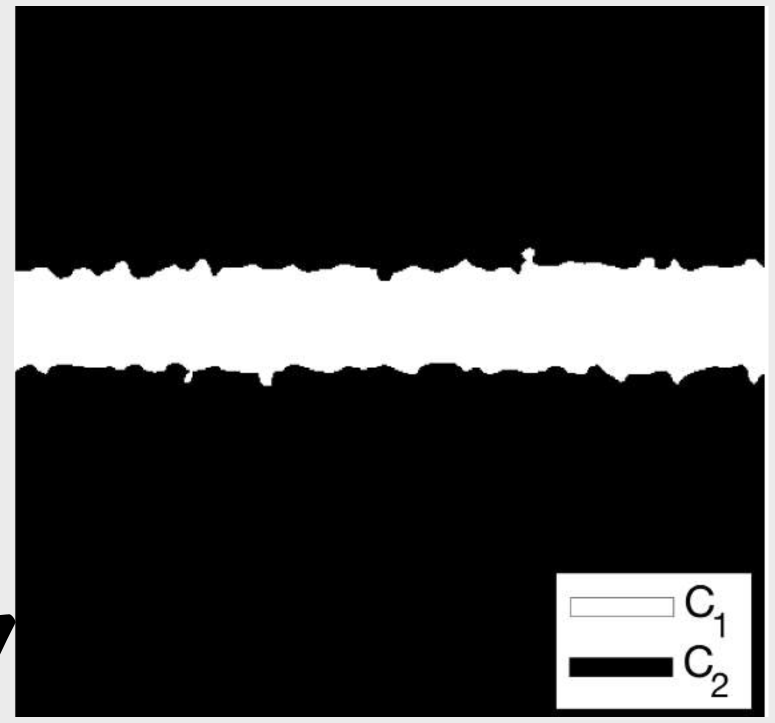
Binary image



The k-means grouping

Area criterion

Segmented image
(output)



VS

Ground truth image
(input)

Performance with Rand Index (RI)

$$RI(A,B) = \frac{TP}{TP + FP + FN}$$

Experiments and results

Dataset

- The dataset consist of
  - **75 speckle packages**, each one of package contains 30 in-vitro straight blood vessels speckle images.
    - **15 exposure times** (***70.6ms***, *138.4ms, 256.6ms, 500ms, 980.2ms, 1883.4ms, 3949.6ms, 5908.6ms, 8204.8ms, 11062ms, 12200.6ms, 20885ms, 26481.8ms, 31760ms,* and ***32789.8ms***).
    - **5 blood vessels depths** (0μm, 190μm, 311μm, 510μm, and 1000μm).

Experiments and results
Dataset

- The dimensions of the speckle images are 640x480 pixels.
- The **ground truth** (GT) is a binary image [0,1] and it is obtained by labeling of the blood vessel at 0*μm* depth.
- The contrast images are calculated with the spatial contrast averaged algorithm (sKavg).

Experiments and results

Settings

- In this methodology, **two parameters** were selected for the wavelet approach: wavelet function ψ and filtering level *j*.

1. The selected wavelet function was **Symlet 5 (52.16±18.23% RI).**

2. The level j selected was **j = 5 (84.22±16.52% RI).**

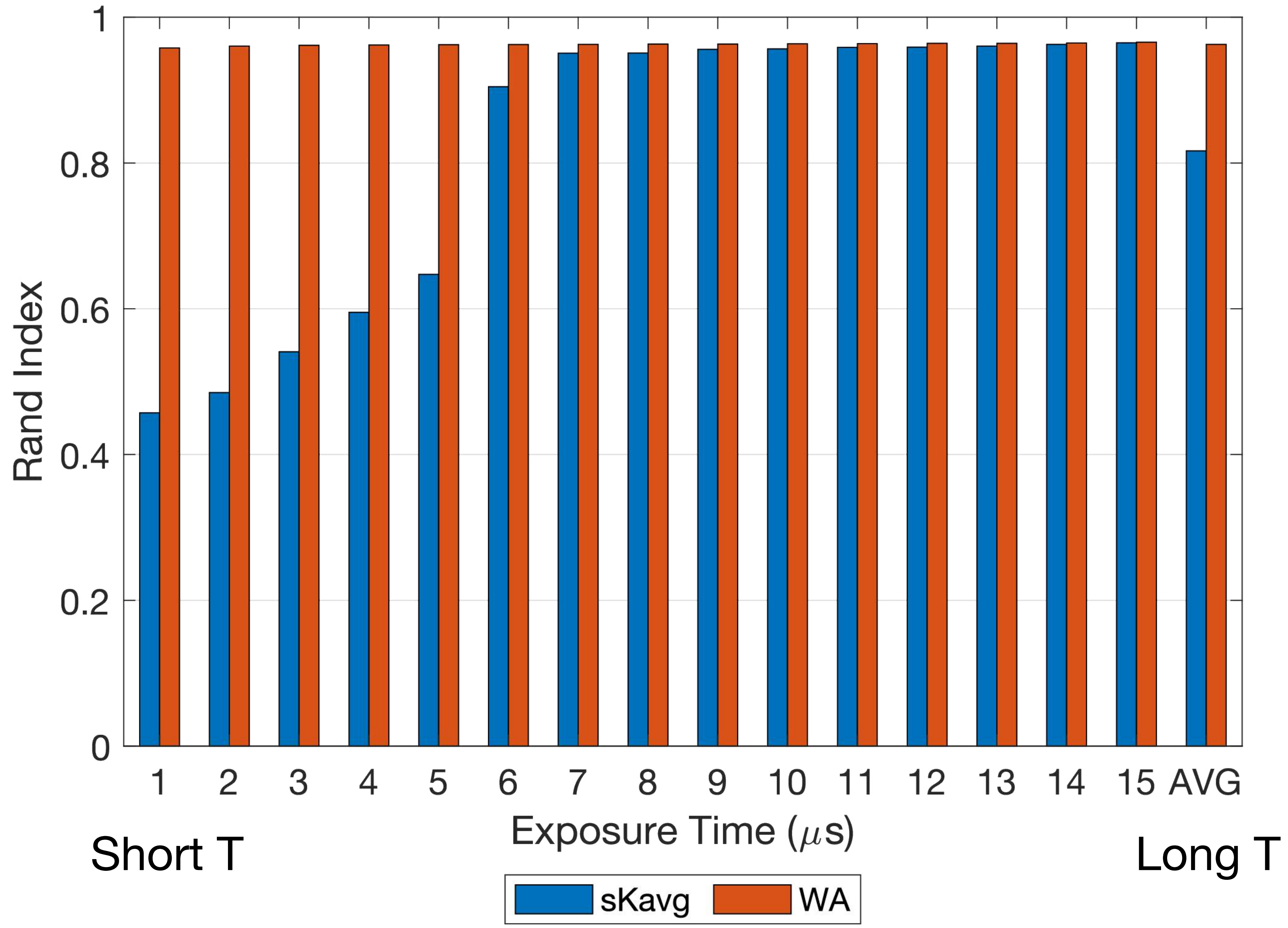
Level	0	1	2	3	4	**5**
Average Error	69.85% 15.12%	71.89% 15.69%	72.70% 17.08%	71.30% 21.10%	75.80% 22.38%	**84.22%** **16.52%**

Experiments and results

Performance of exposure time

In superficial blood vessels (0*μm*):

- WA (96.28% RI) performs well from short exposure times (T>2).
- sKavg (81.67% RI) performs well for longer exposure times (T>7).



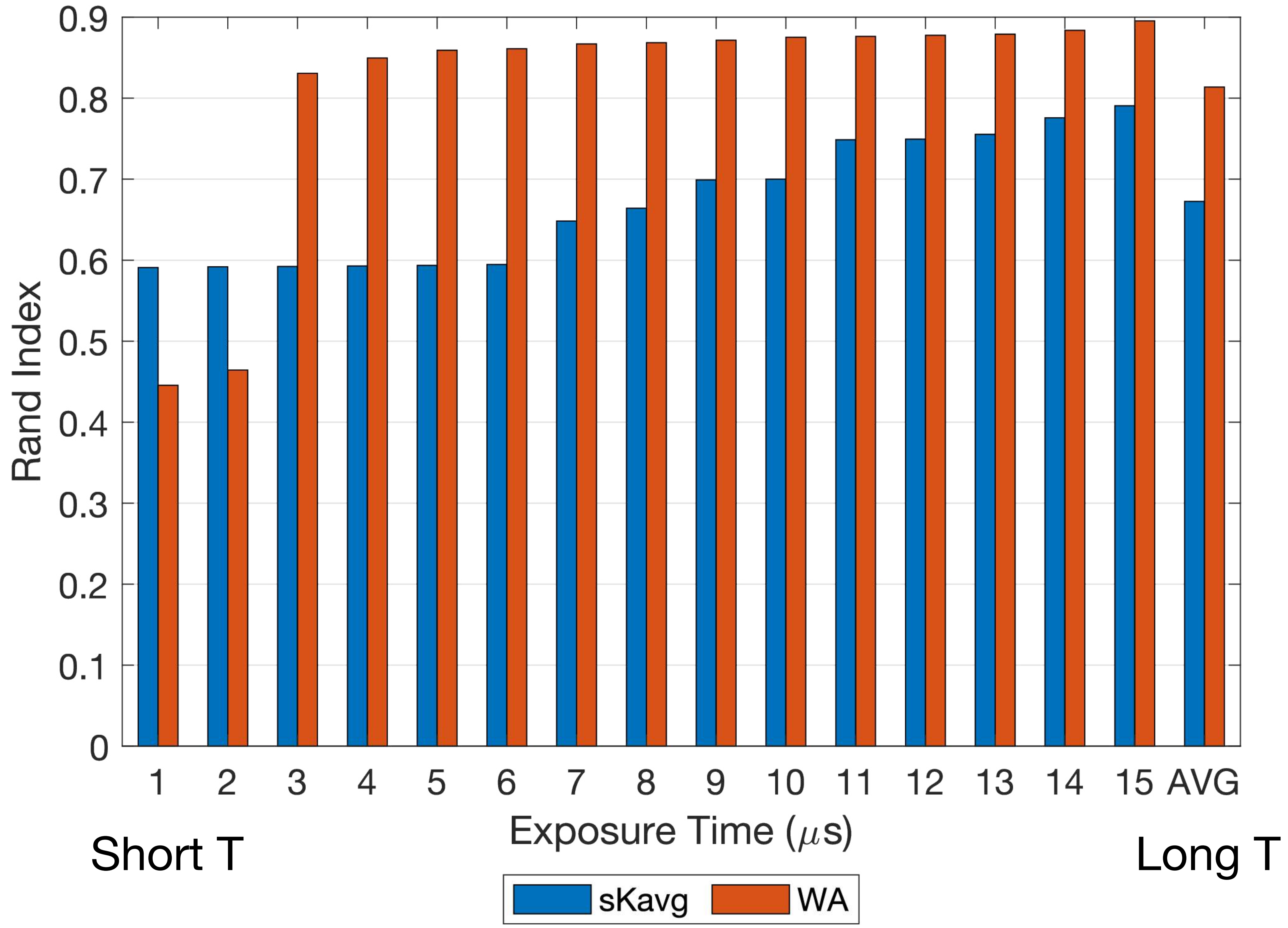
Blood vessel at 0μ*m* depth

Experiments and results

Performance of exposure time

In deep blood vessels (190*μm*, 310*μm*, and 510*μm*):

- WA (83.08% RI) performs well from short exposure times (T>3).
- sKavg (69.90% RI) could perform better in longer exposure times (T>15).



Blood vessel at 510μ*m* depth

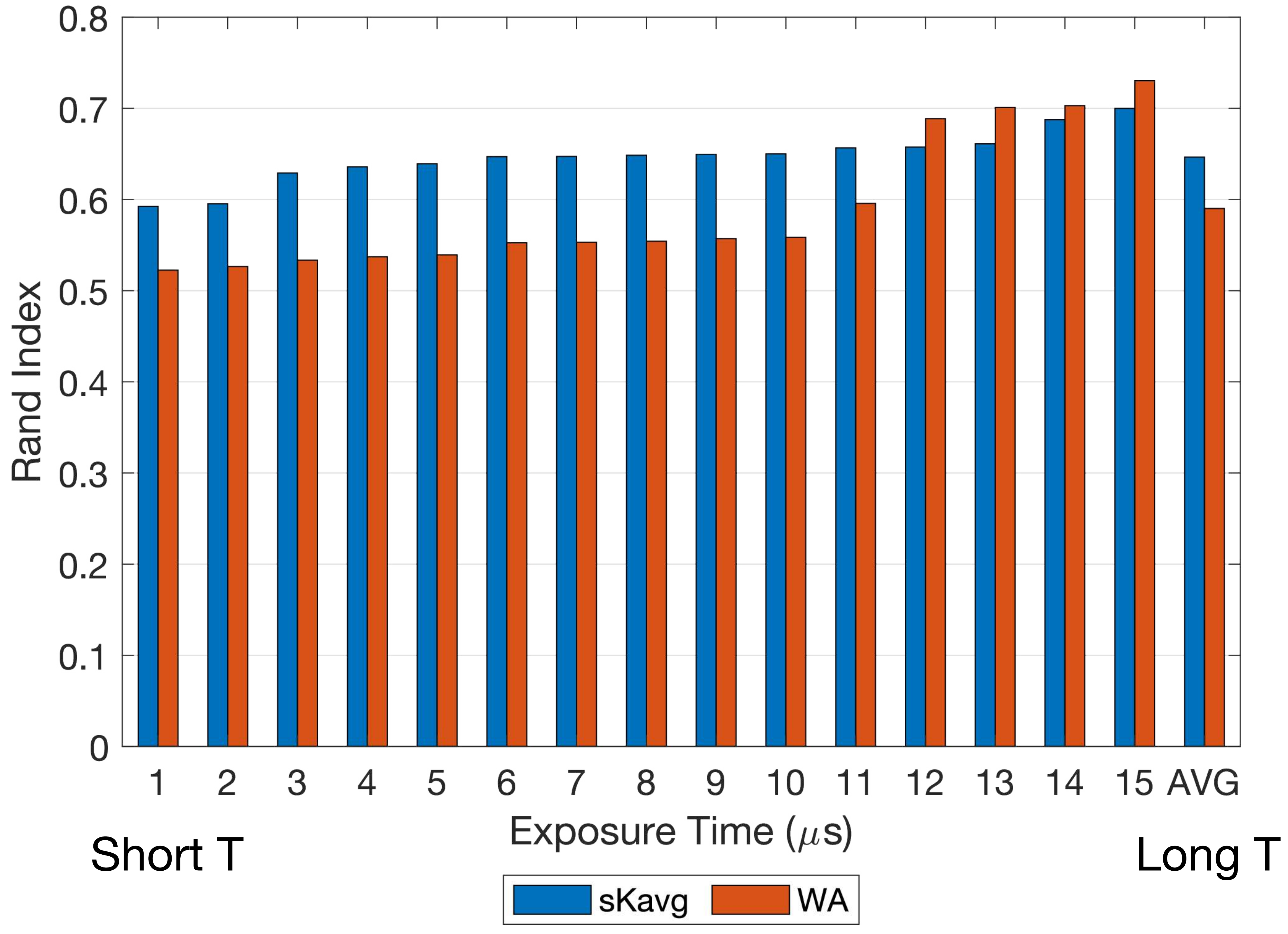
Experiments and results

Performance of exposure time

In the dee blood vessels (1000μm):

- WA (59.58% RI) performs well in long exposure times (T>12).

- sKavg (64.71% RI) performs well from short exposure times (T>3).



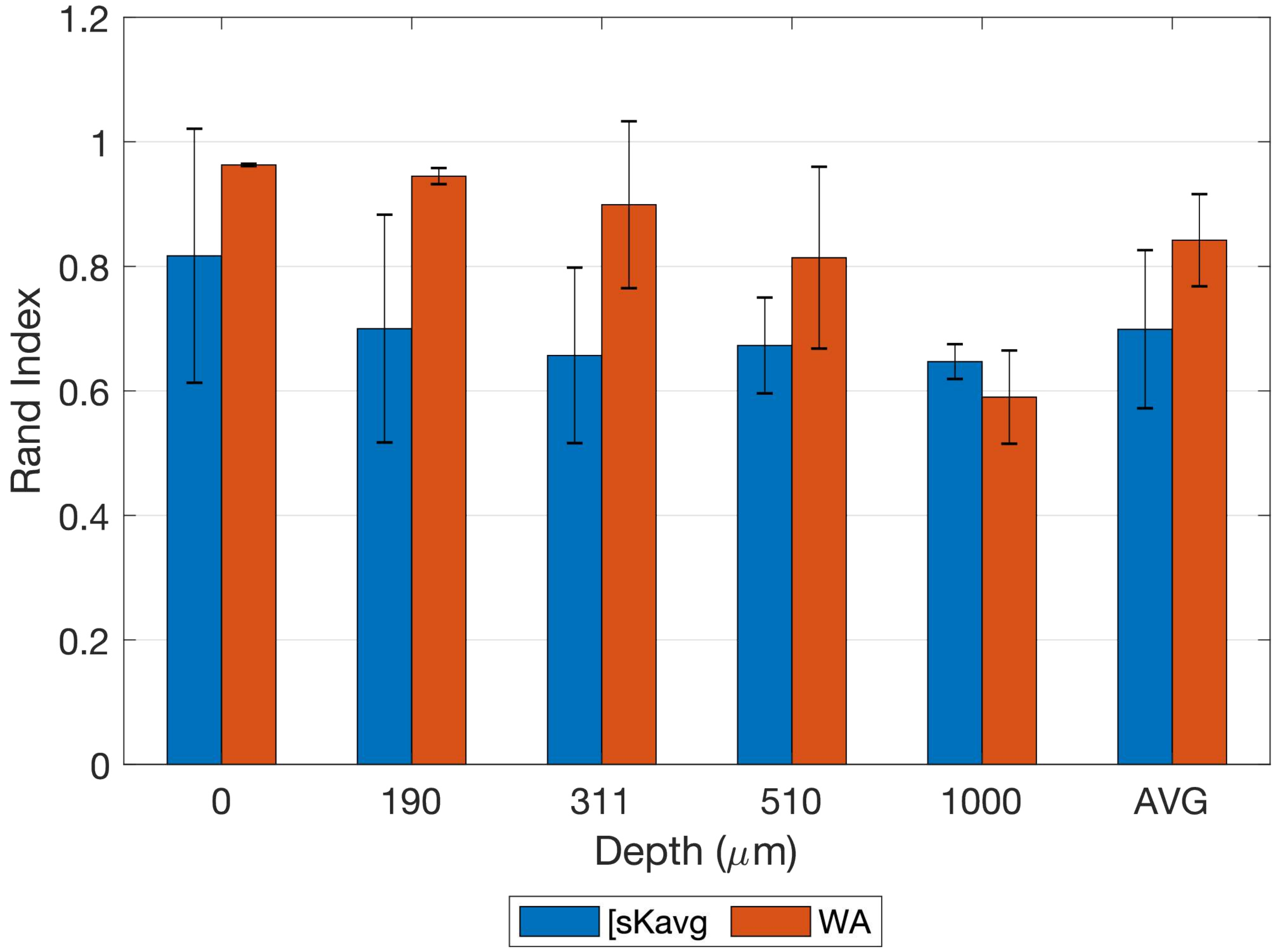
Blood vessel at 1000µm depth

Experiments and results

Performance of exposure time

In general terms,

- In both models, exposure times greater than 12.2 seconds offer better similarity performance.
- The WA model improves the performance of the sKavg model.
- The WA model is useful for locating deep blood vessels up to 510*μm*.



Average similarity performance for depths ρ = {0μ*m*, 190μ*m*, 311μ*m*, 510μ *m*, 1000μ*m*} for *sKavg* and WA models in blood vessels.

Conclusions

- The visualization and localization is an important task to determine the presence of blood vessels in the biological tissue.
- This paper presented a methodology based on a wavelet approach to attenuate noise in contrast images, and improve the localization of blood vessels.
- A useful exposure time was determined to improve the localization of blood vessels and also, high exposure times increase the percentage of similarity in the tested models.

Thank you for your attention!

Questions?

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