Medical Image Application of Robust Principal Component Analysis

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Frontier Medical Engineering
(CFME)
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on Medical Imaging and Artificial Intelligence

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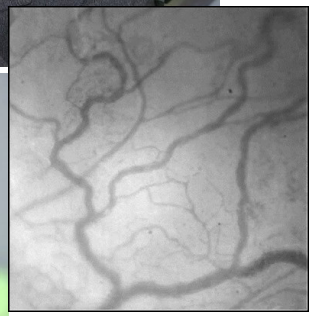
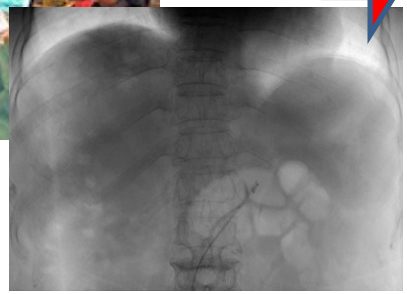
Two Topics Presented

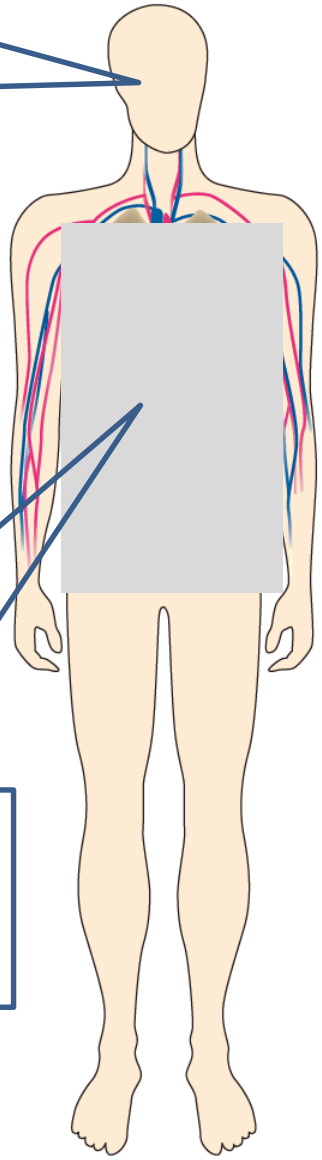


Topic 2: Velocity of blood flow in sublingual microcirculation
Modality: Optics (SDF camera)

Common image processing tool
Robust Principal Component Analysis RPCA



Topic 1: Blood Vessel enhancement in IVR
Modality: X-ray fluoroscopy

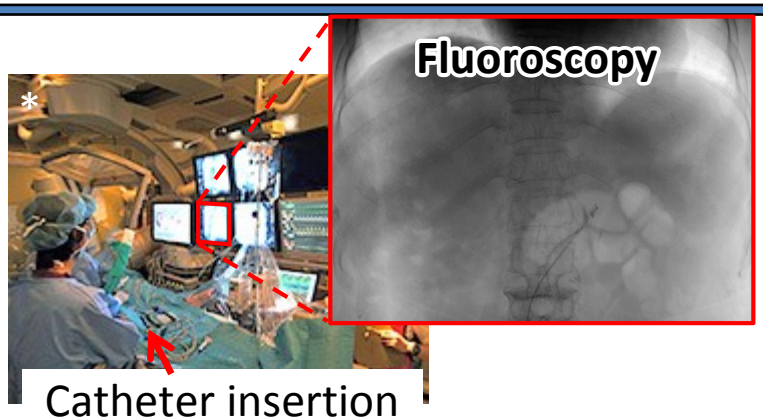


Ms. Kokura

Background of the study

X-ray Fluoroscopy

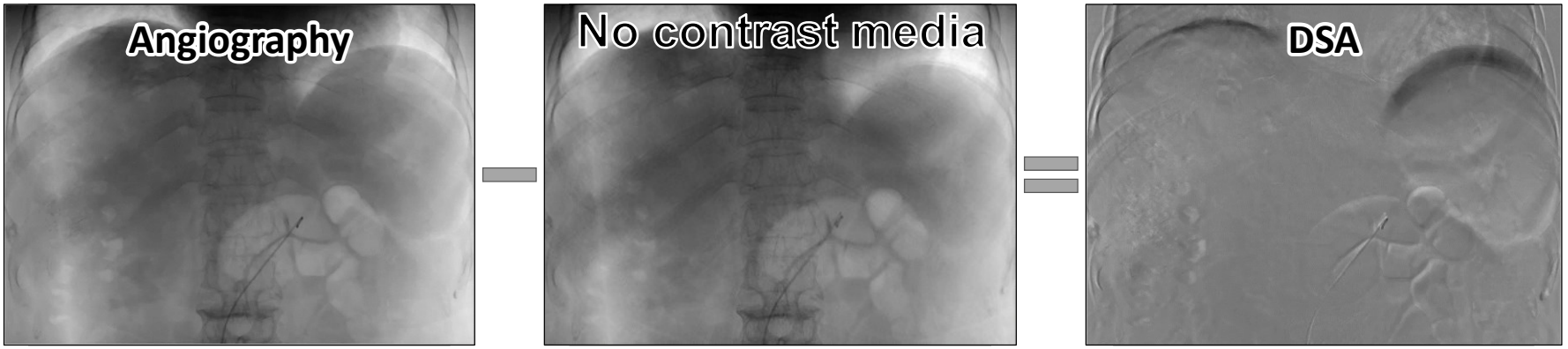
- Modality through which we can observe an internal form and function in real time
- It is used for catheter guidance
- Contrast media is occasionally injected to visualize blood vessels



* https://www.ho.chiba-u.ac.jp/section/junkanki/index.html

Digital Subtraction Angiography (DSA)

Method for blood vessel enhancement by image subtraction



Breath hold is necessary to match the respiratory phase

→ Breath hold is sometimes difficult especially for elder patients

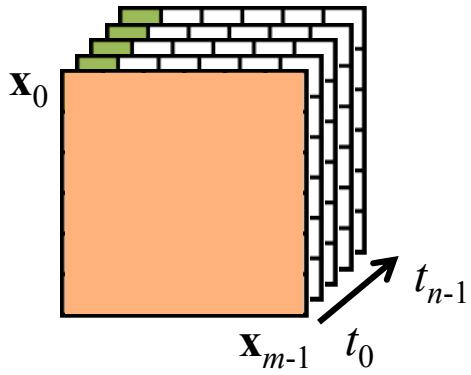
Purpose Blood vessel enhancement using only consecutive angiography **under natural breathing**

RPCA: L+S decomposition

Formulation

Define a matrix $\mathbf{\Gamma}$ using $\gamma(\mathbf{x}, t)$

Candès *et al.*, 2011



Temporal sample at the location $\mathbf{x}_0$

$$\mathbf{\Gamma} = \begin{bmatrix} \gamma(\mathbf{x}_0, t_0) & \Lambda & \gamma(\mathbf{x}_0, t_{n-1}) \\ \mathrm{M} & \mathrm{O} & \mathrm{M} \\ \gamma(\mathbf{x}_{m-1}, t_0) & \Lambda & \gamma(\mathbf{x}_{m-1}, t_{n-1}) \end{bmatrix}$$

SDF image at the frame t_0

- t : Frame number
- m : The number of pixels
- n : The number of frames
- $\mathbf{x}$: The position in an SDF image

$\mathbf{\Gamma}$ is defined as $\mathbf{\Gamma} = \mathbf{L} + \mathbf{S}$

low-rank matrix **sparse matrix**

Optimization problem

$$\arg\min_{\mathbf{L},\mathbf{S}} \left\{ \|\mathbf{L}\|_* + \lambda \|\mathbf{S}\|_1 \right\} \quad s.t.\ \mathbf{L} + \mathbf{S} = \mathbf{\Gamma}$$

$\mathbf{L}$: Low-rank λ: Control parameter

$\mathbf{S}$: Sparse

- $\mathbf{\Gamma}$ is decomposed into Low rank and Sparse by solving the optimization problem

nuclear norm

$$\|\mathbf{L}\|_* = \sum_{i=1}^{\min\{m,n\}} \sigma_i$$

$\|\cdot\|_*$: nuclear norm

σ : diagonal element of diagonal matrix obtained by SVD

l_1 norm

$$\|\mathbf{S}\|_1 = \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \left| s(\mathbf{x}_i, t_j) \right|$$

$\|\cdot\|_1$: l_1 norm

$s(\cdot)$: Operator to return a pixel value at a position

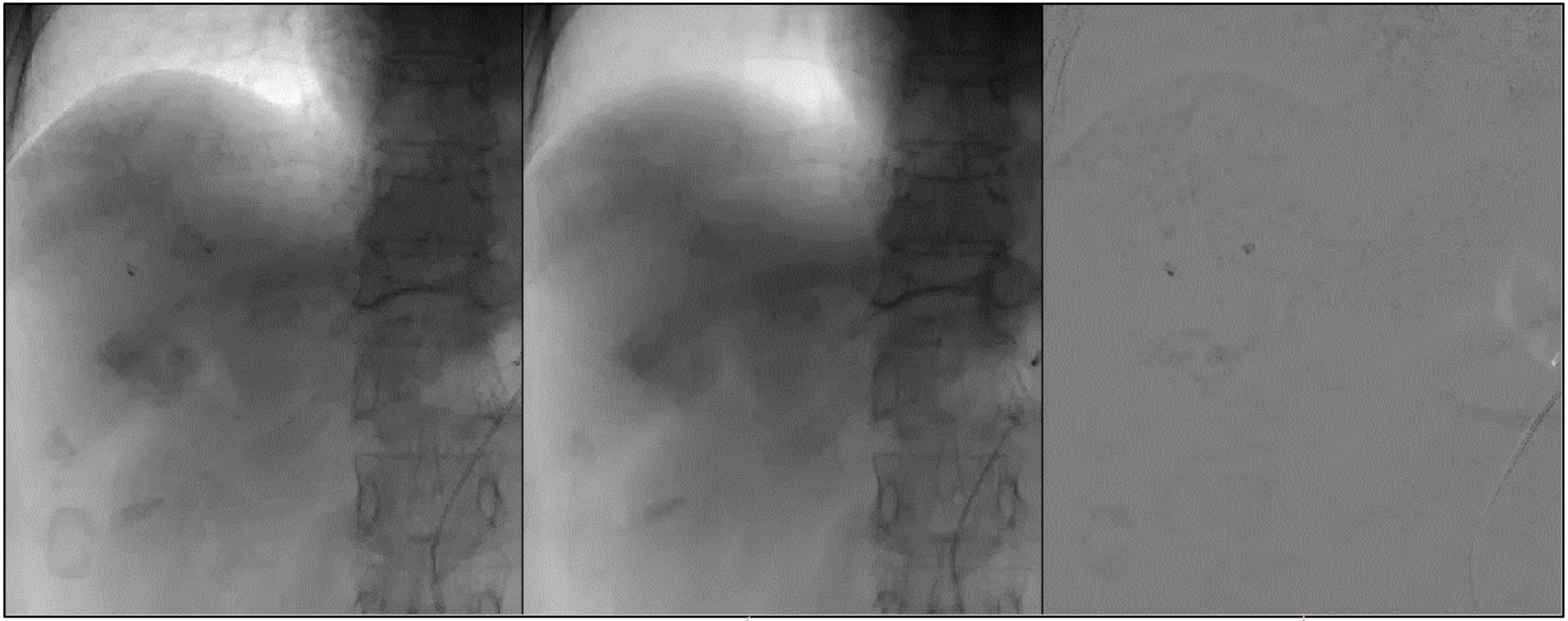
Robust Principal Component Analysis (RPCA)

Γ = L + S

L: Low-Rank

S: Sparse

Angiography = **Background image** + **Vessel image**



unmoving structure (bone) and periodically moving organs along breathing

Sparse pattern such as flow of contrast media

✕ There still exist artifacts such as a small part of background and noise.

Improvement of RPCA

Consider the foreground continuity as prior information

Total variation (TV) was incorporated into conventional RPCA

$$\min_{\mathbf{L},\mathbf{S}} \left\{ \|\mathbf{L}\|_* + \lambda_s \|\mathbf{S}\|_1 + \lambda_{\mathrm{TV}} \|\nabla \mathbf{S}\|_{2,1} \right\} \quad s.t.\ \boldsymbol{\Gamma} = \mathbf{L} + \mathbf{S}$$

$\|\cdot\|_{2,1}$: $l_{2,1}$ norm

Low-rank | Sparse | TV

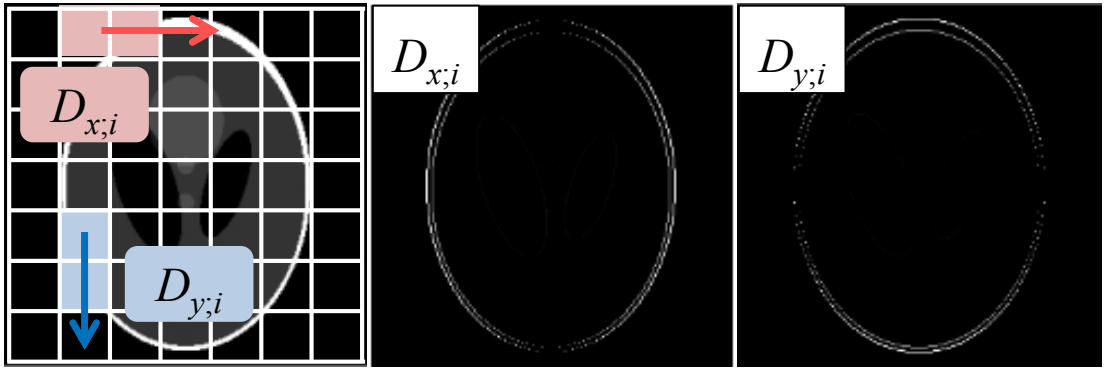
Total Variation

Difference between adjacent values along x, y, and t direction

$$\|\nabla \mathbf{S}\|_{2,1} = \sum_{i=1}^{mn} \sqrt{D_{x;i}^2 + D_{y;i}^2 + D_{t;i}^2}$$

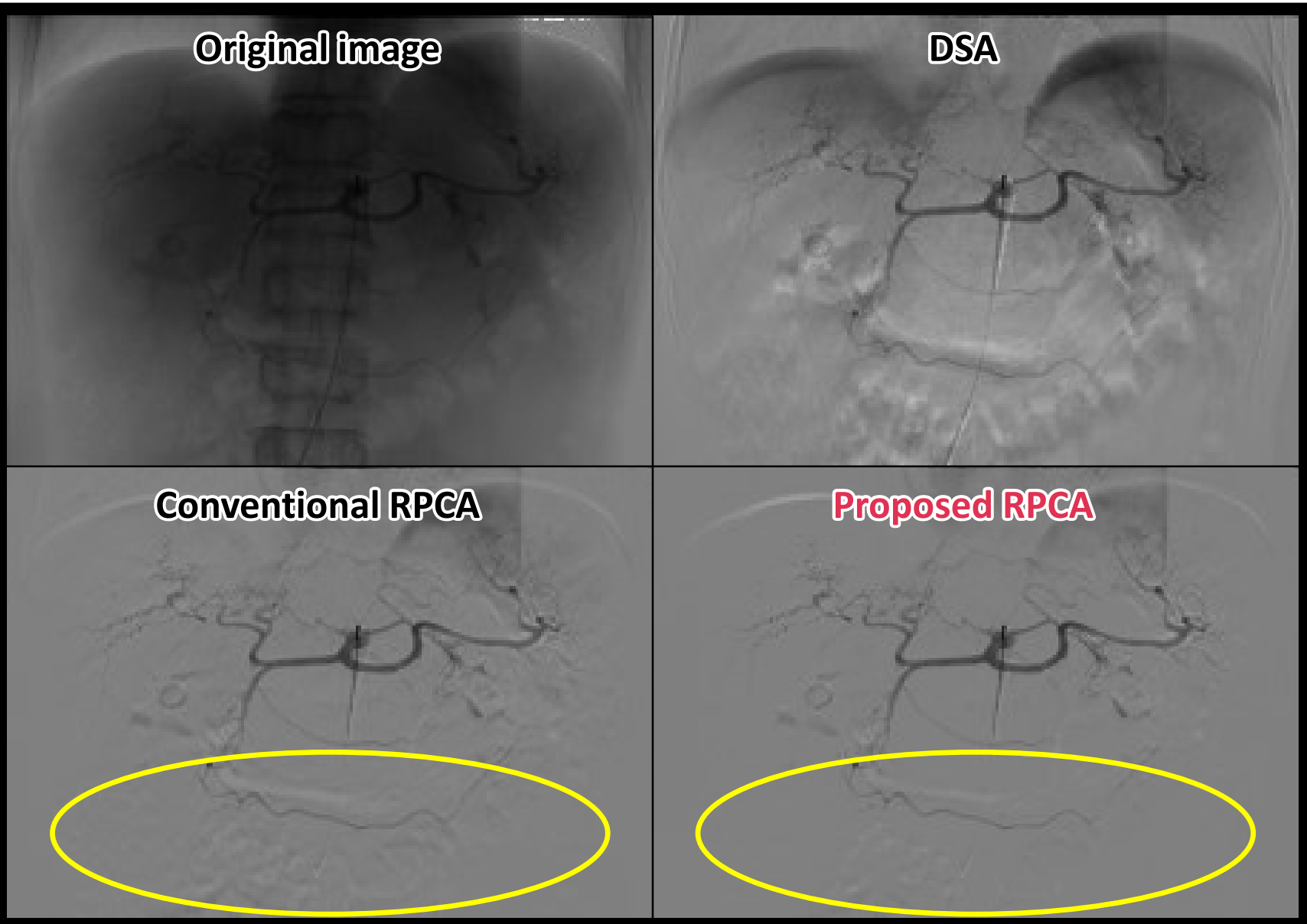
$D_{x;i}$, $D_{y;i}$, $D_{t;i}$

: Difference operation



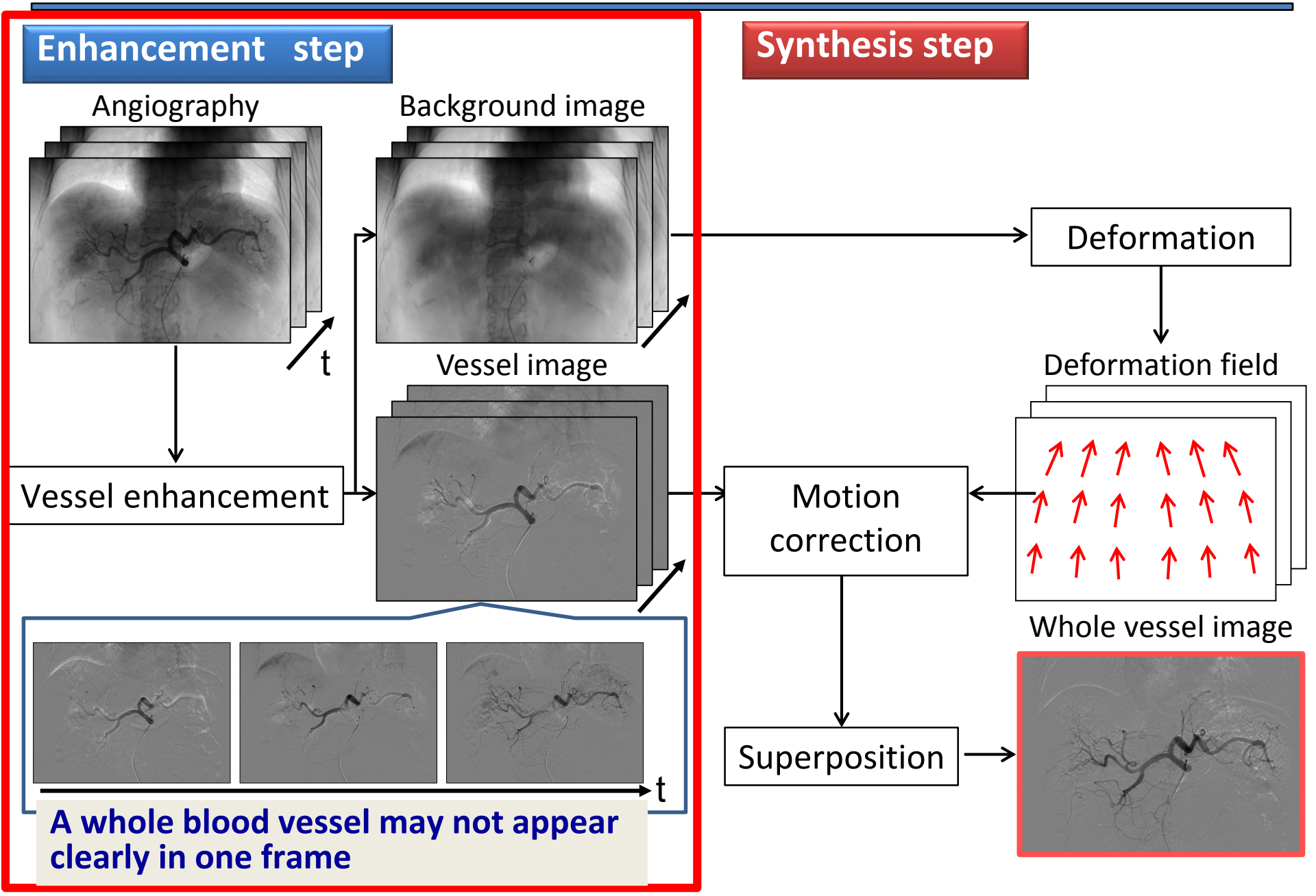
Preserve edges of foreground and efficiently reduce noise

Results

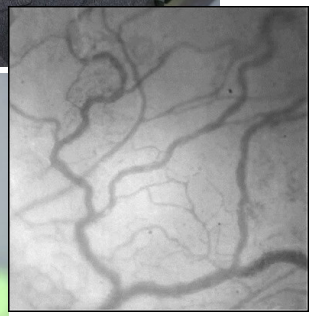


The proposed method reduced artifacts due to the complex motion

Total Scheme of Image Processing



Two Topics Presented



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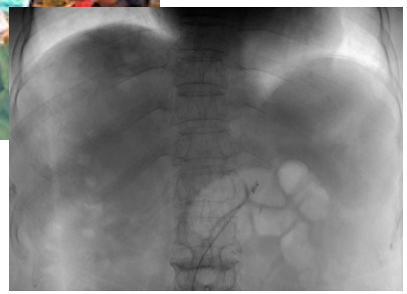
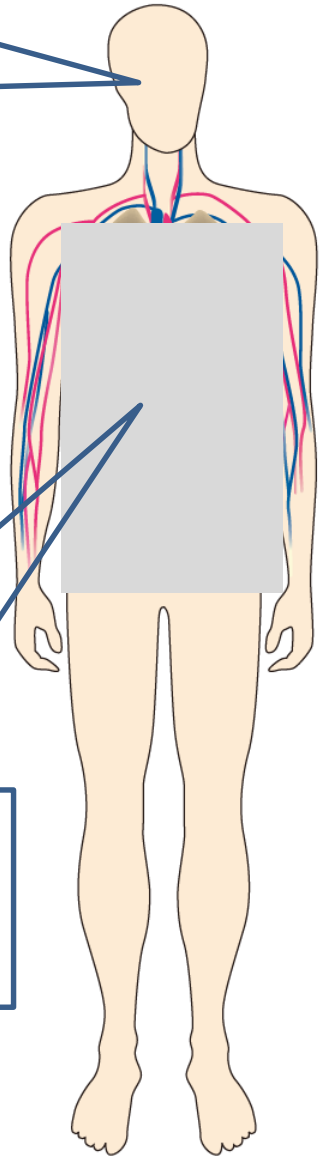


Topic 1 Blood Vessel enhancement under IVR
Modality: X-ray fluoroscopy

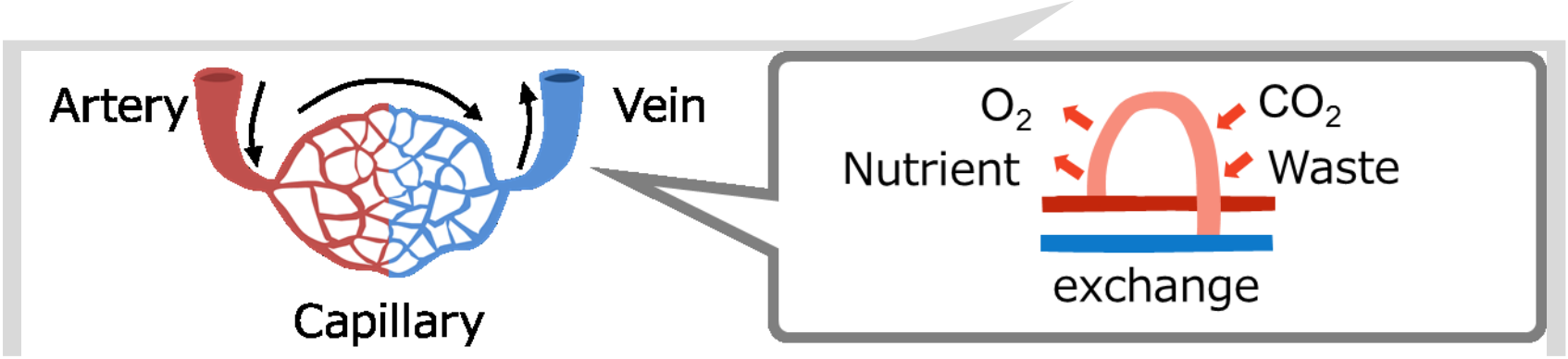


Background

Ms. Takahashi

Septic Shock

Septic shock induces organ dysfunction due to microcirculatory disturbance.



Lactate level in blood

The lactate level has been introduced in recent years as one of the diagnostic criteria for septic shock.

However, the disadvantages are as follows:

- ✖ Require sampling of blood,
- ✖ Require a certain time to analyze.

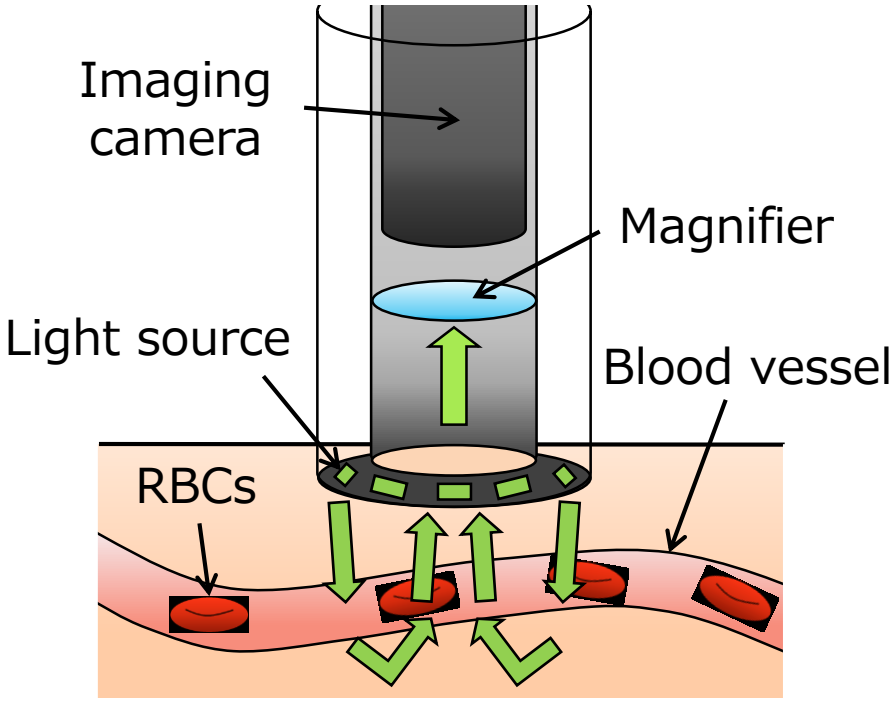
Development of non-invasive and highly-sensitized diagnosis for septic shock is desired.

➡ **Focusing on direct visualization of microcirculation**

Sidestream dark-field (SDF) imaging (Ince *et al.*, 2005)

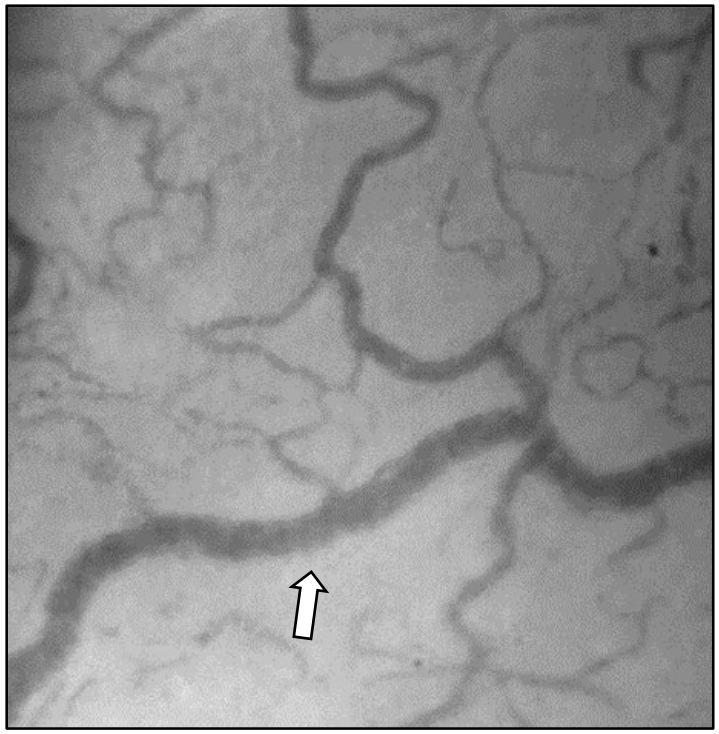
Non-invasive imaging system to observe microcirculation directly

Geometry of SDF probe



Images can be obtained without contamination caused by the surface reflection light.

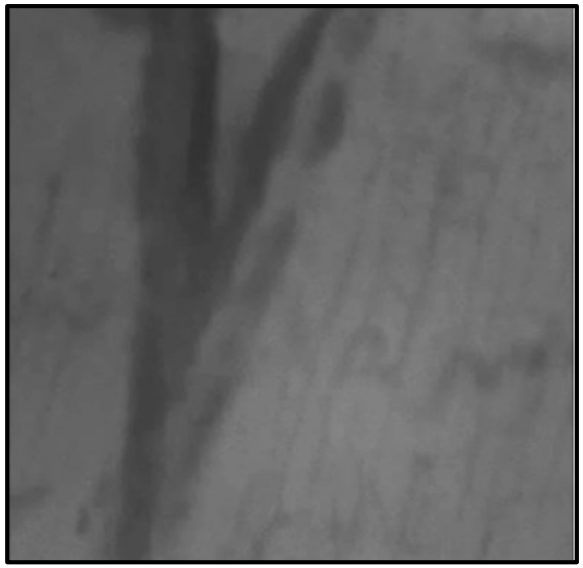
SDF image of dorsal skin of rat



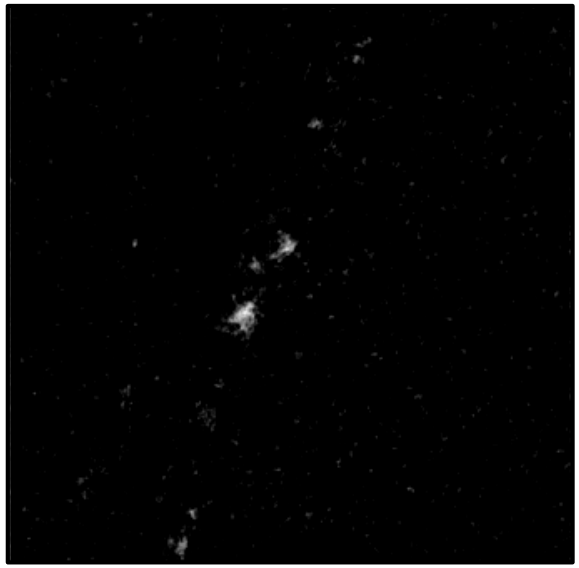
Red blood cells(RBCs) are represented in black by the absorption of hemoglobin.

RPCA: L+S decomposition

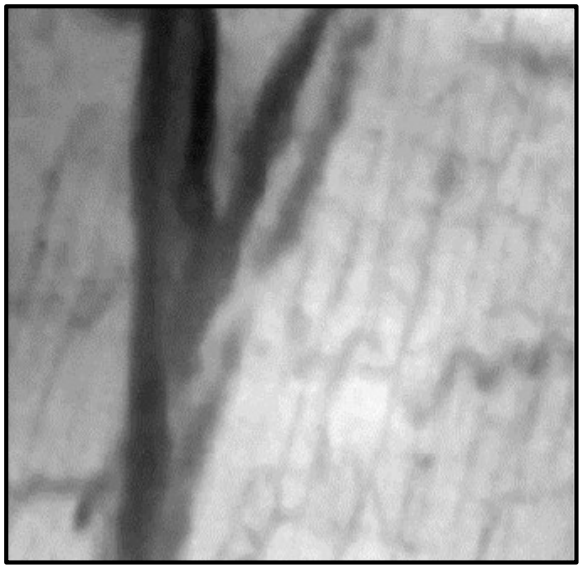
Original image



S: Sparse



L: Low rank



✓ **Sparse**

Rapid dynamic information

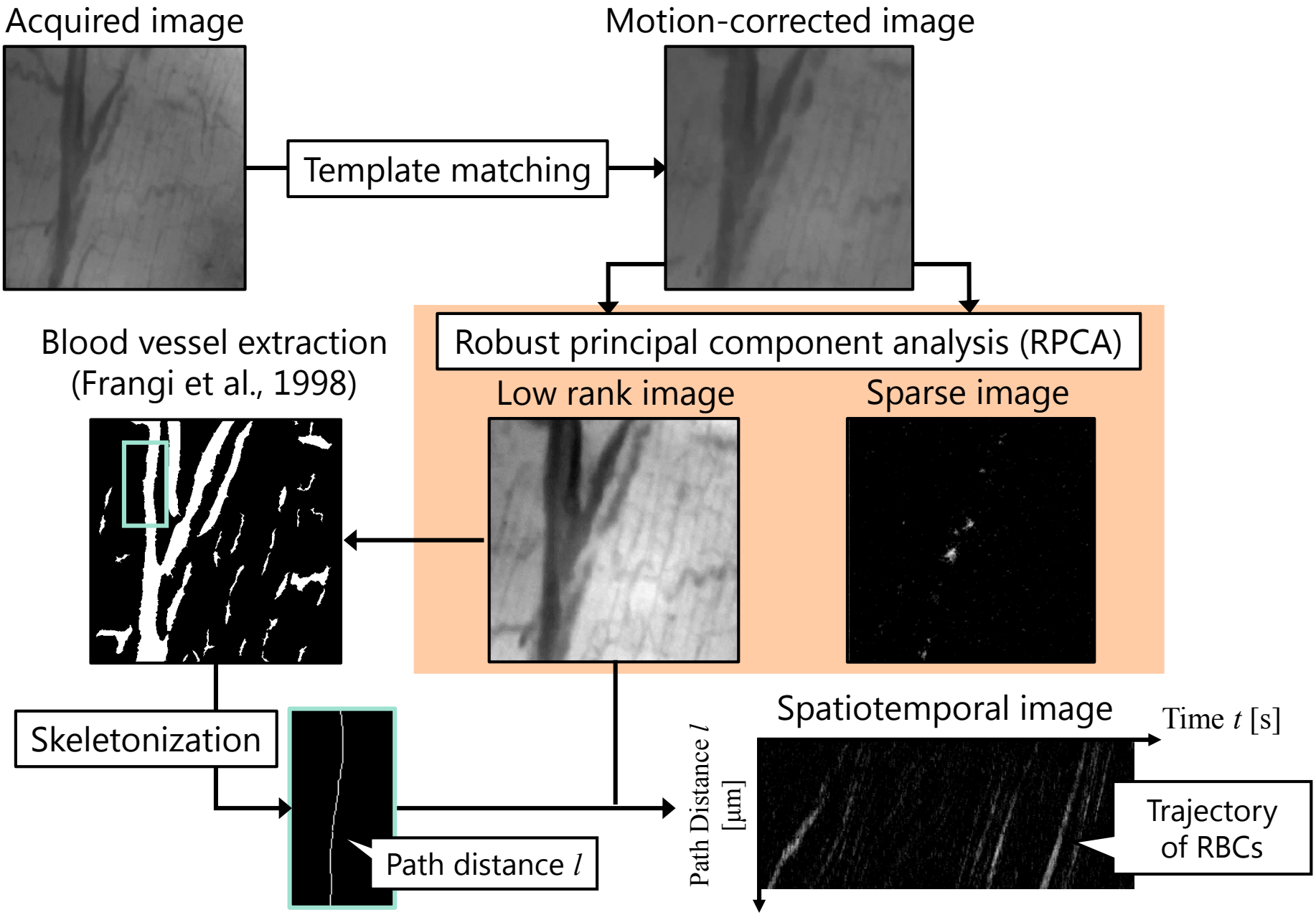
Motion of RBCs and random noise

✓ **Low rank**

Smooth and slowly varying changes

Respiratory motions in the background

Blood flow velocity estimation method

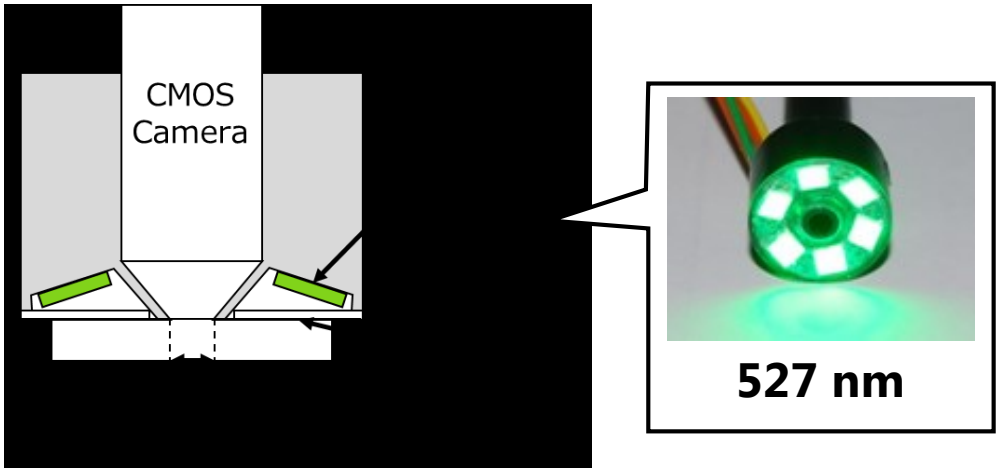


SDF camera development and rat experiment

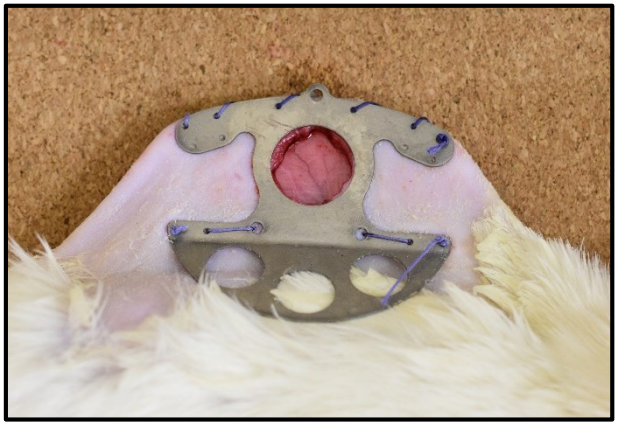
Developed an SDF probe using LEDs

Our spectral SDF probe

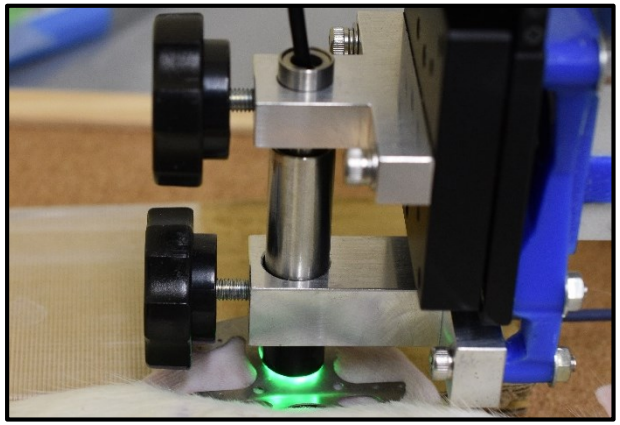
Schematic illustration of SDF probe



Experimental setup



Dorsal skinfold chamber model rats
(Small Dorsal Kit, APJ Trading Co., Inc., United States)

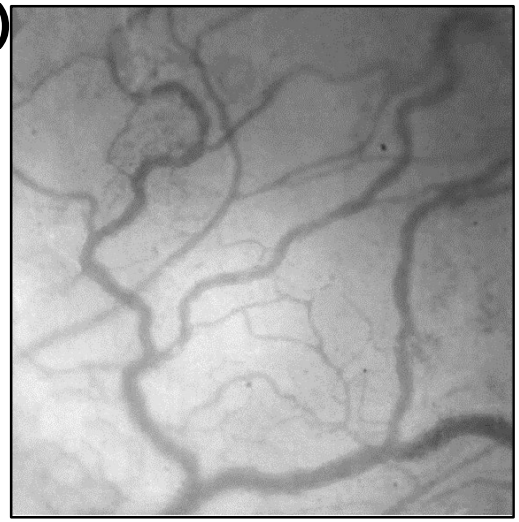


Captured the SDF images

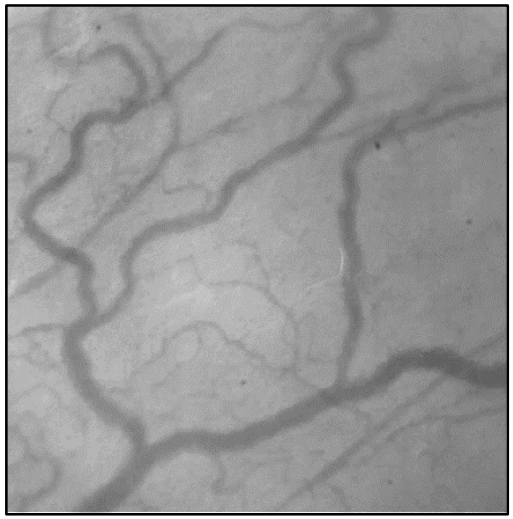
SDF time-series microcirculation images

Sham
(Healthy)

0 hour



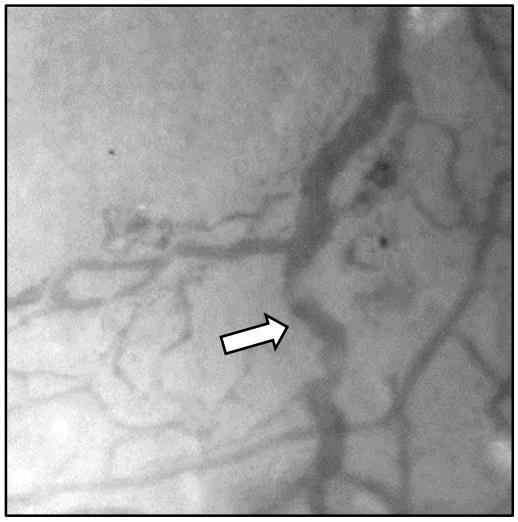
2 hour



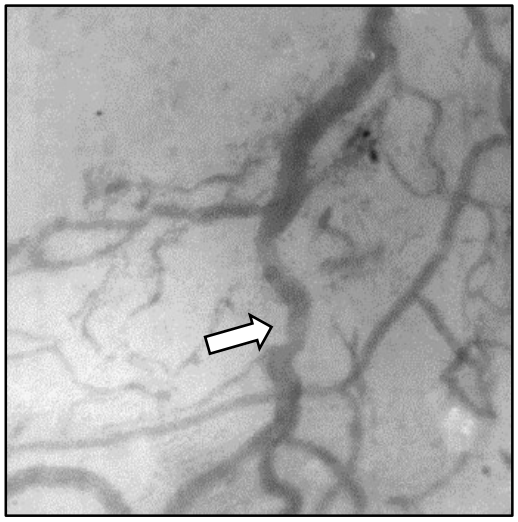
8 hour

CLP
(Sepsis)

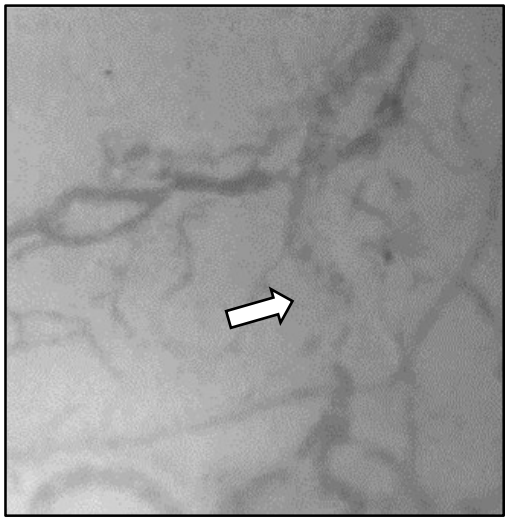
0 hour



2 hour



8 hour

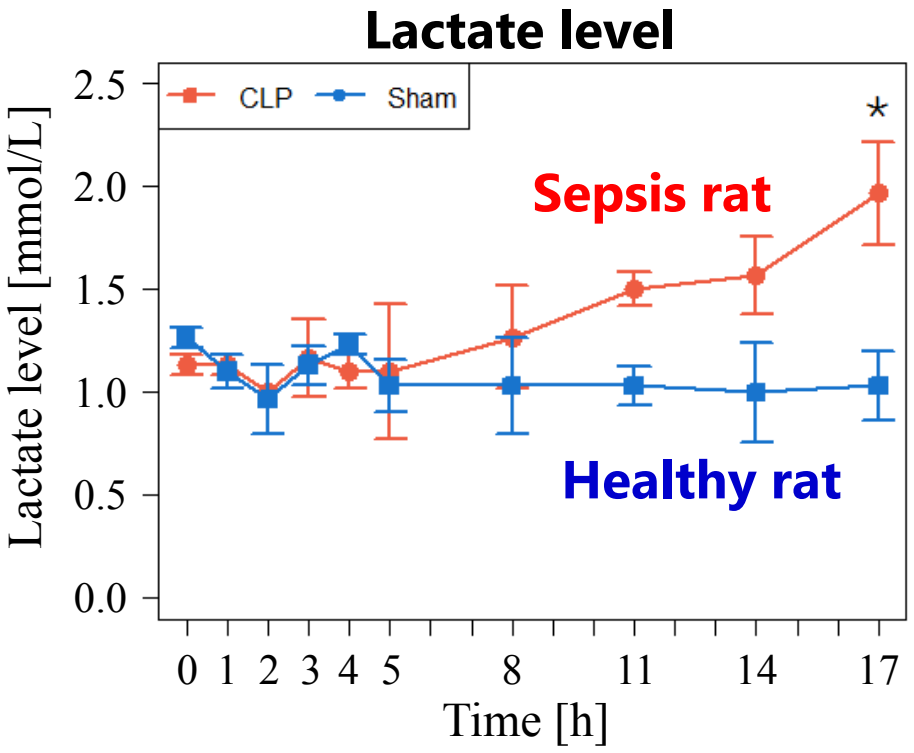


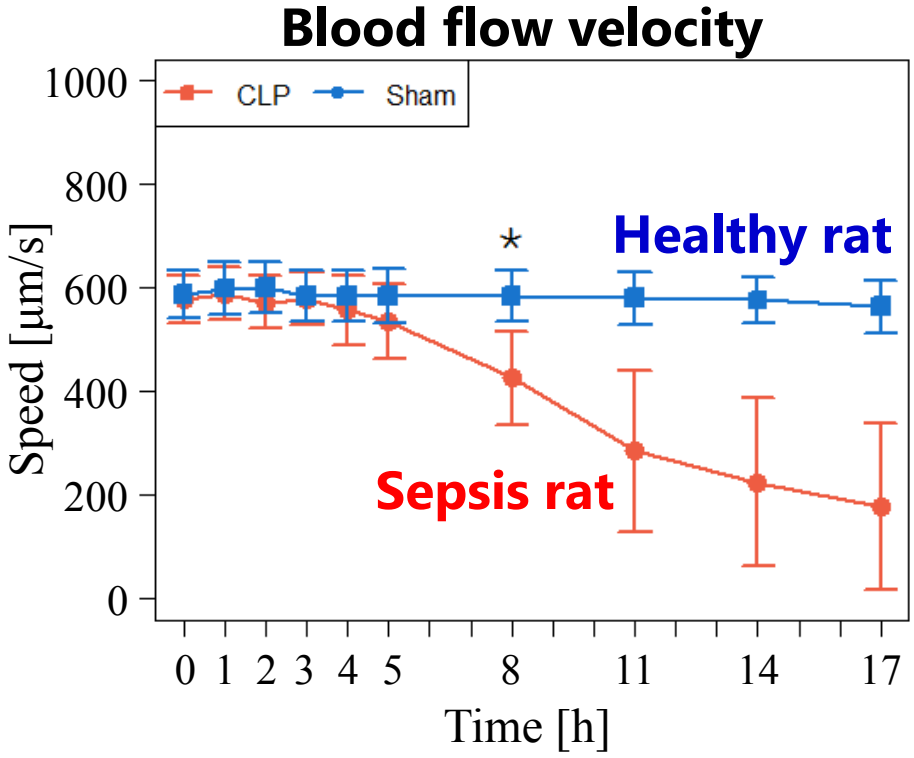
In the image after 8 hours the blood flow is shredded

Estimated blood flow velocities

Temporal change of the average of the lactate level and blood flow velocity

Region of Interest (ROI) : n=9





Change of blood flow velocity appeared earlier than lactate level for septic shock reaction

➡ **Blood flow velocity might be useful for the diagnosis of septic shock**

Conclusions

Two topics using RPCA as an image processing tool were introduced.

- ✓ Velocity estimation of blood flow in sublingual microcirculation
- ✓ Blood vessel enhancement under IVR

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Acknowledgements and Hope

1. AMS and JSPS(Prof. Nobuo Ueno, Director)
   During this stay, we visited
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2. JSPS Core-to-Core Program
   "Multimodal Medical Engineering" 2017-2021
   with
   University of Eastern Finland, Thammasat University, Shanghai Jiao Tong University and University of Waterloo

3. Hope to find a new research collaboration with UK