APPEARANCE ENHANCEMENT OF BLOOD CIRCULATION OF ORGAN DURING SURGERY

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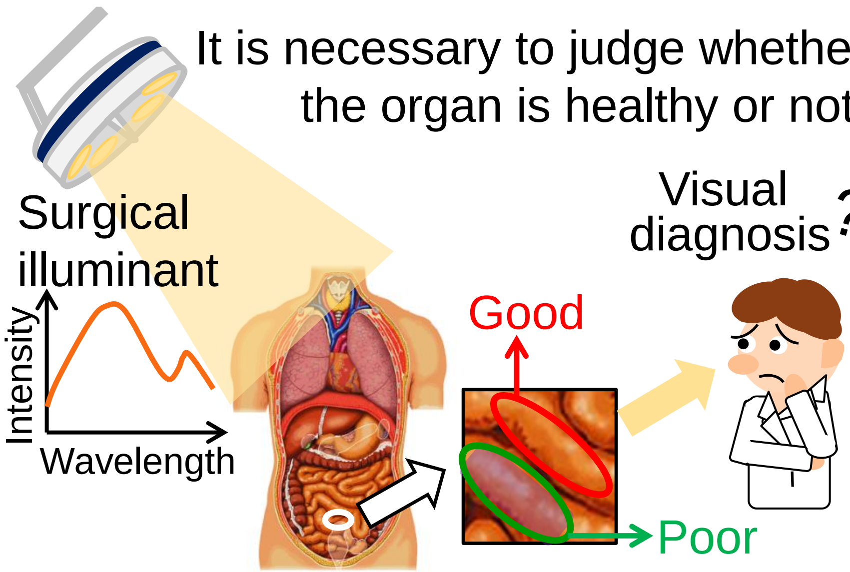
Color of organ in surgery is very important

Autotransplantation

Resect and reconstruct a hollow organ

It is necessary to judge whether the organ is healthy or not.



The condition of organ is appeared in color.
But the difference of color is small.

It is desired that a technology to assist surgeon's diagnosis is developed.

Approach 1

Improving color appearance of organ in surgery by optimally designed visible LED illuminant

Approach 2

Basic Study Toward Quantification of Circulation of the Organ Using Near-Infrared Spectral Image

Improving color appearance of organ in surgery by optimally designed LED illuminant

KINA MURAI AND HIDEAKI HANEISHI

Introduction

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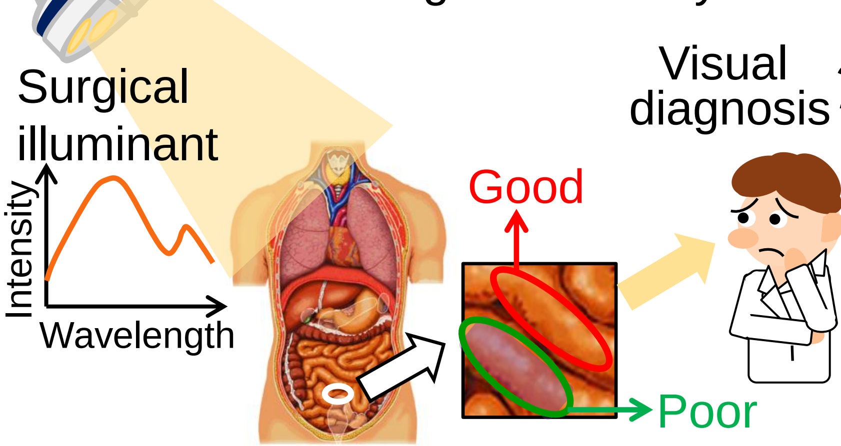
■ Autotransplantation

Resect and reconstruct a hollow organ

It is necessary to judge whether the organ is healthy or not.



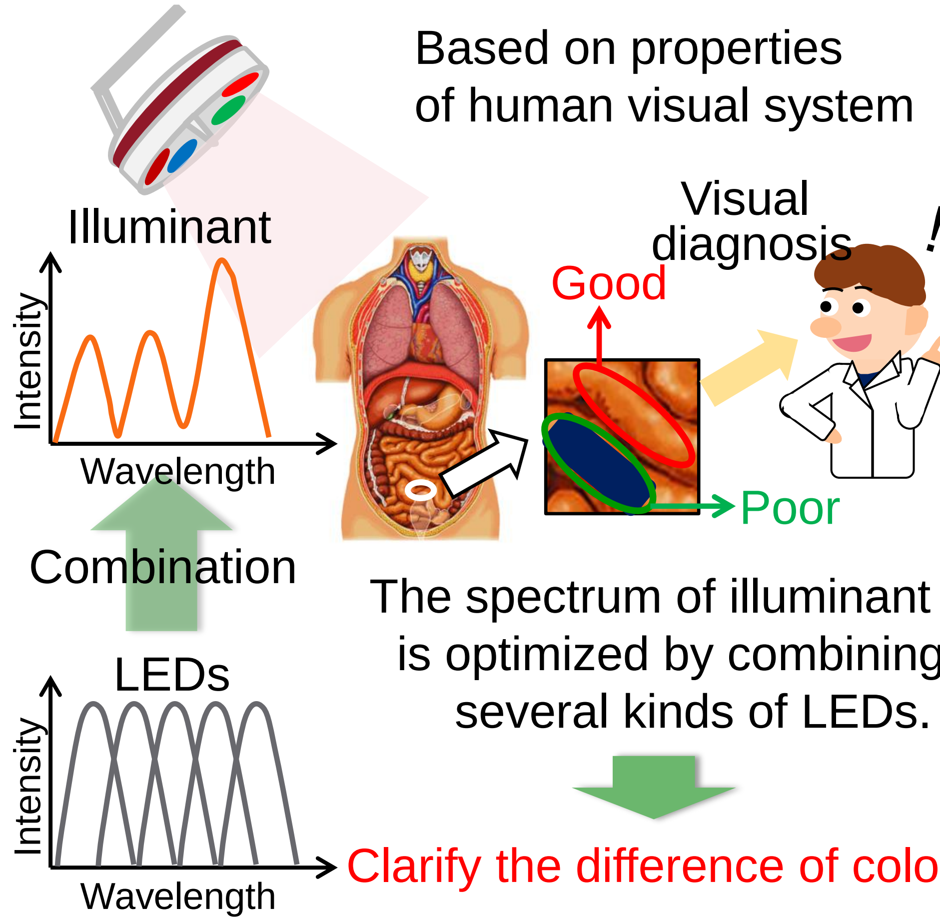
The color reflects the condition of organ.
But the difference of color is small.

It is desired that a technology to support visual diagnosis is developed.

■ Designed an illuminant

Illuminant is designed by using LEDs.

Based on properties of human visual system



The spectrum of illuminant is optimized by combining several kinds of LEDs.

Clarify the difference of color

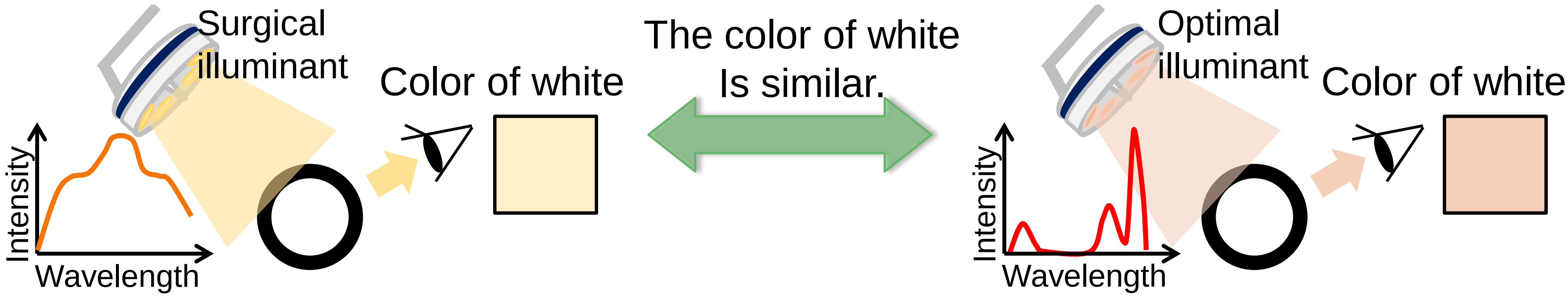
Purpose

For clarifying the blood circulation, the optimal illuminant is designed.

Two approaches of illuminant optimization

Optimal white illuminant

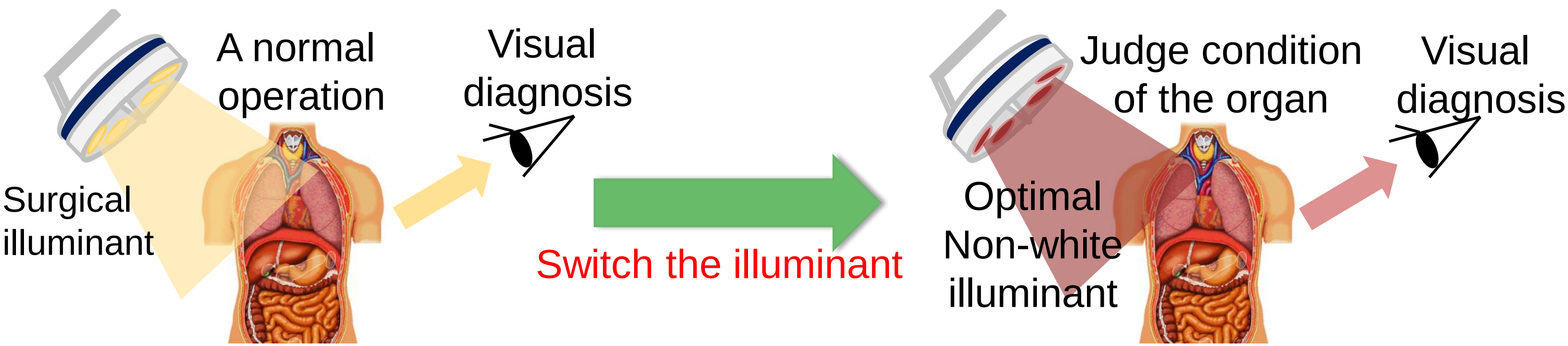
Surgeons are used to the color of conventional shadowless light in operation room.
It is not preferable that color of the optimal illuminant is different from surgical illuminant.



Illuminant is optimized under the metameric condition that the white is maintained.

Optimal non-white illuminant

The optimal illuminant is used only when surgeons judge the condition of the organ.

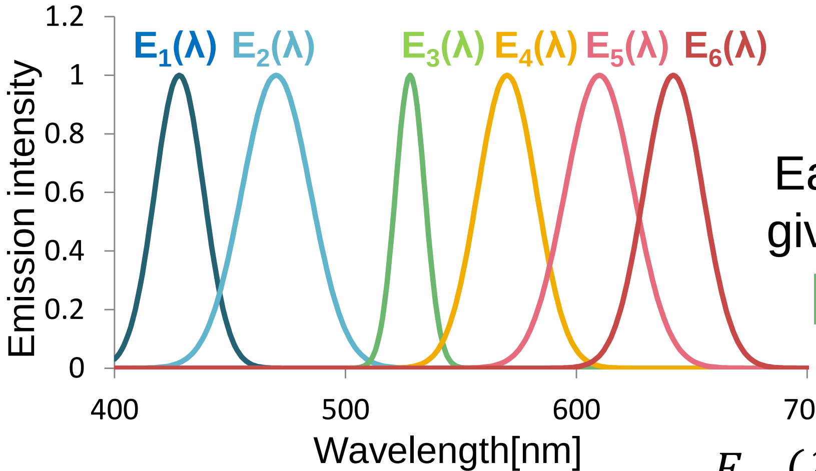


Method

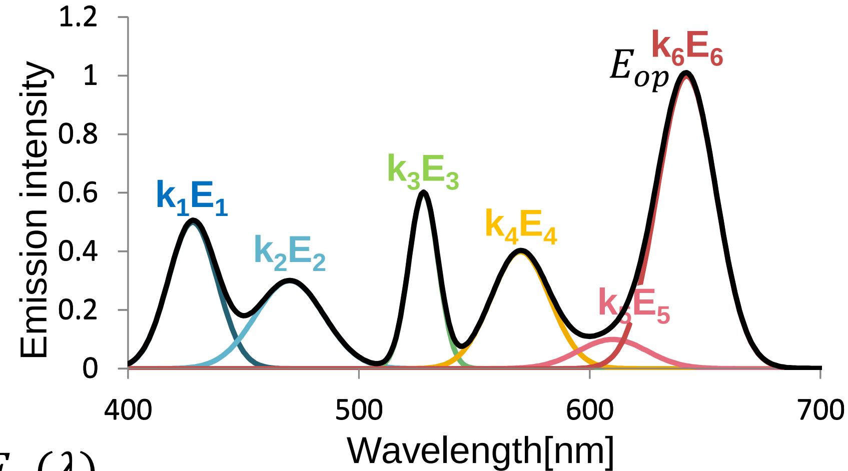
■ The optimal illuminant is designed by weighting and combining some kinds of LEDs.

Combining LEDs

The spectral characteristics of LEDs are known.



Each LED is given weight.

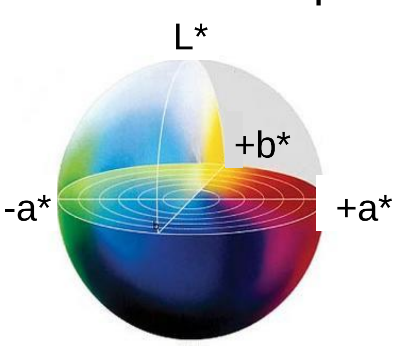


$$E_{op}(\lambda) = \sum_{n=1}^{N} k_n E_n(\lambda) \qquad 0 \le k_n \le 1$$

N:the number of the kinds of LEDs.

Color difference

CIELAB color space



Reflectance 1 → $X_1\ Y_1\ Z_1$ → $L^*_1\ a^*_1\ b^*_1$

Reflectance 2 → $X_2\ Y_2\ Z_2$ → $L^*_2\ a^*_2\ b^*_2$

→ Color difference ΔE_{ab}

$$\Delta E_{ab} = \{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\}^{1/2}$$

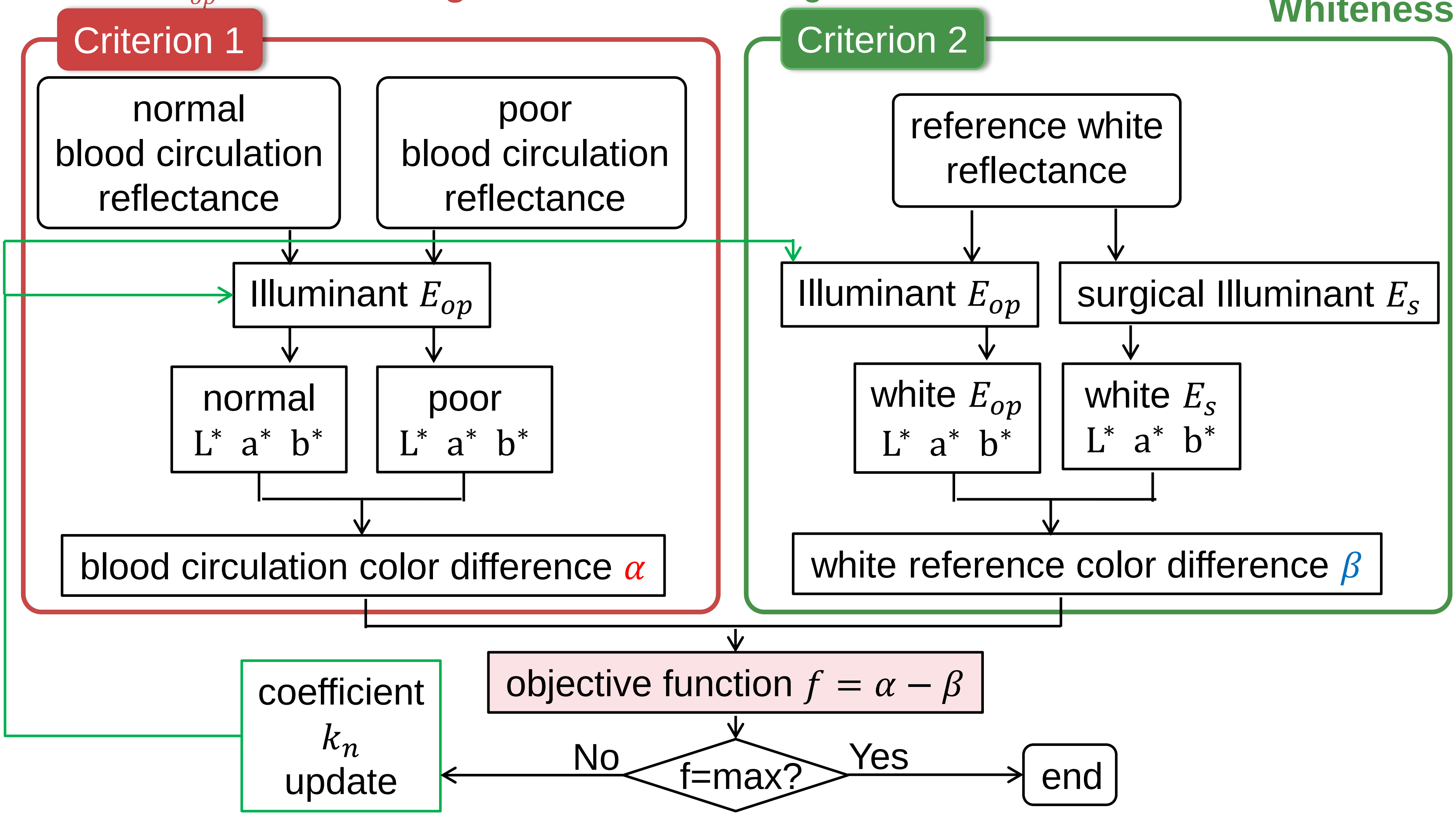
$\Delta E_{ab} > 3$:HVS can perceive the difference of color.

Optimization of white illuminant

Color difference between normal organ and poor circulation organ under the illuminant E_{op} should be **largest**.

Color difference of white object between the illuminant E_{op} and the conventional surgical illuminant should be **smallest**.

Whiteness



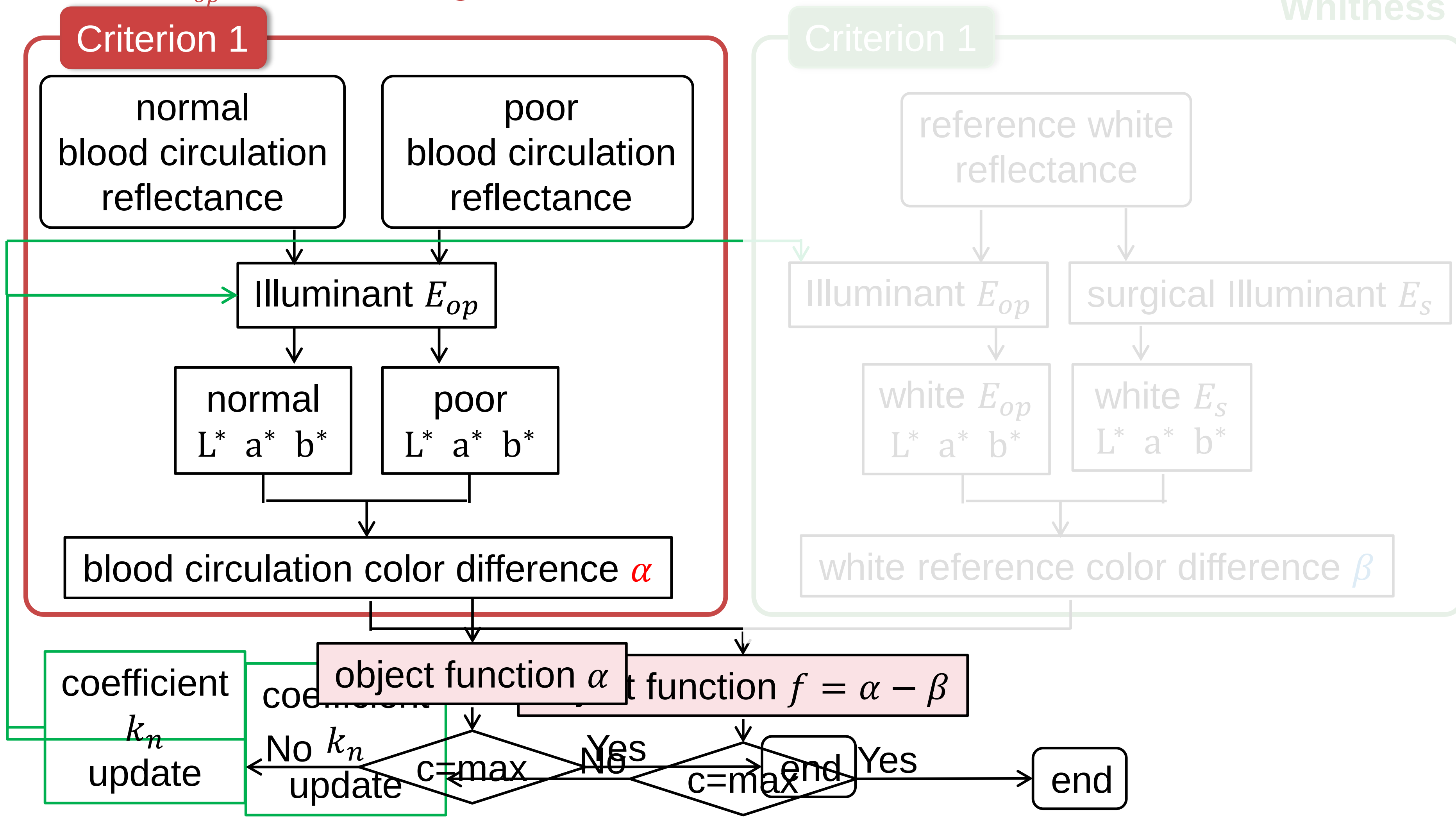
■ The weight k_n is acquired by maximizing the objective function

Optimal non-white illuminant

Color difference between normal organ and poor circulation organ under the illuminant E_{op} should be **largest**.

The color difference under the illuminant E_{op} and the surgical illuminant is the smallest.

Whitness



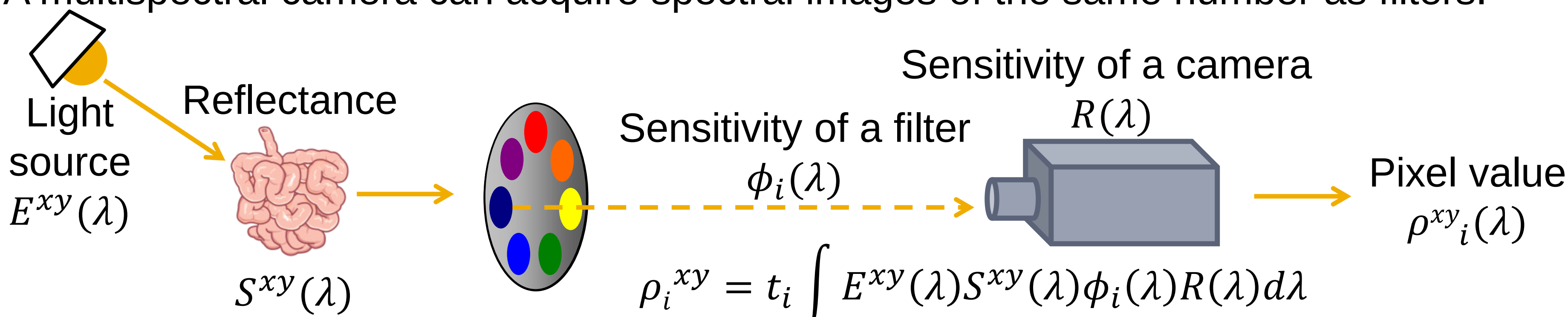
■ The weight k_n is acquired by maximizing the objective function

Experiment

■ The reflectance spectra of pigs' small intestine were collected for designing the optimal illuminant.

Multispectral Image Capturing

A multispectral camera can acquire spectral images of the same number as filters.

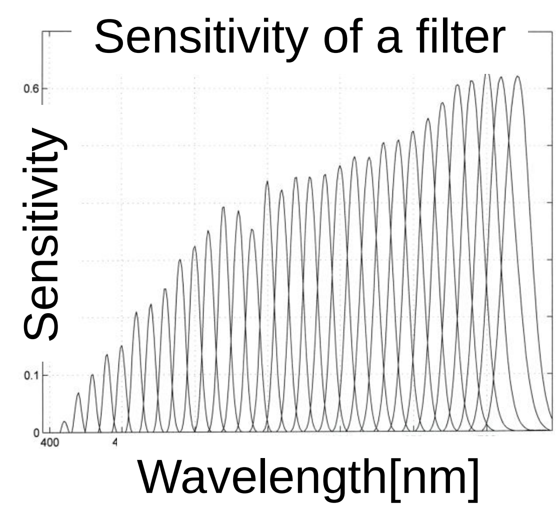


$$\rho_i{}^{xy} = t_i \int E^{xy}(\lambda) S^{xy}(\lambda) \phi_i(\lambda) R(\lambda) d\lambda$$

t_i: Exposure time

Camera : ALTA U260 (Apogee)
Image size : 512×512 [pixels]
Pixel size : 20×20 [μm]

Filter : VariSpec (CRi)
Wavelength band: 400～720 [nm]
Band width : 10 [nm]

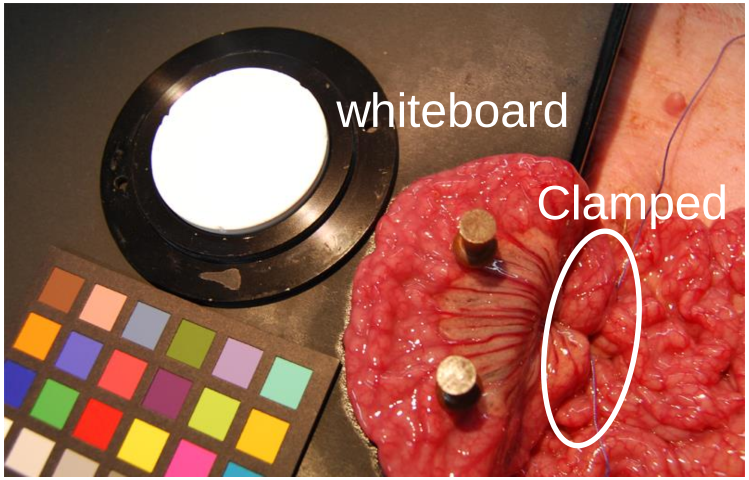


■ 33 filters were used for capturing the images.

Experiment

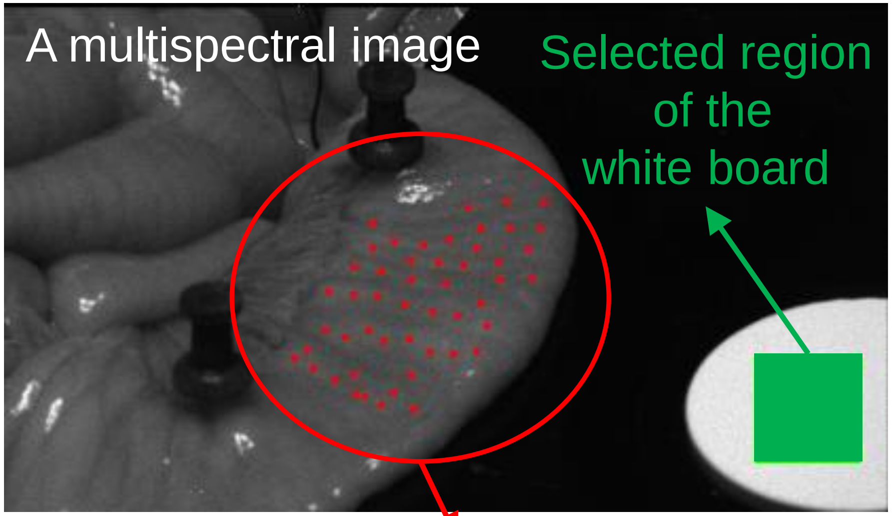
Experiment protocol

① A part of a small intestine was fixed.
② The images of normal blood circulation were captured. **normal**
③ The vessels supplying the blood were clamped.
④ The images of the poor blood circulation were captured. **Ischemia1 （虚血）**
⑤ The images of the worse blood circulation were captured. **Ischemia2**



Data normalization

A white board was used as white reference.



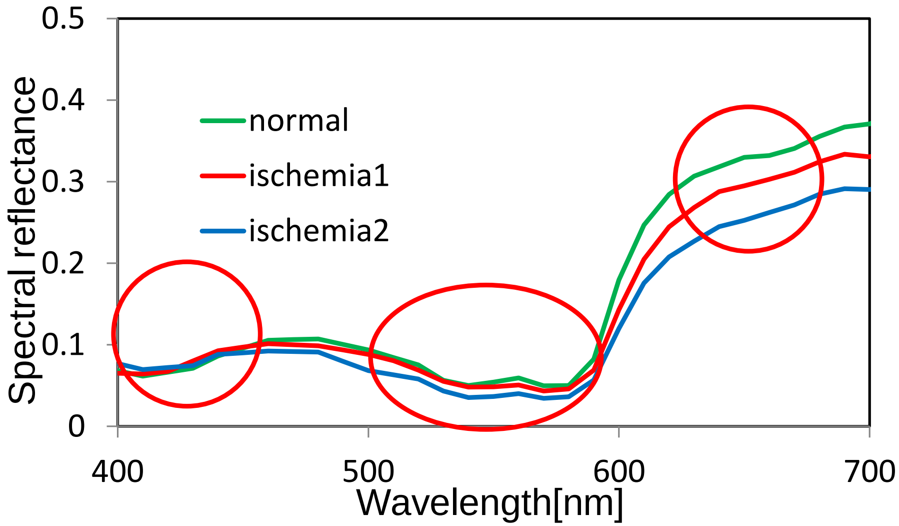
Selected 50 points of the small intestine

$$R(\lambda) = \frac{1}{50}\sum_{i=1}^{50}\frac{S_i(\lambda) - D(\lambda)}{S_{white}(\lambda) - D(\lambda)}$$

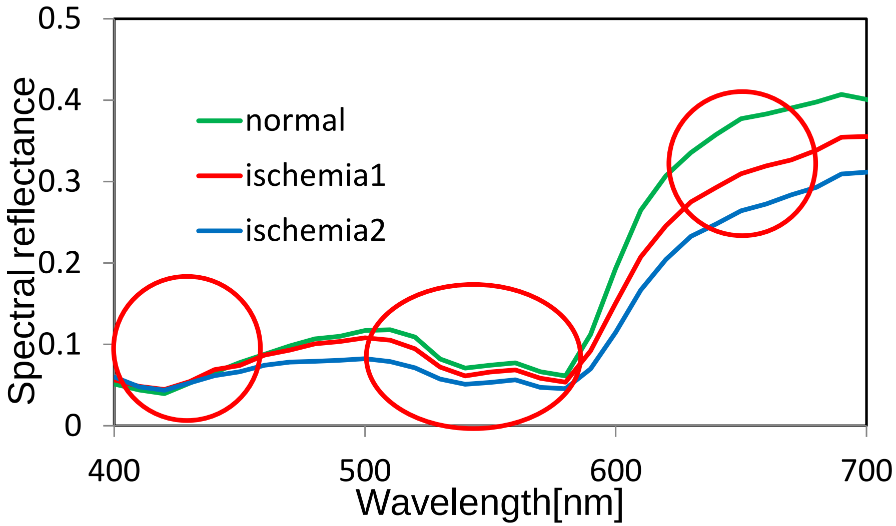
$S_{white}(\lambda)$: an average pixel value of the white board
$S_i(\lambda)$: a pixel value of the intestine of the ith point
$D(\lambda)$: the minimum pixel value in the image

Spectral reflectance

Subject 1



Subject 2



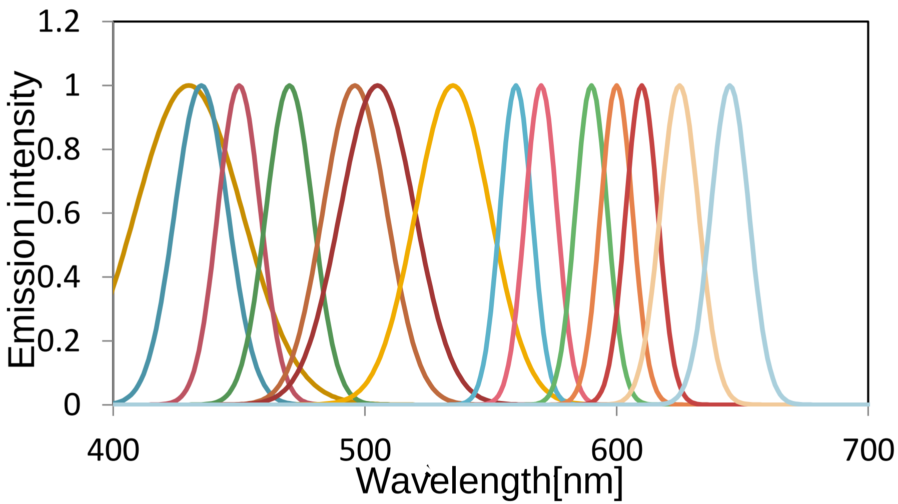
■ A change of the reflectance in long wavelength is larger than that in other wavelength.

Hypothetical LEDs

The spectral characteristics were modeled by Gaussian function.

Use the data of 14 LEDs manufactured by epitex.

430・435・450・470・496・505・535
560・570・590・600・610・625・645



The optimal illuminants were designed by using these data.

The optimal white illuminant

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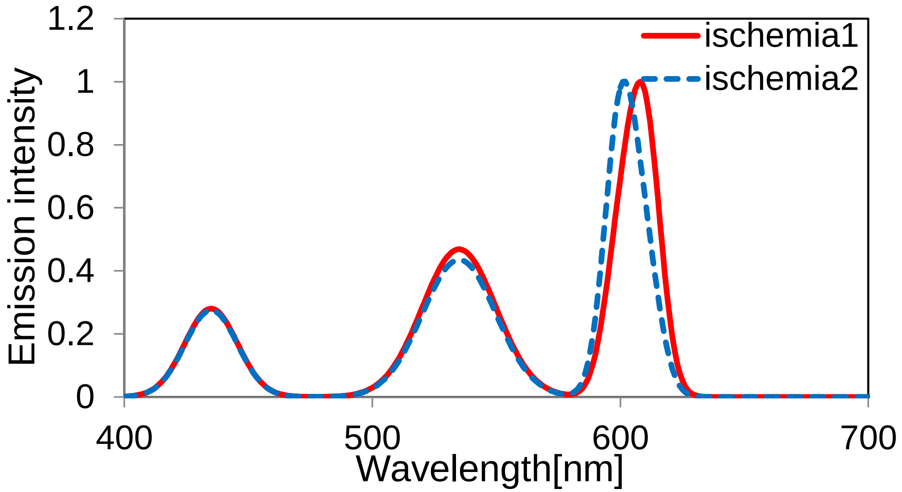
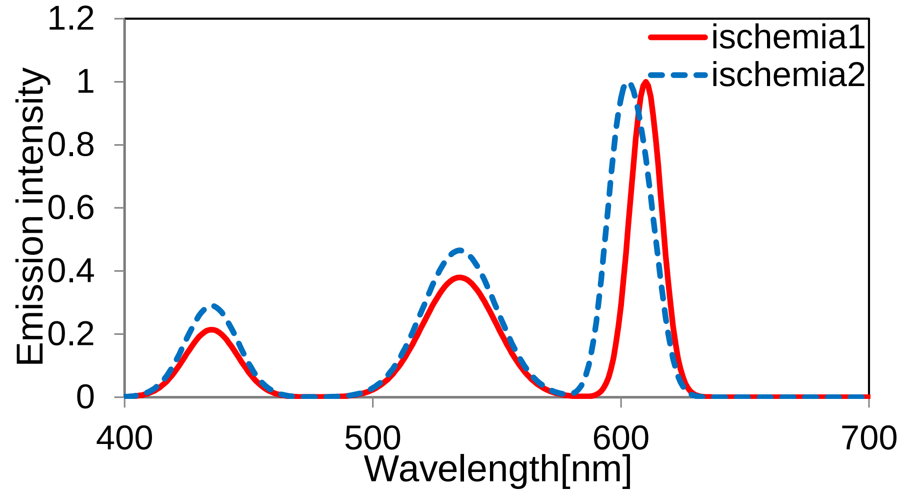
Subject 1



Subject 2



The intensity of the LEDs whose peak wavelength is in long wavelength region are greatest.

	Subject 1		Subject 2	
Condition \ illuminant	Optimal	Surgical	Optimal	Surgical
Ischemia1	8.1	5.1	9.3	7.1
Ischemia2	12.8	9.1	15.2	10.8

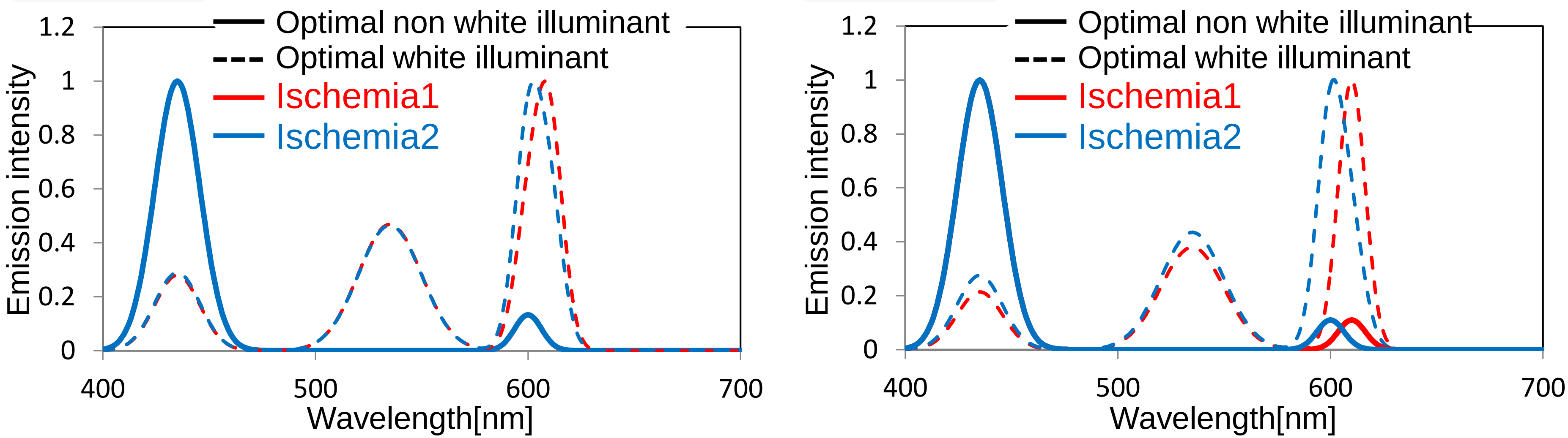
The whiteness has a value less than 0.01.

■ The color difference under the optimal illuminant has larger value than that under the conventional surgical illuminant.

The optimal non-white illuminant

Subject 1

Subject 2



The intensity of the LEDs whose peak wavelength is in small wavelength region are greatest.

	Subject 1			Subject 2		
illuminant / Condition	Non white	White	Surgical	Non white	White	Surgical
Ischemia1	14.8	8.1	5.1	14.8	9.3	7.1
Ischemia2	24.7	12.8	9.1	24.7	15.1	10.8

■ The color difference under the optimal non white illuminant is the largest among that under the optimal white illuminant and the surgical illuminant.

Conclusions

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Conclusions

- For the purpose of enhancing the color of the blood circulation, the optimal illuminants were designed by combining some kinds of LEDs.
- It was suggested through the simulation that the optimal illuminant can clarify the blood circulation better than the conventional surgical illuminant.
- The optimal non-white illuminant could enhance the color difference more.

Future works

- Prototyping those optimal illuminants with LEDs.
- Confirming the advantage of the optimal illuminants through a pre-clinical experiment.

Color of organ in surgery is very important

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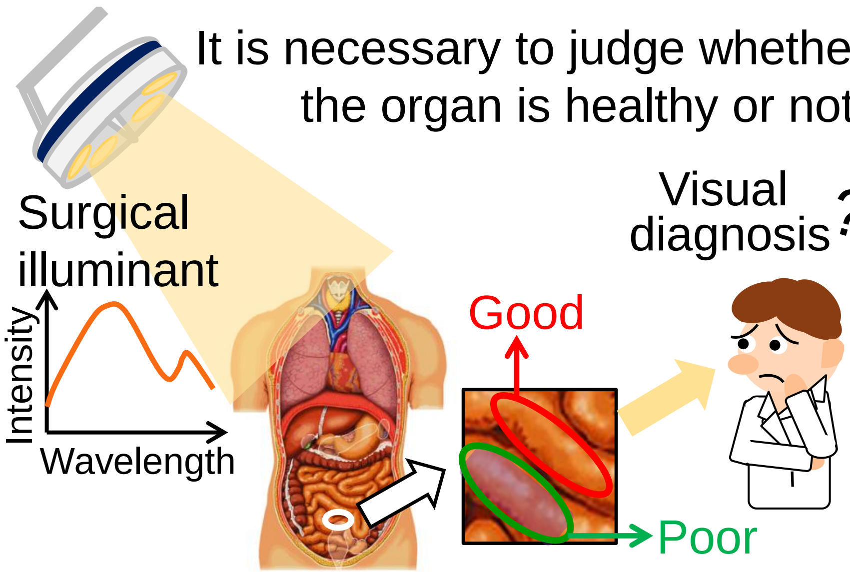
It is necessary to judge whether the organ is healthy or not.



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It is desired that a technology to assist surgeon's diagnosis is developed.

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Approach 2

Basic Study Toward Quantification of Circulation of the Organ Using Near-Infrared Spectral Image

Basic Study Toward Quantification of Circulation of the Organ Using Near-Infrared Spectral Image

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Hideaki Haneishi

Research Center for Frontier Medical Engineering

Objective

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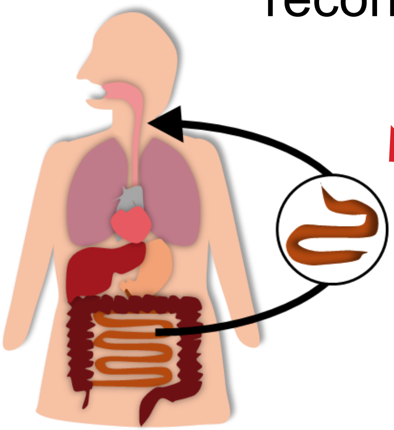
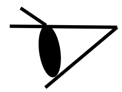
Background

Autotransplantation: Use healthy organ for the reconstruction of other parts of the body.



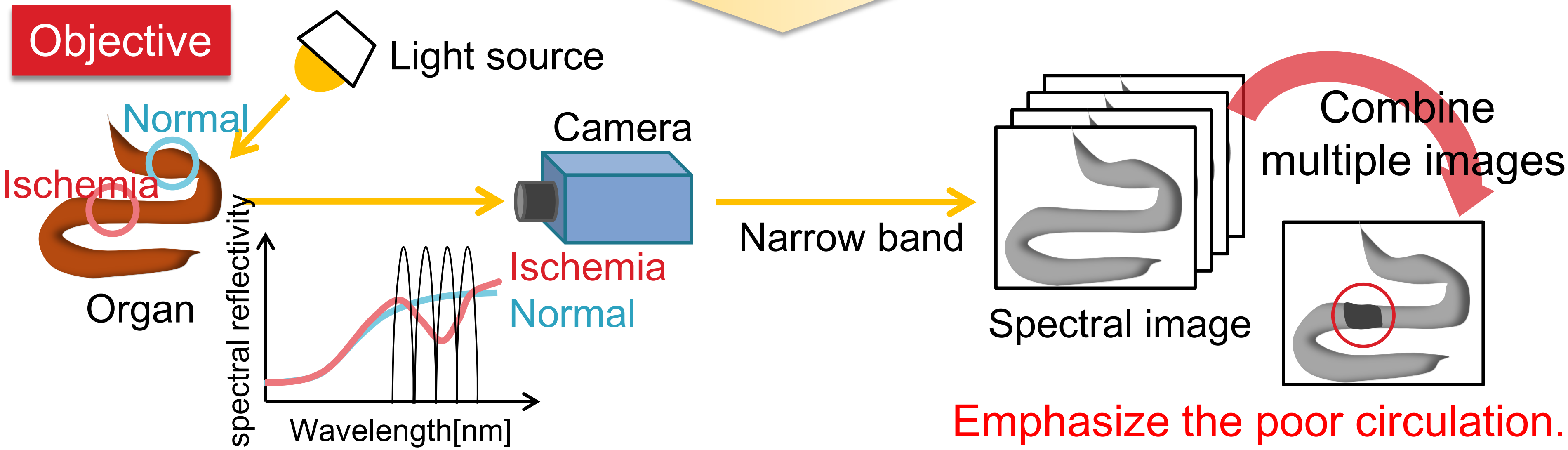
The evaluation of the state of blood circulation is required.



Visual confirmation of the color of the organ is very difficult.

Near-infrared spectral image

Objective



Emphasize the poor circulation.

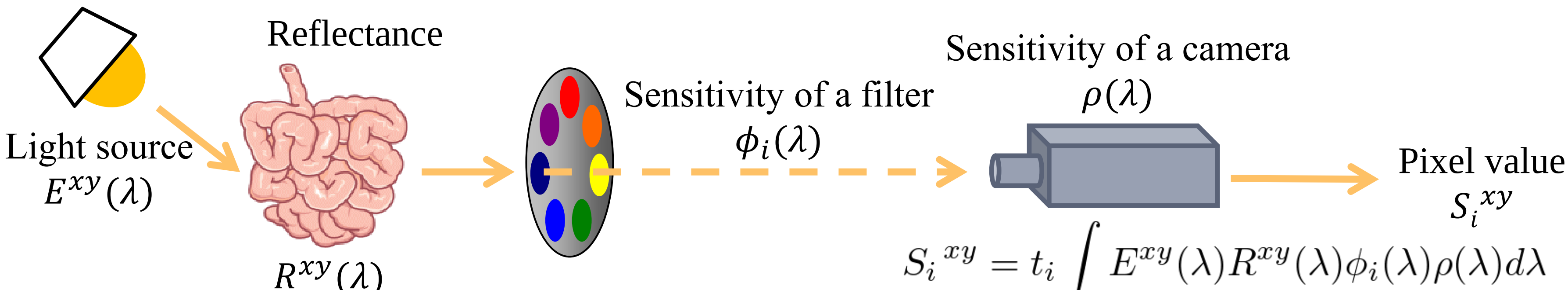
We aim to develop a method for quantitative analysis of circulation of the organ.

Spectral Information Collection

The reflectance spectra of internal organs were collected from pigs' small intestine.

■ Multispectral Image Capturing

A multispectral camera can acquire spectral images of the same number as filters.

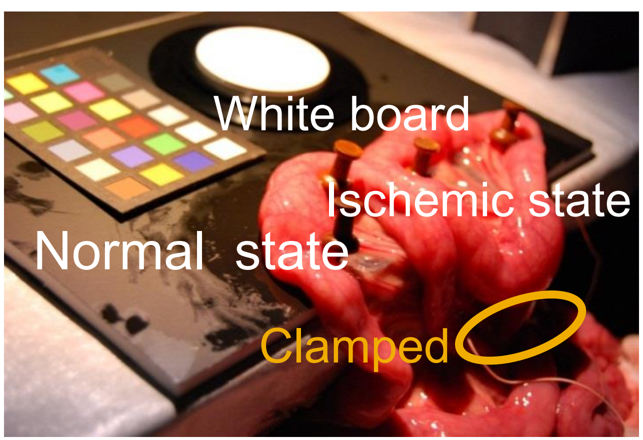


$$S_i^{\ xy} = t_i \int E^{xy}(\lambda) R^{xy}(\lambda) \phi_i(\lambda) \rho(\lambda) d\lambda$$

Filter : Varispec(CRi)

The spectral range of 720-1100nm and a spectral resolution of 10nm.

■ Experimental protocol



① The abdomen of a pig was opened and a part of a small intestine was fixed.

② The vessels supplying the blood were clamped and interrupted of blood flow to a part of a small intestine.

③ At 7 minutes after interruption of the blood flow, the images were captured. → ischemia1

④ At 13 minutes after interruption of the blood flow, the images were captured. → ischemia2

Evaluation of the Spectral Reflectance

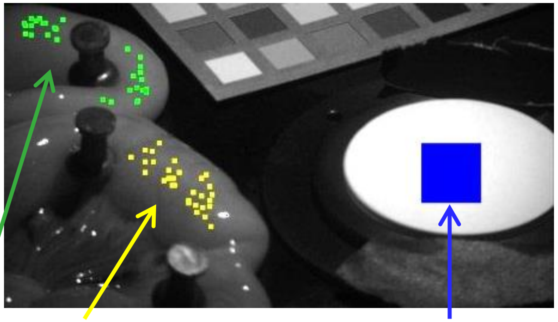
Spectral reflectance was calculated as the mean value of 30 points of the small intestine.

a pixel value of the small intestine

$$R(\lambda) = \frac{I_{\mathrm{raw}}(\lambda) - I_{\mathrm{dark}}(\lambda)}{I_{\mathrm{white}}(\lambda) - I_{\mathrm{dark}}(\lambda)}$$

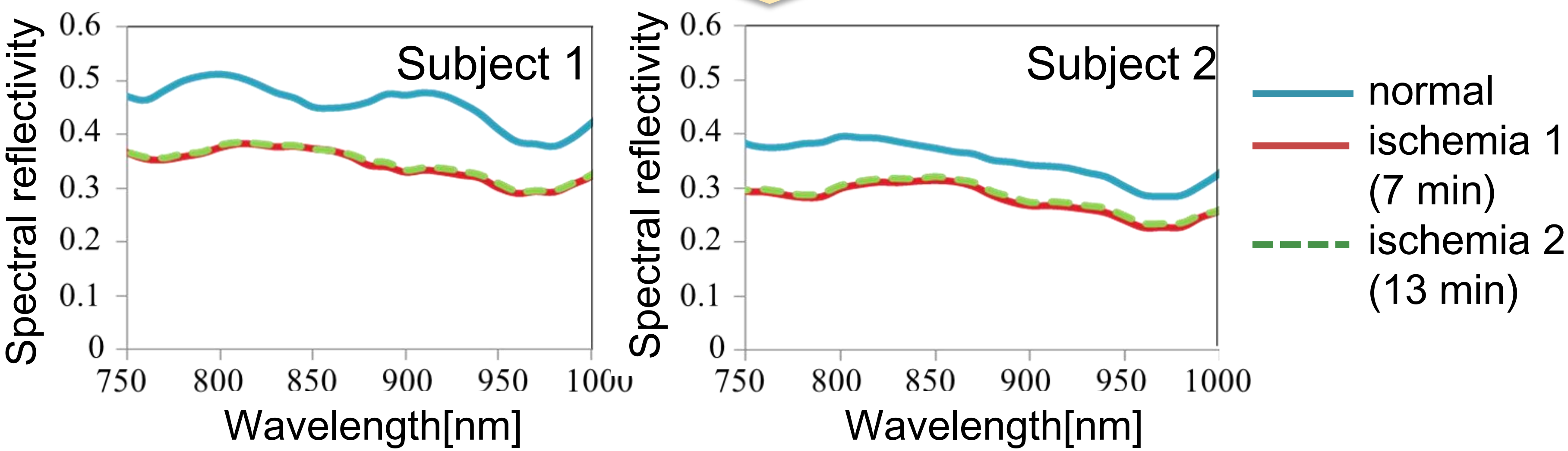
an average pixel value of diffuser

an average pixel value of dark current



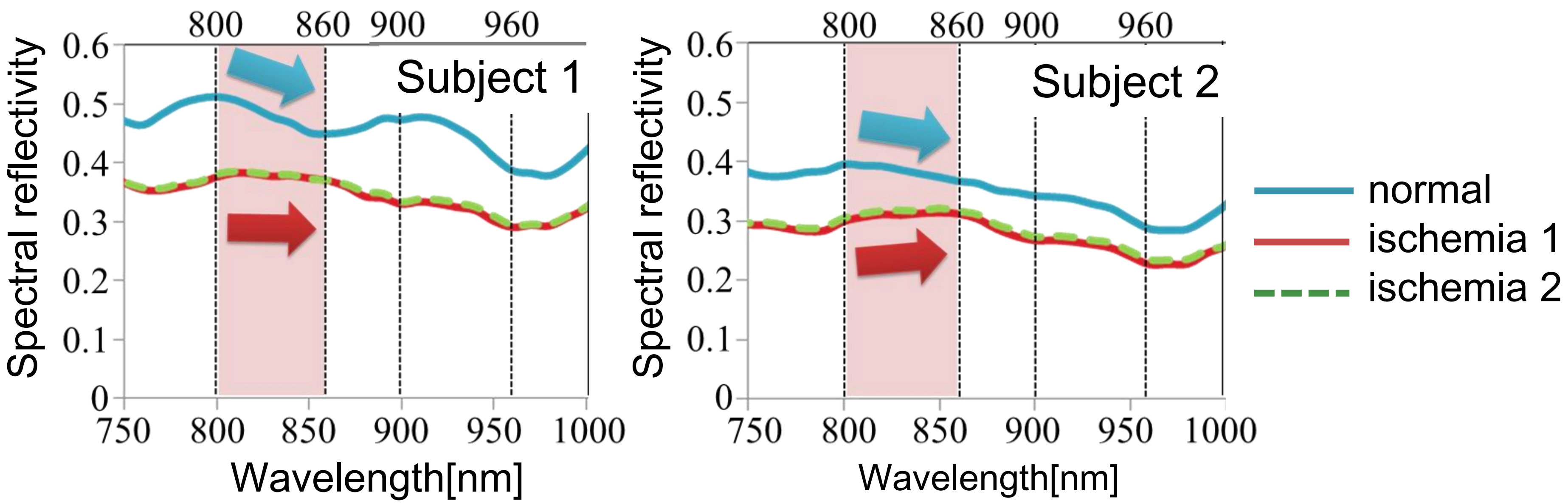
Selected points of the small intestine.

Selected region of white board.



Finding a Specific Wavelength Region

Find a characteristic wavelength range from the spectral reflectance data.

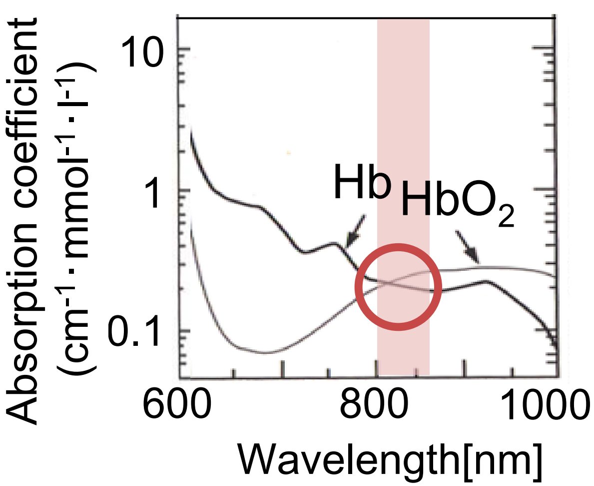


800 ~ 860nm

Common trend to both subject1 and subject2.

Corresponds to the absorption characteristics of hemoglobin.

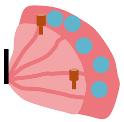
Evaluate the circulation of the organ using this wavelength region.



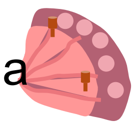
Method- Two steps of quantification -

Preparation step

normal



ischemia



Prepare a large number of data

Feature vector extraction

ischemia

normal

Calculate a reference vector

Evaluation step

The organ to be evaluated

Feature vector extraction

Use the reference vector and evaluate

Method

Step1 : Calculate a Reference Vector

Given 7-dimensional vector for each pixel

$$\mathbf{g}^{(k)} = [g_1, g_2, \cdots, g_7]^T$$

$$\mathbf{g}^{(k)\prime} = \frac{\mathbf{g}^{(k)} - \mathbf{m}^{(k)}}{\|\mathbf{g}^{(k)} - \mathbf{m}^{(k)}\|} \quad \left(\begin{array}{c} \mathbf{m} = [m, m, \cdots, m]^T \\ m: \text{the average value of } g_i (i=1\sim 7) \end{array} \right)$$

7 spectral images captured at 800, 810,…, 860nm

average of 30 vectors

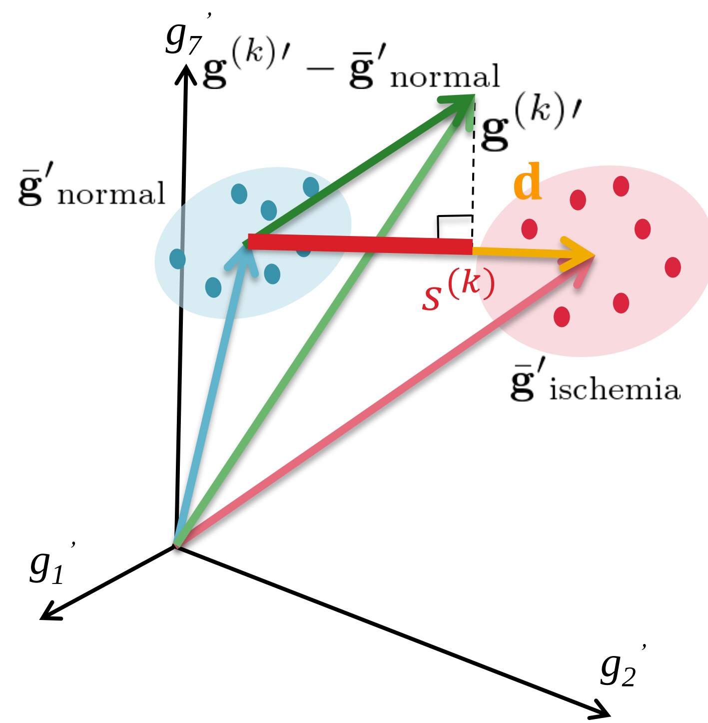
$$\bar{\mathbf{g}}'_{\text{normal}} \qquad \bar{\mathbf{g}}'_{\text{ischemia}}$$

Reference Vector $\mathbf{d} := \bar{\mathbf{g}}'_{\text{ischemia}} - \bar{\mathbf{g}}'_{\text{normal}}$

Step2 : Evaluate A Test Circulation

Project a vector of the pixel of interest $\mathbf{g}^{(k)\prime}$ to $\mathbf{d}$.

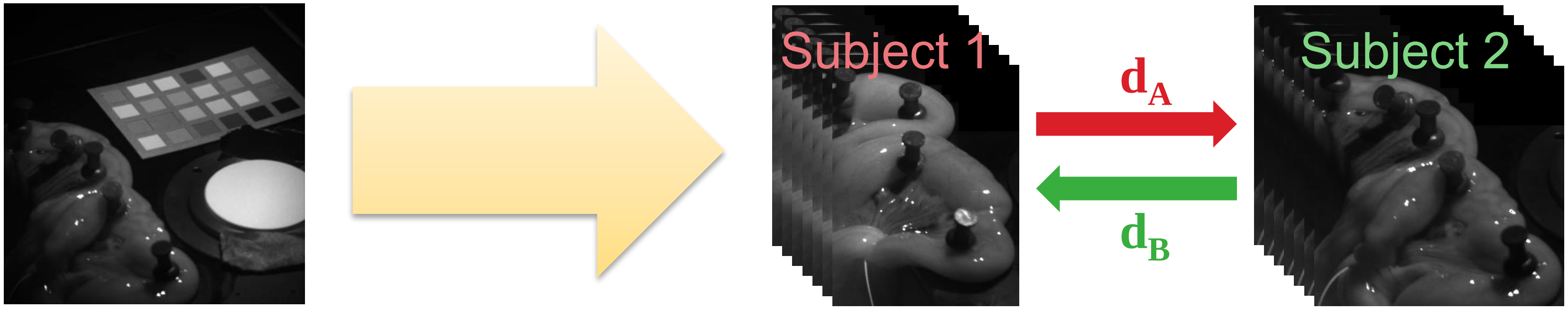
Estimated index s : $s^{(k)} := (\mathbf{g}^{(k)\prime} - \bar{\mathbf{g}}'_{\text{normal}}) \cdot \frac{\mathbf{d}}{\|\mathbf{d}\|}$



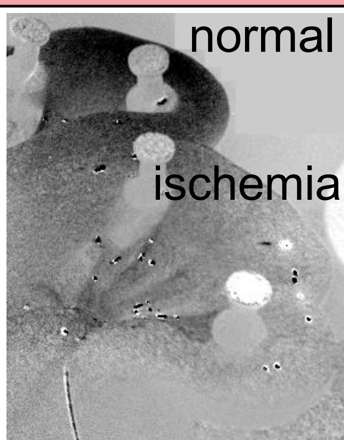
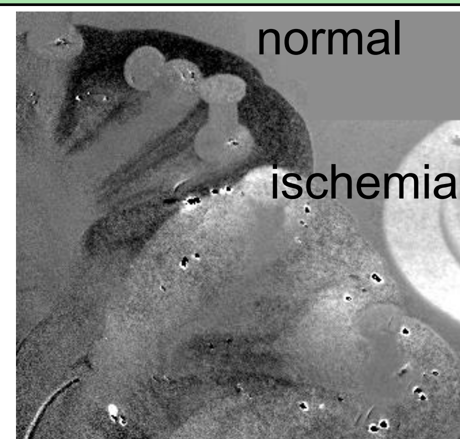
Estimated index s becomes larger as the organs become ischemic.

Verification

Image to use The reference vector calculated from the other data was used.



Results

Subject 1	Estimated index s	Subject 2	Estimated index s
	The average value of 10×10 [pixel] normal 0.81 ischemia 0.86		The average value of 10×10 [pixel] normal 0.66 ischemia 0.70

The circulation of the organ can be evaluated.

Conclusions

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Conclusions

The spectral reflectance in NIR region of pigs' small intestine were collected.

When the blood flow of the small intestine was worsened, optical characteristics of the wavelength range of 800 ~ 860nm changed.

The effectiveness of the proposed method was confirmed.

We can evaluate the circulation of the organ quantitatively by using the proposed method.

Future works

Increase the number of data that have different circulation state.

Provide a versatile reference vector **d**.

Link the estimated index *s* to the oxygen saturation.