Original Article

A proposal of imaging analysis method for accurate extraction of capillary areas using HSV model feature

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Abstract
Purpose of this study is to develop a method for accurate capillary area extraction from a captured image using RGB and HSV features. Experiments were conducted with eleven subjects. The proposed method utilizing OpenCV platform produced clearer capillary images compared to the original images: with capillary information, without capillary information, images with halation, images with black dots. SVM classification of capillary image with acquired numeric features of G, H, S and V values yielded over 90 % accuracy. The results have shown the effectiveness of the proposed method.

Key words
capillary area extraction, median filtering, mask processing, binary processing, SVM

1. Introduction

Blood vessel diseases such as cardio disease or brain vessel disease account for more than 20 % of death in Japan (Ministry of Health, Labour and Welfare, 2017). A contributing factor to these diseases is the status of micro circulation, especially those of capillaries (Nagayama et al., 2014). Micro circulation is an inner body mechanism in which blood circulation provides oxygen and other nutrients necessary for healthy functioning and reproduction of organism and tissues, and also exports metabolites and other body wastes from the organs and tissues (Tsuru and Kawasaki, 1999).

Capillaries are reported to be one of the contributing factors for blood circulation disorder caused by life-style disease. Specifically, first-stage of blood circulation disorder is caused by structural changes in capillaries. Capillary observation methods include lingual mucosa observation and endoscopy (Takeno, 2010). In this study, a device which can observe nail bed capillary is used. Nail bed capillary observation method has several advantages. It uses a simpler device which requires simplified operation compared to capillary microscope observation methods (Tsukimoto, 1988). Also, it does not require blood sampling, hence there is no necessity of any type of invasive operation. Thus, nail bed capillary observation is widely used for patients with collagen diseases, a type of autoimmune disorder which causes inflammation throughout the whole body, and scleroderma, an allergic dermal disease which thickens the patient's skin. However, nail bed observations are executed by visual inspection and time-series data comparison is not easy. Therefore, the systematic research has not be done in this field and development of quantitative evaluation methods are required (Takeno et al., 2015). In order to meet this challenge, there are many issues to be solved. One is the effective noise reduction from nail bed capillary images. The noises include information not related to capillary and halation, the spreading of light beyond its proper boundaries.

In this paper, OpenCV (Nagata, 2007; pythonJapan, n.d.) is used to extract capillary area. Specifically, numeric features of RGB (red, green and blue) values and HSV (hue, saturation and value) values are used. OpenCV offers wider applicability on various operating systems which enables a development of a diagnosis system operated by each individual without medical expertise. Python also has wider applicability and easier comprehensibility of its coding.

2. Existing studies

Predictive medicine is a field of medicine that person's bio-information is used to predict the probability of disease in order to prevent the disease or to decrease its negative impact on that person. It includes prenatal testing (Nicolaides et al., 2012), newborn screening (Bodamer et al., 2007) and genetic testing (Evans et al., 1997). In terms of scientific research, the first surge occurred in the late 1960s, when a journal on biomedical engineering titled Biomedical Sciences Instrumentation started to be published. The second surge occurred in 1990s when, thanks to the progress in gene analysis and international cooperation and competition, mapping of the human genome information was completed (Lander et al., 2001).

Although predictive medicine based on gene information is scientifically valid, it requires advanced devices and multi-stage examinations which result in high costs and longer period (EuroGentest, n.d.; U.S. National Library of Medicie, 2019). Also, the genetic testing arouses ethical controversies over its potential discriminatory implications. (Billings et al., 1992) actual clinical diagnosis is still small in number due to its cost and short history.

Compared to the gene based predictive medicine, those based on capillary image information requires much simpler device and it has long history of clinical cases leading to more accurate prediction (Ogawa, 1994). However, capillary based predictive medicine has several shortcomings: it requires diagnosis by professional medical practitioners. Also, noise contained in the capillary image could lead to inaccurate diagnosis. The development of high-power personal computers, the progress in digital image processing, and widening of the high-speed network are opening up the possibilities of disease prediction from capillary images even by non-professionals. The network allows remote consultation with medical professionals to evaluate self-diagnosis.

There are several studies to identify adequate variables to be used as reference standards for capillary health. Ogawa (1994) adopted following six variables as reference standards: length, thickness, the number, transverse line, murkiness and torsion. Healthy capillary is in regular shape; that is, it runs straight and makes U-turn in the end. It is neither too thick nor too thin. Following this study, Takeno (2010) identifies following five variables for the reference standard for capillary condition: the number of the capillaries (10 capillaries in 1 mm^2), thickness (existence of excessive thick capillaries), shape (existence of torsion and widening), murkiness (in extracellular fluid, unsharpening of capillary shapes), blood flow (existence of slow flow or granular flow). Based on these studies, Torii and Shibata (1997) have developed an automated remote disease diagnosis system by using capillary images. The system is composed of two parts: building a knowledge base linking diseases and capillary images, and diagnosing and inferring the disease from the capillary image.

Knowledge base is a database in which facts and experiences are compiled in a way a computer is able to process. To build the knowledge base, capillary images are registered by manpower through manual operation including clicking and visual checking the images. Edge extraction through high pass filter is applied to extract capillary image. And for feature extraction and noise reduction, the binarization and trimming into hollow shape are applied. Templated filtering is applied to the result for noise reduction and capillary image compensation. Since capillary image has color, distinct threshold is set for hue, saturation and lightness in order to extract color from capillary image. Lateral stripes generated by interlacing are removed by templated filtering. A template matching method was applied for diagnosing disease name. In the template matching, capillary image tilt, reference coordination and scale adjustment are important. Registering the degree of capillary image tilt was done by manpower. Reference coordination was decided by calculating vertical and horizontal information. Captured images were individually set for proper scaling. The results generated capillary images similar to the original images. However, body wastes and halation make capillary images less clear. Sharpening capillary images is necessary to improve the accuracy of image extraction.

Torii and Shibata (1997) have shown that in order to diagnose disease, sharper capillary images are essential for building knowledge base and for collating symptom with the knowledge base. Hence, noise reduction from capillary images are required. However, as mentioned above, capillary images contain murkiness due to body waste and noises such as halation, making knowledge base for image diagnosis difficult. In order to evaluate a health status of a person from capillary images, a method to effectively remove noises from the images is necessary. To sharpen a capillary image, Takeno et al. (2015) employ non-linear equations to process images of nail bed capillaries. Their study uses reaction-diffusion equations for sharpening capillary images. Reaction-diffusion equations are mathematical expressions to formulate changes of space density of certain substance which is subject to two conflicting processes of local chemical reaction and global diffusion. By using FtizHugh-Nagumo equation, a type of reaction-diffusion equations, areas close to capillaries are whitened and those far from are blackened. Pixel data in capillary images are quantified to which the non-linear equation is applied in order to generate a sharper image. The process allows digitization of capillary images. The correlation coefficients between length, thickness, number, transverse line and murkiness, in Ogawa's study (1994) and those obtained by the equation exceed 0.7. However, noise reduction by reaction-diffusion equations have erased thickness of capillaries, one of the features necessary for decease detection. Katsuki and Shibata (2018) develop new filters and by combining them with standard filters and other image processing in order to generate a sharper capillary image. Specifically, they develop original filter 1 which is focused to retain thickness and shape of the capillary, and filter 2 which is focused to reduce noise. They combine other standard image processing method of binary processing, smoothing, color extraction, contracting and expanding, and mask processing. However, some capillary information is mistakenly removed and some halation are not removed from the image.

In this paper, we focused on the feature value of the pixel, examined the value of each RGB and HSV and set it as the threshold value of the mask processing for capillary extraction.

3. Methods

3.1 Experimental overview

Eleven male university students participated in the experiments. They were all in the early 20s and in healthy condition without circulatory diseases. Before participating, they were given written explanation regarding all pertinent information as follows:

- Purpose of the research
- Research implementing entity
- Principal investigator
- No need for stress induction or pain in the experiment
- Data storage and privacy protection
- No disadvantageous treatment to non-participant

After explanation, they were offered to ask questions. The participants voluntarily gave consent in writing. Experiments were conducted in December 2018. For each subject, blood pressure and body temperature were measured every day before the experiment. At the same thiem, their health conditions were assessed orally. The subject sat for five minutes to relax and the measure measurement was conducted for three minutes. A capillary observation device VA201-H (Figure 1, Manufacturer: Toko Co., Ltd.) was used for capturing capillary moving image of the subjects who retained seated position.

Figure 1: Capillary observation device

The capillary area extraction method using numeric features was applied to the captured images to extract clearer capillary images. The image processing program was developed on open source platform including OpenCV and python. Based on the numeric features of each value in RGB and HSV acquired through the preceding experiments, a new classification model has been developed using SVM.

3.2 Image capturing

The third finger of non-dominant arm of the subjects participating in the experiments is employed as a target of the study for its relatively thin skin which allows better observation of capillaries. (1) Moving images of nail bed capillary are recorded in order to avoid potential camera shake, (2) Still images ideal for image processing are captured. (3) Permeable liquid is applied to the target finger since the liquid suppresses light reflection, allowing better capturing of capillaries features.

3.3 Proposed methods

Capillary images are expected to predict various diseases. However capillary observations are mainly evaluated by personal experiences and feelings of experts and quantitative evaluations are rarely conducted. Technical challenges of capillary image evaluation are how to reduce noises such as black dots and halation.

The study aims to extract capillary features by removing noises from nail bed capillary images. For that purpose, features of pixels with capillary information are investigated to identify best threshold to distinguish pixels with capillary information from those without. In the first step, pixels with capillary information and those without are extracted separately to investigate threshold value for RGB values and HSV values. From the steps 1 to 3 described below, pixel values are extracted and tested with 5 % significance level. The test results showed statistically significant difference. Mask processing are applied to B, H, S and V values of nail bed images for 11 subjects. As a final step, the binary processing is applied which generates a sharper capillary image. The steps applied are as follows:

3.3.1 Capillary area extraction method

- As a preprocessing, median filtering is applied to an original image.
- For pixels with capillary information, without capillary information and with noises (halation and black dots), 20 areas are clicked to obtain coordinate value.
- From the coordinate value, RGB and HSV values of the coordinated areas are obtained.
- Mask process stages A and B are applied using B, H, S and V values obtained in step 3. When the results of the mask processing are not unanimous for B, H, S, and V values, majority rule is applied. When the results are divided evenly between with and without capillary information, the results by B, H and V values make the final decision.
- Binary processing is applied to generate a monochrome image.

Median filtering is a non-linear filtering process in which all the pixel values adjacent to the focus pixel are sorted and resulting mean value is selected for the value of the focus pixel (Koeda, Ueda, & Nakamura, 2014). This filtering is robust against outliers, leading to extensive applications in image smoothing. Removing outliers from capillary images can be effective in noise reduction without removing pixels with capillary information. Figure 2 shows a median filtering with 3 by 3 matrix.

Mask processing is a process to extract necessary area (in this study, areas with capillary information) by removing un-

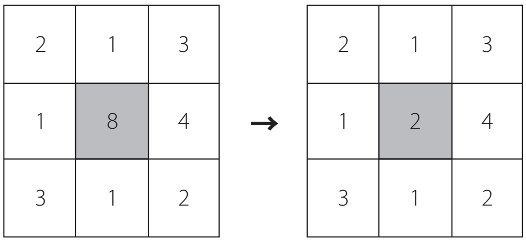

Figure 2: An example of median filtering

necessary noise areas. First, a mask image is generated with white areas for extraction and black areas for removal. Then, a new image is synthesized by combining the mask image and the original image. The mask processing is used in chroma-key composition in which a certain color is set to be transparent so that necessary area is extracted from an image and the extracted images are composed to generate a new image (Koeda et al., 2014). In this study, mask processing is applied to extract area with capillary information by setting certain ranges of RGB values and HSV values as white areas. Binary processing transforms an image into a monochrome image. One threshold is set against which the value of the focus pixel is compared. When the value is lower than the threshold, the pixel is transformed into a black dot; when the value is higher than the threshold, it is transformed into white dot. In some cases, two thresholds are set and pixels with values between the two thresholds are transformed into white pixels (Computer Graphic Arts Society, 2015). Binary processing is applied to extract focus area from an image and to generate a mask to remove unnecessary information. Thresholding methods include fixed threshold in which universal threshold is applied to every pixel in an image and adaptive thresholding in which unique threshold is set for each pixel. In this study, the former method is applied to clearly identify the location of capillary from extracted pixels. Mask processing Stage A is a stage in which masking process is applied by using maximum values of B, H and V for thresholding (maximum value thresholding method). Mask processing Stage B is a stage in which masking process is applied by using minimum value of S for thresholding (minimum value thresholding method).

3.3.2 SVM classification

Based on the numeric features acquired through the preceding experiments, a new classification model has been developed. Specifically, B, H, V and S acquired through proposed mask processing stages A and B were used as learning data for the model using SVM. Scikit-learn machine learning library on python was used for developing and evaluating the model.

4. Results

4.1 Area extraction with numeric features

Table 1 shows RGB and HSV values for pixels with capillary

Table 1: Pixels with capillary for subject E

Pixel No.	Values					
	R	G	B	H	S	V
1	212	172	164	5	58	212
2	207	169	160	6	58	207
3	220	181	176	3	51	220
4	235	190	185	3	54	235
5	227	184	177	4	56	227
6	229	178	175	2	60	229
7	228	183	180	2	54	228
8	231	197	187	7	49	231
9	233	199	187	8	50	233
10	233	182	178	2	60	233
11	232	205	194	9	42	232
12	239	206	197	6	45	239
13	233	205	191	10	46	233
14	227	190	181	6	52	227
15	239	216	200	12	42	239
16	238	208	197	8	44	238
17	221	181	173	5	55	221
18	233	190	183	4	55	233
19	227	171	170	1	64	227
20	233	200	193	5	44	233

Table 2: Pixels without capillary for subject E

Pixel No.	Values					
	R	G	B	H	S	V
1	232	221	203	19	32	232
2	230	222	203	21	30	230
3	232	224	203	22	32	232
4	236	229	211	22	27	236
5	226	211	192	17	38	226
6	230	215	196	17	38	230
7	233	222	202	19	34	233
8	230	219	201	19	32	230
9	228	217	199	19	32	228
10	207	192	173	17	42	207
11	221	200	183	13	44	221
12	236	219	203	15	36	236
13	241	219	205	12	38	241
14	240	223	205	15	37	240
15	237	226	206	19	33	237
16	235	214	197	13	41	235
17	242	227	208	17	36	242
18	246	223	207	12	40	246
19	240	217	203	11	39	240
20	235	213	199	12	39	235

information for subject E. The subject images yielded the clearest contours of capillaries. Table 2 shows six color values (R, G, B, H, S, and V) for pixels without capillary information for the same subject.

For each subject, following 6 value-pairs are calculated:

- R values for pixels with capillary information and those without capillary information.
- G values for pixels with capillary information and those without capillary information.
- B values for pixels with capillary information and those without capillary information.
- H values for pixels with capillary information and those without capillary information.
- S values for pixels with capillary information and those without capillary information.
- V values for pixels with capillary information and those without capillary information.

Average values and standard deviations are calculated for each value. Paired t-test was conducted to confirm the value's effectiveness as mask processing threshold. For significance test, two-sided testing with significance level of 5 % was conducted.

Figures 3 and 4 respectively show B values and S values of each subject. Average values are shown in bar graph with error bars for standard deviation. An asterisk is marked on a subject with significant difference. Bar graphs for average values and error bars for standard deviations on halation and black points regarding S value are respectively shown in Figures 5 and 6. Figure 3 shows maximum B values are larger for pixels without capillary information than those with capillary information. Significant tests reveal all the subjects show significant difference. Similar tendencies were observed for H and V value, validating the effectiveness of proposed mask processing stage A. Figure 4 shows minimum S values are smaller for pixels without capillary information than those with capillary information. Paired t-tests reveal all the subjects show significant difference validating the effectiveness of proposed mask processing stage B. Figure 5 shows average B values of pixels with halation are centered around 250 and their standard deviation is small. From this numbers, average B values of pixels with halation can be inferred to be larger than those with capillary information. The figure also shows average B values of pixels with black dots are centered around 100 and their standard deviation is small. From

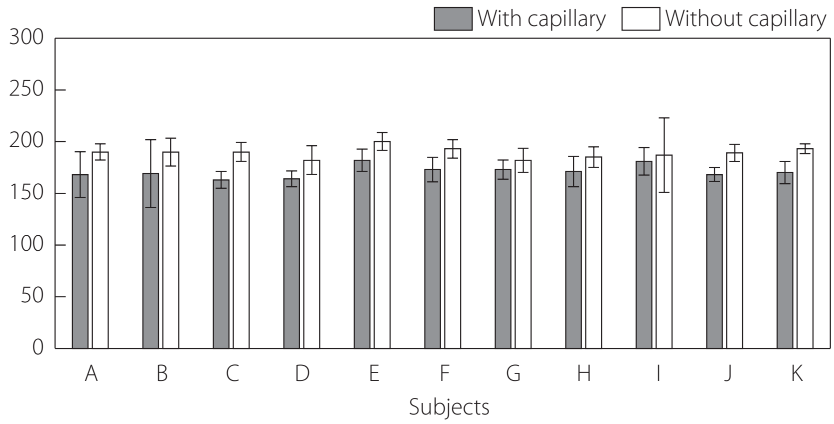

Figure 3: B values (average and standard deviation) of each subject

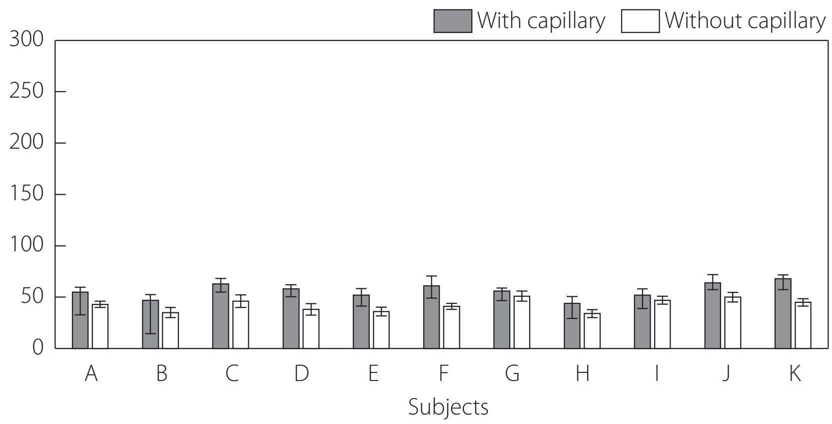

Figure 4: S values (average and standard deviation) of each subject

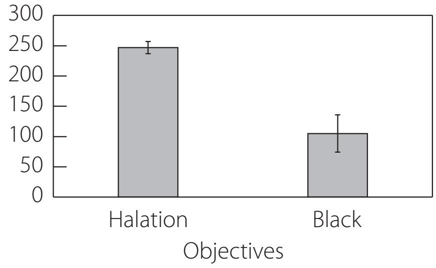

Figure 5: B values (average and standard deviation) of halation and black dots

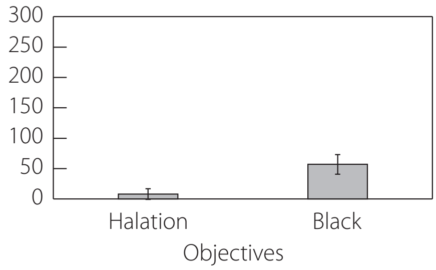

Figure 6: S values (average and standard deviation) of halation and black dots

this numbers, average B values of pixels with black dots can be inferred to be smaller than those with capillary information. Therefore, these values can be utilized as thresholds for detecting pixels with halation or black dots. Figure 6 shows average S values of pixels with halation and their standard deviation are small. From this, average S values of pixels with halation can be inferred to be smaller than the minimum S value of pixels with capillary information. Regarding pixels with black dots, their average values are similar to those with capillary information and the standard deviation is large.

Regarding proper thresholding, using maximum values of B, H, and V and minimum value of S were effective for noise removal. The former thresholding was used for mask processing A and the latter was used for mask processing B. Figure 8 shows the result of mask processing applied to Figure 7,

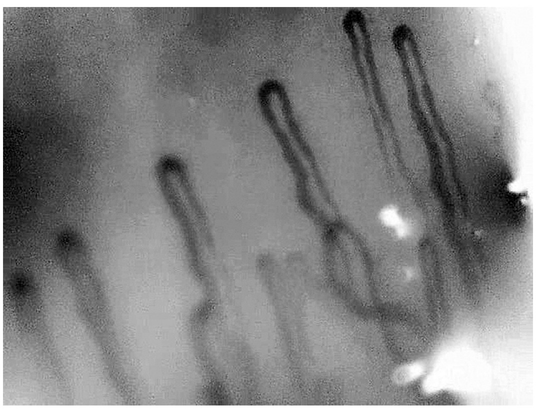

Figure 7: Capillary image of subject E

Figure 8: The result of mask processing stage A

Figure 9: The result of mask processing stage B

which depicted nail bed capillary of subject E. Figure 9 shows the result of mask processing applied to Figure 7.

From Figures 8 and 9, the masking processes were successful in removing halation in the right area originally appeared in Figure 7. However, Figure 9 shows pixels not related to capillary were extracted even after mask processing stage B.

4.2 Classification with SVM

The result is summarized in Table 3, which shows high accuracy rate of more than 90 %. The kernel used for the experiment is linear kernel. Hyperparameter tuning was not applied and default hyperparameters are used.

Table 3: The result of cross validation

Validation method	Accuracy (BHSV values)
k-class cross validation (k = 11)	90.23 %
Leave-One-Out cross validation	93.35 %

5. Conclusions and future directions

The aim of this study was to extract area with capillary information from nail bed capillary images by removing noises including halation and murkiness. Moving images were recorded by nail bed capillary observation device VA-201H. Still images with clearer capillary information were captured from the recorded images. OpenCV, Spyder and Python were used for making codes for extraction. The subjects were 11 university students with no circulatory diseases. The captured images from the subjects were classified into 4 categories: images with capillary information, without capillary information, images with halation, images with black dots. RGB value and HSV value for each category were obtained to identify features which could distinguish among different categories (Figures 3-6). Following results were obtained from the experiments:

Between images with capillary information and those without capillary information, B values and HSV values were significantly different.

In this paper, the following methods were used as a method to extract area with capillary information.

- A combination of HSV conversion
- Median filter
- Mask processing stage A and B
- Binary processing

HSV conversion allowed ordinally color images with three color elements of RGB to be transformed into those with 6 elements by adding HSV information. By applying median filtering, capillary contours could be reproduced in smooth shape similar to real capillary. Preliminary experiments indicated B value of RGB and HSV values showed significant difference among capillary images categorized into 4. Mask processing using these values was applied to extract areas adjacent to capillary. Binary processing was applied to visualize the accuracy of classification. As a result, by applying the proposed method, removal of halation and extraction of capillary images were successfully achieved. However, there remains some issues to be solved. The first issue is that even with this method, areas not related to capillary are extracted. Binary processing using linear kernel in SVM with parameters of B value and HSV value to binary classification of images with capillary information and those without capillary information showed higher than 90% accuracy.

For future research, more accurate recognition of capillary should be explored. To achieve the recognition improvement, removing pixels in certain areas not related to capillary in preprocessing phase and identifying novel indicators for distinguishing pixels with capillary information from those without capillary information would be good start.

References

Billings, P. R., Kohn, M. A., de Cuevas, M., Beckwith, J., Alper, J. S., and Natowicz, M. R. (1992). Discrimination as a consequence of genetic testing. *American Journal of Human Genetics*, Vol. 50, No. 3, 476-482.

Bodamer, O. A., Hoffmann, G. F., and Lindner, M. (2007). Expanded newborn screening in Europe 2007. *Journal of Inherited Metabolic Disease*, Vol. 30, No. 4, 439-444.

Computer Graphic Arts Society (2015). *Digital image processing* (revised edition). Computer Graphic Arts Society.

EuroGentest (n.d.). What happens in a genetic laboratory? Retrieved December 9, 2019, from http://www.eurogentest.org/index.php?id=621.

Evans, D. G., Maher, E. R., Macleod, R., Davies, D. R., and Craufurd, D. (1997). Uptake of genetic testing for cancer predisposition. *Journal of Medical Genetics*, Vol. 34, No. 9, 746-748.

International Human Genome Sequencing Consortium (2001). Initial sequencing and analysis of the human genome. *Nature*, Vol. 409, 860-921.

Katsuki, D. and Shibata, S. (2018). A Study of filtering method for capillary image processing using OpenCV. *Proceedings of the 2018 IEICE General Conference*, 222.

Koeda, M., Ueda, E., and Nakamura, T. (2014). *Introduction to image processing with OpenCV*. Kodansha.

Ministry of Health, Labour and Welfare (2017). Vital statistics of fiscal year 2016. Retrieved December 1, 2019, from https://www.mhlw.go.jp/toukei/saikin/hw/jinkou/kakutei16/index.html.

Nagata, M. (2007). OpenCV: Moving images processing library. *Journal of the Institute of Image Information and Television Engineers*, Vol.61, No.11, 1602–1605.

Nagayama, K., Miura, I., and Kawagoe, K. (2014). Evaluation of blood vessel state from nailfold micro-capillary image (Research Paper, The 38th Symposium on Life Information Science). *Journal of International Society of Life Information Science*, Vol. 32, No. 2, 199-204.

Nicolaides, K. H., Syngelaki, A., Ashoor, G., Birdir, C., and Touzet, G. (2012). Noninvasive prenatal testing for fetal trisomies in a routinely screened first-trimester population. *American Journal of Obstetrics and Gynecology*, Vol. 207, No. 5, 374.e1-374.e6.

Ogawa, S. (1994). *Capillary images and medical practice*. Toriumi Publishing.

pythonJapan (n.d.). *Python*. Retrieved from https://www.python.jp/.

U.S. National Library of Medicine (2019). Genetic Testing, U.S. National Library of Medicine.

Takeno, D. (2010). Capillary microscopic observations of the nailfold microvessels. *Journal of Clinical Laboratory Medicine*, Vol. 54, No. 8, 919-922.

Takeno, D., Nakane, K., Mahara, H., and Miura, I. (2015). Development of a method for quantifying non-invasive nail bed capillary images with non-linear equations. *The Journal of Japan Mibyo System Association*, Vol. 21, No. 2, 98-102.

Torii, H. and Shibata, Y. (1997). Remote automatic decision making of deseases recognition from vessel images. *IPSJ SIG Technical Reports*, Vol. 80, 157-162.

Tsukimoto, A. (1988). A study of nailfold capillary abnormal-

ity patterns in connective tissue diseases. *Journal of Tokyo Women's Medical University*, Vol. 58, No. 6, 473-482.
Tsuru, H. and Kawasaki, H. (1999). Microcirculation. *Folia Pharmacologica Japonica*, Vol. 113, No. 4, 201-202.

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