

On Measurement System for Frequency of Uterine Peristalsis

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SUMMARY The frequency of uterine peristalsis is closely related to the success rate of pregnancy. An ultrasonic imaging is almost always employed for the measure of the frequency. The physician subjectively evaluates the frequency from the ultrasound image by the naked eyes. This paper aims to measure the frequency of uterine peristalsis from the ultrasound image. The ultrasound image consists of relative amounts in the brightness, and the contour of the uterine is not clear. It was not possible to measure the frequency by using the inter-frame difference and optical flow, which are the representative methods of motion detection, since uterine peristaltic movement is too small to apply them. This paper proposes a measurement method of the frequency of the uterine peristalsis from the ultrasound image in the implantation phase. First, traces of uterine peristalsis are semi-automatically done from the images with location-axis and time-axis. Second, frequency analysis of the uterine peristalsis is done by Fourier transform for 3 minutes. As a result, the frequency of uterine peristalsis was known as the frequency with the dominant frequency ingredient with maximum value among the frequency spectrums. Thereby, we evaluate the number of the frequency of uterine peristalsis quantitatively from the ultrasound image. Finally, the success rate of pregnancy is calculated from the frequency based on Fuzzy logic. This enabled us to evaluate the success rate of pregnancy by measuring the uterine peristalsis from the ultrasound image.

Key words: *ultrasound images, female infertility, frequency of uterine peristalsis, Fourier transform, Fuzzy logic*

1. Introduction

The number of infertility treatments is increasing year by year due to late marriage and late birth [1]. The demand for infertility treatment is also increasing. Infertility treatment is broadly divided into general infertility treatment and assisted reproductive technology (ART). A general infertility treatment is firstly performed. ART is considered as the next candidate when the general infertility treatment does not result in successful pregnancy, or the fertility symptoms are severe. ART is costly for the patients because it is not covered by the public insurance in Japan. Further, ART does not

guarantee pregnancy by one treatment, and it is sometimes necessary to repeat itself. As a result, the physical and financial burden on infertility patients becomes large. Some patients cannot choose ART by the economic reasons. Therefore, it is strongly required to improve the success rate of infertility treatment. The Office on Women's Health Trusted Source reported that about one-third of infertility cases can be attributed to female infertility while men's problems account for another third of infertility cases [2].

In female infertility cases, Embryo implantation is the primary factor with the limitation on ART. The uterine has movements called uterine peristalsis. The direction and the frequency of uterine peristalsis changes according to the phase of the menstrual cycle [3], [4]. The upward movement (from corpus to fundus) occurs in the ovulation phase to assist in sperm transport, and the downward movement (from fundus to corpus) occurs in the menstrual phase to assist in drain menstrual blood. In contrast, there are no movements in the implantation phase to wait for the fertilized egg. However, in fact, uterine peristalsis may actually occur in the implantation phase. The ultrasound examination [4]–[7] of the uterus has permitted the non-invasive identification and characterization of uterine contractile activity under physiological condition. Currently, the frequency of uterine peristalsis is evaluated by the number of times per minute on the ultrasound imagery. It is known a strong relationship between the frequency of uterine peristalsis in the implantation phase and the pregnancy rate. Moreover, it has been reported that the high frequency of uterine peristalsis implies the lower pregnancy rate [8]–[11]. In most cases, the frequency of uterus peristalsis is evaluated by visual analysis by the naked eye of the physician based on his/her experience. There is no clear criterion for measuring the frequency of uterus peristalsis. The frequency of uterus peristalsis in the embryo implantation greatly affects the pregnancy rate, thus the subjective evaluation is undesirable. Table 1 shows the relationship between the frequency of uterine peristalsis per minute in the implantation phase and pregnancy rate. This table shows that when the frequency of uterine peristalsis is more than 3.0, the pregnancy rate drops significantly. The uterus may not be clearly displayed on the ultrasound image due to individual differences. Therefore, it is necessary to reproduce the expertness of physicians on a computer. R. Fanchin et al. made 2-D spatio-temporal images with the vertical and time axis at intervals of 2 frames per second from the obtained ultrasound images of the uterine.

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Table 1 Pregnancy rate by frequency of uterus peristalsis [11].

No. of the frequency of uterine peristalsis / min				
≤ 1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.0 <
58.97 %	63.55 %	48.71 %	6.25 %	0.00 %

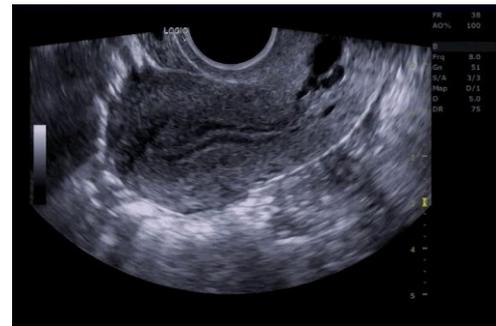
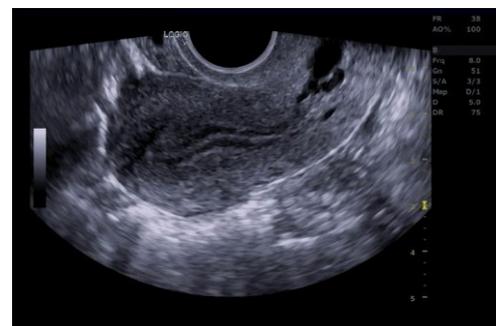
The frequency of uterus peristalsis was determined from the time-dependent variation of the interface between the myometrium and the endometrium in the 2-D spatio-temporal image [8]–[10]. L. Zhu et al. measured the frequency of uterus peristalsis from the average of the results of two observers analyzing the ultrasound image of uterus peristalsis for 5 minutes at 4 times speed [11]. D. Meirzon et al. proposed an automated evaluation method by frequency analysis as a computer-aided diagnosis system [12]. However, it is difficult to apply it to the images without strong contrasts between the Region of Interests (ROI) and the uterus.

This paper proposes a method to semi-automatically measure the frequency of uterus peristalsis from ultrasound images. This original version has published [13]. In it, uterine peristalsis was analyzed by Fourier transform for 3 minutes. The frequency of uterine peristalsis was determined as the frequency with the dominant frequency ingredient with maximum value among the frequency spectrums. In this paper, we proposed a method to calculate a fuzzy degree whether uterine peristalsis is the cause of female infertility using fuzzy membership function [14]–[16]. This method makes it possible to quantitatively and objectively evaluate the frequency of uterus peristalsis in the implantation phase for the images without the clear contrast. This method provides the number of frequency of uterus peristalsis, and it enables us to decide the appropriate period of the implantation. This result would reduce the burden on the physician who evaluates the uterine in the implantation phase. This paper is organized as follows. Section 2 describes the materials used here and the proposed method. Section 3 shows the experimental results. Section 4 concludes our technical results.

2. Materials and Method

2.1 Preliminaries

In general, methods such as inter-frame difference, background difference, and optical flow are often used for moving object detection and grayscale tracking in video. However, it is not easy to detect moving objects by the difference between frames in the ultrasound images used in this study. Figure 1 shows the ultrasound images of the uterus used in this study. Figure 1 shows that the temporal change of the motion is not clear and the change of the brightness value is severe. Moreover, the contour of the ultrasound image is not clear. For these reasons, it was not possible to measure the peristaltic movement frequency from the ultrasound image of the uterus by using the inter-frame difference and optical flow, which are the representative methods of motion detec-

(a) $t = 0$ sec(b) $t = 1$ sec(c) $t = 2$ sec**Fig. 1** Time change of ultrasound image of uterus

tion.

In this study, the ultrasound image of sagittal plane of the uterine in the implantation phase taken in Reproduction Clinic Osaka are employed. The ultrasound image has a $720\text{px} \times 480\text{px}$ grayscale MPEG file acquired at a rate of 30 fps by General Electric (GE) Logic 5 system. Figure 2 shows an example of the ultrasound image of the uterine. The area surrounded by the white line in Fig. 2 is the ROI.

2.2 Method

Figure 3 shows a flowchart of the analysis method. We explain our proposed method according to Fig. 3.

1. Trimming

Grayscale images are acquired from the movie file, the ROI and its surroundings are trimmed manually as shown in Fig. 4.



Fig. 2 An actual ultrasound image of the uterine

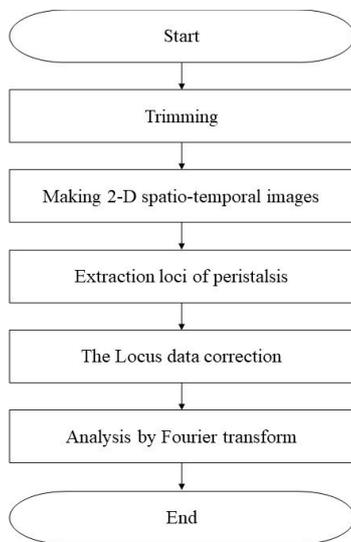


Fig. 3 A flowchart of the analysis method

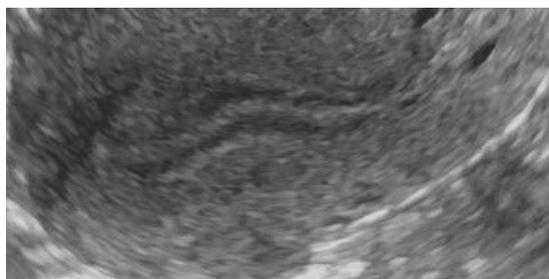


Fig. 4 An example of the trimmed image

2. Making 2-D spatio-temporal image

The brightness of the trimmed image is standardized by using the mean and the standard deviation. Five x -axis values of the trimmed image are fixed, denoted by x'_0, x'_1, \dots, x'_4 as shown in Fig. 5. An example of the obtained 2-D spatio-temporal image shown in Fig. 6 is made by acquiring the pixels on x'_i ($i = 0, 1, 2, 3$ and 4) at intervals of 10 frames. The value of x'_0 is manually determined, and the values of $x'_1 \sim x'_4$ were automatically set in the positive x -axis direction. The interval between x'_i and x'_{i+1} was 5 pixel. They

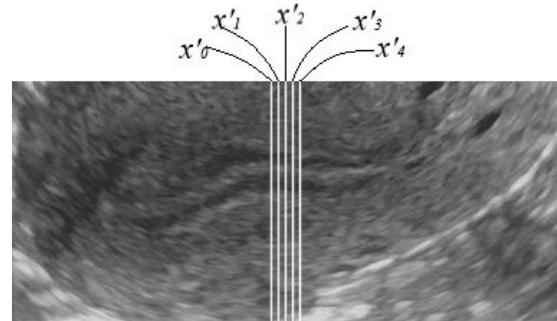


Fig. 5 Points of x'_i set when creating 2-D spatio-temporal images

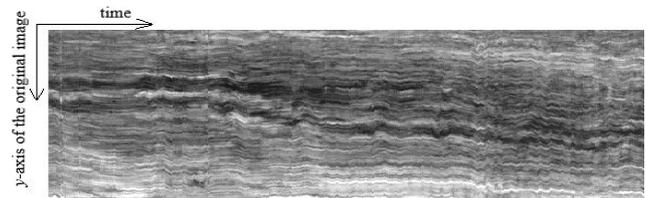


Fig. 6 An example of the 2-D spatio-temporal image

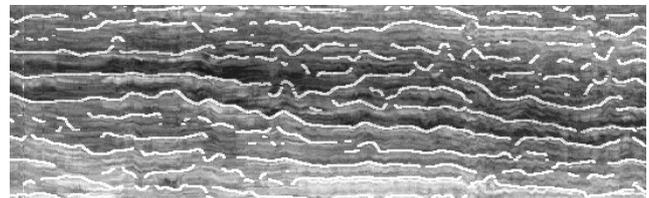


Fig. 7 An example of an automatic extraction result

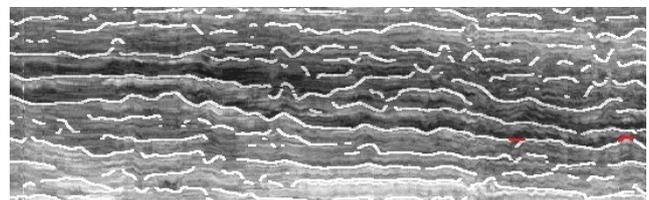


Fig. 8 An example of manual completion (The red lines are the supplemented part)

should clearly be located in uterine peristalsis.

3. Extraction tracks of uterus peristalsis

The 2-D spatio-temporal image is filtered in the order of Gaussian filter (13×13), Laplacian filter (11×11), Median filter (9×9). Sobel filter (3×3) is next applied for only y -axis edge extraction. The obtained image is binarized by discriminant analysis method. A locus of uterus peristalsis cannot be completely extracted as shown in Fig. 7. Therefore, the lacked part of the locus is manually added as shown in Fig. 8. At this time, at least one locus line must be completed. The left edge of the complemented locus is then determined. The red line in Fig. 9 shows the extracted locus of uterus peristalsis from Fig. 6. The position of the uterine

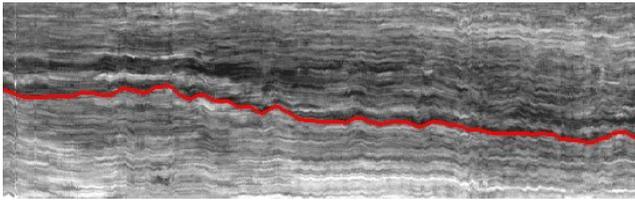


Fig. 9 An example of a locus of uterus peristalsis

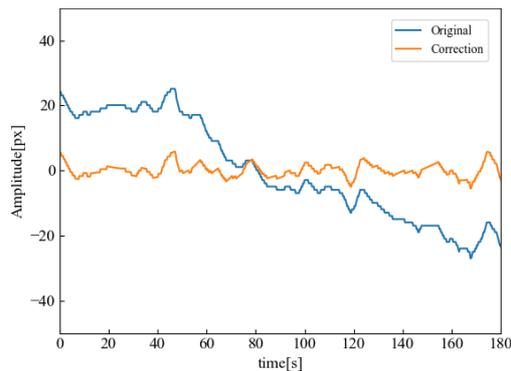


Fig. 10 Comparison between the original locus and the correction locus

is sometimes shifted by movement of the area around the uterus. This fact makes the noise on our frequency domain analysis. Therefore, the shift of the uterine position is adjusted by subtracting the locus line smoothed by the moving average from original locus line. Figure 10 shows the comparison result between the original locus and the obtained locus. This figure shows that the obtained locus is stable and suitable for applying Fourier transform.

4. Analysis by Fourier transform

All the trajectory data of uterus peristalsis obtained by the above are Fourier transformed, and the frequency of a given uterus peristalsis is obtained as the common frequency ingredient among the frequency spectrums. We used the Hanning window as the window function. The calculated frequency of uterus peristalsis is compared with the diagnostic result of the physician. It is not easy to watch it with the 1 times speed ultrasound image, since uterus peristalsis has some slow movements. The physician usually examined the ultrasound image at 10 times speed and visually evaluated by his naked eye.

3. Results

We evaluated the images for nineteen subjects. On the first subject, Fig. 11 shows the locus of uterus peristalsis corrected by extracting from 2-D spatio-temporal image made from x'_i in Fig. 5. Figure 12 shows the frequency spectrums of a common frequency ingredient obtained from the average and minimum values of the frequency spectrum of each uterus peristalsis. Furthermore, the moving average for correction was applied at 75 points. We chose the minimum and average values in the frequency spectrum as the com-

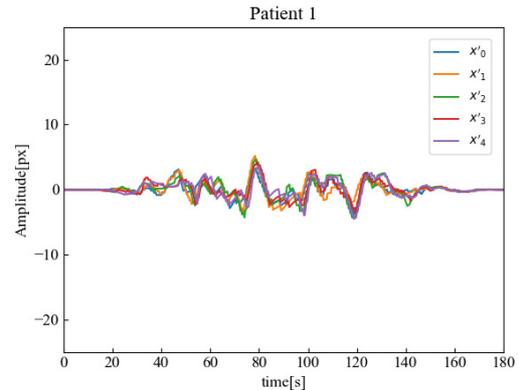


Fig. 11 Loci of uterus peristalsis (Patient 1)

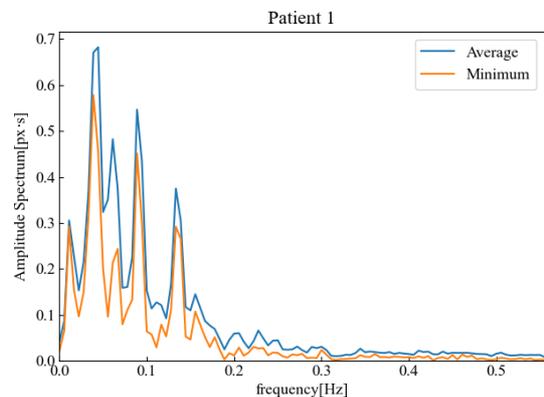


Fig. 12 The frequency spectrum of the common frequency ingredient (Patient 1)

mon frequency ingredient because the low frequency component is primary in our study. From Fig. 12, frequencies with the maximum frequency spectrum were 0.044 Hz for the spectrum obtained with the average value and 0.039 Hz for the spectrum obtained with the minimum value. The notations n_{ave} and n_{min} denote the number of uterus peristalsis of the average and minimum per minute, respectively. Then, Eqs. (1) and (2) hold.

$$n_{ave}/60 = 0.044 \tag{1}$$

$$n_{min}/60 = 0.039 \tag{2}$$

Then, n_{ave} was 2.7, and n_{min} was 2.3. This patient's uterine was estimated to have occurred uterus peristalsis 2.7 or 2.3 times per minute. The physician diagnosed this patient's uterus peristalsis as 2.7 times per minute. This diagnostic result equals to the result obtained from the frequency with frequency spectrum obtained with the average value. Table 2 shows the obtained results and physician diagnostic results of all patients. The mean absolutely error (MAE) and the standard error (SE) wer calculated to evaluate the accuracy of the average and the minimum value spectrums. In Table 2, the MAE and the SE of the average and the minimum value spectrums were 1.4 ± 0.30 (MAE \pm SE) and 1.3 ± 0.29 , respectively.

According to Table 1, the success rate of pregnancy

becomes extremely low when the peristaltic movement frequency per minute exceeds 3 times. We propose a method to calculate a fuzzy degree whether uterine peristalsis is the cause of the infertility. We define a fuzzy membership function [14]–[16] from Table 1. Figure 13 shows the fuzzy membership function defined by Eq. (3). The function is defined as value about 0.5 when the peristaltic movement frequency per minute is 2.5 and approximately 1 when that is over 4 from Table 1. Thus, the higher degree implies the degree of cause of uterine peristalsis being female infertility.

$$\mu(x) = \begin{cases} -0.0039x^5 + 0.018x^4 + 0.025x^3 - 0.12x^2 + 0.052x + 0.41 & (0 \leq x \leq 4) \\ 1.0 & (4 < x) \end{cases} \quad (3)$$

Table 3 shows the fuzzy degrees calculated. This table shows that the degree is smaller if the frequency of uterus peristalsis per minute is less than 3.0.

4. Conclusions

In this study, the frequency of uterus peristalsis was analyzed by 2-D spatio-temporal image and Fourier transform. As a result, the frequency of uterine peristalsis was measured as the frequency spectrum of a common frequency component for a given ultrasound image. Here, we quantitatively evaluated the frequency of uterus peristalsis. This study enables us to measure the frequency for the images without enough contrast between the ROI and the others. Here, the traces of uterine peristalsis were done from thinned 2-D spatio-temporal images by manual delineating. Finally, we provide fuzzy degrees for uterine peristalsis. As the results, the fuzzy degrees of Patients 1, 5, 8, 12, 15, and 19 were smaller than the others. We guess that these have problems of the movements. Patient 19 has the big difference between our result with that of physician.

As the future study, it remains that we develop an automatically extraction of the track of uterus peristalsis, and

Table 2 No. of the frequency of uterine peristalsis of all subjects

Patient	True number by the physician	The number obtained by average spectrum	The number obtained by minimum spectrum
1	2.7	2.7	2.3
2	3.3	3.3	3.3
3	4.0	4.7	4.7
4	4.0	2.6	2.6
5	0.67	2.7	2.0
6	3.3	2.6	2.6
7	8.0	3.6	3.3
8	2.0	2.0	3.0
9	4.0	3.0	3.3
10	3.0	3.0	3.0
11	4.0	4.0	4.0
12	1.3	2.3	2.3
13	3.3	2.7	2.7
14	4.7	2.7	2.7
15	1.0	2.3	1.3
16	8.0	4.3	4.6
17	4.0	2.0	1.7
18	4.0	1.7	4.6
19	0.67	3.6	3.6
MAE ± SE		1.4 ± 0.30	1.3 ± 0.29

Table 3 Evaluation result by fuzzy membership function

Patient	Result by the physician	Result obtained by average spectrum	Result obtained by minimum spectrum
1	0.58	0.58	0.46
2	0.82	0.82	0.82
3	1.0	1.0	1.0
4	1.0	0.54	0.54
5	0.40	0.58	0.40
6	0.82	0.54	0.54
7	1.0	0.93	0.82
8	0.40	0.40	0.70
9	1.0	0.69	0.82
10	0.69	0.69	0.70
11	1.0	1.0	1.0
12	0.37	0.46	0.46
13	0.82	0.58	0.58
14	1.0	0.58	0.58
15	0.38	0.46	0.37
16	1.0	1.0	1.0
17	1.0	0.40	0.37
18	1.0	0.37	1.0
19	0.40	0.93	0.93

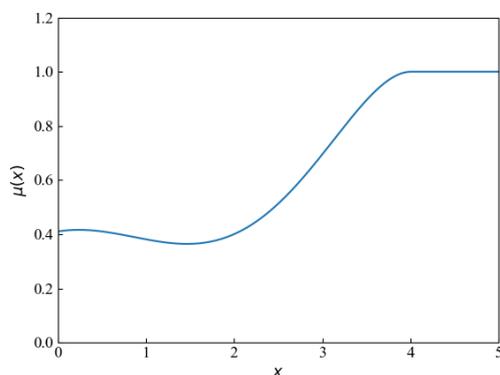
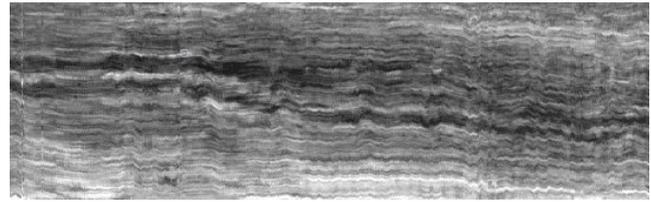


Fig. 13 Fuzzy membership function

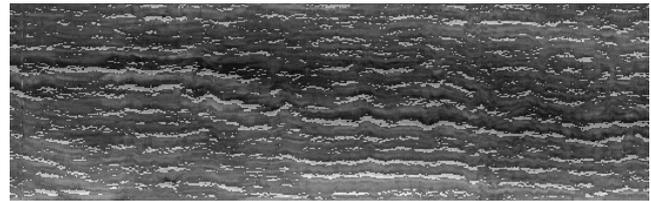
a method to reduce the error such as Patient 19.

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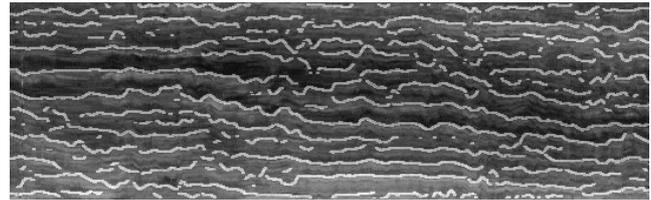
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(a) Original image



(b) 3×3



(c) 11×11

Fig. A·1 Effect of Laplacian filter + Sobel filter (only y-axis)

Appendix

Our process of applying the Sobel filter after applying the Laplacian filter in our method is shown as appendix. The Laplacian filter takes the second derivative of the image, and the Sobel filter takes the first derivative of the image. In other words, performing the filtering process in the order of the Laplacian filter and the Sobel filter will lead the same as taking the third derivative of the image. Then, Eq. (4) holds.

$$\frac{\partial}{\partial y} \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right) \quad (\text{A} \cdot 1)$$

Here, the Laplacian filter used here has 11×11 size, and the Sobel filter has 3×3 . They have a big difference in their sizes. Then, the Sobel filter performs local processing on the Laplacian filter, and therefore Eq. (4) does not hold. Figure A·1 (b) and (c) shows the result of applying the Laplacian filter and then the Sobel filter (only y-axis edge extraction) with 3×3 and 11×11 sizes of the Laplacian filter, respectively. Figure A·1 (c) demonstrates that the edge image is clearly extracted for the original image.



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