Analysis of Average Hand-Drawing and Its Application

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Abstract. In this paper, we applied averaging method to hand-drawn illustrations, and clarified characteristics of the averaged hand-drawings. We then implemented a prototype system that can realize better hand-drawings for user based on the characteristics.

Keywords: Hand drawing · Averaging · Comics · Illustrations · Drawing tool

1 Introduction

The opportunities for hand-drawing illustrations on a computer are increasing because of the spread of computers equipped with a pen-based interface, such as tablet PCs, and smartphones. In addition, the opportunities to share these illustrations with others are also increasing because of starting Web services for sharing user-generated illustrations such as pixiv [1].

However, some people do not like to draw illustrations even if they liked doing so in childhood. There are many reasons for this change in preference. One reason is that people are no longer satisfied with their hand-drawn illustrations because he/she hand-drawn illustrations tend to differ from their ideal shape and style. Here, the ideal shape and style of hand-drawn illustrations has not been clarified yet because people have trouble visualizing the image in their heads.

In our previous work, we designed a method to generate an average handwritten character from several handwritten characters by expressing users' strokes as equations [2]. In user-based experimental tests, we clarified that the average handwritten Japanese Hiragana characters were more beautiful than the original handwritten characters. Thus, the average handwritten Japanese Hiragana characters are similar to their ideal shape and style. We guess that the characteristics of the average hand-drawn illustration are similar to the average handwritten Japanese Hiragana characters.

In this work, we first clarify the characteristics of the average hand-drawn illustrations and the ideal image. Here, we make two hypotheses about the average hand-drawn illustrations and ideal image of users:

- A user's average illustrations are more beautiful than his/her hand-drawn illustrations (Hypothesis 1).

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- The average illustrations of several users are more beautiful than each user's average illustrations (Hypothesis 2).
  Here, if averaging illustrations reproduce the ideal illustration, the illustrations would not change in either case of dominant hand or non-dominant hand. Thus, we make hypothesis:
- The average non-dominant-hand illustrations become similar to the average dominant-hand illustrations (Hypothesis 3).

We test these hypotheses by conducting evaluation experiments. If the average illustrations are valued by users, these average illustrations might be similar to the ideal image. In addition, if the average non-dominant-hand illustration is similar to the average dominant-hand illustrations, the averaged illustrations might be the ideal for the user.

Thus, we implement a prototype system to help users to hand-draw illustrations on the basis of the characteristics of the average hand-drawn illustrations clarified in this work and the ideal image of the user's hand drawing. In addition, we herein discuss the usefulness of our system.

2 Related Work

There are many studies to support hand-drawing by showing guides or examples. ShadowDraw [3] is a system that shows the drawing guide of a user's target illustration as shadow images in the background on a canvas on the basis of numerous illustrations while a user is drawing. In addition, DrawFromDrawings [4] is a system that supports users to hand-draw their illustration by using large illustration databases. In this method, a user firstly hand-draw an illustration and specify a part of the illustration in order to improve from the illustration database and can select a target model from illustration database to merge a part of his/her stroke and a part of model depending on the user's operation. These systems enable users to hand-draw illustrations easily.

There are many methods to beautify strokes in hand-drawn illustrations based on knowledge or large database. Pegasus [5] is a system to help users to draw geometric diagrams. This helps users to easily draw difficult illustrations such as parallelograms or experimental apparatus. Limpaecher et al. [6] proposed a method that adjusted users' blurry strokes in real-time by finding a consensus stroke generated from a crowd-sourced large collection of hand-drawn illustrations with mobile application. In addition, Zitnick [7] proposed a method that beautified hand-drawn strokes by calculating a curvature of strokes and averaging the curvature with user's previous stroke. An objective of our work is to clarify the characteristics of beautification by averaging hand-drawings. We believe that our results assist these methods.

dePENd [8] is an assist system for hand-drawing physically. This system controls movement of user's sketch by using ferromagnetism of a ballpoint pen and their desk-type device set actuator with magnet. That allows user to draw difficult diagrams and pictures consisting of lines and circles. If we apply our averaging method to this system, users may be able to hand-draw beautiful averaging stroke easily.

In our previous work, we proposed a method to practice hand-drawing illustration [9] based on averaging method [2]. The method merges a user's stroke and model's stroke dynamically depending on the specified merge rate, and increase the user's motivation because he/she can hand-draw more beautiful illustration than his/her skill. This work is one of the application based on our knowledge.

3 Averaging Method

An illustration consists of several strokes. Then, the averaging method [2] generates a mathematical expression for each stroke and generates its average stroke from corresponding strokes by using arithmetic calculations. Thus, the method makes an average illustration by combining these average strokes.

First, the method enables users to draw on a canvas and obtains all of the users' strokes as a series of points. Then, the method interpolates intervals between these points by using spline interpolation. After that, the method generates a mathematical expression for each stroke through all interpolated points by using the Fourier series expansion (Fig. 1).

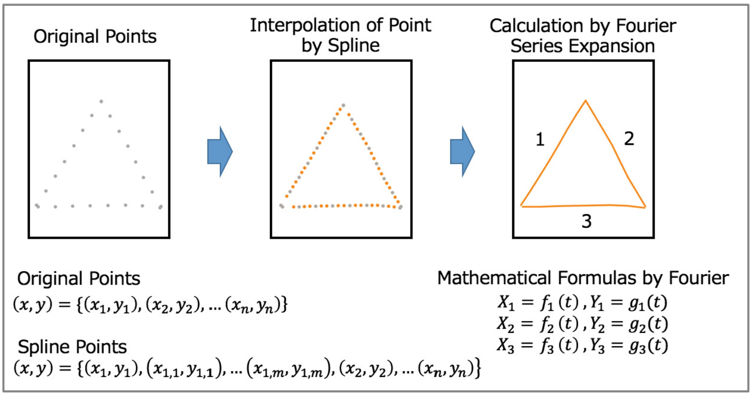

Fig. 1. Method of generating mathematical formulas of hand-drawn illustrations.

A stroke is expressed by a parametric representation as

$$\begin{cases} x = f(t) \\ y = g(t) \end{cases} -\pi \le t \le \pi. \tag{1}$$

Here, the method doubles back the interpolated points at the end of the points because the series of points has to be a closed curve in order to use the Fourier series expansion. If a distance exists between the start and end points, the ends of a particular stroke become wavy because both ends are connected by the Fourier series expansion. Although $f(t)$ is not a periodic function, it can be considered as a periodic function by the following definition ($g(t)$ is the same as $f(t)$)

$$f(t) = f(t + 2n\pi) \qquad n \ : \ integer. \tag{2}$$

Furthermore, $f(t)$ can be expressed using the Fourier series expansion as follows

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty}(a_n \cos nt + b_n \sin nt). \tag{3}$$

a_n and b_n can be calculated as follows

$$\begin{cases} a_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(t) \cdot \cos\, nt\, dt \\ b_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(t) \cdot \sin\, nt\, dt \end{cases}. \tag{4}$$

Here, interpolated points are discrete data. Therefore, we calculate the approximate a_n and b_n by summing these data.

However, computers cannot use an infinite series of a mathematical expressions. Therefore, the method truncates it to degree n places by comparing the distance between n series and n + 1 series with a threshold, which we set 2px in this paper.

As a result, the i_{th} hand-drawn stroke is expressed as $(x, y) = (f_i(t), g_i(t))$. The method generates the average stroke from N strokes as follows

$$\begin{cases} x_i = \frac{1}{N}\sum_{k=1}^{N} f_{i,k}(t) \\ y_i = \frac{1}{N}\sum_{k=1}^{N} g_{i,k}(t) \end{cases} 0 \le t \le \pi. \tag{5}$$

The method displays the average stroke by changing the value t from 0 to π, since the rest half also shows the same stroke in the opposite direction.

4 Dataset for Illustrations

We created a dataset of hand-drawn illustrations to test our hypotheses.

4.1 System of Creating Dataset

The system of creating datasets was implemented by Processing, programming language. Figure 1 shows this system. The system shows what kind of character the user should hand-draw, how many strokes the user hand-draw, the progress of creating the dataset, the “Undo” button, “Next” button, and the canvas for hand-drawing.

First, a user types his/her name. At the same time, the system automatically makes the user a folder in which to save his/her illustration data. After that, the screen changes the appearance, as shown in Fig. 2. The screen is W520px × H600px, and the hand-drawing canvas is W500px × H500px.

When a user is drawing a stroke by hand inside this canvas field by using a stylus, the stroke is displayed as a series of points in red (see left of Fig. 2). Our system obtains and plots 60 points per second (60 fps). When the user releases the stylus from the surface of the display, the system connects each continuous point with a line and displays them in blue (see right of Fig. 2). The system ignores the user’s input when it

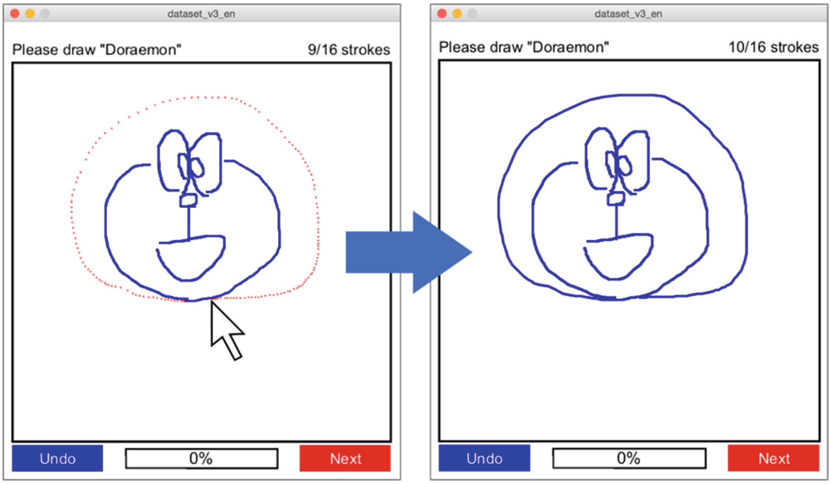

Fig. 2. Screen snapshot of system for generating datasets of hand-drawn illustrations. (Color figure online)

draws a stroke outside of this canvas. The user can remove previous hand-drawn strokes by clicking "Undo." When the user finishes drawing the target illustration and clicks "Next," the system refreshes the canvas field and displays the name of the next target illustration. At the same time, the system automatically saves the hand-drawn data, which contain x- and y-coordinates of the points of the strokes, and saves the illustration as a PNG image.

In this paper, we selected four hand-drawn illustrations of characters well known in Japan for the target illustrations: Doraemon (©Fujiko-Pro, Shogakukan, TV-Asahi, Shin-ei, and ADK), Anpanman (©Yanase • F • T • H ©APDLLP), Baikinman (©Yanase • F • T • H ©APDLLP), and Cook San. In addition, we prepared instruction Web pages consisting of images of illustrations and the stroke order and the stroke direction (Fig. 3).

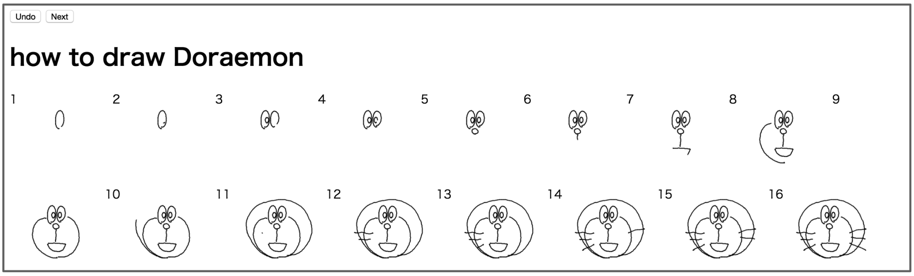

Fig. 3. Web page showing how to hand-draw Doraemon.

In creating the dataset, we asked eight users to hand-draw four illustrations following the stroke order and the stroke direction showed by the Web page in order to generate average hand-drawn illustrations using our method.

Here, users are undergraduate students in Meiji University, 20–22 years old, seven right-handed persons and one left-handed person, and four men and four women. None of the students had professional level talent at drawing. They drew each illustration five times using their dominant hand and then five times using their non-dominant hand.

We prepared CINTIQ 13HD produced by Wacom as an input interface. In addition, we used Apple MacBook Pro (Retina 13-inch Processor 2.8 GHz Inter Core i5 Memory 16 GB 16 MHz DDR3) computers to run this system.

4.2 Average Illustrations

We generated images of the hand-drawn illustrations and the average hand-drawn illustrations from the dataset. After that, we generated the following illustrations for each target character. Figures 4 and 5 shows an example. In this, there are 428 images generated by our method.

- Each user's original illustrations drawn using the dominant hand:

$$(4\,characters \times 8\,users \times 5\,times = 160\,patterns)$$

- Each user's original illustrations drawn using the non-dominant hand:

$$(4\,characters \times 8\,users \times 5\,times = 160\,patterns)$$

- Each user's average illustrations drawn using the dominant hand:

$$(4\,characters \times 8\,users = 32\,patterns)$$

- Each user's average illustrations drawn using the non-dominant hand:

$$(4\,characters \times 8\,users = 32\,patterns)$$

- Each user's average illustrations drawn using both hands:

$$(4\,characters \times 8\,users = 32\,patterns)$$

- All users' average illustrations drawn using the dominant hand:

$$(4\,characters = 4\,patterns)$$

- All users' average illustrations drawn using the non-dominant hand:

$$(4\,characters = 4\,patterns)$$

- All users' average illustrations drawn using both hands:

$$(4\,characters = 4\,patterns)$$

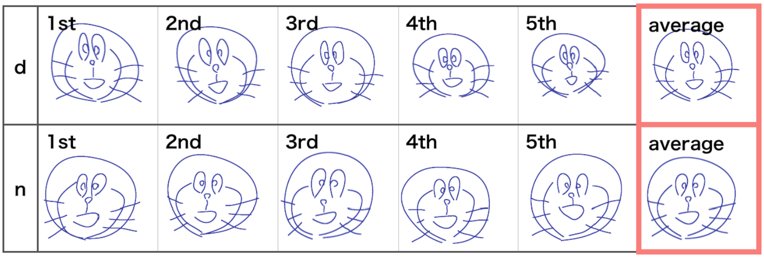

Fig. 4. User's hand-drawn Doraemon and averaged Doraemon ('d' stand for dominant hand and 'n' stand for non-dominant hand)

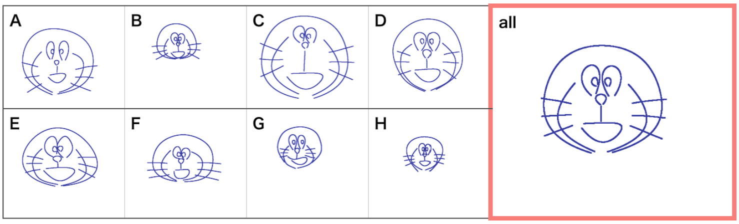

Fig. 5. Each user's average Doraemon and all users' average Doraemon.

5 Evaluation Experiment

To test the three hypotheses described in the above, we implemented a web-based experiment system (Figs. 6 and 9) and 16 undergrads (14 men and 4 women; 20–22 years old) were participated. These participants were asked to evaluate illustrations generated from the dataset by this system. In this experiment, eight participants of them contributed to generate the dataset. We conducted following experiments for each hypothesis.

5.1 Experiment1

5.1.1 Procedure

In this experiment, we compare participant's average illustrations with participant's original illustrations. We asked participants to rank the first, second and third best illustrations from 13 patterns (four dominant-hand's and four non-dominant-hand's original illustrations, and average illustrations by dominant-hand and by non-dominant, and the average of both hands) depending on the degree of beauty in each target character and in each user (see Fig. 6). They rank illustrations 32 times ($= 8\,users \times 4\,illustrations.$)

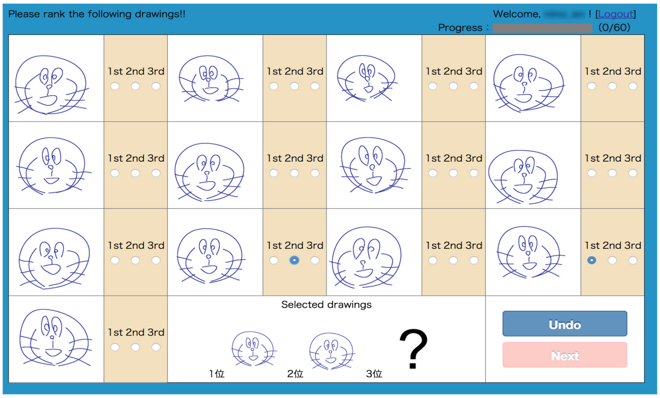

Fig. 6. Web system for experimental test to rank illustrations.

5.1.2 Result

Figure 7 and Table 1 shows the results of experiment 1. In this figure, ‘d’ stands for the dominant hand, ‘n’ the non-dominant hand, and ‘avg’ the averaged illustrations.

In Fig. 7, the horizontal axis shows the first to fifth dominant-hand illustrations, first to fifth non-dominant-hand illustrations, and the averaged dominant-hand, non-dominant-hand, and both-hand illustrations. Here, we assigned three points to first ranked illustrations, two to second ranked ones, and one to third ranked ones. The evaluation score was the average value of these points. The expected value for one illustration was 0.4615 because the sum value of scores was 6.

Figure 7 shows the averaged illustrations were evaluated higher than the original hand-drawn illustrations. Furthermore, the averaged illustrations drawn using both hands had the highest score.

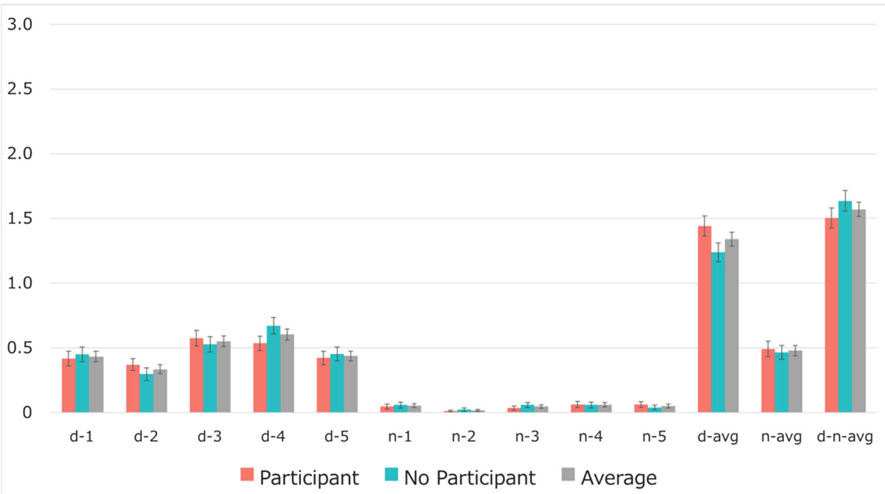

Fig. 7. Experimental results comparing average illustrations with hand-drawn illustrations.

Table 1. Experimental results comparing average illustrations with hand-drawn illustrations.

	d − 1	d − 2	d − 3	d − 4	d − 5	n − 1	n − 2	n − 3	n − 4	n − 5	d-avg	n-avg	d-n-avg
AVG	0.43	0.33	0.55	0.60	0.44	0.05	0.02	0.05	0.06	0.05	1.35	0.48	1.58
SD	0.90	0.78	0.96	0.97	0.85	0.34	0.17	0.30	0.37	0.32	1.20	0.90	1.26
SE	0.04	0.03	0.04	0.04	0.04	0.01	0.01	0.01	0.02	0.01	0.05	0.04	0.06

These results clarified that the user's average illustrations were more beautiful than the user's hand-drawn illustrations. Thus, hypothesis 1 was validated.

5.2 Experiment2

5.2.1 Procedure

In this experiment, we compare the average illustration of all participants and each participants' average illustrations. We asked participants to rank the first, second and third best illustrations from nine patterns (the average illustration of eight participants and eight participants' average illustration) depending on the degree of beauty in each target character and in each hand (see Fig. 6). They rank illustrations 12 times $(= 4\,characters \times 3\,hands.)$

5.2.2 Result

Figure 8 and Table 2 shows the results of experiment 2.

This figure shows the evaluation scores for A's to H's averaged illustrations and the average illustrations by all users. Here, we again assigned three, two, and one points to the first, second, and third ranked illustrations. The evaluation score was the average value of these points, so the expected value for one illustration was again 0.4615 because the sum value of scores was 6.

Figure 8 shows all users' average illustrations were evaluated higher than each user's average illustrations.

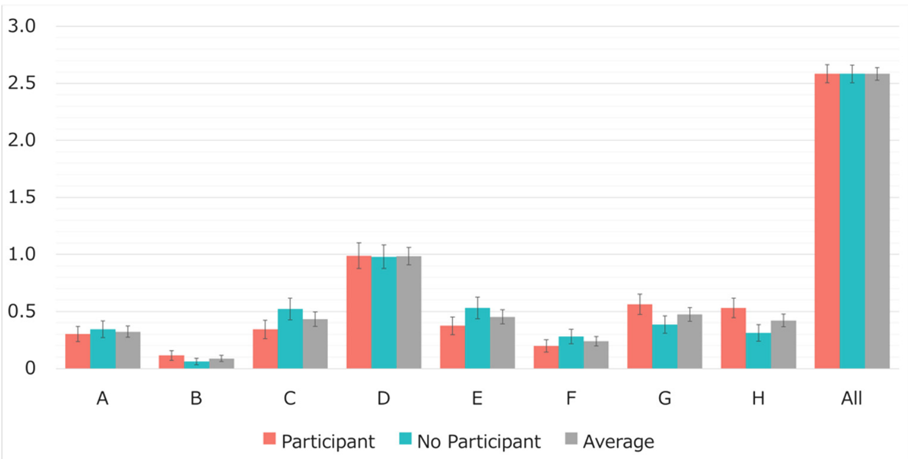

Fig. 8. Experimental results comparing each user's average illustration with all users' average illustrations.

Table 2. Experimental results comparing each user's average illustration with all users' average illustrations.

	A	B	C	D	E	F	G	H	All
AVG	0.32	0.09	0.43	0.98	0.45	0.24	0.47	0.42	2.58
SD	0.68	0.36	0.87	1.06	0.85	0.58	0.82	0.78	0.77
SE	0.05	0.03	0.06	0.08	0.06	0.04	0.06	0.06	0.06

These results clarified that all the users' average illustrations were more beautiful than each user's ones. Thus, hypothesis 2 was validated. We suppose that these results mean that averaging illustrations cancels out each person's blurry hand drawings by moving them toward ideal illustrations.

5.3 Experiment3

5.3.1 Procedure

In this experiment, we check how similar dominant-hand's illustration and non-dominant-hand's illustration based on participants' evaluation. We asked participants to pair each user's average dominant-hand illustration and each user's non-dominant-hand illustration depending on the similarity (see Fig. 9). They rank illustrations four times ($= 4\,characters.$)

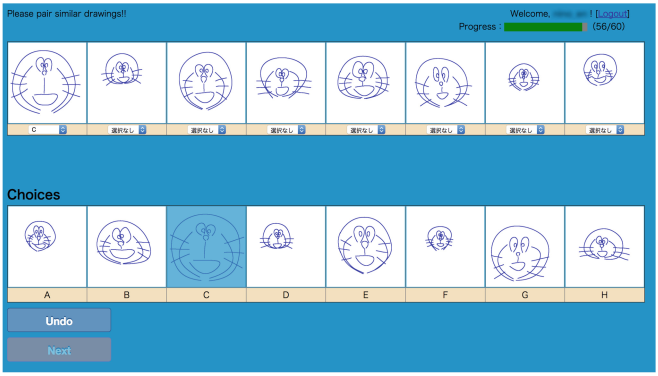

Fig. 9. Web system to pair dominant-hand and non-dominant–hand illustrations.

5.3.2 Result

Figure 10 and Table 3 shows the results of experiment 3.

This figure shows the percentages of correct pairings of dominant-hand and non-dominant-hand illustrations. The expected percentage of correct pairings was 13%.

Figure 10 shows the percentage of correct answers was more than 70% for all illustrations. This means that the dominant-hand illustrations were similar to the non-dominant-hand illustrations.

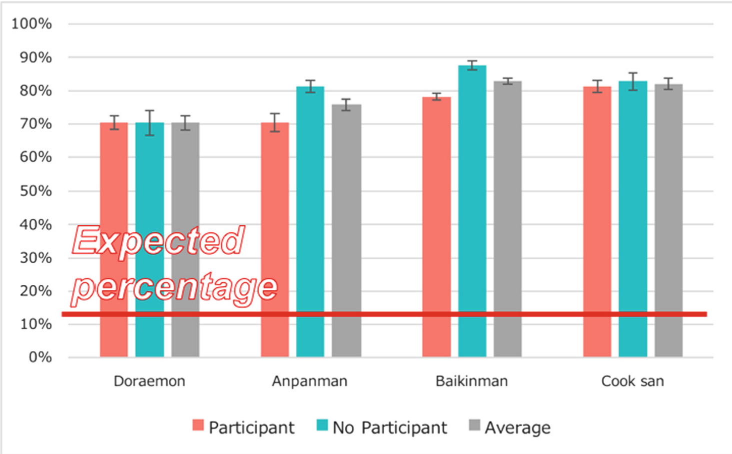

Fig. 10. Experimental results for pairing dominant-hand and non-dominant-hand illustrations.

We think there are two reasons for this. First, the blurred non-dominant-hand illustrations were made more beautiful by averaging them. Second, the averaged illustrations kept their hand-drawn traits regardless of whether the dominant or non-dominant hand was used. These results clarified that the average non-dominant-hand illustrations became similar to dominant-hand illustrations. Thus, hypothesis 3 was validated (Table 3).

Table 3. Experimental results for pairing dominant-hand and non-dominant-hand illustrations.

	Doraemon	Anpanman	Baikinman	Cook San	Average
AVG	0.70	0.76	0.83	0.82	0.78
SD	0.24	0.19	0.11	0.18	0.10
SE	0.02	0.02	0.01	0.02	0.01

6 Average Painter

When a user is unsatisfied with his/her hand-drawn stroke, he/she might undo that stroke and redraw it. Here, we clarified the average illustrations were more beautiful than individual hand-drawn illustrations (Hypothesis 1). In fact, the user was able to draw beautiful strokes if the system automatically generated the average stroke from these redrawn strokes.

To realize such drawings, we introduce a beautifying function based on averaging strokes to painting software (Fig. 11). This function is based on the users' behaviors and Hypothesis 1 and works as follows:

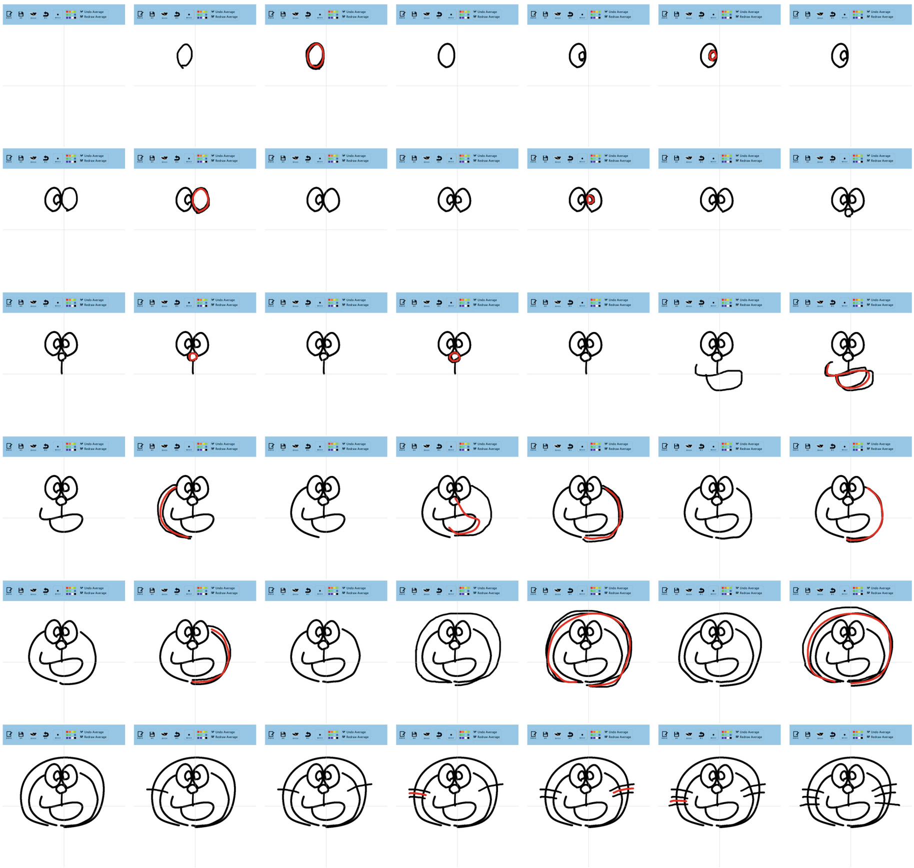

Fig. 11. Screen shot of "Average Painter" system.

- When a user draws a stroke, undoes the stroke, and redraws a stroke similar to the undone stroke, the function generates an average stroke from the undone stroke and redrawn stroke in order to beautify his/her drawings.
- When a user draws a stroke and redraws a stroke similar to the last stroke, the function generates an average stroke from these two strokes in order to beautify his/her drawings.

In this study, we implemented a prototype of the drawing system "Average Painter" with this function by processing to assist users in hand-drawing illustrations.

This system automatically shows the candidate of a user's ideal stroke by averaging the current stroke and last stroke or by averaging the current stroke and undone stroke.

This system automatically shows the candidate stroke in red if the system judges that a user's current stroke is similar to his/her last stroke or undone stroke. If the user clicks this candidate stroke, the system deletes the current stroke and last stroke and shows the average stroke as his/her hand-drawn stroke (Fig. 12).

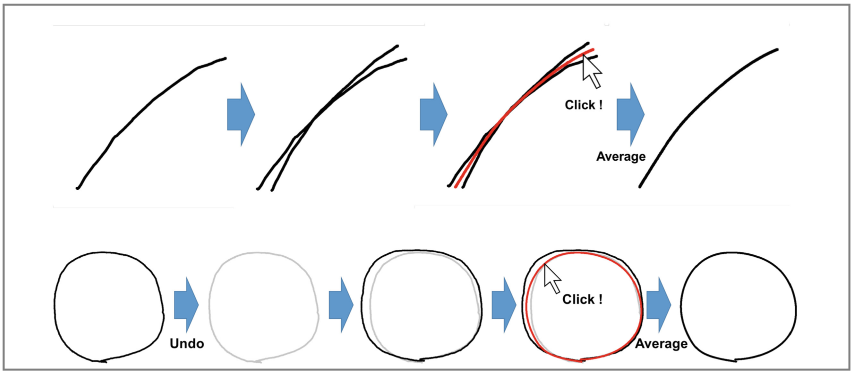

Fig. 12. Method for averaging hand-drawing. (Color figure online)

To judge the similarity of strokes, the system calculates the similarity on the basis of the length, the distance between the current stroke and last stroke (or undone stroke), and the aspect ratio of the stroke based on a threshold, as shown in Fig. 13.

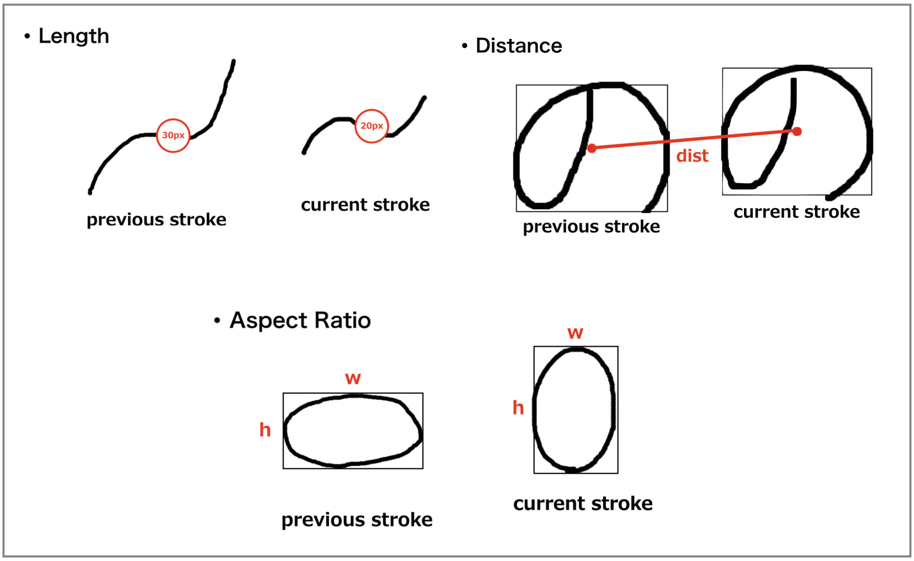

Fig. 13. The similarity is calculated by using the difference of length, distance, and aspect ratio of each stroke.

We demonstrated our system to many participants and asked them to try using it to hand-draw illustrations. We were told in feedback that if the user was unsatisfied with the hand-drawn stroke, the stroke became more beautiful by using the averaging function. Thus, the user was satisfied with his/her hand-drawing when our system assisted him/her.

However, several participants reported that they could not draw complex strokes smoothly. In the future, we will solve this problem by fixing software bugs.

Figure 14 shows examples of illustrations, which three participants draw without the averaging function and with that as users like. They are students in Meiji University and their age is 22. In this test, we showed the model's characters, and asked three participants to draw the character with our system and without our system. After that, we got feedback from them. They said "I could draw more beautiful illustration with average function than drawing by one time" or "I was hard to draw whisker by being shown average stroke with average function."

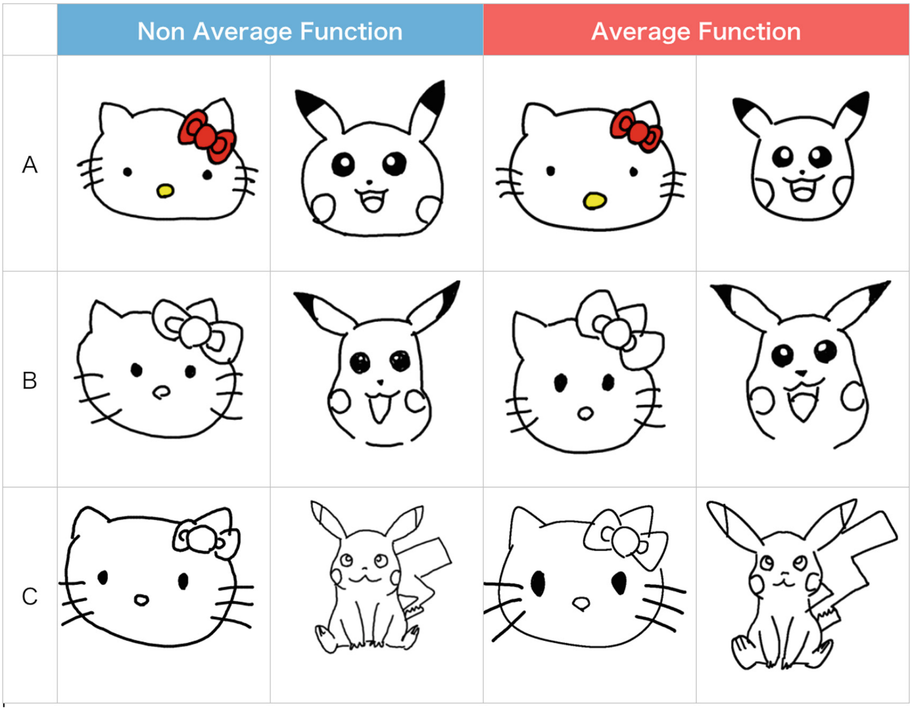

Fig. 14. Example of illustrations by using Average Painter system.

7 Conclusion and Future Tasks

In this paper, we made three hypotheses about hand-drawing illustrations.

- A user's average illustrations are more beautiful than his/her hand-drawn illustrations
- The average illustrations of users are more beautiful than each user's average illustrations
- The average non-dominant hand illustrations become similar to the average dominant hand illustrations

Then, we described an averaging method, our collection of four types of hand-drawn illustrations, and some experiments we conducted to test these hypotheses. The experimental results verified the hypotheses.

In the experiments, we required users to keep to the stroke order and direction of illustration. Some users had difficulty drawing illustrations, so we will implement an averaging system to sort hand-drawn strokes automatically in the future. If we use such a system, the results should become more accurate because users would be able to draw more easily.

In addition, we implemented a prototype system of a drawing tool for assisting with hand-drawing by using an averaging method based on hypothesis 1. As a result, the majority of users enjoyed using our system to hand draw illustrations. However, this system is not suitable for illustrations requiring many strokes such as the hair of cartoon characters. In the future, we are planning to solve this problem by estimating the user's intentions.

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