A Proposal of Calligraphy Learning Assistant System with Letter Portion Practice Function Using Projection Mapping

***Abstract*—Purpose - For several decades, *calligraphy* has been popular among people in Japan, China, even in the world. Traditionally, a teacher teaches how to write letters on a paper with a brush, and a student will imitate them by referring to the model letters. However, if a teacher is not available, this method will become not applicable either. In this paper, we propose a *Calligraphy Learning Assistant System (CLAS)* using *projection mapping*, which allows a student to learn calligraphy by him/herself.**

Design/methodology/approach - By following the letter writing video of a teacher that is directly projected on the paper, a student is able to learn the stroke order and writing speed in addition to the letter shape. Moreover, the *letter portion practice function* is incorporated in CLAS to allow a learner to repeat practicing hard portions of each letter.

Findings - For evaluations, we implemented CLAS using *Raspberry Pi* and open-source software, and asked students to use it. The results confirmed that CLAS is effective in improving calligraphy skills of novice students.

Originality/value - With CLAS, a student can practice calligraphy using a conventional brush, ink, and paper at a desk while looking at the model letter writing of a teacher projected on the paper using projection mapping.

***Index Terms*—Calligraphy, Learning Assistant System, Projection Mapping, Raspberry Pi**

Paper type Research paper

I. Introduction

For several decades, *calligraphy* has been a popular activity worldwide since it is beneficial in relaxing and improving concentration and creativity. As well, it is addressed that people will boost their logic while practicing *calligraphy* (Nakashima [2007]; Iezzi [2013]).

In general, a teacher will write the letters on a paper with a calligraphy brush, and then, explain the stroke order and brushwork rules to a student. The teacher may hold the brush to show the proper strength between the brush and the paper (Taylor [2007]). If the brush is strongly pressed on the paper, the line will become wide and not smooth. That is, a student will practice writing letters on papers while observing the letters written by the teacher on the left side. Then, the teacher will correct the letters. Figure 1 illustrates this conventional calligraphy learning method.

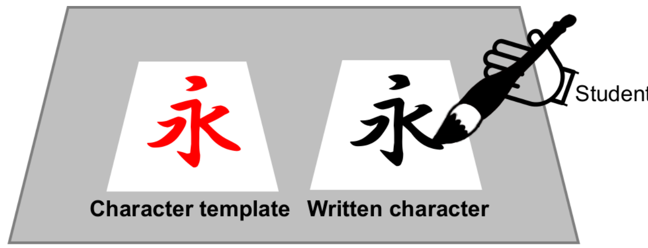

Fig. 1. Conventional calligraphy learning method.

However, this method requires a teacher to be present all the time. Besides, the details of letter writing, such as the dynamic brushwork of the stroke order and the writing speed, are not involved in the static letters on the paper.

In this paper, we propose a *Calligraphy Learning Assistant System (CLAS)* using *projection mapping*, which allows a learner to practice calligraphy writing, including the dynamic brushwork by him/herself. By following the letter writing video of a teacher projected on the paper, a student will learn the stroke order as well as the writing speed. To produce a content, CLAS needs video-recording of letter writing by a teacher. Besides, the *letter portion practice function* is incorporated in CLAS, to allow a learner to repeat practicing hard portions of a letter, since it is very useful for improving the whole letter writing.

Projection mapping can offer presentations with high realistic sensations by projecting videos or images on various types of surfaces, such as building/room walls, small objects, tunnels, and vehicles. As one *augmented reality (AR)* technology, *projection mapping* has been extensively applied, including exhibitions, concerts, entertainments, and advertisements (Projection Mapping Central [2019]; Kanazawa et al. [2014]; Rodriguez et al. [2015]; Kushihashi and Mizumura [2017]).

To evaluate CLAS, we adopt *Raspberry Pi* as the computing device and open-source software for projection mapping. Then, we ask students in our group from Japan, China, Indonesia, Kenya, Myanmar, and Bangladesh, to write letters with CLAS and the conventional method respectively. The results have confirmed the effectiveness of CLAS in improving calligraphy skills of novice students.

The rest of this paper is organized as follows: Section II discusses relevant studies. Section III overviews the *projection mapping* technology. Section IV presents the *calligraphy learning assistant system*. Section V describes the letter portion practice function. Section VI shows evaluation results. Finally, Section VII concludes this paper with future works.

II. Related Works

In this section, we discuss works related to this study. Some of them focus on evaluating the quality of calligraphy using a tablet or image processing, and on helping calligraphy practices with the computer aided technology such as *Augmented reality (AR)* and *virtual reality (VR)*.

Han et al. [2008] proposed an interactive calligraphic guiding system to grade the score of written letters by using the image processing and fuzzy inference techniques. Three statistical features of locations, sizes, and widths of them are utilized to measure the score of calligraphic quality. That is, this tool can be used in our system to evaluate calligraphic quality, which will be included in future works.

Xu et al. [2018] introduced a brush movement evaluation method for learners to understand the quality of brush movements without involvements of experts. It adopts a neural network technique to extract brush trajectories from a video stream, and compares them with the templates by experts to produce scores in the writing quality. In future studies, we will consider evaluating brush movements of learners.

Wang et al. [2016] introduced a comprehensive evaluation method of Chinese calligraphy that involves global (whole character) and local (stroke) similarities. First, it identifies the candidate characters from the database according to the angular difference relations. Then, it matches the candidates with the most appropriate character. It considered various situations of positions, sizes, and tilt angles of characters without knowing what the character is.

Wang et al. [2016] studied quantitative evaluations of calligraphy characters. The main evaluation focused on two parts, the straight section analysis and the curved section analysis, which are used to examine the distribution of the ink. Then, the system will recognize the contour line, and calculate the cut-point identification roundness index, the width index, the smooth index, and the ink ratio to extract the characteristics of the font shape numerically.

Liang et al. [2011] proposed a calligraphy writing system based on VR techniques. It adopts a force-reflection joystick as the input device, and develops the brush model that describes the brush skeleton and geometrical-based deformation of the brush surface based on physics, to achieve realistic effects by simulating the haptic sensation similar to that of manipulating a real calligraphy brush. Through comparisons with a traditional calligraphy brush and a graphic tablet, the effectiveness is confirmed.

Shin et al. [2013] developed a calligraphy learning system using a pen tablet on a PC, which focuses on the eight fundamental brush strokes in calligraphy, and compares each stroke using the coordinates of the starting and ending points of each stroke. However, the writing touch on a pen tablet is greatly different from that on a real paper with a brush.

Wu et al. [2013] proposed a *Chinese calligraphic training system* based on VR. That is to say, a learner will not only acquire the brushwork rules, but also practice *calligraphy* as a mobile application in a virtual way, so that he/she may repeat practices without the consumption of papers and ink.

Wang et al. [2014] presented the hierarchical evaluation approach of learning calligraphy. This method evaluates both the stroke sequence similarity and the character shape similarity between the characters written by a student and a teacher. In future works, we will also assess the quality of the stroke from a student.

Soontornvorn et al. [2015] presented an AR system, which contains both the static writing path and the dynamic writing process of model characters. The learner needs to use a head mounted display to gain the visual information. However, the writing using a real brush and ink could be exceedingly different from that of the proposed system. It is noted that the brushwork cannot be substituted completely and accurately for a tablet or a touch screen of a smart-phone.

Matsumaru and Narita [2017] introduced a *calligraphy-stroke learning support system* using a projector and a motion sensor called *Leap motion*. VR is used to show the static and animated models of characters on the paper. It provides visual information about the brush position obtained by a sensor. Unfortunately, it is not clear how to obtain the brushwork of a calligraphy expert.

Nishino et al. [2011] developed a VR-based calligraphy training environment to enable learners to acquire calligraphy skills intuitively. It adopts a Phantom device to allow a haptic interaction. The learner can pick up essential skills such as the appropriate tilting of the brush and the pen pressure. However, this system may create uncomfortable feeling to learners due to use of this extra device.

III. Overview of Projection Mapping Technology

In this section, the overview of the projection mapping technology is presented.

Projection mapping is a technology of projecting videos or images on various types of objects to offer realistic presentations. A projection mapping system basically consists of a *computer* with the dedicated software and a *projector*. As shown in Figure 2, the software maps each mesh of a visual content onto a surface mesh of the object, called *meshing*, and processes each content mesh using image conversion techniques so that it can naturally appear on the corresponding surface mesh using a *projector*. The ordinary projector can be used in projection mapping (Projection Mapping Central [2019]). *Projection mapping* has been used in various applications, such as music visualizations, product presentations, or educational purposes (Kanazawa et al. [2014]; Rodriguez et al. [2015]; Kushihashi and Mizumura [2017]).

IV. Proposal of Calligraphy Learning Assistant System

In this section, we propose a *calligraphy learning assistant system (CLAS)* using *projection mapping*.

A. System Configuration

Figure 3 illustrates the system configuration of CLAS. *Raspberry Pi* is used as the computer to process the visual content or video for projection mapping. It has been popular as a

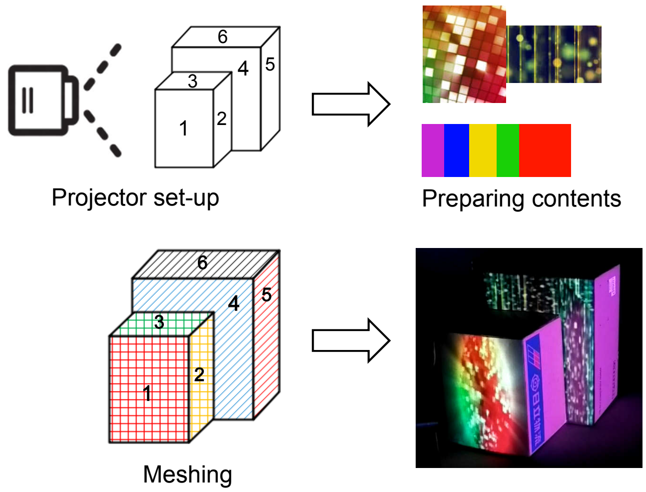

Fig. 2. Content generation for projection mapping.

low-cost minicomputer, which owns the processing capability of a high-definition video. Then, *openFrameworks* is adopted as an open source creative coding toolkit, and *OfxPiMapper* (Krisjanis [2015]; Krisjanis [2019]) is installed as an open source projection mapping software, which acts as an *add-on* of *openFrameworks*.

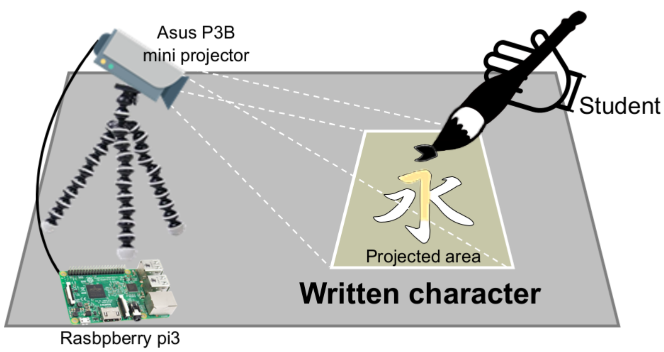

Fig. 3. System overview.

Besides, *ASUS P3B* is adopted as a portable projector to project the video onto the surface of the paper on a desk. It supports until $800 lumens$ light with $12,000 mAh$ power built-in. This projector is set on the left side of the paper to project the video onto the paper surface.

B. CLAS Utilization

CLAS can be utilized through the four steps: 1) content recording, 2) content processing, 3) projection setup, and 4) calligraphy practicing. More details are as follows:

1) Content Recording: First, the video of calligraphy writing of a teacher is video-recorded. In our implementation of CLAS, a smart-phone is used as the device and is mounted in the proper position on the desk before recording. Also, a person with over 40 years of calligraphy experiences will help the video-recording.

2) Content Processing: Then, the CLAS content is generated from the video. To assist a novice learner efficiently practicing calligraphy writing, each content consists of a movie and an image. The *movie* offers the dynamic brushwork movement of each letter written by a teacher. Using *FFmpeg* (FFmpeg [2019]), the brush and letter parts in the movie are highlighted, and the other parts such as the teacher ' s hand are diluted, to improve the visibility of letter writing.

The *image* represents the contour of each letter, which is used to help a learner write the correct shape. The letter contour is obtained by scanning the paper with the complete letter of a teacher using a scanner, and extracting the contour from the scanned letter using an open source software *inkscape* (Inkscape [2019]).

Finally, *FFmpeg* is used to produce one content by blending the movie and the image, as revealed in Figure 4.

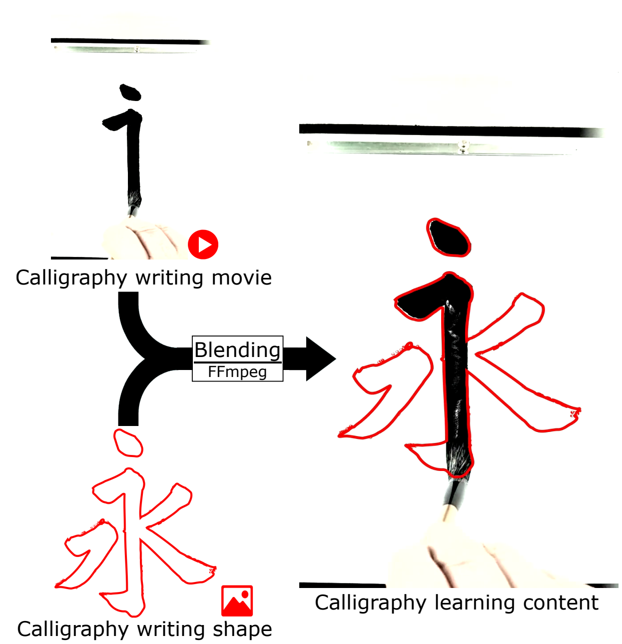

Fig. 4. CLAS content production.

3) Projection Setup: In CLAS, the square paper in a video content must be projected exactly on the real square paper on a desk using a projector that is installed on the desk at the left oblique projection of the paper. To realize the system, it is a must to adjust the projection parameters in the software. This adjustment should be done once the projector and the paper are set up on the desk.

C. Calligraphy Practicing

At CLAS, a learner will practice calligraphy writing using a real brush, ink, and paper on the desk, by tracing the letter writing in the content. By following the brushwork of the teacher and the letter contour in the content, a learner is expected to realize the stroke order, the writing speed, and the writing pressure of the teacher.

V. Letter Portion Practice Function in CLAS

In this section, we present the *letter portion practice function* in CLAS.

A. Letter Portions

A Japanese letter including a *kanji* usually consists of several portions or strokes. For example, “永” consists of five portions shown in Figure 5. “永” has been often used in calligraphy learning, because it has the eight basic brush strokes called *Eiji-happo* (Japan visitor [2019]). They include *Ten* (dot), *Yokoga* (horizontal stroke), *Tatega* (vertical stroke), *Hane* (upflick from a horizontal or vertical stroke), *Migihane* (rightward upflick), *Hidaribarai* (leftward downstroke), *Hidarihane* (leftward downflick), and *Migibarai* (rightward downstroke). For the proposed function, we prepare a video of writing each letter portion only several times by a teacher. Then, a learner could repeat practicing the portion by imitating the video.

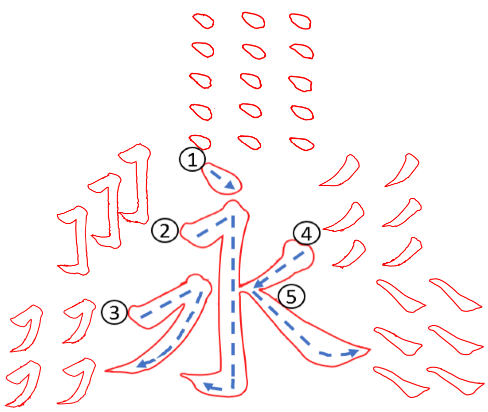

Fig. 5. Five letter portions of “永”.

B. Implementation

The user interface in Figure 6 is implemented using *LibreOffice*, to allow a learner to select one portion or whole letter writing for practice. By clicking a button, the corresponding video is automatically projected on the paper. In the implementation, the *macro function* and the *shell script* are used.

Figure 7 demonstrates the letter portion practice by a student using the proposed function. A student is able to repeat the difficult portion by following the writing of a teacher that is directly projected on the paper.

VI. Evaluations

In this section, we evaluate the *calligraphy learning assistant system* through applications to students in Okayama University.

A. Evaluation Indexes

To evaluate calligraphy writing results from students quantitatively, *difference rate* and *teacher grade* are used in this paper.

Fig. 6. User interface for selecting the learning practice modes.

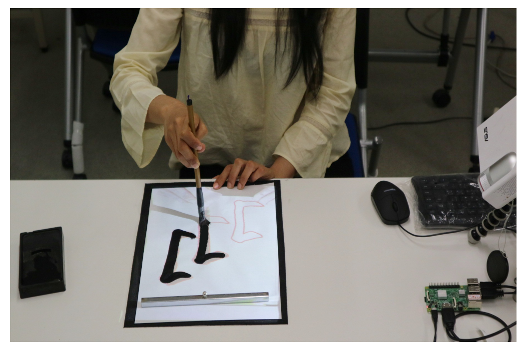

Fig. 7. Letter portion practice using proposal.

1) Difference Rate: The *difference rate* indicates the rate of the number of the pixels whose binary values are different between the teacher’s calligraphy image and the student’s calligraphy image against the total number of pixels in the image. It represents the similarities of the letters from the teacher and the student respectively. The *difference rate* can be calculated by the following procedure:

1. The calligraphy result paper by a teacher or a student is converted into the digital RGB image using a scanner.
2. The RGB image is converted into the gray-scale image using *inkscape*.
3. The gray-scale image is converted into the binary image using *inkscape*.
4. The binary image is resized to the image of 512×512 pixels using *inkscape*.
5. The number of different pixels between the teacher’s image and the student’s image is calculated.
6. The difference rate is calculated by dividing the number of different pixels with the total number of pixels using *ImageMagick* (ImageMagick Studio [2019]).

2) Teacher Grade: The *teacher grade* signifies the five point score of the calligraphy result on the paper that is given by a teacher subjectively in terms of the shape and the smoothness. 1 means the worst and 5 represents the best.

B. Comparison with Conventional Method

In the first evaluation, we verify the effectiveness of CLAS in writing higher quality calligraphy than the conventional method.

1) Application Process: In this evaluation, we asked 14 Japanese and non-Japanese students in our group, to write "永" as a common character for calligraphy by using CLAS and the conventional method, and then compared the two indices of the calligraphy results, in three stages. The Japanese students have learned *calligraphy* in elementary schools, while the non-Japanese students have no experience at all.

In the first stage, we asked the students to write "永" with the conventional method, and divided them into two groups, such that the average value of *difference rate* is similar between them. Then, in the second stage, we asked the students in the first group to write the letter again by CLAS, while the students in the second group do so by the conventional method. In order to improve calligraphy skills, each student repeated letter writing five times. Afterwards, in the third stage, we asked them to write the letter by the conventional method.

2) Application Result: Table I shows the minimum, maximum, and average of *difference rate* and *teacher grading* in each group. This table indicates that both the indices are similar between the two groups in the first and third stages, and the indices by CLAS are better than those of the conventional in the second stage.

TABLE I
TWO INDICES FOR TWO METHODS.

stage		CLAS		conventional	
		difference rate (%)	teacher grade	difference rate (%)	teacher grade
1st	min.	17.98	2	17.09	2
	max.	23.00	3	23.70	4
	ave.	19.85	2.57	19.63	2.71
2nd	min.	14.56	2	17.33	2
	max.	23.15	5	25.60	5
	ave.	18.46	3.51	20.29	2.97
3rd	min.	19.28	2	16.69	3
	max.	23.72	4	24.18	4
	ave.	21.03	3	20.53	3.43

3) T-test *Verification:* To verify the observations, the *independent sample T-test* is applied to investigate the significant difference between the results of the two groups as shown in Table II. Here, if *t-value*$<-$*t-table and p-value*$<$*0.05*, it is regarded that there is a significant difference between the two groups (yes). If *t-value*$<-$*t-table and p-value*$<$*0.1*, it is assumed that there is a notable difference tendency (maybe). Otherwise, there is no significant difference (no). If *t*-value is negative, the average value of the proposal is lower than that for the conventional.

Table II suggests that CLAS generates the better calligraphy in the second stage, while both methods are similar in the other stages. Thus, it is concluded that CLAS appears to be effective in writing superior quality calligraphy. Through improving the satisfaction, CLAS can encourage novice students to continue learning calligraphy on their own. However, the results in the third stage imply that more practices by CLAS are necessary to improve calligraphy by the conventional method.

TABLE II
T-TEST RESULT WITH α=0.05.

phase	T-test	difference rate	teacher grade
1	*t*-value	0.195543755	-0.40824829
	t-table	1.782287556	1.782287556
	p-value	0.424119645	0.345140929
	result	no	no
2	*t*-value	-2.007348298	1.551343504
	t-table	1.782287556	1.782287556
	p-value	0.033887595	0.073390691
	result	yes	maybe
3	*t*-value	0.414863684	-1.441153384
	t-table	1.782287556	1.782287556
	p-value	0.342781205	0.087561566
	result	no	maybe

C. Effectiveness of Letter Portion Practice Function

In the second evaluation, we verify the effectiveness of the *letter portion practice function* in CLAS in improving whole letter writing.

1) Application Process: In this evaluation, we asked 12 non-Japanese students who have used CLAS before, to practice "永" using CLAS in three stages. In the first stage, we asked them to write the whole of "永". Then, in the second stage, we asked them to freely select two hard portions among the five ones of "永" in Figure 5, and to practice them using the *letter portion practice function* up to three times for each portion. After that, in the last stage, we asked them again to write the whole letter using CLAS, and compared the two indices of the calligraphy results in the first and last stages.

2) Application Results: Table III shows the minimum, maximum, and average of *difference rate* and *teacher grade* of the letters before and after applying the letter portion practice function. It indicates that after the application, the average *difference rate* is reduced by 4.8% and the average *teacher grade* is increased by 31.6%. In general, most of the students obtained the highest grade after the application.

TABLE III
TWO INDICES FOR LETTER PORTION PRACTICE FUNCTION.

	Learning times	difference rate (%)		teacher grade	
		before	after	before	after
Min.	1	18.09	16.27	2	3
Max.	3	20.67	19.10	4	5
Ave.	2.58	19.28	18.34	3.08	4.5

3) T-test *Verification:* Table IV exhibits the *paired T-test* results. It suggests *t-value*$>$*t-table and p-value*$<$*0.05*, which means that there are significant differences between before and after the application in both indices. Therefore, the effectiveness of the letter portion practice function is confirmed even in the short time use.

TABLE IV
PAIRED *T-test* RESULT WITH α=0.05.

T-test	difference rate	teacher grade
t-value	3.634374427	−7.340392083
t-table	2.20098516	2.20098516
p-value	0.003926501	0.000014659
result	yes	yes

4) Hard Letter Portions: Table V presents hard letter portions for the students. The portions 2 and 3 consist of multiple basic brush strokes. Thus, they need to write different brush strokes continuously, which is considered challenging for novice students. The portion 5 needs the slow brush work in *Migibarai*, which can be also difficult for them.

TABLE V
SELECTED HARD PORTIONS BY STUDENTS.

hard portions	# of students
2 & 3	4
2 & 5	4
3 & 5	4

Figure 8 provides the example calligraphy results by students before and after applying the proposed function. It is observed that the result after application is better than the one before applying.

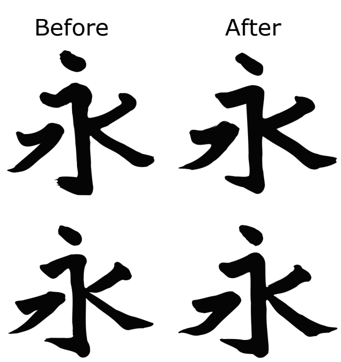

Fig. 8. Example calligraphy results by students.

D. Application to Various Letters

In the last evaluation, we validate the effectiveness of CLAS in writing other letters than “永”.

1) Application Process: In this evaluation, we prepared the model letters by the teacher and the CLAS contents for “一”, “十”, “山”, and “岡大”, and asked 13 Japanese and non-Japanese students in our group, to practice their calligraphy writing, first following the conventional method, and then, using CLAS. In addition, we asked them to answer the four questions in the questionnaire with five points.

2) Application Results: Table VI shows the minimum, maximum, and average of *difference rate* and *teacher grading* by the students for each content. This table indicates that the both indices by CLAS are better than those of the conventional in any content. It also suggests that “一” is much easier than the others where the *difference rate* is much smaller.

TABLE VI
TWO INDICES FOR FOUR CONTENTS.

letter		CLAS		conventional	
		difference rate (%)	teacher grade	difference rate (%)	teacher grade
一	min.	8.91	2	7.22	1
	max.	12.75	4	17.41	4
	ave.	10.89	3.23	12.89	2.54
十	min.	10.32	2	14.20	2
	max.	17.62	4	22.87	4
	ave.	15.55	3.38	19.21	2.62
山	min.	9.16	2	16.31	2
	max.	18.14	4	26.60	4
	ave.	15.90	3.08	22.19	2.85
岡大	min.	14.87	2	17.01	1
	max.	21.04	4	22.97	3
	ave.	18.01	2.85	20.17	2.46

3) Questionnaire Results: Table VII offers the questionnaire results. For further details, 64% of the students answered that they could learn *calligraphy* more efficiently by CLAS than the conventional method. 65% reported that they could write excellent calligraphy, whereas 7% of them did not. 85% agreed that CLAS is simple to operate for learning *calligraphy*. 64% expressed that their motivations for learning calligraphy were increased after using CLAS, whereas 7% did not agree because they have been familiar with the conventional method.

TABLE VII
QUESTIONNAIRE RESULTS ON SYSTEM USABILITY.

		1	2	3	4	5	
learning speed	slow	0	0	5	6	3	quick
calligraphy shape	poor	0	1	4	5	4	beautiful
easy use	hard	0	0	2	9	3	easy
learning motivation	useless	0	1	4	6	3	useful

However, specific students may find it challenging since they cannot see the brushwork in the video occasionally that is covered up by the teacher's hand, as shown in Figure 9. The alleviation of this cover-up problem will be discussed in future works. Besides, several students commented that adding the brushwork instructions and adjusting the play back speed can be effective to further improve this system, which will be also included in future works.

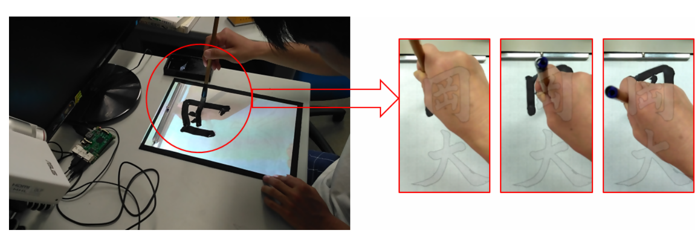

Fig. 9. Hidden brushwork by teacher ’ s hand.

VII. CONCLUSION

This paper presented the *calligraphy learning assistant system (CLAS)* using *projection mapping* for self-learning of *calligraphy*. The *letter portion practice function* was incorporated in CLAS to allow a learner to repeat the hard portions of each letter. The effectiveness of CLAS was verified through applications to students in Okayama University coming from various countries. In future works, CLAS should be improved by tackling the brushwork cover-up problem by the teacher's hand, adding brushwork instructions, adjusting the play back speed, and implementing the evaluation method of the stroke quality.

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