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Title	CalliShadow: Interactive User Guidance for Calligraphic Practice
Author(s)	何, 之舟
Citation	
Issue Date	2020-03
Type	Thesis or Dissertation
Text version	author
URL	http://hdl.handle.net/10119/16332
Rights	
Description	Supervisor: 宮田　一乗, 先端科学技術研究科, 修士（知識科学）

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Japan Advanced Institute of Science and Technology

Master's Thesis

CalliShadow: Interactive User Guidance for Calligraphic Practice

HE, Zhizhou

Supervisor: Kazunori Miyata

Graduate School of Advanced Science and Technology
Japan Advanced Institute of Science and Technology
(Knowledge Science)

February. 2020

Abstract

The number of overseas Japanese language learners have increased largely in recent decades, it’s about 28.7 times compared to 30 years according to the statistical data from the Japan National Foundation. The number of students studying in Japan is also growing every year. This tendency is an opportunity for Japan to effectively export their cultural industries, such as anime culture, flower arrangements, and Japanese scriptures, overseas.

Meanwhile, it has brought a lot of development opportunities for China due to China's rapid economic growth in recent years. The business economy has developed rapidly, and more and more foreign investors are willing to cooperate with Chinese companies. With the support language and culture from the Chinese government, the Confucius Institute has spread Chinese culture to all parts of the world, including the traditional Chinese calligraphy and painting.

The calligraphy is similar in both Japanese and Chinese. Because of the global implementation of the soft power of Japanese and Chinese cultures, more and more foreigners are fond and want to participate in the specialized learning of calligraphy. However, the study of calligraphy has always been a challenging task for people without cultural background. It is difficult for novices to understand the features of Chinese characters such as balance, stroke order, and stroke thickness.

In the previous works of calligraphy practice training and support, one study has analyzed the speed of calligraphers writing of specific fonts, detected the pressure of the writing brush in strokes, and visualized different parts of the character with different colors. Finally, the previous study projected the images onto paper to guide calligraphy learners. The other approach used electrically stimulation on the wrist to notice the learners the correct length and angle of strokes in calligraphy fonts. Besides, there are researches on the mobile terminal's form, which demonstrates the correct stroke order of calligraphy characters in 2D and 3D modes and captures the user's font and target font to evaluate the user's calligraphy quality through algorithms accurately.

However, these calligraphy practice training and support studies are not enough for calligraphy learners to experience the joy of calligraphy practice. The calligraphy support system proposed in this thesis takes into account the traditional immersion of maintaining calligraphy practice and the accuracy of calligraphy practice. The projector camera system is used to provide a variety of calligraphy learning modes for calligraphy learners, it can provide writing suggestions for each stroke of calligraphy font. The user can choose the most suitable font shape based on learner's calligraphy font style.

The proposed calligraphy support system can blend a variety of font pictures and provide users the choice of guidance through font transparency projections. Meanwhile, the user can select the gray font recommendation mode and color font recommendation mode. The principle for realizing these functions is to perform image contour matching multiple times and sort the similarity between fonts in the database and current writing fonts. Then, font images of different layers are selected to be blended, and the colors of the pixels of the font image can be replaced, according to the user's needs of the calligraphy support mode selected.

To verify the effectiveness and reliability of the calligraphy support system, the proposed system performed evaluation experiments using the proposed system. A questionnaire is used to analyze the subjective evaluation of users. Meanwhile, the user study compared the standard type difference between the typeface written by the user in the traditional calligraphy practice mode and using the calligraphy support system. In terms of the subjective and objective analysis results, this thesis concludes that the proposed system can help user understand the stroke order and font structure for beginners unfamiliar with Calligraphy characters and improves the early learning effect of calligraphy practice. In addition, the system can help them adjust the calligraphy font and deepen their understanding of brush movement for advanced learners who are already familiar with calligraphy writing.

As future work, this work can use more accurate font matching algorithm to reduce the mismatching error rate. A new interaction mode can also be adopted for users to adjust the refresh interval of font projection with more freedom.

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Chapter 1 Introduction

The research background, research purpose, research contribution, and thesis structure constitute this chapter.

In the research background section, this chapter introduced that learning calligraphy has gradually become a trend, which has led to a shortage of calligraphy education sources and a lack of calligraphy teachers. Meanwhile, this chapter pointed out some calligraphy writing mistakes that beginners often make and some places that are difficult for beginners to understand.

To make the calligraphy teacher resources more effective and reasonable, this thesis has developed calligraphy learning support system to help calligraphy learners better feel and understand calligraphy learning.

In the thesis' structure section, we briefly introduced the structure of the whole thesis.

1.1 Research Background

1.1.1. Survey of Japanese learners

As a developed country, Japan has always attracted people from all over the world with its economic strength and excellent cultural industries. According to statistics from the National Foundation of Japan, the number of overseas Japanese language learners has been increasing in recent decades.

Looking at the results of the past 11 years surveys from the 1979 survey to the 2015 survey, the number of Japanese schools increased from 1,145 to 16,179 (14.1 times), the number of teachers increased from 4,097 to 64,108 (15.6 times). Meanwhile, the number of Japanese learners has increased significantly from 127,167 to 3,655,024 (28.7 times) [1].

Figure 1.1 shows the number of Japanese language learners in different years and their growth trends. Meanwhile, Table 1.1 shows the distribution and number of Japanese learners, Japanese teachers, and Japanese schools in 2015. From the table, the number of Japanese language learners in the world is far higher than the number of Japanese teachers.

Region	Institution		Teacher		Learner	
	(Institution)	%	(people)	%	(people)	%
East Asia	5981	37.0	37868	59.1	1763420	48.2
Southeast	3913	24.2	10357	16.2	1094437	29.9

Asia						
South Asia	408	2.5	1277	2.0	40795	1.1
Oceania	1965	12.1	3277	5.1	392348	10.7
North America	1640	10.1	4621	7.2	190599	5.2
Central America	102	0.6	424	0.7	11637	0.3
South America	481	3.0	1719	2.7	38152	1.0
Western Europe	1127	7.0	2786	4.3	83559	2.3
Eastern Europe	398	2.5	1346	2.1	27154	0.7
Middle East	75	0.5	187	0.3	4054	0.1
Northern United States	21	0.1	120	0.2	1777	0.0
United States	68	0.4	126	0.2	7092	0.2
worldwide	16179	100.0	64108	100.0	3655024	100.0

Table 1.1: The numbers of institutions, teachers and learners in 2015. In: Survey Report on Japanese-Language Education Abroad 2015(English Ver.). Japan Foundation

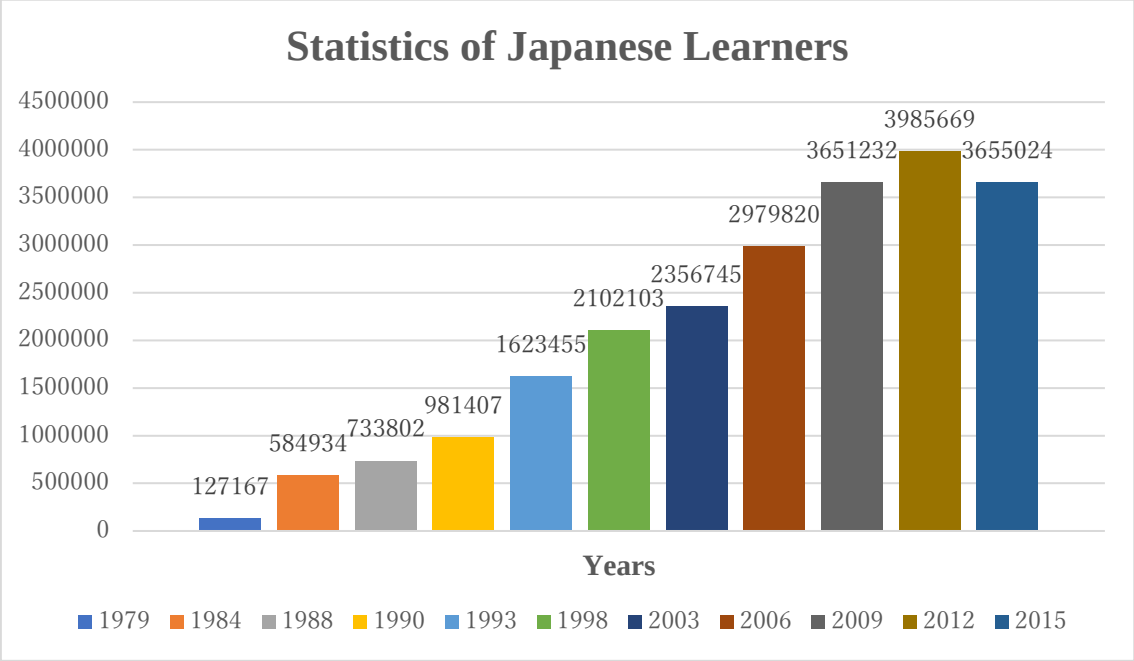


Figure 1.1: Number of Japanese learners over the years. In: Survey Report on Japanese-Language Education Abroad 2015(English Ver.). Japan Foundation

The growing trend of Japanese language learning means that more and more people will come to study in Japan every year. According to statistics from the Japan Student Services Organization, the number of international students in Japan in 2018 reached 298,980, an increase of 31,938 compared with 2017, a growth rate of 12% [2]. Figure 1.2 shows the number of international students studying in Japan from 1978 to 2018. It is clear from the figure that the number of international students studying in Japan is increasing every year.

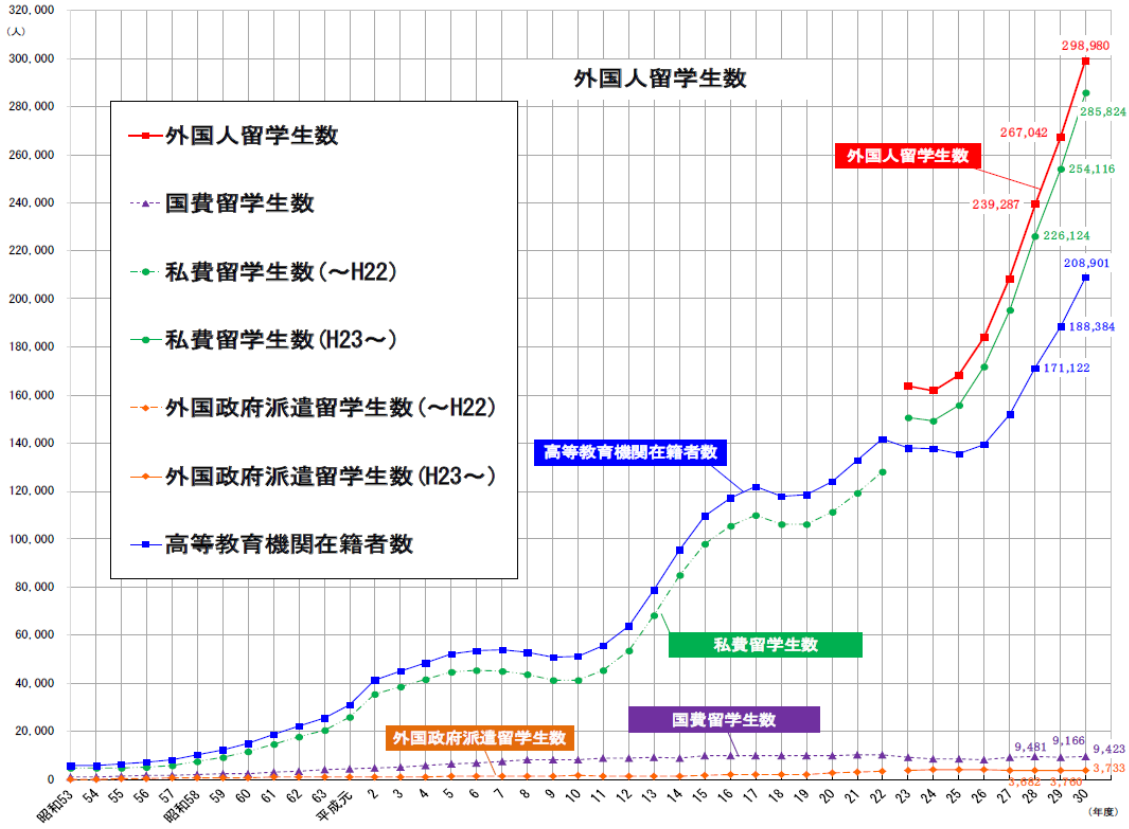


Figure 1.2: Number of students studying in Japan over the years. In: Survey on enrollment status of foreign students in 2018. Japan Student Services Organization

Japanese developed economy occupies a dominant position in all countries in the world, attracting people from all over the world to come to learn. In addition, the successful export of the cultural industry is also the main driving force to attract a large number of overseas people to learn Japanese and study in Japan. Thriving cultural industries include anime culture, geisha, flower arrangements, Shodo Calligraphy, and so on.

In the above-mentioned background, more and more people from non-East Asian culture countries are willing to learn about calligraphy and want to try to write calligraphy fonts by themselves.

1.1.2. Survey of Chinese learners.

Compared with Japan, which has stable economic growth, China's rapid economic growth in recent years has brought China a lot of development opportunities. The business economy has developed rapidly, and more and more foreign investors are willing to cooperate with China. The prerequisite for successful cooperation is language communication, so the language foundation is particularly important. At the same time,

in recent years, the Chinese government has vigorously encouraged the development of the cultural industry economy, promoted the export of cultural soft power, and actively established Confucius Institutes overseas. Under the dual role of economy and policy, there are more than 100 million Chinese speakers and Chinese learners overseas.

According to the 2018 Confucius Institute Annual Development Report, 548 Confucius Institutes 1,193 Confucius Classrooms and 5,665 teaching sites in 154 countries (regions) have been established by the end of 2018. In 2018, 6.8 million people took the Chinese Proficiency Test. The number of candidates taking the Chinese proficiency test increases at a rate of 15% -25% each year. Figure 1.3 shows the number of foreigners who took the Chinese Proficiency Test from 2008 to 2018.

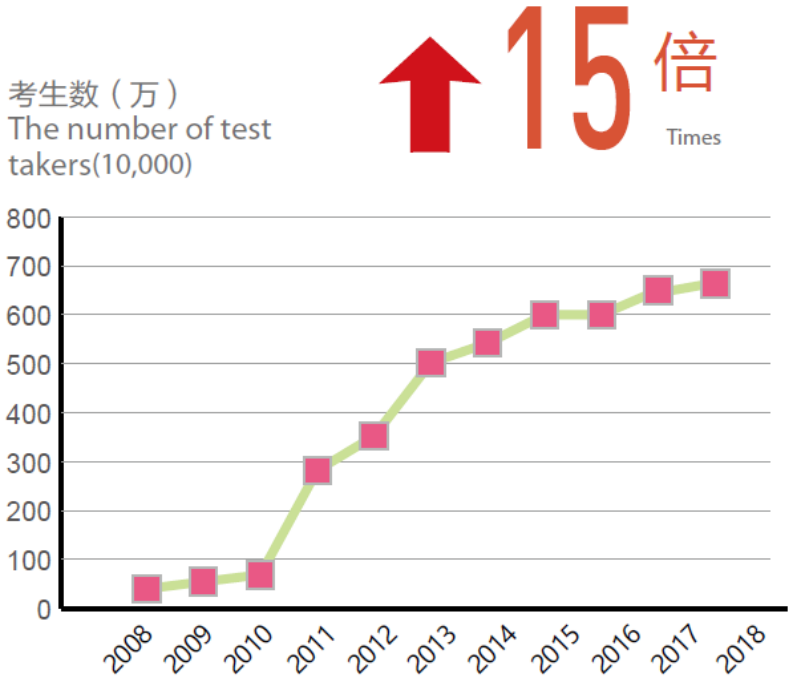


Figure 1.3: Students taking Chinese language tests. In: Confucius Institute Annual Development Report 2018. Confucius Institute Headquarters (Hanban)

The rapidly growing trend of Chinese language learning has also led to the hosting of Chinese cultural events. According to statistics, in the last decade, 220,000 cultural activities have been held by Confucius Institutes (classrooms) worldwide, attracting a total of 100 million participants. In 2018, more than 12 million people participated in Chinese cultural events (see in figure 1.4). These Chinese cultures include traditional Chinese calligraphy and painting. Figure 1.5 shows the "Chinese Painting and Calligraphy Exhibition" organized by the Confucius Institute. Most people involved in cultural activities have great passion and interest in calligraphy [3].

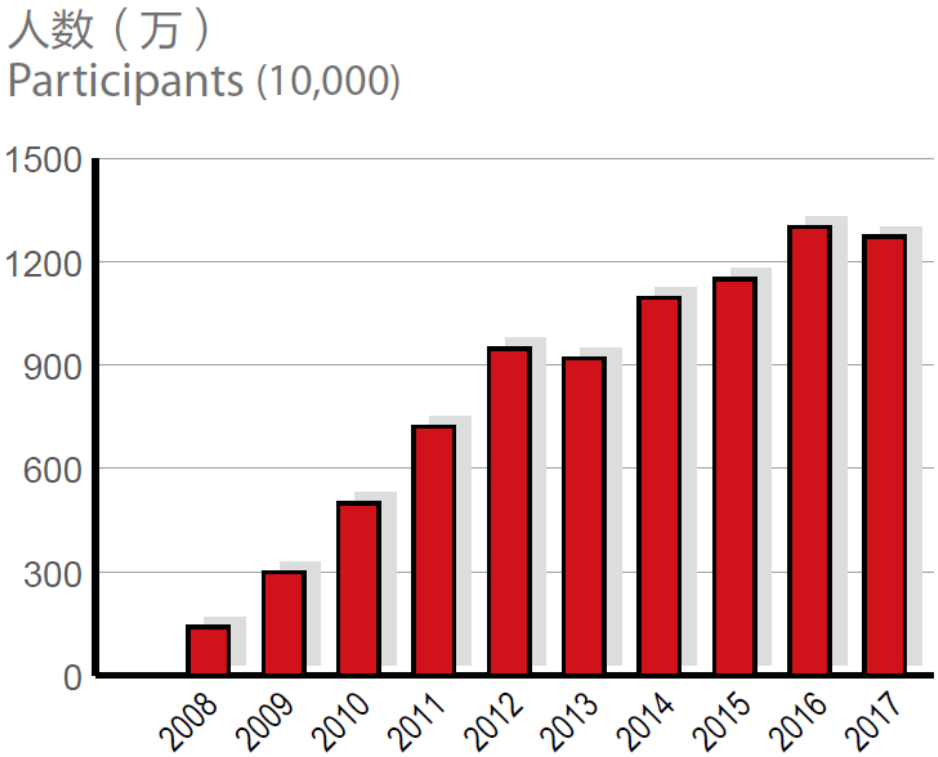


Figure 1.4: The number of participants in cultural activities. In: Confucius Institute Annual Development Report 2018. Confucius Institute Headquarters (Hanban)

Figure 1.5: the "Chinese Painting and Calligraphy Exhibition" organized by the Confucius Institute. http://www.hanban.org/article/2014-10/13/content_556298.htm [Accessed: 6 January 2020].

1.1.3. Calligraphy classification

Calligraphy originated from China and has developed in Japan. At present, the mainstream calligraphy in the world is Japanese “shodo” and Chinese “shufa”. "shufa" and "shodo" are very similar and versatile in brush use. Calligraphy is not only loved and supported by the people of China and Japan but also attracts people of different nationalities to learn and experience calligraphy.

The American Society of “Shufa” Calligraphy Education conducted a survey of calligraphy interest in primary and middle schools in Cleveland, and the results showed that 80% of students and teachers in Cleveland primary and secondary schools were interested in calligraphy [4].

1.1.4. Novice’s common mistakes

A previous study is aimed at analyzing the errors and causes of calligraphy practice for beginners of American calligraphy [5]. This work pointed out that beginners often make 8 mistakes:

1) Lack of application of Chinese philosophy
2) Missing partial strokes
3) Misplaced strokes
4) Mismatched strokes
5) Misshapen curved strokes
6) Wrong stroke size or overall font size error
7) Angled vertical strokes
8) Font size out of proportion.

This work pointed out that some students, especially those who have never practiced Chinese in the past, often needed repeated instruction when they started practicing calligraphy.

Limited by time and place, calligraphy instruction only can be taught in the classroom by professional teachers. meanwhile, students have the problem of forgetting skills, which requires an enormous labor cost to correct the mistakes of beginners repeatedly. Besides, beginners of calligraphy may experience the wrong order of writing strokes in the process of calligraphy.

1.2 Research Purposes

Because the increasing number of calligraphy learners, more calligraphy professional teachers are required to provide guidance. However, the American Society of Shufa

Calligraphy Education has confirmed that the supply of calligraphy professionals cannot meet the demand of a large number of overseas calligraphy learners. At the same time, beginners often make some elementary mistakes when learning calligraphy. Repeatedly correcting the elementary mistakes of beginners in calligraphy is not efficient in the use of teacher resources.

We aim to make more effective and reasonable Teacher sources so that calligraphy teacher resources can be used more to transform beginners into advanced learners of calligraphy. Therefore, we have developed a calligraphy learning support system, which can be used to support calligraphy learning for beginners of calligraphy anytime, anywhere, without any time and place restrictions through simple equipment construction. Finally, the effectiveness of the calligraphy font evaluation algorithm is verified. In terms of font weight, font outline, and font balance. We compare the calligraphy fonts written by the experimenter before and after using the calligraphy support system and evaluate them.

1.3 Research Contributions

In the proposed calligraphy support system, this work projects over laid font images to guide calligraphy learners. We compared with previous related research, our system has the following advantages:

- Multi-layer matching calligraphy style recommendation.
- Restore real traditional calligraphy practice environment.
- Visualize calligraphy stroke shape details.
- Visualize calligraphy stroke writing order.

1.4 Thesis' Structure

This thesis consists of 6 chapters. Chapter 1 describes and introduces the research background, research purpose, and contribution of the calligraphy support system proposed in this thesis. In Chapter 2, the thesis focuses on research related to calligraphy writing practice and calligraphy support. Chapter 3 introduces the system design from the system framework, system assembly, and system operation process. Chapters 4 and 5 are designed to verify the validity of the system and evaluate the efficacy of the experimental results. Chapter 5 proves the effectiveness of the proposed calligraphy support system through both subjective evaluation and objective font data statistics. In chapter 6, we make a conclusion that *CaliiShadow* effectively guide calligraphy learners to learn calligraphy.

Chapter 2 Related Works

This chapter briefly introduces the research results and contributions made by researchers in the field of calligraphy writing and calligraphy fonts.

2.1 Calligraphy support system.

2.1.1. Calligraphy-assisted practice

Nakamura et al. proposed a novel font called "Beautifying Font" to assist calligraphy learners in learning Chinese calligraphy skills [6]. By analyzing the speed at which a calligrapher writes a particular typeface and detecting the pressure generated by the brush when writing strokes, they painted different parts of the typeface with different colors. These colors represent how fast the strokes are written, red for pauses, and green for fast writing. Experts rate the fonts written by users to verify the effectiveness of the system. The Beautifying Font system's implementation overview is shown in figure 2.1.

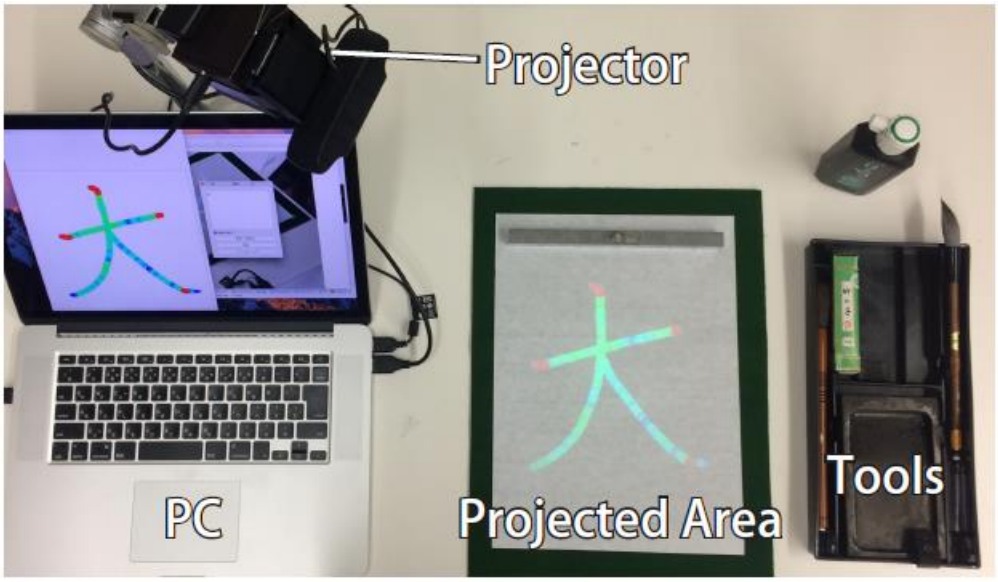


Figure 2.1: The Beautifying Font system's implementation overview.

Narita et al. used another method to support calligraphy learners [7]. They capture the three-dimensional information of the brush to the nib to achieve the speed, pressure, and direction of the writing brush required to guide calligraphy learning. This method can visualize the position and orientation of the brush, and at the same time, it can display the stroke track of the teacher through the projector. They verified the effectiveness of the

system by performing replication experiments using the proposed method. Figure 2.2 shows the overview of the calligraphy stroke learning system. Leap-motion is used to detect the three-dimensional position of the calligraphy brush.

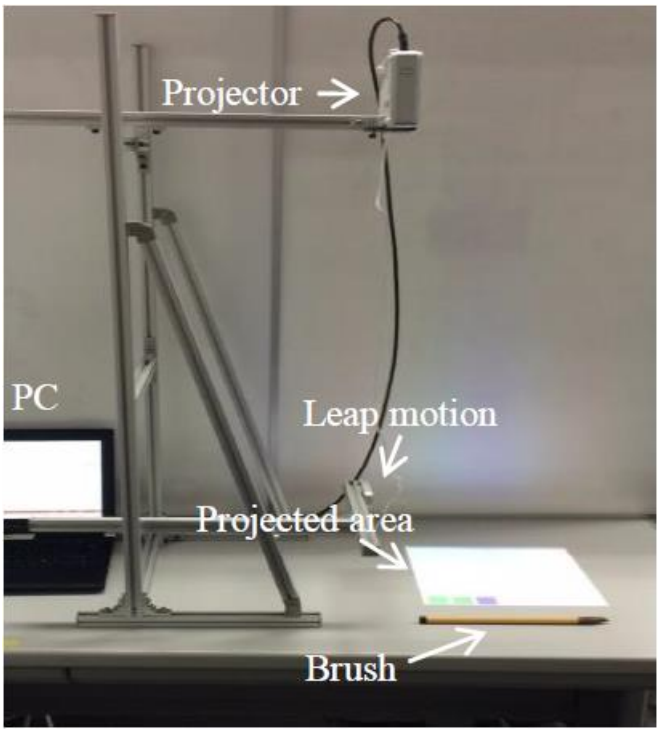


Figure 2.2: The overview of calligraphy-stroke learning support system.

2.1.2. Calligraphy font balance support system

Nonami et al. had built a font balance support system for calligraphy beginners [8]. This system solves the problem of separating paper from sample images in traditional calligraphy exercises, and users can intuitively observe the balance of fonts. Because the calligraphy practice paper has translucency, the calligraphy paper is covered on the tablet computer for writing, and then the tablet computer records user writing track data. They built a font balance algorithm to check the balance of the font.

2.1.3. Virtual Reality based calligraphy simulation

Some studies have supported the study of calligraphy by simulating the calligraphy learning process through virtual reality. N. Muranaka et al. believes that the feel of a calligraphy writing brush cannot be felt from a traditional tablet pen [9]. Therefore, they developed a brush-type input device that display the feel of a brush. Meanwhile, by using a half mirror to filter out part of the hand image, so as to achieve the combined effect of

simulation virtual and reality. The user completes the practice of calligraphy according to the prompts of the calligraphy font animation, thereby achieving the effect of supporting calligraphy learning.

Because the calligraphy ink would cause dirt and odor, Makoto Kobayashi et al. built a calligraphy practice system based on Leap-motion to improve this traditional learning environment [10]. The system can realize virtual writing with a brush on a computer. The purpose is to make calligraphy easy and fun while taking into account the study of calligraphy techniques. They proved that the handwriting formed by the system has a high quality through a questionnaire survey.

2.2 Calligraphy and painting training system

2.2.1 Research on calligraphy training system

In the research of calligraphy training systems, many researchers have made efforts. Ami Morikawa et al. had developed a self-training system for calligraphy strokes to guide and correct learners' correct calligraphy strokes [11]. The Leap-motion sensor measures the student's strokes, and if the handwriting is incorrect, it will irritate the student's wrist. In this way, learners are told the correct length and angle of the strokes in the calligraphy font.

Weiliang Chang et al. constructed a calligraphy learning training system in a virtual environment [12]. The system uses a force-reflex joystick as an input device to achieve the effect of copying traditional calligraphy. Besides, the system provides visual and tactile feedback to immerse users in a virtual writing environment. Comparing the images produced by calligraphy learners before and after using the system, the validity of the experiment is verified.

To enable calligraphy learners to intuitively learn skills that are difficult to inherit in Japanese calligraphy training, Hiroaki Nishino et al. constructed a virtual calligraphy training system [13]. This system uses a commercially available haptic device called PHANTOM to simulate a writing brush in a virtual training space and implements a function of recording and replaying teacher’s actions. When writing calligraphy fonts, system records their writing skills, such as strokes and pressure, and effectively copy and present them to learners through the PHANTOM device. In this system, there is no need to worry about the consumption of ink and paper, and calligraphy training can be repeated.

Yingfei Wu et al [14]. realized the virtual Chinese calligraphy training system based on iOS. The system demonstrates the correct stroke order of calligraphy characters in 2D and 3D modes. Besides, it accurately evaluates the user's calligraphy quality by

comparing the captured user's font and the target font.

2.2.2 Research on painting training system

Mai Otsuki et al. improved the previously developed MR painting system, adding touch and movement effects that simulate the use of a brush device to paint on a virtual canvas to the existing MR system mechanism [15]. Meanwhile, a new painting brush device called MAI was constructed, which combined the brush with the upgraded MR system to give users the feeling of painting on virtual three-dimensional objects.

Yong Jae Lee et al. created the Shadowdraw system, which is a system for guiding the free graphics drawing of objects [16]. When the user draws, ShadowDraw dynamically updates the image outline under the user's stroke. The user draws an image based on the contours suggested by the shadows indicated by the system. Shadowdraw would match the images in the database according to the current stroke status of the user in real-time.

2.3 Research on Font Morphing

2.3.1 Coherent point drift algorithm

Zhouhui Lian et al. proposed a method that can deform the shape of Chinese characters in different styles [17]. First, they generate shape templates for each character in the standard Chinese font library, including skeletons, strokes, key points, and triangles connected by non-rigid point sets. Then, by applying the Coherent Point Drift algorithm, the two fonts are disassembled correspondingly, and a corresponding relationship is established. Finally, they constructed an isomorphic triangulation for the source and target character shapes. It solves the problem of establishing an accurate correspondence between two characters and also realizes the natural deformation of a complex shape composed of multiple discontinuous components.

2.3.2 Application of neural networks in calligraphy

Pengyuan Lyu et al. proposed a deep neural network-based model that can generate calligraphy images directly from standard font images [18]. Yue Jiang et al. used neural network to build a Chinese font generation system[19]. By training the CNN model, the system can synthesize high-quality structured fonts.

2.4 Calligraphic strokes trajectory reproduction.

Reproducing famous calligraphy works has always been a research area of great concern. Lijie Yang et al. Proposed work to progressively reproduce the writing process

of Chinese calligraphy works based on stroke trajectory estimation and writing rhythm control [20]. Their work has enabled the famous calligraphy "Wang Xizhi" 's representative work "Preface to Orchid Pavilion" to show the trajectory of calligraphy in real-time through animation.

Pengfei Xu et al. proposed a novel approach to help calligraphy learners understand the quality of the calligraphy fonts they write [21]. This method uses a deep neural network to combine multiple CNNs and LSTMs to detect the state of the writing brush. Their approach effectively enables learners to track the movement of brushes through video.

The calligraphy support system proposed in this thesis does not choose from the perspective of font deformation but instead decides to give users more calligraphy guidance while restoring the feeling of traditional calligraphy practice. Users can choose different guidance schemes by their wishes.

Chapter 3 System Design

This chapter will introduce the system design and elaborate on these three significant modules from system framework, system assembly, and system operation process.

In System Framework part, I will use the system input, data pre-processing, database preparation, system mode and algorithm principle, data projection, these six items to fully introduce the system framework part.

The System Assembly part includes the placement of the camera, the deployment of the projector, the limitation of the user's calligraphy writing area, the placement and selection of calligraphy tools.

Regarding the system operation process, I will explain the actual operation and precautions of CalliShadow from the two different calligraphy practice modes of the calligraphy support system.

This calligraphy support system was developed in Python.

3.1 System Framework

Figures 3.1 and 3.2 show the system framework of CalliShadow. Figure 3.1 represents the system framework of a single stroke hints mode, and Figure 3.2 represents the system framework of the whole stroke font hints mode. CalliShadow is suitable for calligraphy learners at different levels. Single stroke hints mode is used to help people who have no idea about the composition and stroke order of the font. Whole stroke font hints mode is for those who have a preliminary understanding of the structure of fonts and those who have experienced calligraphy practice.

In single stroke hints mode, learners use calligraphy brushes dipped in traditional Chinese calligraphy practice ink to write calligraphy on white paper as a system input. The camera captures every state of the user's calligraphy in real-time and matches the user's font data with the font model of database one in real-time and finds several models with higher matching. *CaliiShadow* has database 1 and 2 for single stroke hints mode, and database 3 and 4 for whole stroke hints mode. The database 1 stores images of the font after each writing, and the database 2 stores images of the font strokes. Here, the order of the pictures in the database 1 and database 2 is correspondingly marked. According to the corresponding relationship established between database 1 and database 2, find the next stroke picture corresponding to the model. According to the degree of matching, the image blending weight is determined. The higher the matching degree, the higher the weight of the font image when the image is mixed. The calligraphy support

system provides users with the next stroke suggestion through projection as an output part of the entire system.

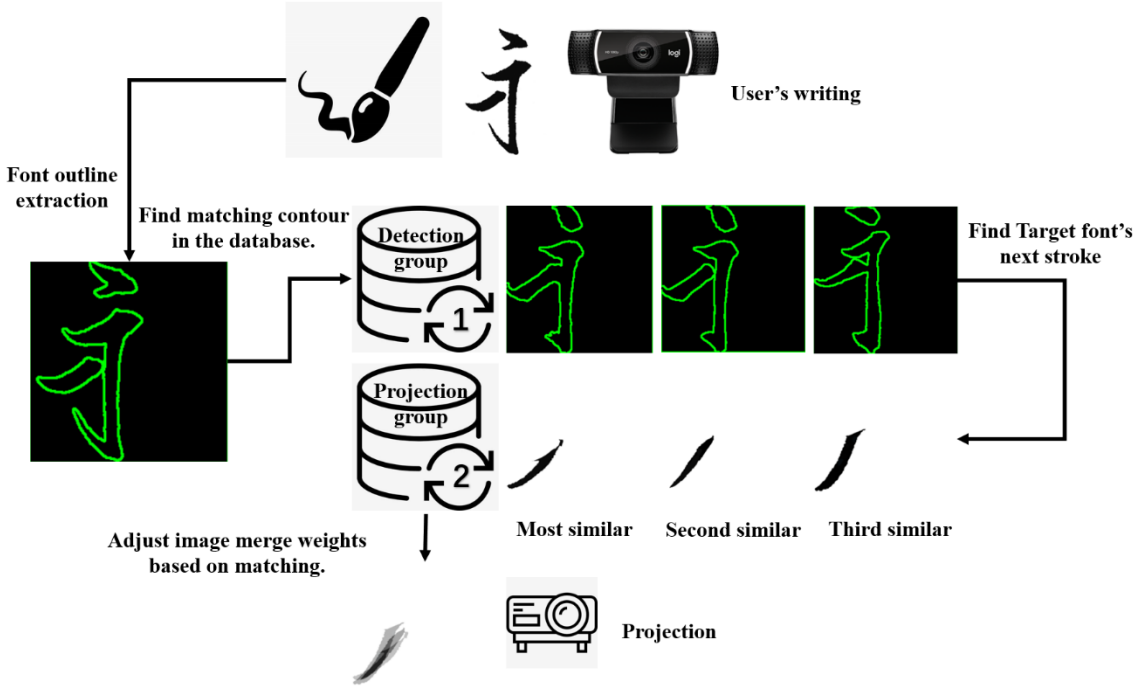


Figure 3.1: The Single stroke hints mode of calligraphy writing support system

In the whole stroke font hints mode, the learner uses the brush dipped in Chinese traditional calligraphy practice ink to write the first stroke of the calligraphy target font on white paper as a system input. The camera captures the current font writing status by taking pictures, and then the system compares the user's font with the font in the database. Database 3 stores the image of the first stroke of the font, and database 4 stores the complete image of the calligraphy font. The order of pictures in the database 3 and the database 4 also has a one-to-one correspondence. The system finds the most matching sets of data and find the entire font stroke corresponding to the model according to the correspondence between database 3 and database 4. According to the matching score, the image blending weight is determined. If the image matching score is high, the weight of the blending image is high. The whole stroke font hints mode provides users with the entire font stroke suggestions through projection as an output part of the system.

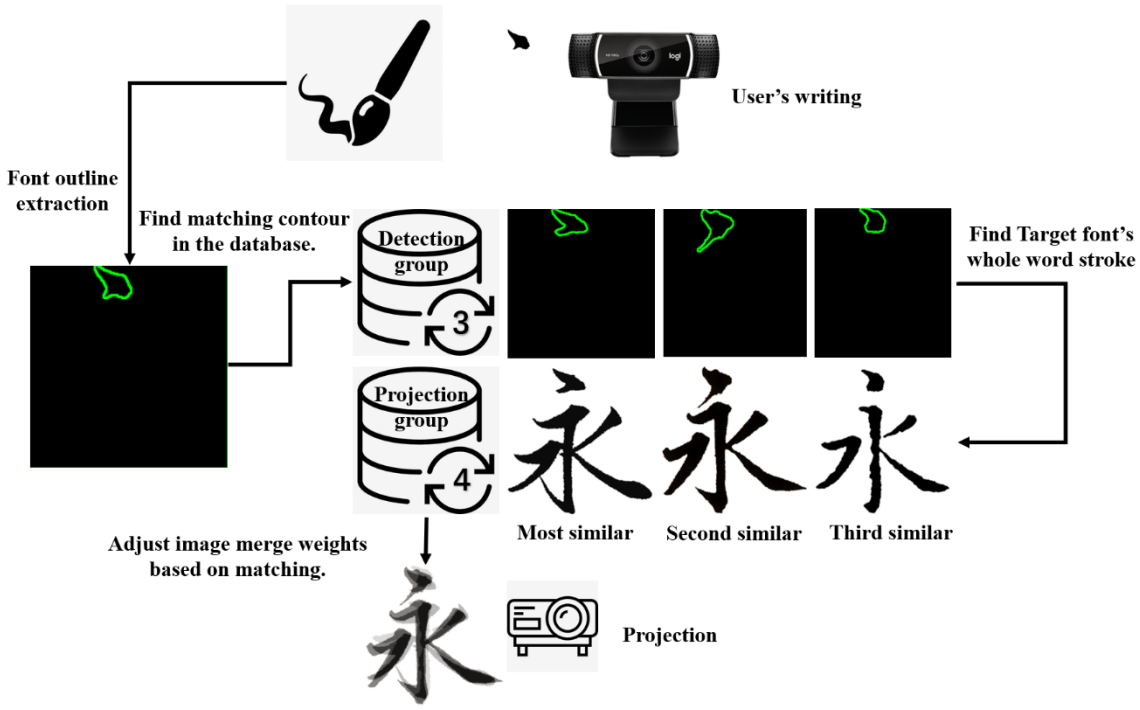


Figure 3.2: The Whole stroke font hints mode of calligraphy writing support system

3.1.1. System Input

The traditional calligraphy tools, including writing brush, ink, paper, ink tray, and Logitech C920 camera, are the components of the input part. Figure 3.3 shows all the tools used in the prototype system.

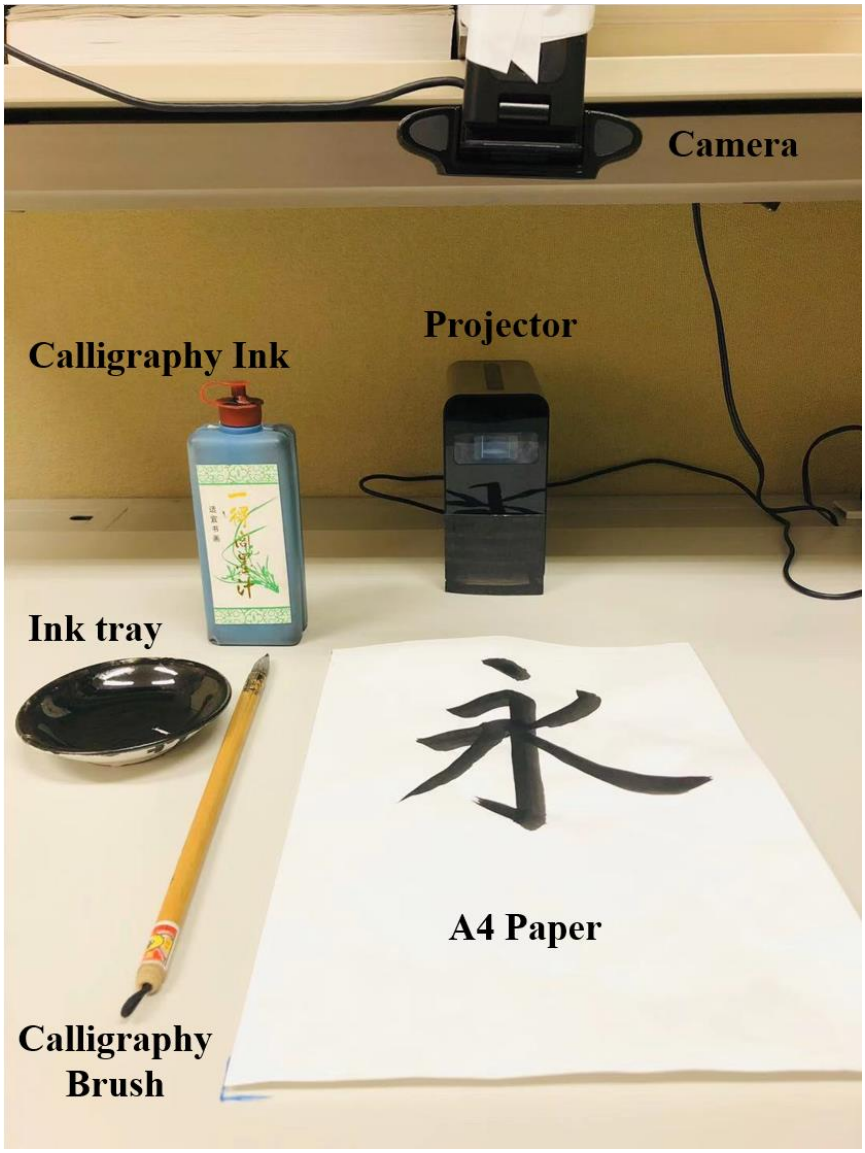


Figure 3.3: The developed prototype of calligraphy support system

The user writes calligraphy on A4 paper with a brush dipped in calligraphy ink, and the camera takes pictures of A4 paper by setting a fixed time interval and stores the photos in a specific folder. The vertical height of the camera is about 20cm ~ 25cm from the paper. Setting this distance can not only capture the entire content of the paper but also leave some free move space for the users.

In the prescribed writing area, the user can operate the paper to move it in a small range. The camera can still capture the entire contents of calligraphy fonts on calligraphy practitioner's paper.

3.1.2. Data pre-processing

Callishaow requires a certain number of pictures of the same font. With the open-source information on the Internet, we could find the works of calligraphers of different styles who have written this word in history. Many documents in Chinese history record the method called "yong" eight laws, and many famous calligraphers have commented on this method. The renowned Chinese calligrapher Xizhi Wang once said: "Although the writing and structure of the Chinese character "yong" is simple, its stroke composition includes all the strokes of Chinese characters in Chinese history. If you have written the word "yong" very well, then congratulations, your calligraphy study is half done. "

Thus, we found 20 masterpieces of Chinese character "yong" by very famous calligraphers, including Xizhi Wang, Gongquan Liu, Zhenqing Yan, Xun Ouyang, etc.

Their writing styles are completely different. Figure 3.4 shows the original artwork of a famous calligrapher in history. Some of the fonts are captured from the stele, and some of fonts are from historical documents that have been preserved for a long time. Therefore, there is a big difference in font color and background color. In addition, due to the aging of the material, some fonts are missing and eroded. We need to do some image processing on these source calligraphic picture data.

Figure 3.4: The word "yong" written by different famous calligraphers in history

The proposed system manually changes the font background color to white and the

font color to black by Adobe Photoshop. For the background image of the font with stains and small defects, we erased them uniformly. Under the premise of not affecting the shape and outline of the font, fill the small spots in the picture font. The reason for the filling operation is to ensure the sharpness of the font contour and to reduce the data interference caused by the calligraphy support system when it works.

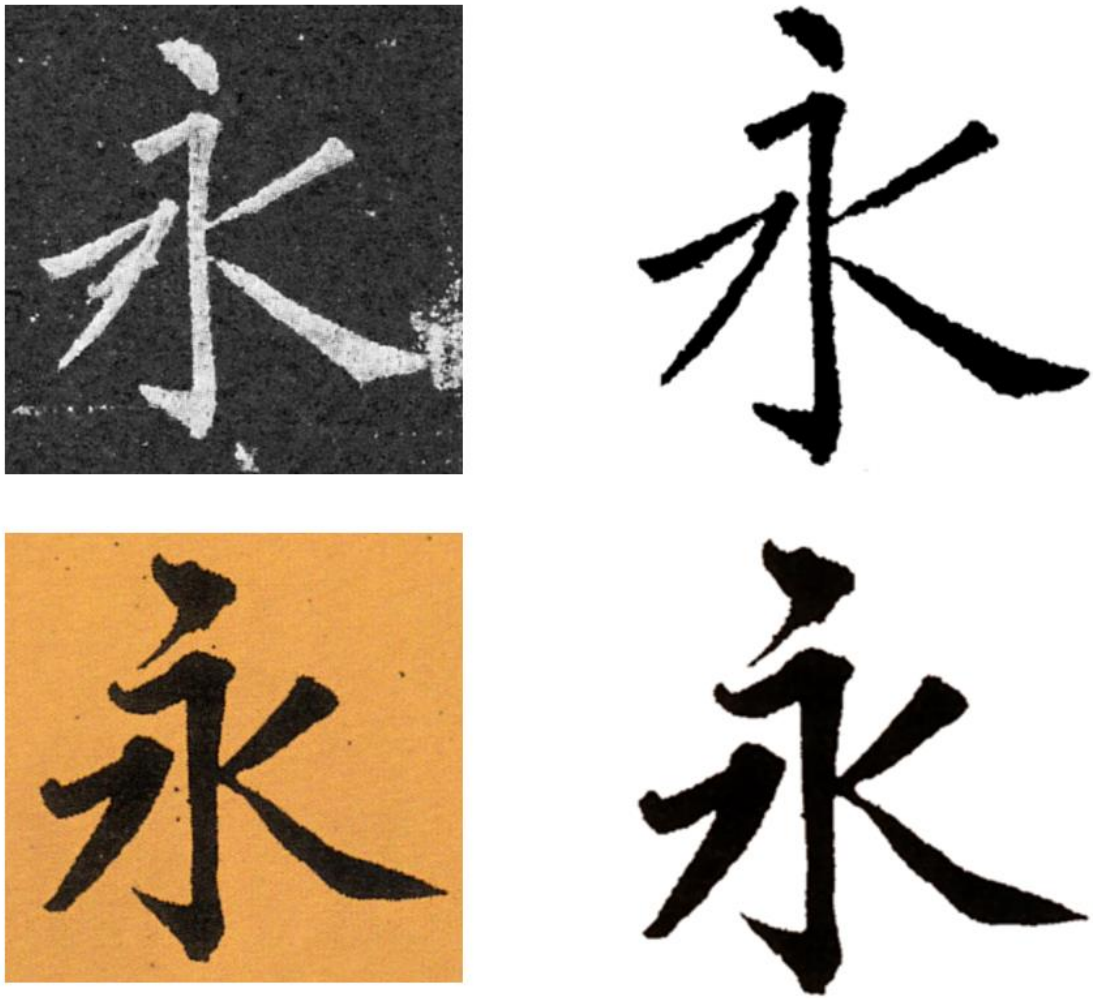


Figure 3.5: Image processing on the source calligraphic picture
Before image processing (left) and after the image processing (right)

Figure 3.6: Processed font image

Figure 3.6 shows the processed font data. we remove the unnecessary space around the font image and each processed font image, and set each font image to the same pixel size. The width is 227 pixels, and the height is 232 pixels. Under this setting, the computer can not only keep fast when processing a large number of pictures at the same time, but also have a better font projection effect.

3.1.3. Database Construction

The database of the calligraphy support system is composed of four groups. Due to different needs, we disassembled the "yong" font images into different states and put them into different database groups.

According to the writing order of the Chinese character "Yong", we divided "Yong" into 7 parts, which represent the possible shapes of the font in different writing states. For the user to complete the specified stroke writing within a specific time interval, we split the second stroke of the Chinese character "Yong" into two parts. Therefore, the font state of the database 1 is not completely divided according to the rules for writing strokes in Chinese characters, as shown in Figure 3.7.

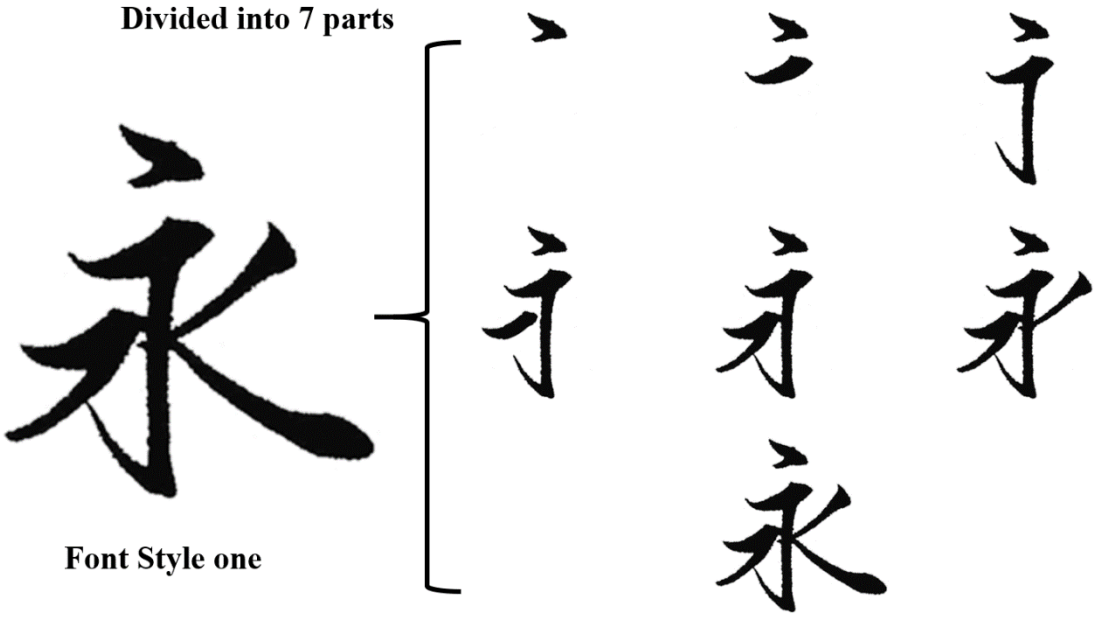


Figure 3.7: Font segmentation method for database 1

As mentioned in the sub-section 3.1.2 on preprocessing data, the font source data used by this calligraphy support system are 20 Chinese calligraphy works of "yong" from different styles of calligraphers in different historical periods. Database 1 divides each character into 7 parts, and there are 140 pictures in 20 words. Every 7 pictures are grouped, and the group represents the calligraphy state of a calligrapher's font.

Figure 3.8 shows the method of segmenting a single font in database 2. We segmented each "yong" character from the second stroke order to the last stroke order in the calligraphy writing and added the whole stroke image of the font to form a small group in database 2. Similar to database 1, there are 20 small groups and 140 images in database 2.

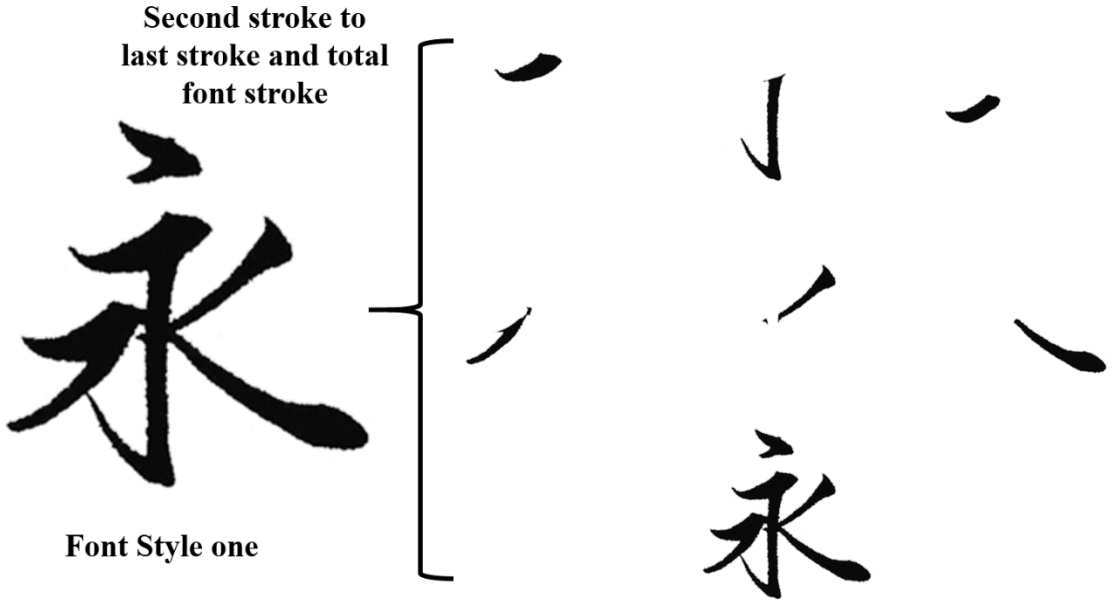


Figure 3.8: Font segmentation method for database 2

The database 3 is formed by extracting the first strokes of 20 pre-processed calligraphy fonts. In the database 3, the relationship between the number of pictures and the stroke extraction corresponds to the pre-processed font. The database 4 stores 20 pre-processed font pictures.

According to the functions to be implemented by the system, we divided database 1, 3 into detection groups, and database 2 and 4 into matching groups. Two detection group databases are used to match the user's current calligraphy writing trajectory in real-time. Two projection group databases are used to give users feedback on the most suitable writing style and font stroke order. Figure 3.9 shows the composition and quantity of the database.

Figure 3.9: Detection group database and matching group database

3.1.4. System operation principle and mechanism

This sub-section will introduce the operation and mechanism of the calligraphy

support system from three modules as follows: (1) Font contour extraction; (2) Images matching principle; (3) 4 modes of calligraphic support system.

(1) Font contour extraction

In the system input section, I have introduced the user 's font picture. By setting a fixed interval, the user 's font is taken with the camera and cropped to the same size as the picture in the data and stored in a specific folder. The image is 227 pixels wide and 232 pixels high.

Next, the user font image is binarized. Use the Python programming language to run the *Findcontour* instruction to mark and extract the outline of the font image. About the principle of the *Findcontour* algorithm [22]. The previous approach mainly introduced two algorithms for topological analysis of digital binary images. The first algorithm is to determine the surrounding relationship of the binary image boundary, which is to determine the outer boundary, the hole boundary and their hierarchical relationship. Because these boundaries have a one-to-one correspondence with the areas of the original image (the outer boundary corresponds to a connected area with a pixel value of 1 and the hole boundary corresponds to an area with a pixel value of 0), we can use boundaries to represent the original image. The second algorithm is a modified version of the first algorithm, which is essentially the same, but it only looks for the outermost boundary.

The idea of coding is used to determine outer boundaries, hole boundaries, and their hierarchical relationships. Because different integer values are assigned to different edges, we can determine where the edge is and the hierarchical relationship. The input binary image is an image of 0 and 1, and f (i, j) is used to represent the pixel value of the image. Each scan is terminated in two cases:

- $f\ (i, j-1)\ =\ 0,\ f\ (i,j)\ =\ 1$ $f\ (i,j)$ is the starting point of the outer boundary
- $f\ (i,j) >=\ 1,\ f\ (i,j\ +\ 1)\ =\ 0$ $f\ (i,j)$ is the starting point of the hole boundary

From the starting point, the pixels on the border are marked. Assign a unique identifier to the Newly Discovered Boundary (NDB). Initially, NDB = 1, each time a new boundary is found, plus 1. In this process, when f (p, q) = 1 and f (p, q + 1) = 0, f (p, q) is set to - NDB. This means that the endpoint of the right boundary was encountered.

(2) Images matching principle

While obtaining the outline of the user's calligraphy font, we also need to binarize all the images in the database and extract their font outlines. According to the different calligraphy practice modes required by calligraphy learners, image processing is performed on different database fonts. In this section, we will choose a three-layer font blended with a single stroke hint mode and a five-layer font blended with all font hint mode as an example to introduce CalliShadow's images matching mechanism, algorithm, and principle.

In a three-layer single stroke hints mode, we need to take pictures of the user's font status and extract contours at regular intervals, which means that we need to know the current writing status of the user's font. In 3.1.3 section, we have introduced the different functions of the four databases in detail. Therefore, in single stroke hints mode, we need to match the user font with the 140 pictures in the detection group database 1 one by one. And then, the system sorts the image by matching score from high to low. In the system mode shown in this example, we need to mix three layers of font pictures, so we need to find top three images from the matching score and record their image numbers. Then, through the correspondence between the detection group database and the projection group database. The system finds the same sequence of pictures in the projection group database and performs image blending. Finally, the image blending results are presented through a projector. The image is blended in pairs from the lowest matching image to the highest one, and the blended weight of the two images is set to 50% each. The system blended the selected matching pictures in the database 1 multiple times to form a blended picture with gradually decreasing transparency (see Figure 3.10).

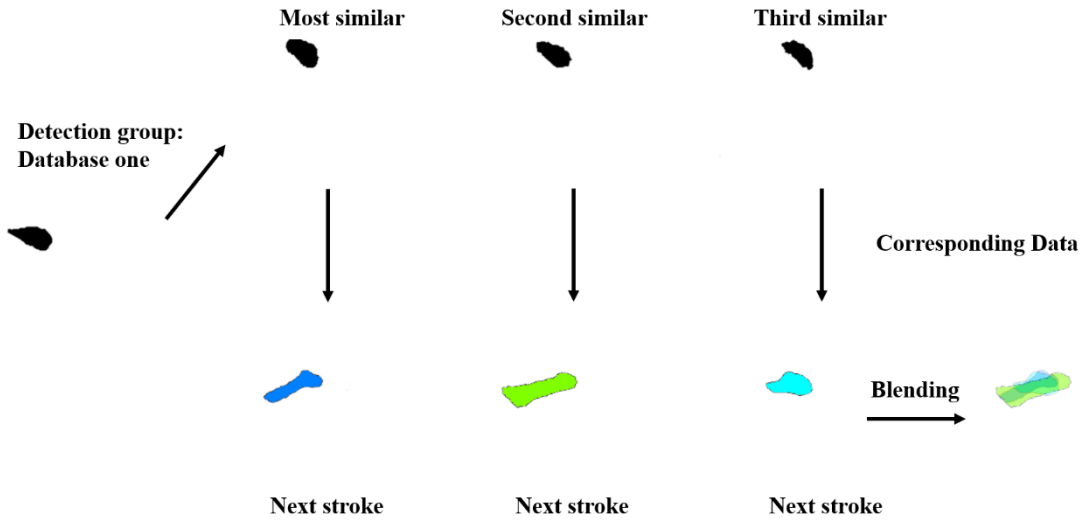


Figure 3.10: Three-layer color single stroke hints mode's framework

In a five-layer whole stroke hints mode, the system operation mechanism is similar to a three-layer single stroke hints mode, but there is no need to set a fixed time interval to take pictures and extract contours. Only after the user finishes the first stroke of the calligraphy font "yong", takes a photo and extracts the outline, and then performs database font matching, and finds a corresponding picture of the entire font according to the database correspondence. The mode operation mechanism is shown in Figure 3.11.

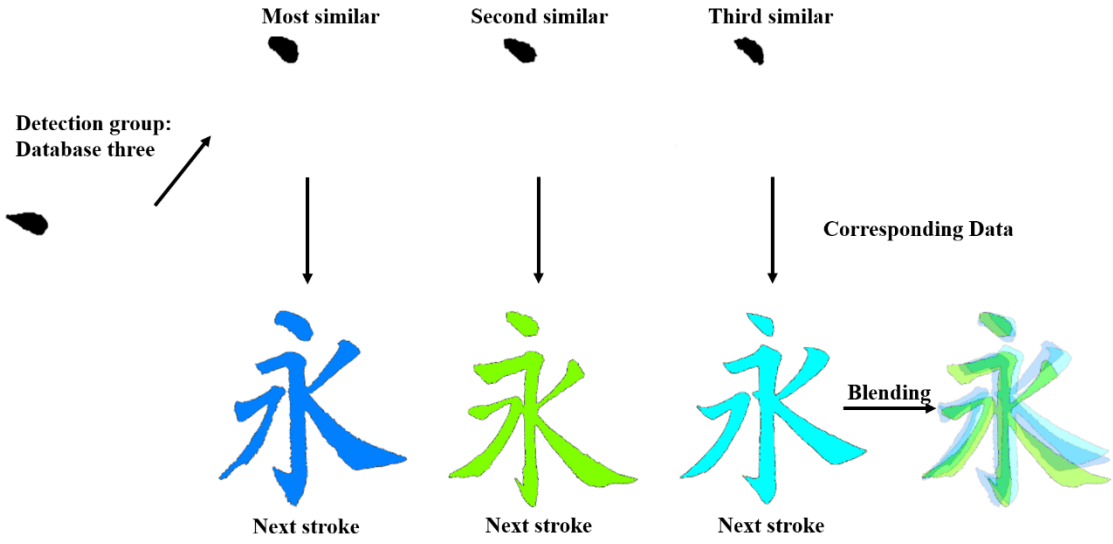


Figure 3.11: Five-layer color whole stroke hints mode's framework

The algorithm principle of font contour matching is derived from the HU moments theory [23]. Half a century ago. When the density distribution function changed, the

essence of the image did not change, but the density distribution shifted. Although the values of the moments may change at this time, the invariant moments calculated from the moments still have a translation, rotation, and scale invariance.

Our proposed system adopted the image features of the HU moments with translation, rotation, and scale invariance.

In the continuous case, the image function is f(x,y), then the p + q order geometric moment (standard moment) of the image is defined as:

$$m_{pq} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x^p y^q f(x,y)\,dx\,dy \qquad p,q = 0,1,2\ldots \qquad (1)$$

The center distance of p + q order is defined as:

$$\mu_{pq} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (x-\overline{x})^p (y-\overline{y})^q f(x,y)\,dx\,dy \qquad p,q = 0,1,2\ldots \qquad (2)$$

Where $\overline{X}$ and $\overline{Y}$ represent the center of gravity of the image.

$$\overline{x} = m_{10}/m_{00} \qquad \overline{y} = m_{01}/m_{00} \qquad (3)$$

For discrete digital images, use summation instead of integration:

$$m_{pq} = \sum_{y=1}^{N}\sum_{x=1}^{M} x^p\, y^q f(x,y) \qquad p,q = 0,1,2\ldots \qquad (4)$$

$$\mu_{pq} = \sum_{y=1}^{N}\sum_{x=1}^{M} (x-\overline{x})^p (y-\overline{y})^q f(x,y) \qquad p,q = 0,1,2\ldots \qquad (5)$$

N and M in Equations (4) and (5) represent the height and width of the image, respectively.

The physical meaning of each moment:

- 0th moment (m00): the quality of the target area
- 1st moment (m01, m10): the centroid of the target area
- 2nd moment (m02, m11, m20): the radius of rotation of the target area
- 3rd moment (m03, m12, m21, m30): the orientation and slope of the target area, reflecting the distortion of the target

The normalized center distance is defined as:

$$\eta_{pq} = \mu_{pq}/({\mu_{00}}^{\rho}) \qquad \rho = (p+q)/2 + 1 \qquad (6)$$

Using the second- and third-order normalized center moments, seven invariant moments M1 ~ M7 are constructed:

$$M1 = \eta_{20} + \eta_{02}$$

$$M2 = (\eta_{20} - \eta_{02})^2 + 4{\eta_{11}}^2$$

$$M3 = (\eta_{30} - 3\eta_{12})^2 + (3\eta_{21} - \eta_{03})^2$$

$$M4 = (\eta_{30} + \eta_{12})^2 + (\eta_{21} + \eta_{03})^2$$

$$M5 = (\eta_{30} + 3\eta_{12})(\eta_{30} + \eta_{12})((\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2)$$

$$M6 = (\eta_{20} - \eta_{02})((\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2) + 4\eta_{11}(\eta_{30} + \eta_{12})(\eta_{21} + \eta_{03})$$

$$M7 = (3\eta_{21} - \eta_{03})(\eta_{30} + \eta_{12})((\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2) - (\eta_{30} - 3\eta_{12})(\eta_{21} +$$

$$\eta_{03})(3(\eta_{30}+\eta_{12})^2-(\eta_{21}+\eta_{03})^2) \quad (7)$$

These seven invariant moments constitute a set of feature quantities that are used to identify large objects in the image, such as characters, which have better results.

(3) 4 modes of calligraphic support system.

There are four main modes of *CaliiShadow* proposed in this thesis for users.

(1) Gray-scale whole word hints
(2) Gray-scale whole stroke hints
(3) Color whole word hints
(4) Color single stroke hints

In each mode, the system can provide three different types of font images blending projection. They are one-layer font image projection hint, three-layer font image blended projection hint, and five-layer font image blended projection hint.

Figure 3.12 shows a five-layer font image blended projection hint. Color hints are a slight improvement on gray-scale hints. Before mixing the pictures, the RGB pixel color conversion is performed on the font image selected by the system according to the matching degree with the user font. The color arrangement is red (R: 255 G: 0 B: 0) and orange (R: 255 G: 128 B: 0), green (R: 128 G: 255 B: 0), blue (R: 0 G: 128 B: 255) and cyan (R: 0 G: 255 B: 255).

Figure 3.12: The mode of the five-layer color whole stroke hints
color hints (left) and gray-scale hints (right)

3.2 System Assembly

3.2.1. Camera placement

The camera used in this calligraphy support system is a Logitech C920 HD 1080P camera. With the front of the camera facing down vertically, adjust the horizontal direction of the camera so that the pictures taken are not inverted. Setting the vertical height of the camera is about 20cm ~ 25cm from the paper. In this distance the camera can not only capture the entire content of the paper but also leave some free move space for the users.

Logitech C920 HD 1080P camera has an automatic focus function. We need to turn off the automatic focus function and change it to manual focus. The reason for this setting is to reduce the error caused by the refocusing of the camera due to the hand and writing pen entering the camera shooting range during system use. The characters with the focal length fixed on the paper can be displayed most clearly. The specific parameter settings are shown in Figure 3.13.

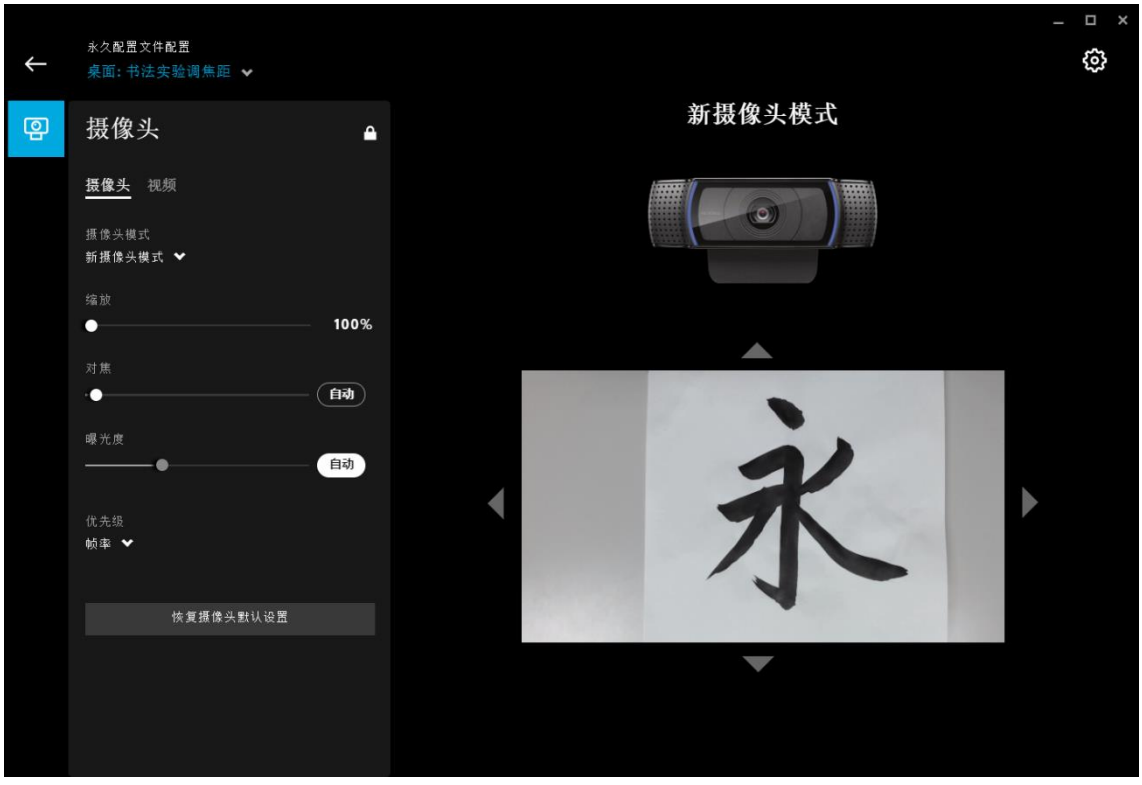


Figure 3.13: Input from web camera

3.2.2. Projector placement

The projector used in CalliShadow proposed is the Sony Xperia Touch G1109. We will use the horizontal image projection function of this projector. Just place the projector directly in front of the calligraphy practice area, as shown in Figure 3.14.

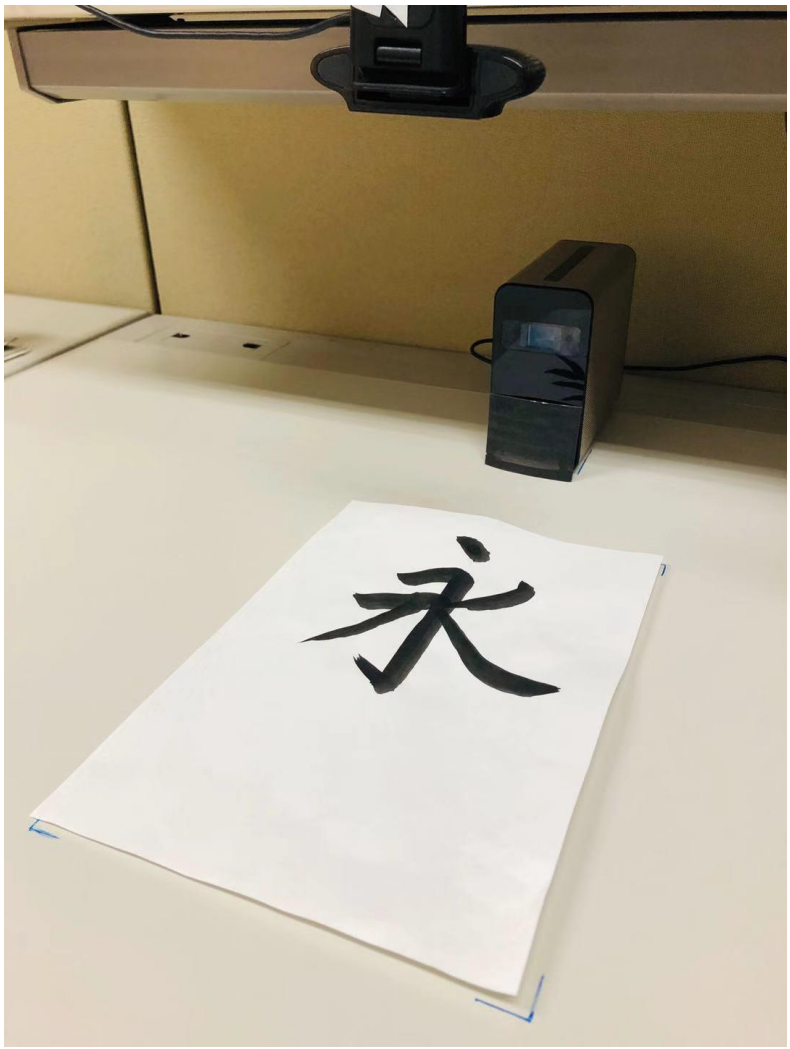


Figure 3.14: The placement of the system's projector

3.2.3. Delimit writing area

First, measuring the projector range and camera shooting range is required. Then, we need to find a common area between the scope of the projector and the range of the camera. Finally, the paper area of A4 paper size is divided into the user practice area of the calligraphy support system. The marked blue area in Figure 3.14 is the prescribed calligraphy writing practice area.

3.2.4. Specifications and placement of calligraphy utensils

CalliShadow requires calligraphy tools similar to those used in traditional calligraphy practices. A medium-sized wool writing brush, a bottle of traditional Chinese calligraphy ink (brand: Yidege), an ink tray, and A4 paper, as shown in Figure 3.15.

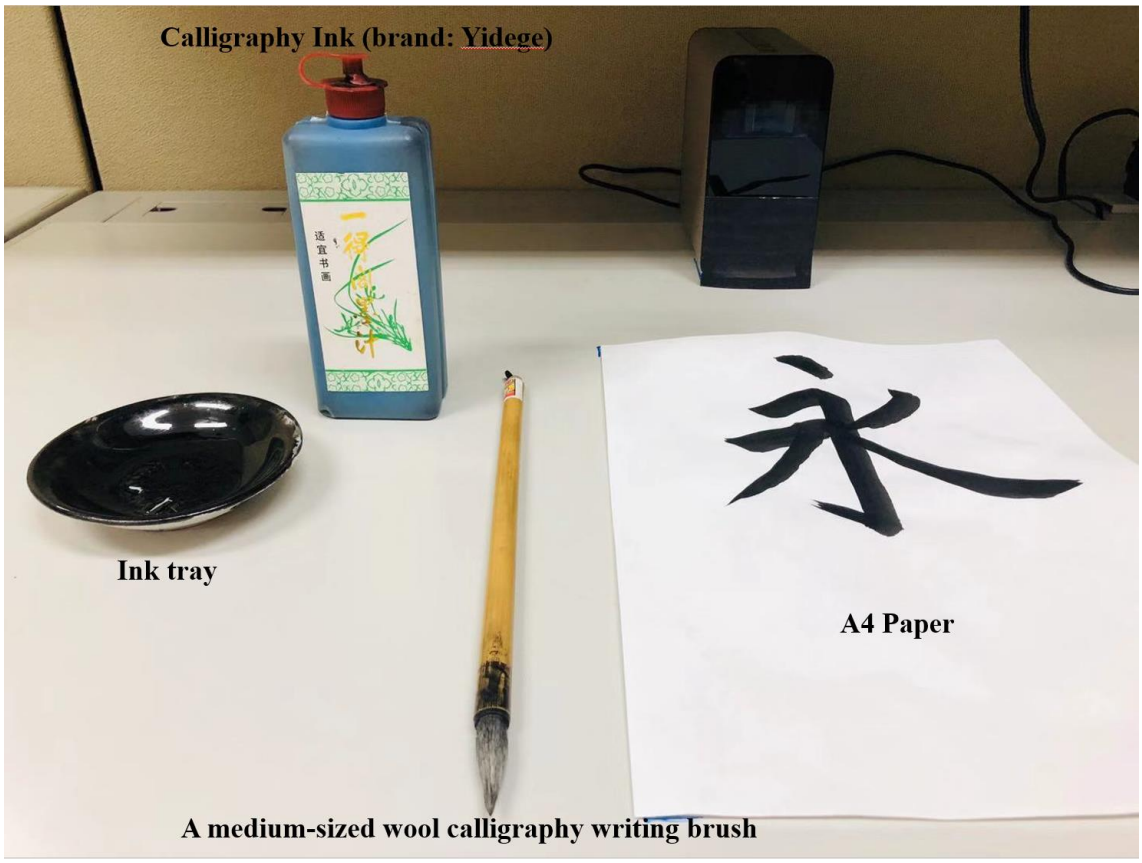


Figure 3.15: The placement of the system's projector

There are no particular restrictions on the placement of calligraphy utensils. Just stay away from the camera coverage area and the projector projection area. According to your personal preference, you can place the calligraphy utensils on the left or right side of the system.

3.3 System Operation Process

3.3.1. Whole word hints mode

In whole word hints mode, users only need to imitate the projected calligraphy image font's writing according to the entire stroke hint of the font. It should be noted that in the

three-layer whole word hints mode and the five-layer whole word hints mode, the user can imitate and write the font and image recommendations of any layer according to his/her preference. However, when writing, the user can only choose one imitation method to complete a stroke, and user cannot select multiple different strokes in the same stroke at the same time.

Figure 3.16: Operation demonstration of whole word calligraphy font hints mode gray-scale whole word hints (top) and color whole word hints (bottom)

3.3.2. Single stroke hints mode

In Single stroke hints mode, the user needs to complete a stroke of the font within a fixed time interval, and then wait for the system to refresh the new next font stroke hint to the calligraphy learner. Set the time interval for the system to recognize the user's font based on the individual writing speed difference of the learner. In this experiment, we set the time interval to 5 seconds. It means that the camera in the Figure 3.17 will take a picture of the current font status of the user every 5 seconds, then match the fonts in the database, and give the user a next stroke writing suggestion based on the database correspondence.

When using this mode, the user needs to pay attention to the system refresh prompt. Whenever the red cross in the upper right corner of the projected writing box lights up, it means that the system will refresh the font prompt immediately. At this time, the user is required to put back his/her hand and the calligraphy writing brush from the shooting area of the camera to avoid errors and misidentification of font matching. Besides, as same as the whole stroke hints mode, in the three-layer single-word hint mode and the five-layer single-word hint mode, users can imitate and write the font and image recommendations of any layer according to their preferences. However, when writing a calligraphy font, the user can choose only one writing style per stroke, and multiple different strokes cannot be selected at the same time in the same stroke. Figure 3.18 shows the writing process in this calligraphy support mode, the user writes the font according to the red stroke prompt provided by the system.

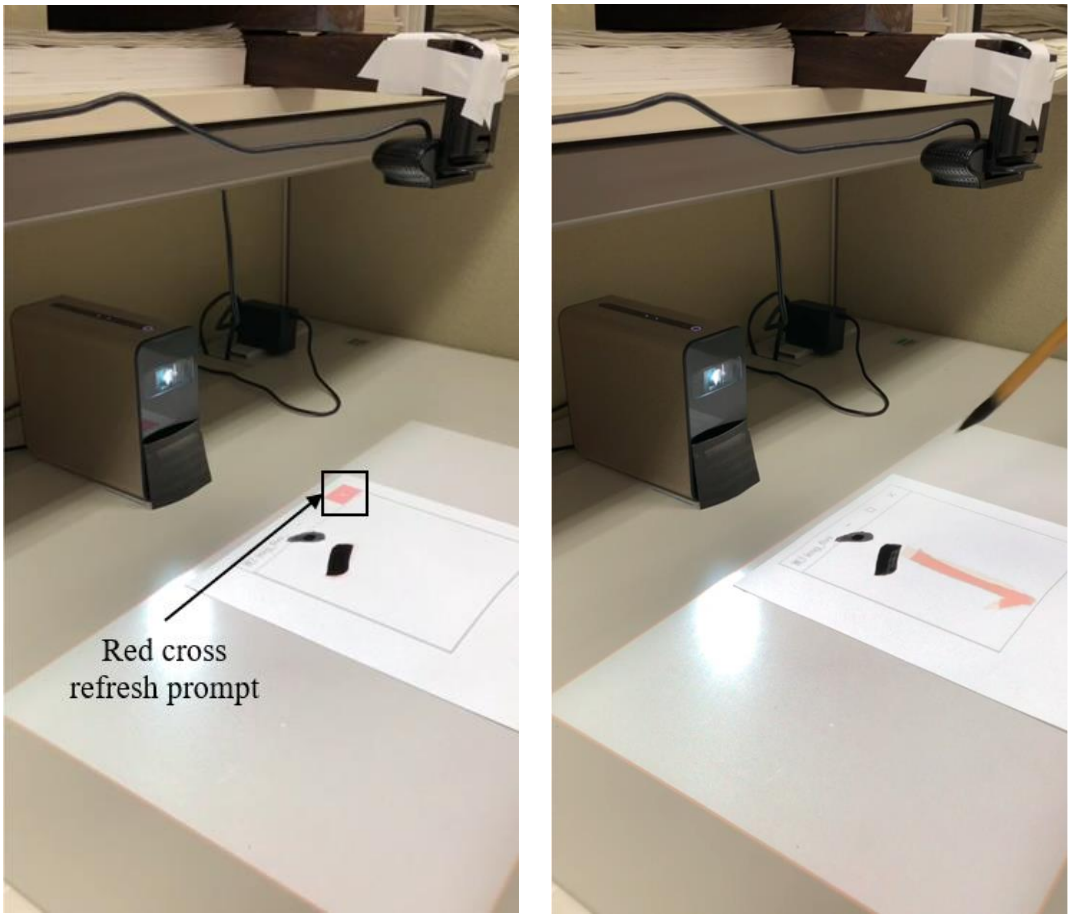


Figure 3.17: The system refresh prompt

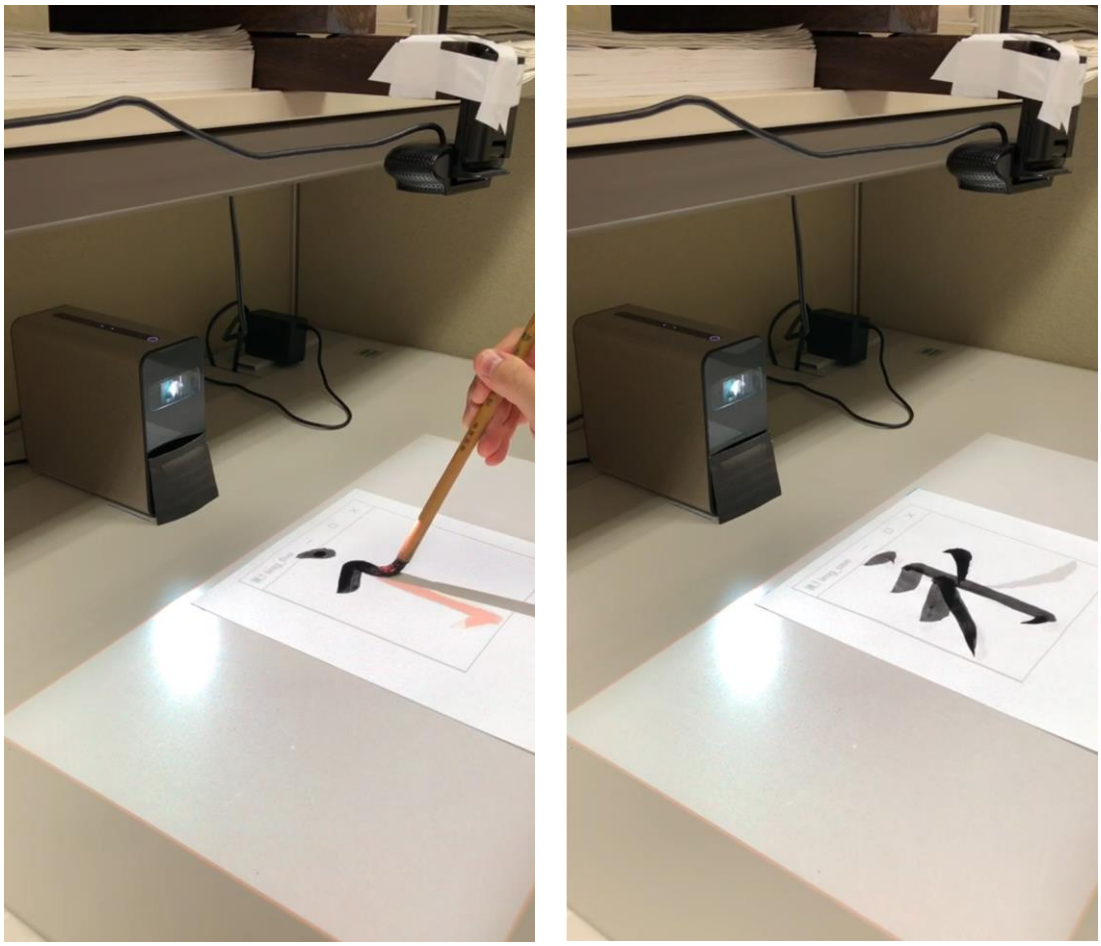


Figure 3.18: Operation demonstration of single word calligraphy font hints mode

Chapter 4 Experimentation

This chapter will introduce CalliShadow's experiment in detail from the purpose of experimental design, target group, experimental content, and experimental environment.

4.1 Experimental Design

4.1.1 Experiment purpose

The purpose of the experiment is to verify and evaluate the effectiveness, reliability, and fun of the calligraphy support system proposed in the thesis. The experiment includes experiments with and without the support system. Subjective evaluation of participants' system use experience was conducted through a questionnaire survey to verify the system's interest.

We collect experimental calligraphic font picture data and use an evaluation system to compare the outline differences between the traditional calligraphy practice method and the typeface in the copybook. Meanwhile, we compare the difference between the user font under the calligraphy support system and the target font in the copybook. The data of two contour differences are analyzed to objectively evaluate the effectiveness and reliability of the calligraphy support system.

4.1.2 Target groups of the experiment

There were 20 participants in the experiment, which were divided into 10 people who were familiar with calligraphy (3 females, 7 males) and 10 people who were completely unfamiliar with calligraphy (4 females, 6 males).

The reason for such staffing is to analyze the impact of the calligraphy support system on advanced calligraphy learners and junior calligraphy learners, respectively. At the same time, try to maintain the balance between the number of male and female to achieve the purpose of controlling the effects of variables generated by gender factors on the experiment.

4.1.3 Experimental content

The experiment was divided into a control group and a system test group. In the control group, the experimenter needs to use the traditional calligraphy practice method to learn the calligraphy font. In the experimental group, the experimenters learned the calligraphy fonts with the assistance of the calligraphy support system. By comparing the

experimental group and the control group, the following two factors are used to objectively determine the effectiveness and reliability of the calligraphy support system proposed in this paper. (1) The balance of the calligraphy font written by the experimenter is good or bad; (2) The difference between the outline of the font stroke and the standard font stroke in the database.

The experiment sequence is as follows: the experimenter first needs to participate in the control group experiment and use the traditional calligraphy learning method. The user observes the shape and characteristics of the typeface in the copybook and then imitate it. Figure 4.1 shows the process of conventional calligraphy practice and the copybook used in calligraphy practice.

Figure 4.1: The process of conventional calligraphy practice (Left) and calligraphy copybook (Right)

The experimenter then experienced the calligraphy support system in all font prompt modes. The system mode experience proceeds in a certain order. The sequence is as follows:

(1) Gray-scale low-level font image blending hints mode

(2) Gray-scale multi-layer font image blending hints mode

(3) Color low-level font image blending hints mode

(4) Color multi-layer font image blending hints mode

The specific experience order of the calligraphic support system mode is as follows:

1) One-layer grayscale whole word hints
2) Three-layer grayscale whole word hints
3) Five-layer grayscale whole word hints
4) one-layer color whole word hints
5) Three-layer color whole word hints
6) Five-layer color whole word hints.

Finally, the experimenter used the single-stroke hints mode in the calligraphy support system to practice calligraphy fonts.

The entire experiment was 40 minutes long. After completing the experiment, the experiment participants need to fill out an experiment evaluation questionnaire. We will introduce the design and content of the questionnaire in detail in Chapter 5.

Figure 4.2: The experimenter used the whole-word hints mode of the calligraphy support system

4.1.4 Experimental environment

There are no strict requirements for the experimental environment. The experiment only needs to be performed in a quiet room with enough space for calligraphy practice.

Chapter 5 Evaluation

This chapter analyzes and verifies the interest, effectiveness, and reliability of the calligraphy support system from two aspects: subjective evaluation of users and objective evaluation of experimental data.

In the subjective evaluation of users, this chapter divided it into three sections to conduct a comprehensive questionnaire analysis and evaluation method introduction. (1) Design of experiments questionnaires; (2) Collection of questionnaires for experimenters; (3) Analysis of questionnaire results.

In the objective evaluation of experimental data, this chapter divided it into two sections to demonstrate the effectiveness and reliability of the calligraphy support system. (1) Effect analysis of the entire calligraphy font; (2) Effect analysis of each stroke of the font.

5.1 Subjective Evaluation of Users

5.1.1 Design of experiments questionnaires

The design of the questionnaire is based directly on the experimental process. After using the calligraphy support system, the user selects the preference of each mode of the calligraphy support system and the number of layers of picture mixing and answers the reason for selection. The questionnaire survey has a total of 8 questions. The specific design is as follows:

1. Are you familiar with Chinese characters and calligraphy?

   A. Familiar B. Not familiar

(If you choose A, start with question 3. If you choose B, answer question 2 and skip question 3.)

2. Is the CalliShadow system helpful for your primary calligraphy practice compared to the traditional method of practicing calligraphy against pictures?

   A. Very helpful B. helpful C. Not obvious D. helpless

3. Compared with the traditional method of practicing calligraphy against pictures, is the CalliShadow system helpful for your advanced calligraphy practice?

   A. Very helpful B. helpful C. Not obvious D. helpless

4. How many stroke tips do you think the system provides, which will be the most helpful for your calligraphy practice.

   A. Five layers B. Three layers C. One layer

Why do you think this number of stroke hints will be helpful for you?_____

5. Gray-scale hints and Color hints, which one do you think will help you more?

   A. Gray-scale hints B. Color hints C. Both

The reason you choose this option:_____

6. Whole word hints and single stroke hints, which one do you think is more helpful to understand the structure of calligraphy strokes and stroke order?

   A. whole word hints B. single stroke hints C. Both

7. Which system mode do you prefer?

   A. Gray-scale whole word hints B. Gray-scale single stroke hints

   C. Color whole word hints D. Color single stroke hints

Why did you choose this model?_____

8. What do you think is the most helpful point of this calligraphy support system? (For example: visualization of stroke thickness; visualization of stroke order)

   _____

5.1.2 Questionnaires results

A total of 20 people participated in the experiment, including 13 males and 7 females, all aged between 22 and 30 years old. 10 participants in the experiment were familiar with calligraphy writing, and 10 were completely unfamiliar with calligraphy writing.

After the experiment, 20 questionnaires were collected. The questionnaire recovery rate is 100%.

Table 5.1 shows the choice of questionnaire options for participants who are completely unfamiliar with calligraphy. When asked about the preferences of gray-scale hints and color hints, two of them choose both. When asked to like whole word hints or single stroke hints, the participants P1 thought that both modes would be of great help to himself. In this group, all participants considered the calligraphic support system to be helpful, P7 thought it was very helpful, and P3 thought it was somewhat helpful.

	Image blended layer	**Gray or color**	**Hints mode**

people	1 layer	3 layers	5 layers	Gray	Color	Whole	Single
P1	✓				✓		✓
P2		✓			✓		✓
P3			✓		✓	✓	
P4	✓			✓	✓	✓	
P5			✓	✓	✓		✓
P6		✓			✓	✓	
P7	✓			✓		✓	
P8		✓		✓		✓	✓
P9		✓		✓		✓	
P10			✓		✓		✓
Total	3	4	3	5	7	6	5

	Help degrees				
People	Very helpful	Helpful	Not obvious	Helpless	**Favorite CalliShadow mode**
P1	✓				1-layer color single word hints
P2	✓				3-layer color single word hints
P3	✓				5-layer color whole word hints
P4	✓				1-layer gray whole word hints
P5	✓				5-layer color whole word hints
P6		✓			3-layer color whole word hints
P7		✓			1-layer gray whole word hints
P8	✓				3-layer gray whole word hints
P9		✓			3-layer gray whole word hints
P10	✓				5-layer color single word hints
Total people	7	3	0	0	

Table 5.1: Unfamiliar with the calligraphy writing group's survey collection

Table 5.2 shows the choice of questionnaire options for experimenters who are familiar with calligraphy. When asked about the preferences of gray-scale hints and color hints, four people chose to like both. When asked to like whole word hints or single stroke hints, three experimenters thought that both modes would be of great help to themselves. In this group, all 10 participants considered the calligraphic support system to be helpful, 7 thought it was very helpful, and 3 thought it was somewhat helpful.

	Image blended layer			Gray or color		Hints mode	
people	1 layer	3 layers	5 layers	Gray	Color	Whole	Single
P1	✓			✓	✓		✓
P2		✓			✓		✓
P3	✓			✓	✓	✓	
P4		✓			✓		✓
P5			✓	✓	✓	✓	✓
P6			✓	✓	✓	✓	
P7			✓		✓	✓	✓
P8		✓			✓	✓	
P9			✓		✓	✓	
P10		✓			✓		✓
Total	2	4	4	4	10	6	6

	Help degrees				
People	Very helpful	Helpful	Not obvious	Helpless	**Favorite CalliShadow mode**
P1		✓			1-layer color single word hints
P2	✓				3-layer color single word hints
P3		✓			1-layer color whole word hints
P4	✓				3-layer color single word hints
P5	✓				5-layer color single word hints
P6	✓				5-layer color whole word hints
P7	✓				5-layer color whole word hints
P8	✓				3-layer color whole word hints
P9		✓			5-layer color whole word hints
P10	✓				3-layer color single word hints
Total people	7	3	0	0	All people choose color hints

Table 5.2: Familiar with the calligraphy writing group's survey collection

5.1.3 Analysis of questionnaire results

The questionnaire results show that the proposed support system is helpful for the balance practice of calligraphy fonts in contrast to the traditional calligraphy practice mode(20 participants in the experiment, 14 participants chose very helpful, 6 chose some help, and 0 chose options that were not obvious and helpless). The participants who are

unfamiliar with Chinese characters found that the stroke support to help them understand the composition and writing order of Chinese characters well. Those who are familiar with calligraphy also find that the calligraphy support system is helpful to their understanding of the overall grasp of calligraphy fonts. (see in Figure 5.1).

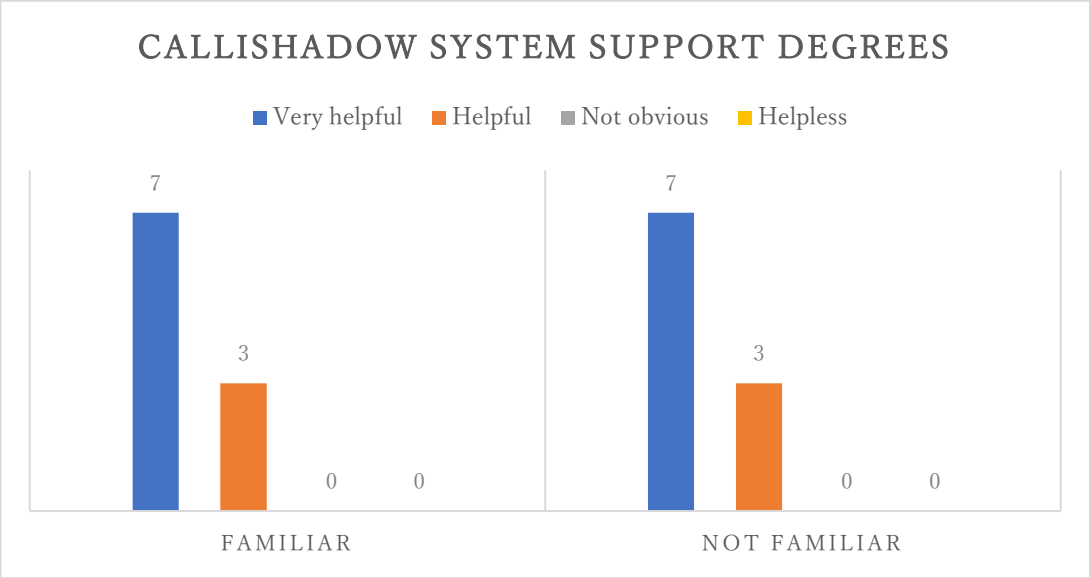


Figure 5.1: CalliShadow system support degrees

Figure 5.2 shows the statistics of the experimenter's tendency to the font blended images' numbers. The vast majority of people like multi-layer font image blended hints. The experiments think that the mixed hints of multi-layer fonts and pictures can give them more font choices, which not only makes the practice of calligraphy becoming novel, but also gradually forms their own calligraphy writing style.

One-layer font image hints has been chosen by 5 participants and the reason was that they were unwilling to make a choice. 9 participants found the effect of a three-layer font image blended hints is very comfortable. It won't look too confusing and has a variety of fonts to provide users with calligraphy learning options. Besides, 6 people chose five-layer font image blended hints. The reason for the choice was that they needed more font references to help them make calligraphy writing judgments.

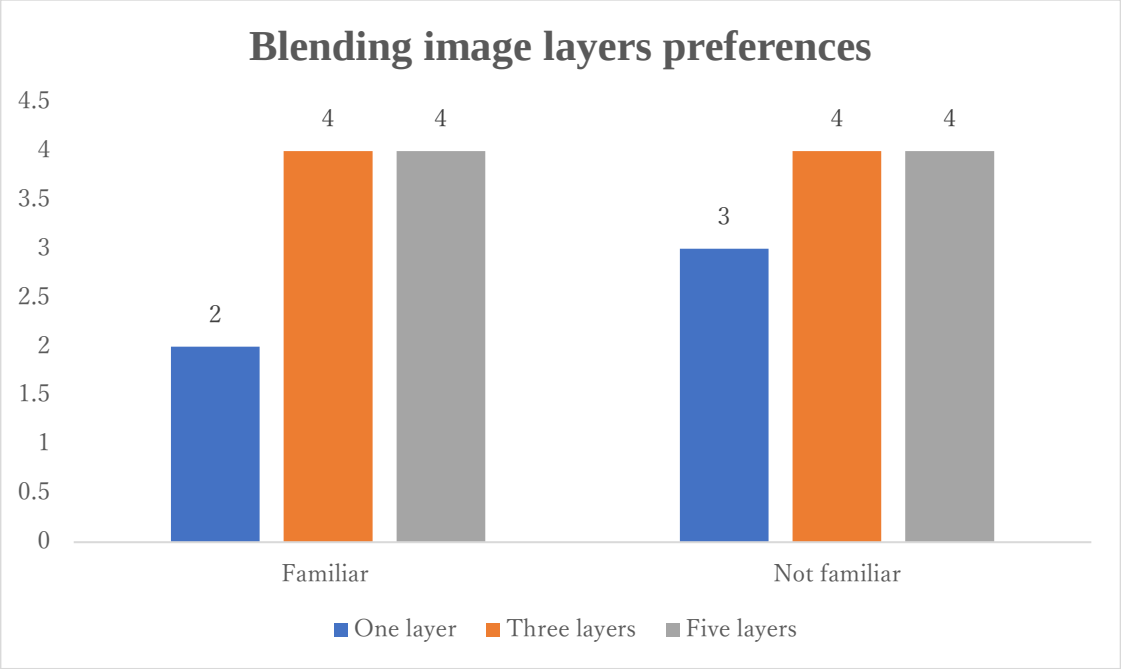


Figure 5.2: Blending image layers preferences

The experimenter data collected in Table 5.1 and Table 5.2 show a particular pattern and user preference. 16 of the 20 experimental participants felt that colored font hints were better. Only 4 people prefer grayscale font tips. Color single stroke hints mode and color whole word hints mode both have 8 participants, and 4 participants choose gray whole word hints mode.

According to the questionnaire of the 16 experimenters who chose the color font mode, 9 people thought that the color font hints were easier to see the hints fonts than the gray font hints, and they could find the font they want to imitate more clearly. 5 people think that the color is brighter and can attract their interest. Among the 4 experimenters who chose the grayscale font mode, 2 of them felt that the gray font suggested a sense of traditional calligraphy practice, and they liked it. The remaining 4 experimenters thought that the grayscale font hints felt similar to the color font hints, and the effect was the same. Figure 5.3 shows the questionnaire of the participants in the experiment and the reason they chose this option.

Experimental Evaluation Questionnaire

Name: JIA Yinghui Student ID: 1910058 Laboratory: Kim Lab

1. Are you familiar with Chinese characters and calligraphy?
   A. Familiar B. Not familiar

(If you choose A, start with question 3. If you choose B, answer question 2 and skip question 3.)

2. Is the CalliShadow system helpful for your primary calligraphy practice compared to the traditional method of practicing calligraphy against pictures?
   A. Very helpful B. helpful C. Not obvious. D. helpless

3. Compared with the traditional method of practicing calligraphy against pictures, is the CalliShadow system helpful for your advanced calligraphy practice?
   A. Very helpful B. helpful C. Not obvious. D. helpless

4. How many stroke tips do you think the system provides, which will be the most helpful for your calligraphy practice.
   A. Five layers B. Three layers C. One layer

5. Gray-scale hints and Color hints, which one do you think will help you more?
   A. Gray-scale hints B. Color hints C. Both

6. Whole word hints and single stroke hints, which one do you think is more helpful to understand the structure of calligraphy strokes and stroke order?
   A. whole word hints B. single stroke hints C. Both

7. Which system mode do you prefer?
   A. Gray-scale whole word hints B. Gray-scale single stroke hints
   C. Color whole word hints D. Color single stroke hints

Your opinion or suggestion: 单字笔顺时间扫描间隔过快

5. When using grayscale mode, I feel very calm. The color mode hints is easier to distract, and the traditional calligraphy fonts are all black. I'm used to this ~~clor~~ color

6. The 5-layer font image blended is too much for me, and the 1-layer font image hint is too few. I think the 3-layer is just right.

7. Grayscale feels more calm. In addition, since I have no experience in writing calligrahy fonts, if there is a hint on the whole font, then I can have a clear position feeling when writing calligraphy fonts.

8. This system is very good, reducing the difficulty of learning calligraphy

Experimental Evaluation Questionnaire

Name: ZHANG Yi Student ID: 17[illegible]22 Laboratory: Yoshitaka

1. Are you familiar with Chinese characters and calligraphy?
   A. Familiar B. Not familiar

(If you choose A, start with question 3. If you choose B, answer question 2 and skip question 3.)

2. Is the CalliShadow system helpful for your primary calligraphy practice compared to the traditional method of practicing calligraphy against pictures?
   A. Very helpful B. helpful C. Not obvious. D. helpless

3. Compared with the traditional method of practicing calligraphy against pictures, is the CalliShadow system helpful for your advanced calligraphy practice?
   A. Very helpful B. helpful C. Not obvious. D. helpless

4. How many stroke tips do you think the system provides, which will be the most helpful for your calligraphy practice.
   A. Five layers B. Three layers C. One layer

5. Gray-scale hints and Color hints, which one do you think will help you more?
   A. Gray-scale hints B. Color hints C. Both

6. Whole word hints and single stroke hints, which one do you think is more helpful to understand the structure of calligraphy strokes and stroke order?
   A. whole word hints B. single stroke hints C. Both

7. Which system mode do you prefer?
   A. Gray-scale whole word hints B. Gray-scale single stroke hints
   C. Color whole word hints D. Color single stroke hints

Your opinion or suggestion: 精彩限定

5. I think colored ones can help me better. I think color is more interesting. If the importance of stroke is distinguished by color, I think it will help to learn calligraphy characters!

6. I think the 3-layer font ~~img~~ image blending mode looks great.

7. I think the color ~~font~~ mode is more interesting. Strokes can help me understand the writing order of calligraphy fonts.

8. Visualizing the stroke order is useful for me.

Figure 5.3: Some participants' questionnaire and their comments

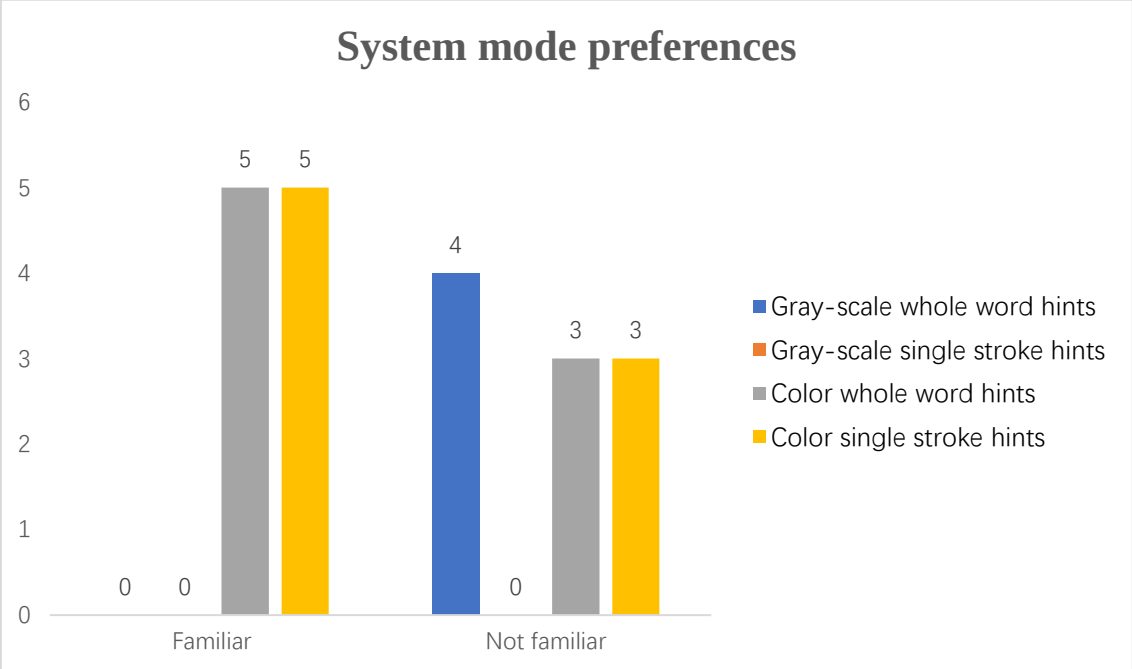


Figure 5.4: CalliShadow system mode preferences

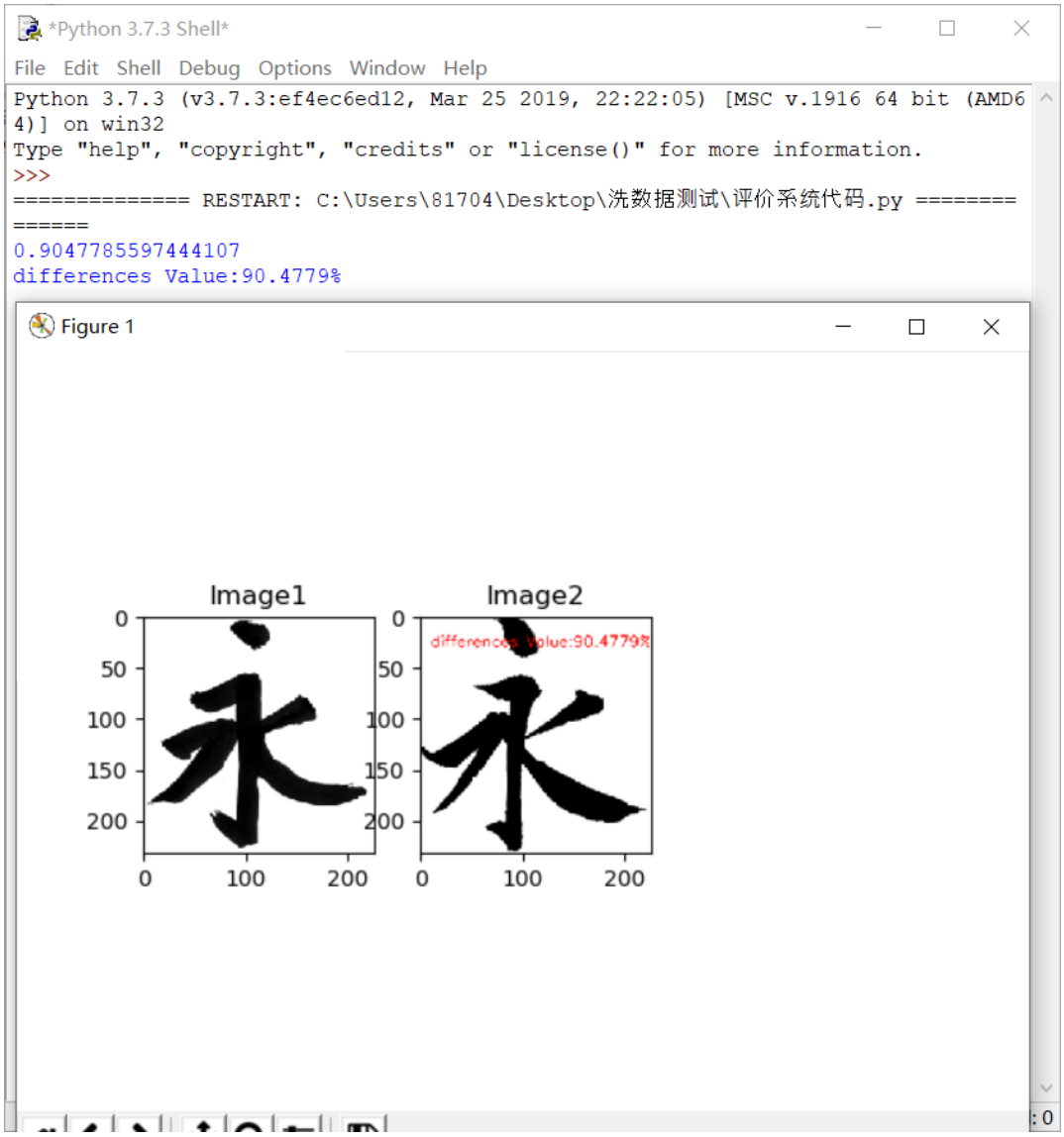
5.2 Objective Evaluation of Experimental Data

In this section, objective data evaluation is performed on the collected font images of the experimenter. User font images are divided into two groups for evaluation:

1) Before using *CaliiShadow*'s group
2) After using *CaliiShadow*'s group

The overall font image of the user font image in each group and the best matching font image in the database are used to determine the contour similarity. The smaller the value, the higher the similarity. At the same time, outline similarity judgment is performed for each stroke of the user font picture. Figure 5.5 shows part of the operation flow of the evaluation system. Each comparison will generate data, and the data is tabulated, and tables 5.3 and 5.4 can be obtained.

Table 5.3 shows the similarity data of font outlines between the user fonts and the most matching fonts in the database after using *CaliiShadow*. Table 5.4 shows the font outline similarity data between the user fonts before using *CaliiShadow* and the most matching fonts in the database.


Python 3.7.3 Shell
File Edit Shell Debug Options Window Help
Python 3.7.3 (v3.7.3:ef4ec6ed12, Mar 25 2019, 22:22:05) [MSC v.1916 64 bit (AMD64)] on win32
Type "help", "copyright", "credits" or "license()" for more information.
>>>
========== RESTART: C:\Users\81704\Desktop\洗数据测试\评价系统代码.py ==========
0.9047785597444107
differences Value:90.4779%
Figure 1
Image1
Image2
differences Value:90.4779%

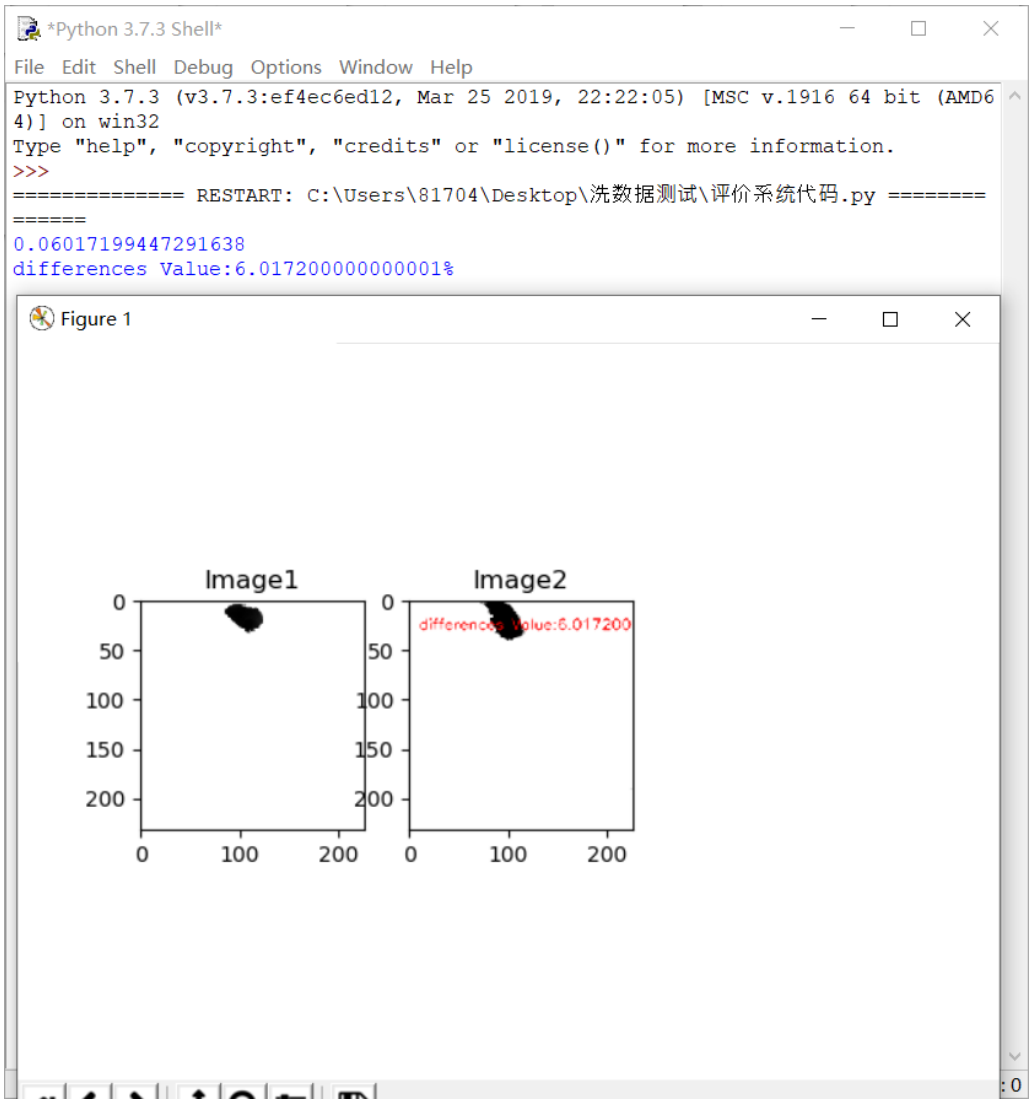


Figure 5.5: Example of whole font and partial stroke evaluation whole font evaluation (top) and first stroke evaluation (bottom)

People	Database font	whole word	Font Strokes						
			first	second	third	fourth	fifth	sixth	seventh
1	5	0.9047	0.0601	0.4490	12.792	1.2068	8.6959	0.4698	1.7366
2	3	0.8125	0.1245	0.5052	60.578	0.1656	1.4807	1.1377	2.4633
3	1	0.8599	0.4130	0.5535	1.7976	0.2977	9.1277	0.4148	2.9798
4	9	0.9393	0.1037	0.4772	5.0554	0.6620	2.8997	0.5886	2.7606
5	18	3.7223	0.3597	1.0540	30.170	0.3058	7.6960	2.6704	3.3759
6	11	1.0671	0.1095	0.2505	58.127	2.2785	2.1324	1.2157	9.2903
7	2	0.2913	0.0334	1.6789	2.6227	0.3011	3.7010	1.3307	4.1527
8	4	0.7094	0.2353	2.8902	1.7761	0.0952	0.4625	1.2252	6.7733

9	9	1.7053	0.3564	0.3011	16.008	1.3687	16.423	0.4381	1.7913
10	8	0.5736	0.1520	0.6505	0.6722	0.8835	10.061	0.6325	4.5324
11	16	0.7457	0.0537	0.6407	7.4929	0.5572	4.9212	0.9647	0.5244
12	13	1.8883	0.1756	0.5341	42.075	0.4387	0.9407	0.5071	5.3196
13	16	4.4362	0.3230	0.8115	8.3197	0.9027	8.8800	0.5394	1.3739
14	16	0.5794	0.2831	0.2053	1.9866	1.6963	1.2619	1.0511	7.1226
15	2	0.3150	0.4591	0.4304	1.9597	0.3863	3.3696	2.5098	8.4680
16	12	1.0485	0.6401	0.6488	6.6143	0.5028	2.1032	0.8040	13.207
17	2	2.7115	0.2062	0.1459	15.162	0.6217	2.9731	1.6374	1.3326
18	2	1.7820	0.4722	0.3075	7.3801	1.4907	1.7268	5.4585	4.5256
19	3	0.9408	0.2523	0.9787	68.543	0.9302	1.1610	1.6218	2.5657
20	4	0.6455	0.4056	1.3293	34.691	0.7172	0.7207	1.7698	1.5707
Average		1.3339	0.2609	0.7421	19.191	0.7904	4.5369	1.3493	4.2933
Variance		1.2367	0.0273	0.4041	483.42	0.3231	17.973	1.3610	10.533

Table 5.3: Similarity data of font image outline after using *CaliiShadow*

People	**Database font**	**whole word**	**Font Strokes**						
			first	**second**	**third**	**fourth**	**fifth**	**sixth**	**seventh**
1	5	1.1936	1.0072	3.9359	18.166	1.7945	7.7916	2.6015	7.9599
2	3	1.3600	1.3555	1.1517	85.889	0.7885	1.1752	1.2786	2.3295
3	1	1.0389	1.0248	0.9807	1.7976	2.2458	7.3899	2.6369	5.0537
4	9	1.8054	0.1486	0.9176	70.940	0.6530	9.0358	1.6161	2.6184
5	18	2.4980	1.3455	0.5083	40.879	0.8253	84.365	1.8302	10.406
6	11	3.2387	0.2245	20.115	43.978	4.8983	20.098	1.9547	23.773
7	2	0.8419	0.8898	4.4200	31.279	5.0547	10.569	5.0778	6.5004
8	4	33.642	2.7610	14.018	21.411	39.447	92.154	7.6248	10.726
9	9	1.5634	0.4977	0.8631	62.085	2.3929	16.327	0.6752	3.0363
10	8	0.1691	0.3754	0.9510	1.9573	1.0582	2.2364	4.0324	2.8893
11	16	1.6505	1.6141	7.8956	8.8056	2.0136	2.3256	5.7280	6.7113
12	13	17.615	0.3510	4.3101	71.976	0.9563	20.410	3.8403	17.546
13	16	6.3678	0.9915	5.7436	23.422	6.7294	2.0916	1.1732	4.4943
14	16	13.234	0.1126	0.9233	4.2429	3.6108	1.1162	2.1368	11.361
15	2	14.957	2.3923	8.8511	27.384	13.855	563.20	8.1657	87.292
16	12	3.0371	0.7150	4.1828	15.100	0.3943	11.957	1.2372	45.928
17	2	0.6607	0.6689	2.5658	8.5473	8.6633	5.4916	1.7834	3.8640

18	2	1.7976	4.8390	3.4218	1.7976	2.2436	2.8336	1.6238	2.7548
19	3	0.5490	0.1330	0.6148	69.976	0.6901	43.805	1.7552	1.0316
20	4	0.4618	0.3939	0.1142	2.5526	0.4820	2.8523	1.9567	1.1559
Average		5.3840	1.0920	4.3242	30.609	4.9398	45.361	2.9364	12.871
Variance		70.808	1.3016	26.130	772.96	77.400	15535	4.6189	415.38

Table 5.4: Similarity data of font image outline before using *CaliiShadow*

In addition, Tables 5.3 and 5.4 calculated the mean and variance before and after using Callishadow, respectively. The average of the two groups of data is compared and plotted in Figure 5.6. From the data in the Figure 5.6, it can be seen that after using CalliShadow, all the data have different reductions compared to before using CalliShadow. In the Figure 5.6, the first column of data is the average of the entire font, and the data from the second column to the eighth column represent different stroke ID. Therefore, it can be concluded that CalliShadow has effectively helped calligraphy learners.

Using CalliShadow's average data	1.3339	0.2609	0.7421	19.191	0.7904	4.5369	1.3493	4.2933
Without Using CalliShadow's average data	5.384	1.092	4.3242	30.609	4.9398	45.361	2.9364	12.871

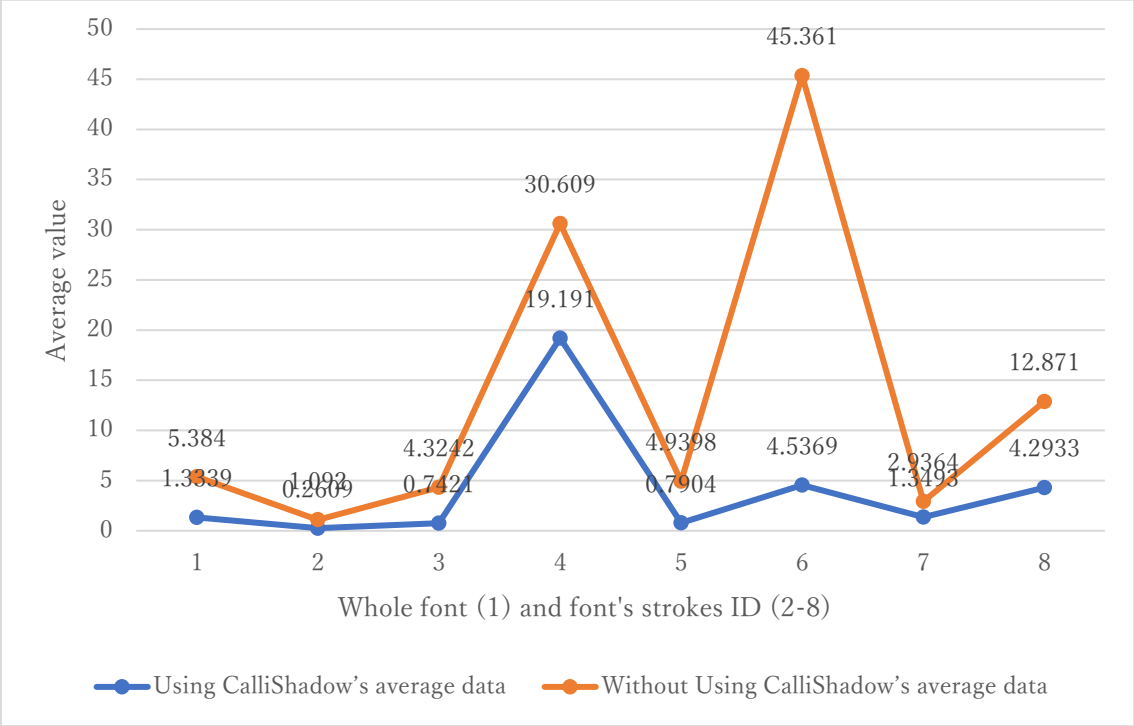


Figure 5.6: Comparison between without using CalliShadow's average data and using CalliShadow's average data

To further validate the conclusions, the variance values of the two groups of data are compared and plotted in Figure 5.7. It can be seen from Figure 5.7 that the variance of data generated using CalliShadow is much smaller than that without CalliShadow. This shows that the fonts written by users after using CalliShadow have no significant fluctuations in the font similarity matching value. Meanwhile, the credibility of the average value comparison was verified. Combining Figure 5.6 and Figure 5.7 can draw certain conclusions. CalliShadow indeed helps calligraphy learners effectively.

Using CalliShadow's variance	1.2367	0.0273	0.4041	483.42	0.3231	17.973	1.361	10.533
Without Using CalliShadow's variance	70.808	1.3016	26.13	772.96	77.4	15535	4.6189	415.38

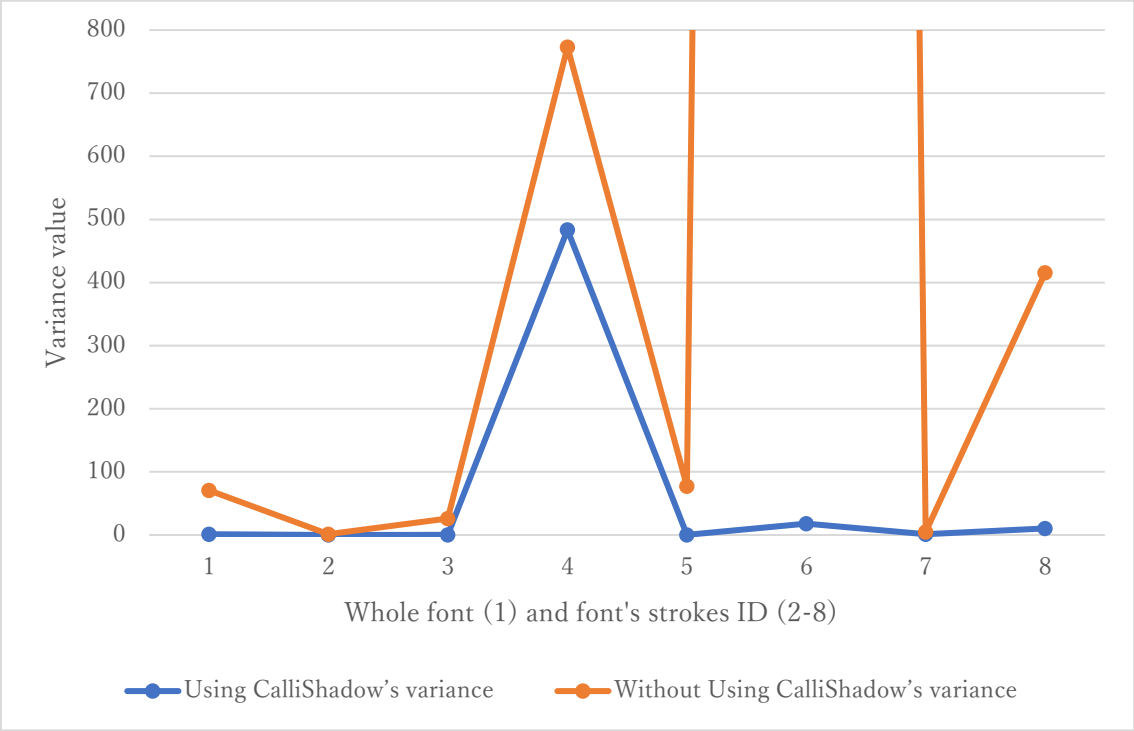


Figure 5.7: Comparison between without using CalliShadow's variance value and using CalliShadow's variance value

Based on the data in Tables 5.3 and 5.4, we have drawn boxplots as shown in Figure 5.8. The boxplots show that the values of stroke 3 and stroke 5 change significantly, which means that these two font strokes are very difficult for calligraphy learners before using the system. After using CalliShadow, font accuracy has been greatly improved.

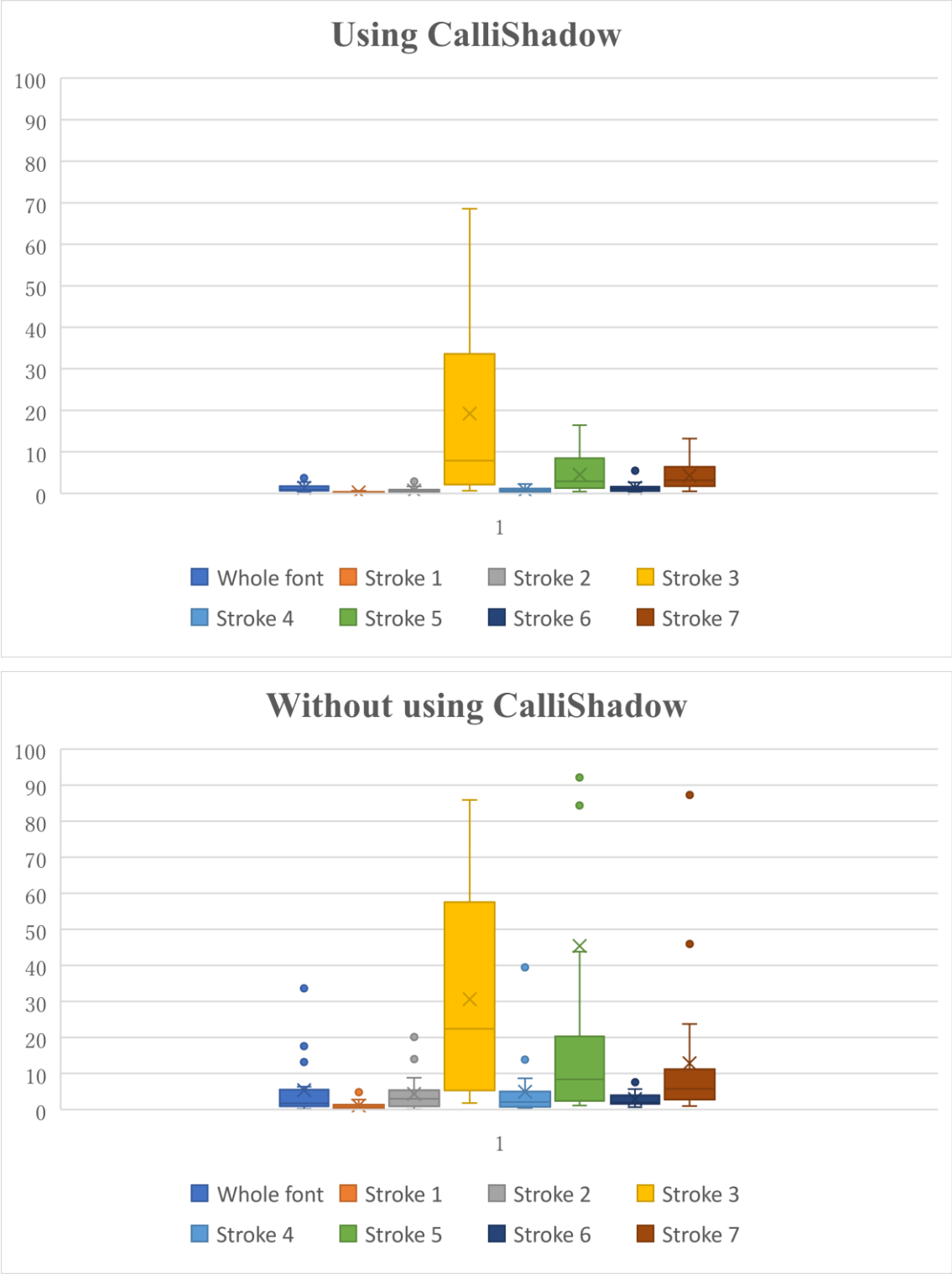


Figure 5.8: Boxplots of using CalliShadow and without using CalliShadow

Chapter 6 Conclusion

This thesis proposed a calligraphy writing support system using camera-projector system. The proposed system provides users with multiple font's writing suggestions based on current writing, and guides users on writing the correct strokes. The proposed calligraphy support system provides four guidance modes for users to choose. In each system mode, the different numbers of blending layers font pictures can be selected. To verify the effectiveness and reliability of the system, we conducted a user evaluation experiment.

In the user study, this work utilized user questionnaire survey and font image outline similarity detection. Statistics and analysis of the user's choice tendency and choice reason based on the statistical data. The contour similarity between the entire font written by the user and the most similar font in the database is detected. Meanwhile, the proposed system detected the outline similarity of each stroke of the font and each stroke of the most similar font from the database.

To verify the calligraphy support system's effectivity for the calligraphy learners, this work compared the variance values and average values of calligraphy fonts practice with and without the proposed system. As a conclusion, the proposed system can effectively guide calligraphy learners to learn calligraphy fonts.

The results of evaluation experiments also show that the system can help understand the stroke order and font structure for beginners who are not familiar with Chinese characters and can dramatically improve the early learning effect of calligraphy practice. This proposed system can help advanced learners adjust the calligraphy font and deepen their understanding of brush movement.

As future work, the proposed system needs more accurate algorithm to improve real-time matching due to the limitations of the contour matching algorithm. In addition, it will be helpful to set a more flexible interaction to the user. For example, a possible solution can use a sensor in single stroke mode to refresh the font and picture recommendations freely, which is based on the interaction between the user's finger and the projection.

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