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Master’s Thesis

Eye-makeup Guidance System Based on Eye-shape Analysis

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Abstract

Eye makeup plays an important role in facial makeup. However, it is a difficult task for common users with few experiences in makeup to accomplish perfectly. Therefore, the user often seeks makeup tutorials from video sites or other social medias, but these tutorials are often difficult to match to personal facial features. It is known that there is a significant relationship between eye shape and eye makeup, which means a good eye makeup should fit the shape of the eyes well. In this thesis, we proposed an interactive system based on the analysis of user’s eye shape which can help less-experienced users in makeup draw eye makeup that suits their own eye shape features.

We reviewed the research about makeup guidance in recent years. Among them, it is a common approach that provides corresponding makeup suggestions based on the user's facial features. In addition, there are lots of related approaches that show the virtual makeup effect on the user's face in real-time as a reference. We compared these approaches and found that for inexperienced users in makeup, it is more intuitive and effective to provide eye-makeup recommendations and guidance based on facial features.

We conducted eye shape classification, and extracted the features of the eye contour and compared it with several typical eye shapes, which is an effective way to classify eye shapes in contrast previous studies. In this study, we summarized shape features of different typical eye shapes: almond eyes, round eyes, downturned eyes, close-set eyes, etc. Based on these features, we designed a classification model to obtain the label of the user's eye shape features by inputting three feature values of the user's eyes: eye aspect ratio, toward of eye’s outer corner, and eye distance.

In addition, we investigated and studied several typical eye makeup styles and their features. Based on the eye feature points obtained from the system, we reproduced the eye makeup styles and displayed them on the user's eyes in real-time as guidance to support the user completing the eye makeup.

We designed and conducted an evaluation experiment to verify the feasibility of the proposed system, then discussed users' evaluations of various aspects of the system. We compared and analyzed the effects of eye makeup drawn by users in two conditions: without using the system and using the system. We found that the proposed system can effectively help people with less makeup experience to draw a better eye-makeup that suits their eye shape. Besides, from the collected participants’ feedbacks, we noticed that the system can also help users understand their eye features and improve their eye-makeup skills.

To improve the user experience of our system and help users draw makeup, we discussed and summarized the limitations of our system and the possible feature works. In this study, the recognition model could not effectively identify the eyelids when the system recognized the user's eye contour, thus may decrease the classification accuracy of the user's actual eye shape. To solve this issue, we plan to build a novel dataset containing images of eyes with labeled eyelid shapes and train a machine learning model to optimize the effect of eye shape recognition. Furthermore, some participants indicated that our system provided few eye makeup styles, which may not be suitable for some rare eye shapes, so we need to design more eye makeup styles as guidance in the future to meet the more needs.

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Chapter 1 Introduction

1.1 Research Background

1.1.1. About Makeup

In recent years, the popularity of makeup has increased significantly worldwide. Especially with the popularity of social media and video sites, many people will seek instructional videos about makeup on these platforms [1]. People refer to the makeup techniques of others and combine integrates them with their facial features to create makeup that suits them. However, for those who are new novices to makeup or are unfamiliar with a certain part of makeup, it may be difficult to draw a suitable makeup look that suits them. Especially because the eye part of the makeup is not an easy thing for most people common users. Because everyone's eyes are different in shape, the eye makeup corresponding to different shapes will also differ in detail due to the different eye shapes of each individual. And for people who are is not familiar with eye- makeup, it is not easy for them challenging to find explore the right type of eye- makeup and technique for themselves.

1.1.2. Eye Makeup & Eye Shape

Eye makeup is commonly defined as a type of makeup that uses specific makeup tools by drawing eyeliner and eye shadow around the eyes. It is usually used to refine the shape of your eyes or to make your eyes look bigger. Usually, for women, large eyes are perceived as attractive for females [2]. In their previous study [3], they found that the eyes applied with the eye-makeup will make an illusion to observers, and this illusion made the makeup wearer's eyes look bigger.

Generally, a person's eyes have the following characteristics: single and double eyelids, overall size and length of the eyes, angle of the eye corner, and the distance between the eyes. People use these characteristics are used as the basis for classifying human eyes into different types of shapes, such as round eyes, almond eyes, and phoenix eyes [4][5]. For example, almond-eye always looks longer than round eyes and its shape tapers at a point of eye corners; the downturned-eye have an upper eyelid which clearly drop lower at the outer corner of eye (Figure1.1 shows these two eye types.)

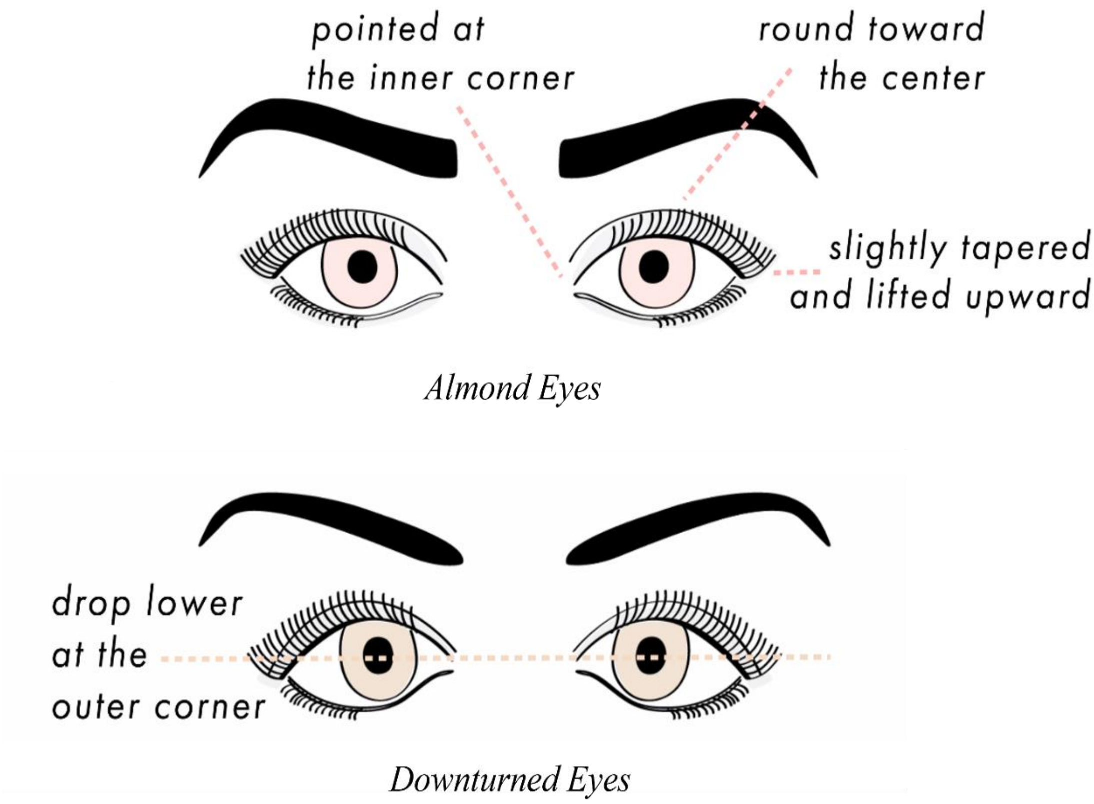

Figure 1.1 Almond Eyes & Downturned Eyes
(https://www.cosmopolitan.com/style-beauty/beauty/a25394115/different-eye-shapes/)

For different eye types, the types of eye makeup and the drawing approach that fit their eye shapes are also different. By reviewing the related webpage [6], the makeup for almond eyes is described as *"Since this eye shape tends to be most symmetrical, it can handle any liner look, but the easiest technique is to follow the natural shape of the eye while building thickness towards the outer third half"*; for the makeup of upturned eyes, it is described as *"Using a bright pencil liner, draw on a very thin cat-eye, flicking the end up toward your temples to create a little lift at the outer corners of your eyes."* Figure1.2 shows the effect of these two types of eye makeup.

Figure 1.2 Almond eye & downturned eye with makeup
(https://www.cosmopolitan.com/style-beauty/beauty/a25394115/different-eye-shapes/)

1.1.3. Makeup Guidance

Eye makeup is a difficult skill because the effect of makeup depends on the makeup technique, the use of cosmetics, and the familiarity with the features of the face. A good makeup artist can use her/his experience and knowledge to choose the right cosmetics and create a suitable look, but an unskilled makeup artist may hardly do a beautiful look that suits. Therefore, there are many approaches that help people choose cosmetics and draw a good look. The most common approach is to refer to makeup videos, which show the viewers makeup techniques and the real effects of various cosmetics by demonstrating how to choose and apply them (Figure1.3).

Figure 1.3 Example of YouTube makeup video
(https://www.youtube.com/watch?v=nf8ySuesAPg)

In addition, the traditional media, such as beauty magazines, allow the reader to see pictures and read the text for knowing about makeup techniques and the effects of makeup. Most people choose to seek makeup guidance and improve their makeup skills by watching videos nowadays. However, this approach lacks interactivity, and the effect shown in the video is likely to vary for different subjects. Even if the viewer can learn the makeup method in the video, it is difficult to reproduce it properly. In addition to traditional media, software applications have emerged to help users apply makeup. Figure1.4 shows the image of a mobile beauty application "Sephora" [7]. This application combines actual cosmetics and their simulated effects on the face, allowing users to preview how their face will look after applying certain cosmetics as a reference to help customers better buy the right cosmetics. This application also can tell the user the basic technique for each cosmetic product.

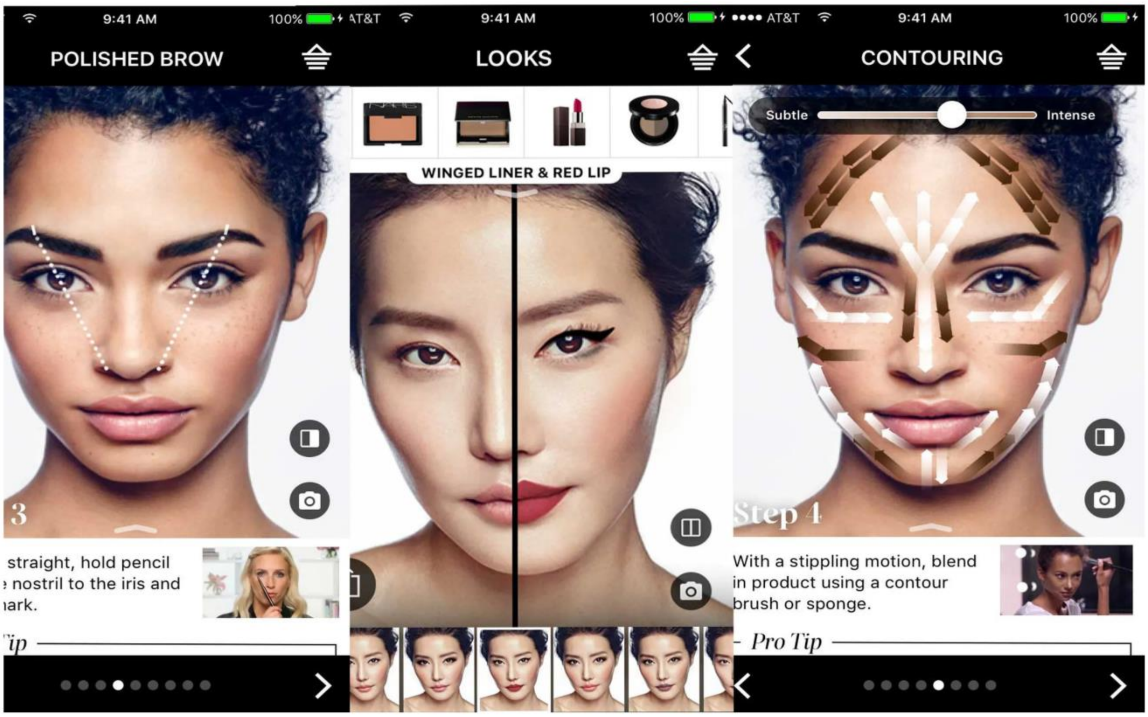

Figure 1.4 Application developed by Sephora [7]

1.2 Research Objective

Eye makeup is often not an easy task for common makeup users, so we focused on the issue of helping makeup novices to draw a suitable and reasonable eye makeup in this study. After analyzing the steps required to draw eye makeup, we found the reasons why it is not easy to draw eye makeup. Firstly, people who are not familiar with eye makeup may not understand which shape their eyes belong to and thus which eye makeup should match. Secondly, when the type of eye makeup to be drawn is determined, the makeup user feels difficult to find the correct eye makeup area and the position of the eyeliner because the drawing area around the eyes is too small to clarify, which requires delicate makeup technique. Good eye makeup is often closely related to the shape of one's eyes. Therefore, we propose a makeup guidance method: firstly, the system obtains the user’s eye contour. After analyzing the contour, the system shows values of the eye’s features by text. Then, a guidance corresponding to eyes features is shown on the screen as a reference, and the user can draw eye makeup by following this guidance.

1.3 Contribution

We propose a novel guidance system for supporting the user to draw better eye-makeup, especially for eyeliner. To recommend a suitable eyeliner pattern for the user, we design a rule-based model to classify 3 eye features: eye aspect ratio, eye outer corner toward, and eye distance. We also design typical eyeliner patterns by referring to feature points of the eyes. The proposed system can automatically generate eyeliner patterns corresponding to the results of the classifier as guidance. This guidance allows a user to draw eyeliner by referring to it in real-time.

The users with poor eye-makeup experience and skill can refer to the guidance to accurately draw an eyeliner match to their eyes more for them. Besides, users could get know of the eye features and suitable eyeliner patterns, which can be the knowledge for improving their eye makeup skills.

1.4 Thesis’s Structure

This thesis consists of five chapters. Chapter 2 introduces the related works and papers of this research, confirming the contribution of this research in the area of makeup guidance. Chapter 3 details a system we proposed, containing how to get to the user's eye features, the design of the algorithm to analyze the eye shape, and the user interface (UI) and interaction of the system. In Chapter 4, we designed user experiments and evaluation experiments, and by analyzing the data and evaluations obtained after the experiments, we verified the feasibility of the system and some limitations of the system at the current stage. Finally, in Chapter 5, we provide the conclusion of this study and the possible future works.

Chapter 2 Related Works

In this section, we will present the works related to this research. This research aims to analyze the user's eye shape and provide the recommendation makeup guidance based on the eye shape analysis. We will first introduce the research related to eye recognition and eye-contour detection, as well as some prior research on classifying eye shapes. Then, we will introduce the studies related to makeup guidance, which are mostly belonging to the HCI (Human-Computer Interaction) research field. Finally, we will describe the direction and position of our research.

2.1 Eye-shape

In this study, the analysis of the shape of the eyes is a crucial part of the whole system. How to correctly detect the user's eye position and identify the eye contour is the first issue that needs to be solved in this study.

2.1.1. Eye Detection

Eye recognition, as part of the field of face recognition, there are many contributions to the problem. Bhat et al [8] proposed a method for detecting eye contours by using ASM (Active Shape Model). Fuhl et al [9] proposed a more efficient method for detecting eye contours in real-time and provided a dataset for the eye contour. Nowadays, many face recognition tools are developed to solve the eye recognition problem [10][11].

2.1.2. Eye-shape Classification

In the problem of shape classification of eyes, Sun et al [12] proposed an approach to determine the eye types based on the similarity comparison between eyelid contour curves and other typical eye shapes. Alzahrani et al [13] summarized the characteristics of each class of eye shapes and designs eye shape classification rules, and after measuring each features' value of the eye, the eye is classified based on the designed rules (Figure2.1).

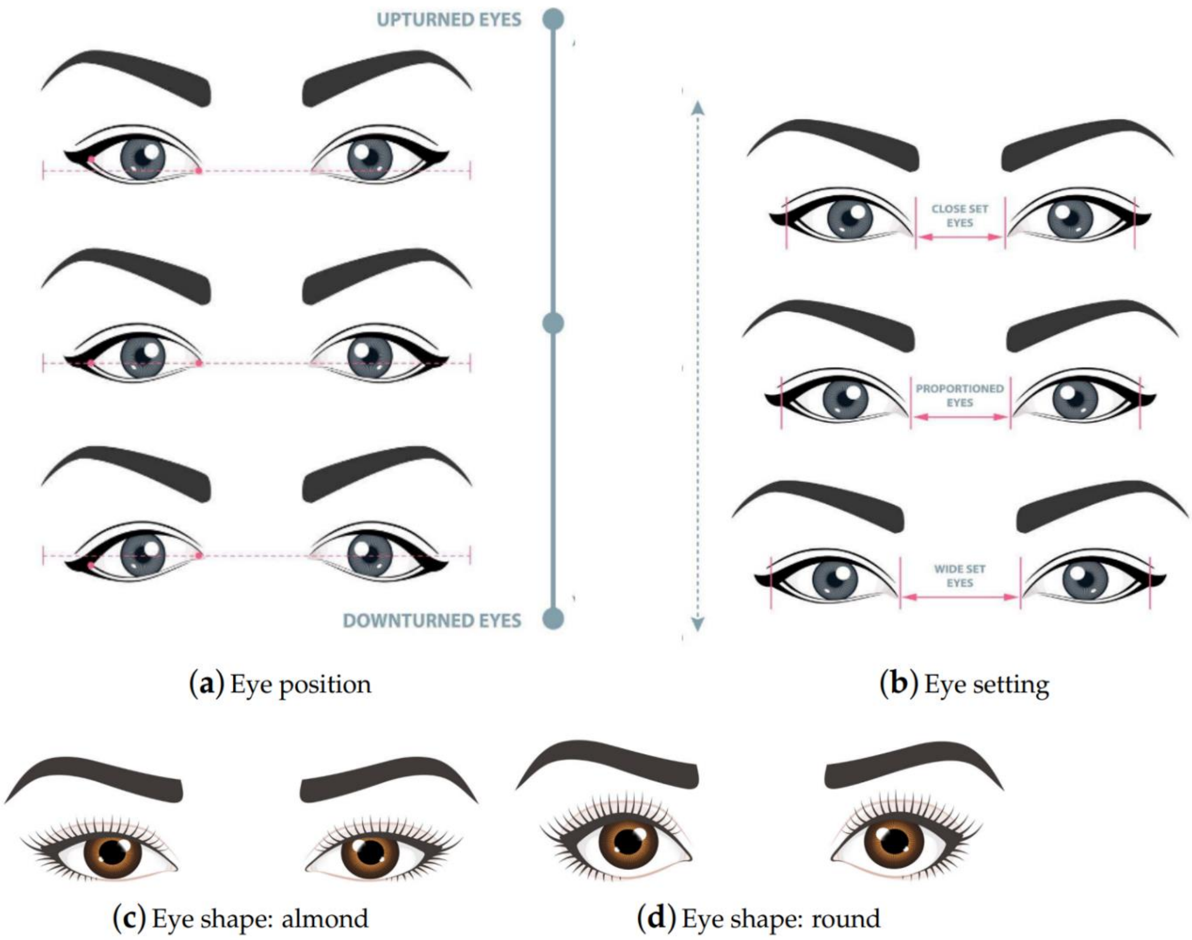

Figure 2.1 Eye attributes proposed by Alzahrani et al. [13]

2.2 Makeup Guidance

Makeup is a skill like other human creative activities such as painting, sculpting, which requires the makeup user to be able to mastery skillful techniques of makeup and a high-level understanding of makeup and facial features. In recent years, the possibility of using computer technology to support makeup tasks has been explored extensively. There have been several cases where computer technology has been used to support humans in creative tasks. As shown in Figure2.2, Z. He et al [14] developed a system for user to do Chinese calligraphy practice by referring to the guidance, Xie et al [15] utilized 3d projection to create guidance that support the fabrication of balloon art.

Figure 2.2　left: Chinese calligraphy practice with guidance[14];
right: balloon art fabrication with guidance[15]

2.2.1. Makeup Recommendation

A complete makeup look could be roughly divided into several parts based on facial features: eye-makeup, cheek-makeup, lip-makeup, and overall effect. Therefore, in most studies, a makeup always is structured and transferred to a mathematical model. With the development of facial recognition technology, which eases the extraction of facial features, it has become a general makeup recommendation method of giving suitable makeup solution based on the features of the user's face.

Chiocchia et al [16] developed a mobile application to help users select cosmetics and show users makeup tutorials as shown in Figure 2.3. The system uses a neural network to classify the user's eyes and then recommends suitable cosmetics and makeup tutorials for the user through a rule-based model based on eye makeup knowledge. The evaluation of the makeup effect relies most on the visual aspect, so the makeup support system needs to let the user know how he/she will look after applying the recommended solution. Thus, performing the makeup solution onto the image of the user's face, and providing the user with a preview of the makeup effect becomes the main approach to verify the effectiveness of the system's recommendation model.

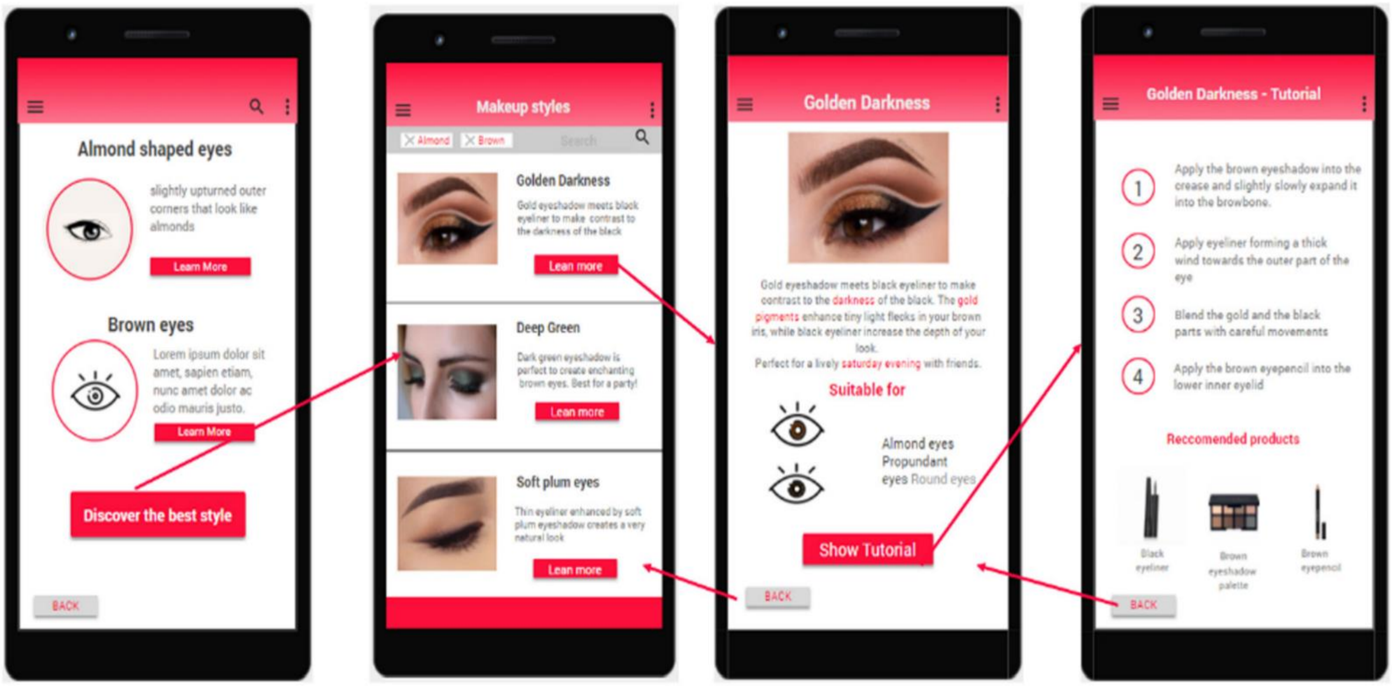

Figure 2.3 Recommendation system developed by Chiocchia et al.[16]

Guo et al [17] proposed a method to extract features from a makeup image and generate a virtual model of that makeup, which can be applied to other face photos then output a synthesized image of a face with another person's makeup. Liu et al [18] built a dataset containing many beautiful women photos and used this dataset to analyze the attributes related to attractiveness to build a tree model to solve the what-to-recommend problem. Sun presented a user’s face photo aligned with the attractive face which is predefined by comparing the facial features and used text to suggest recommended makeup techniques and orders. Takagi et al [20] proposed a system that, by inputting a photo of the user's face, would detect the landmarks of the face and determine where to draw makeup through the screen, and would also provide the user the recommendations and makeup techniques by text (Figure2.4). Alashkar et al [21] analyzed more facial features and built a rule-based system that can automatically classify the user's face and suggest the makeup solution, the result of the solution is output by a synthesized image of the user’s face and virtual makeup as shown in Figure2.5.

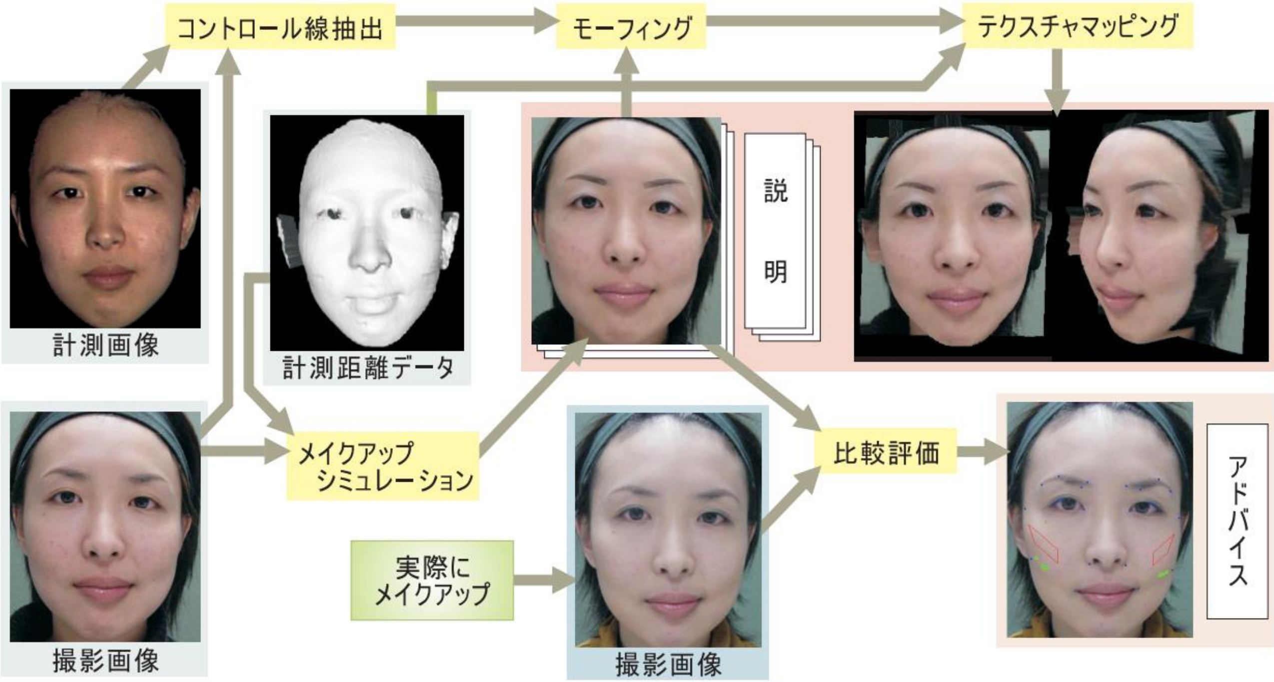

Figure 2.4 Makeup techniques advice system proposed by Takagi et al [20]

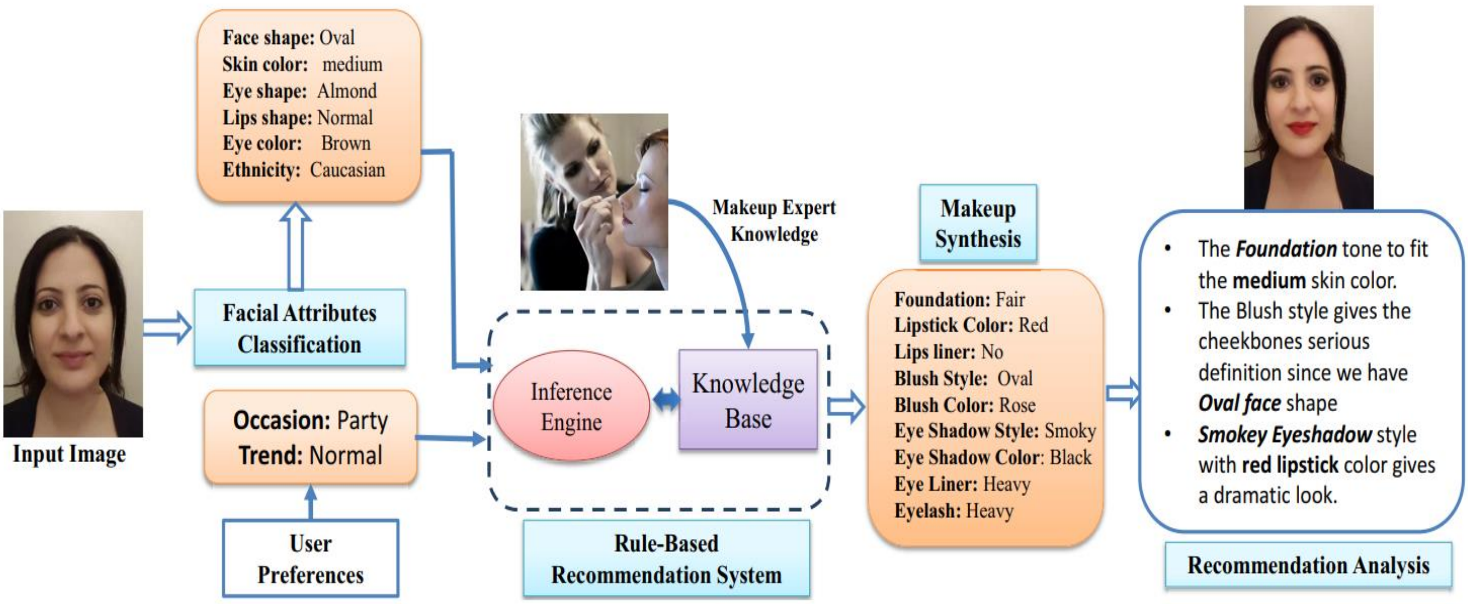

Figure 2.5 Rule-based recommend system proposed by Alashkar et al. [21]

In addition, Nishimura et al [22] proposed a novel eye-makeup design system called "iMake", which extracts the color and shape features from any picture selected by the user and generates an eye-makeup sheet (Figure2.6). Users can preview the virtual pattern applied to their eyes through Augmented Reality (AR), and they can print this sheet to apply as an eye makeup product. In this study, however, they focused on helping users design a makeup look rather than completing a makeup.

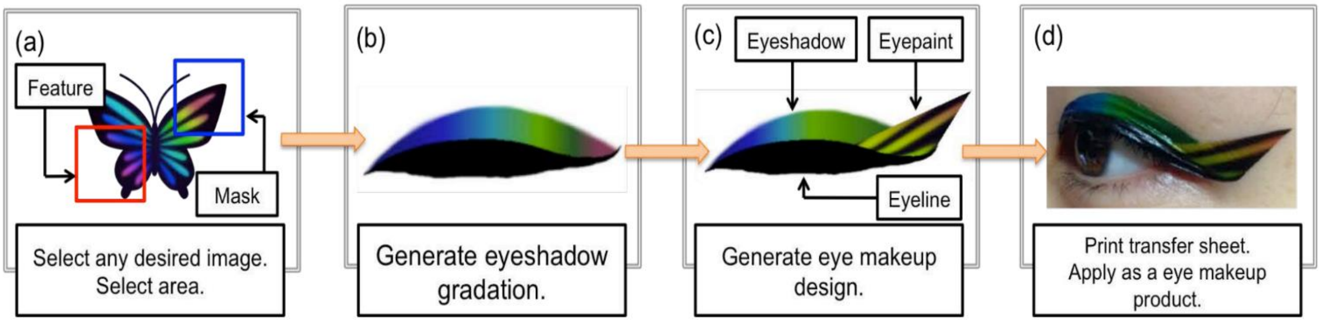

Figure 2.6 Makeup design workflow of iMake.

2.2.2. Makeup with AR

With the widespread use of AR technology in facial applications, many researchers begin to apply AR to makeup. Benefits from the characteristics of AR, it can perform virtual content on the user's face in real-time, improving the interactivity when using the makeup assistance system and providing more realistic feedback of the results to the user.

Cai et al [23] designed a system for simulating specific types of Peking Opera makeup. They extracted several characteristic patterns of Beijing Opera faces and used AR technology to represent the virtual face on the user's face in real-time. Rahman et al [24] designed a smart mirror system utilizing AR. This device captures and analyzes the features of the user's face and the features of the using cosmetics in real-time, and the system gives several other brands cosmetics with the same feature of currently using and displays the virtual effect of the makeup on the face so that user can watch the virtual makeup looking through the mirror.

Oliveira et al [25] proposed an interactive mobile application for makeup tutorials, where the system will prompt the user step by step with the recommended makeup order. And through the AR performance, as shown in Figure2.7, the beige color part on the user's face are the areas that need to be drawn makeup indicated by the system.

Figure 2.7 Mobile application developed by Oliveira et al. [25]

On the issue of combining makeup instruction with AR technology, Treepong et al [26] proposed a novel system by manufacturing special makeup tools as shown in Figure 2.8, including lipstick, eyebrow brush, and cheek brush, which are equipped with sensors that can record the area where the user applies makeup and the hand-technique used in applying makeup, meanwhile, the depth camera in front of the user captures the face data and generates virtual makeup effect in real-time. The generated effect images are projected by a projector using 3D mapping on the area where users have drawn makeup. Finally, the user can confirm the effect of the virtual makeup by observing his/her face in the mirror, to practice and improve makeup techniques.

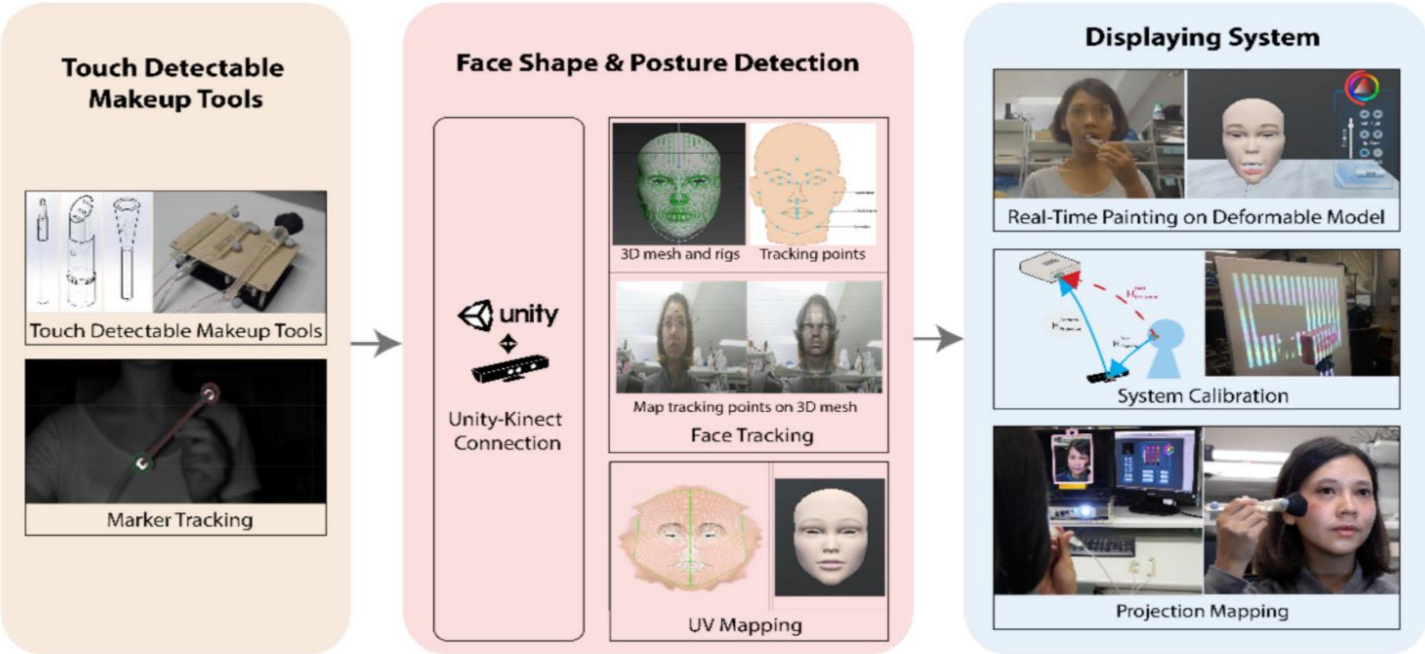

Figure 2.8 The process of system by Treepong et al. [26]

2.3 Research Position

In this study, we propose a guidance system that helps users to complete their eye makeup by analyzing the acquired eye features and presenting them with the corresponding eye makeup guidance in real-time.

First, the main problem of this research is to help makeup novices to draw suitable eye makeup. In this problem, we can find from the related works that there are two ways to help draw makeup, one is to give direct makeup advice and tell users through text or image; the other is to simulate the effect after makeup so that users can refer to their face after using certain cosmetics to better draw their makeup. We consider that makeup beginners, are not yet capable of imitating a makeup look perfect by themselves, so it is a more effective way to give direct advice during drawing makeup than showing the user the simulated effect after the makeup application. At the current stage of eye-makeup support, there is no effective visual approach to directly support people to draw a suitable eye-makeup. For that reason, we proposed a novel method that supports users to draw recommended makeup by referring guidance image in real-time. The system we proposed is to convert the analyzed result of eye-shape into makeup guidance, show it to the user visually, and tell the user makeup suggestions and the area that needs to be drawn.

In addition, on the problem of how to give corresponding eye makeup suggestions according to eye shape, the previous works always proposed methods of classifying the eye shape by overall eye contour. Besides, Alzahrani et al[10] extracted and separated various features of the eyes and determined which type of eye makeup to be drawn according to the features. However, in that work, the feature points are only 6 landmarks per eye, which are not sufficient to describe a correct eye shape. For making the classify results of eye shape more accurate than Alarhzarni et al[10], we utilized a new eye contour detection model that allow us to get 16 landmarks per eye that can be used for describing eye shape with more detail.

Chapter 3 Guidance System

In this chapter, we describe the framework of our proposed system and introduce the details about the technology and algorithm we utilized.

3.1 System Framework

Figure 3.1 shows the overall workflow of the proposed system. Regarding the proposed system, it consists of three main parts and utilizes two open-source libraries: OpenCV [27] and MediaPipe [28]. In the first part, the proposed system detects the user's eyes through the web camera and obtains the geometric information of the eye-contour to calculate it for the next analysis process. In the second part of the system, we design a rule-based model using geometric computation to classify eye features based on the knowledge of eye-shape classification. The last part is based on the knowledge of eye-makeup, the proposed system generates a recommended eye-makeup guidance based on the previously analyzed classification results and represents it on the image of the user's eyes in real-time. The proposed system enables the user to observe the guidance pattern on the screen while drawing an eyeliner that suits him/her.

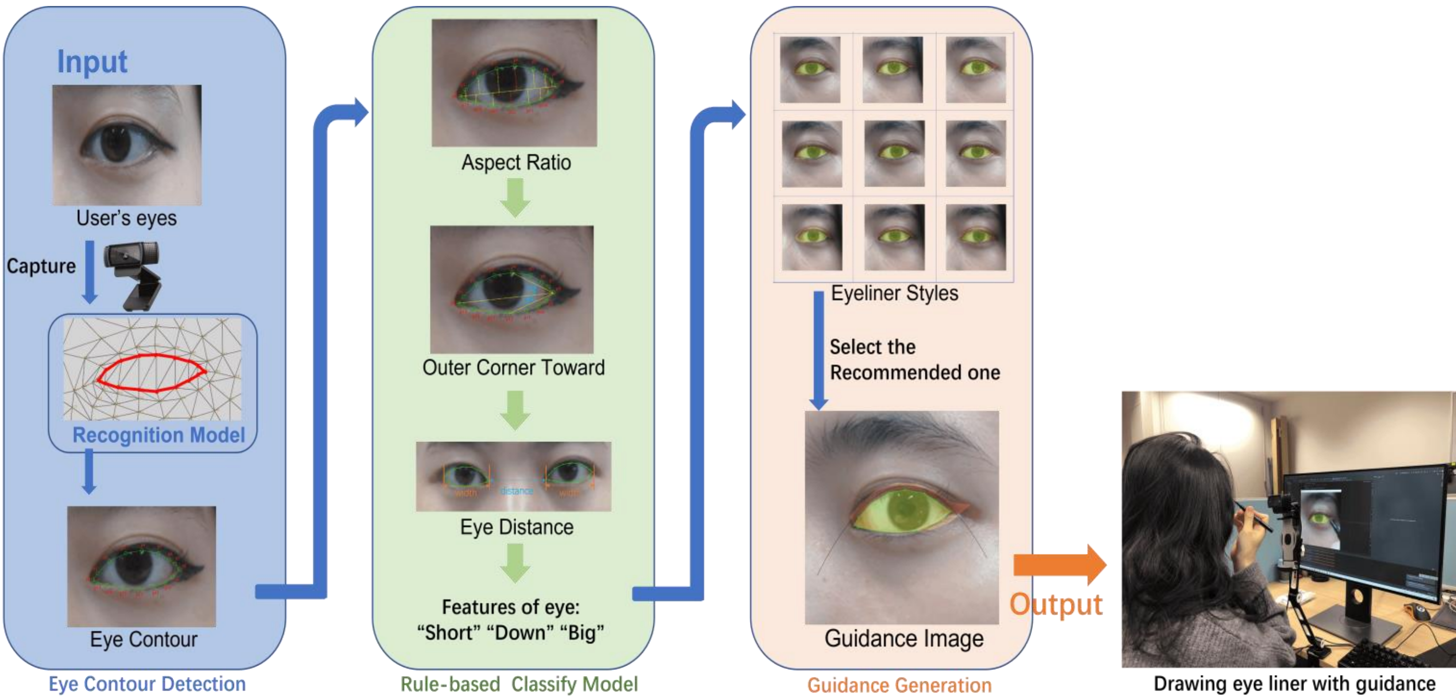

Figure 3.1 Workflow of the proposed system

3.1.1. Face Detection & Eye Detection

In the early stage of designing the system, our main problem was how to accurately recognize the user's eyes and be able to detect eye-contours more precisely. We tried to use some of the now common open-source face recognition tools to help us recognize the user's face and detect the shape of the eyes on the user's face. We started to achieve eye shape detection by implementing Dlib [10], which is an open-source library for image processing that can run in Python and contains face recognition models, the main approach of this recognition model is based on the Harr-cascade detection model [29]. This model is a machine learning object detection algorithm that uses edges or lines called "Harr-like features" to detect visual objects rapidly. With this recognition model, we can accurately recognize the face in the image and detect the eyes. Generally, in the face recognition model, the landmark is used to label the feature points on the face, which consists of x-coordinate and y-coordinate in the current image. For the output of the recognition model using Dlib, it is a face mesh map with 68 landmarks. However, this mesh map only uses 6 landmarks to describe each eye contour as shown in Figure 3.2, which is not available to our requirements.

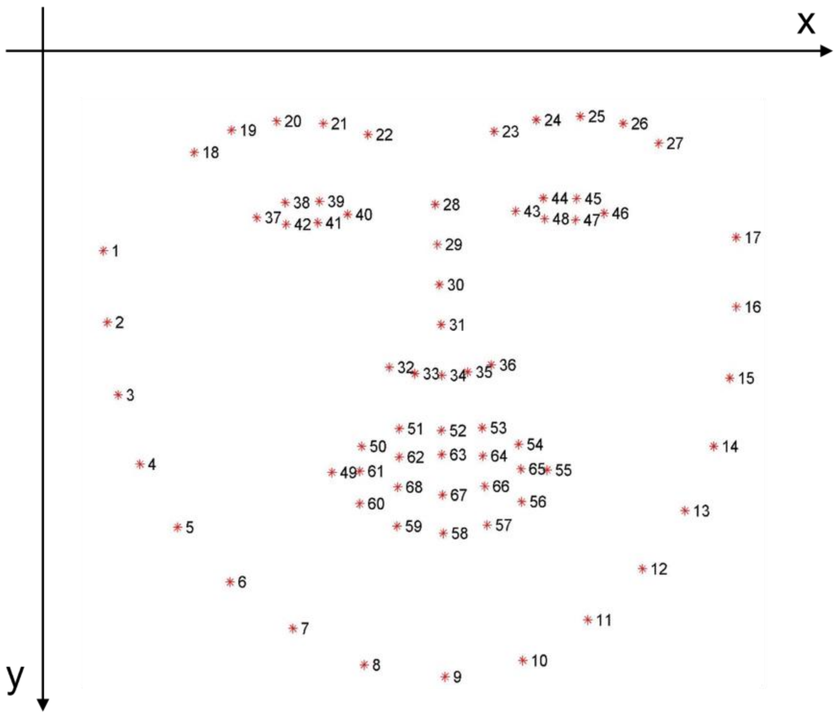

Figure 3.2 Face landmarks by Dlib

After exploring the possibilities of Dlib and other open-source tools, such as OpenFace [30], we try to solve this issue by using MediaPipe developed by Google, an open-source tool library containing many solutions and models related to face recognition and body recognition (Figure3.3). In our proposed system, we utilized the "face_mesh.solution" from MediaPipe, which contains a trained face recognition model with higher speed and accuracy. The model is trained by TensorFlow, and the output is a face mesh map (Figure3.4) containing 486 landmarks. In this map, 16 feature points can be used to describe the eye contour (Figure3.5). Through practical testing, we found that this model can effectively identify the shape of the eye contour with high accuracy to meet the expectation.

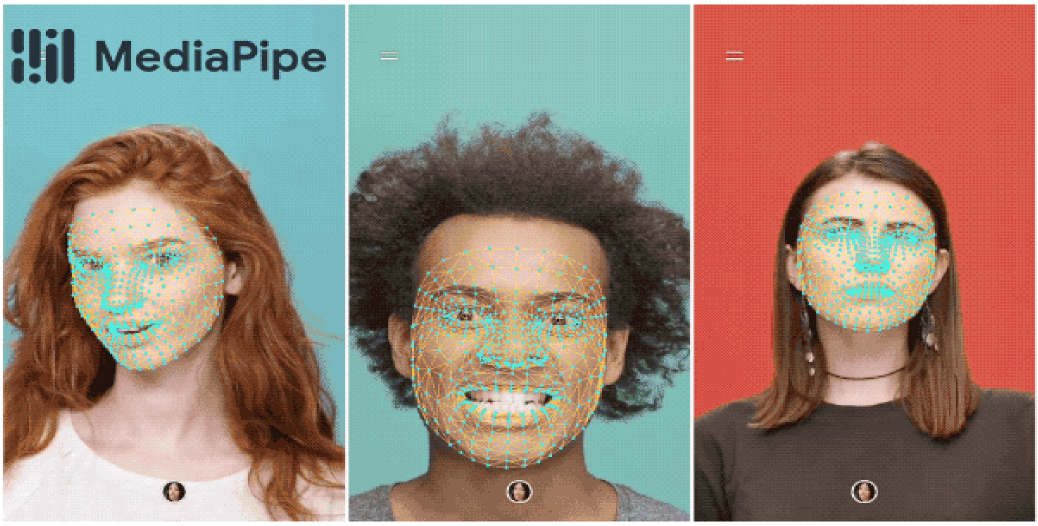

Figure 3.3 Face mesh by MediaPipe[28]

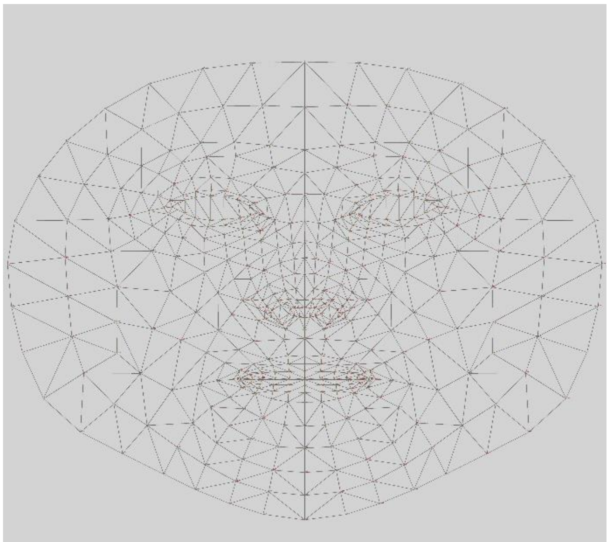

Figure 3.4 Mesh map with 486 landmarks[28]

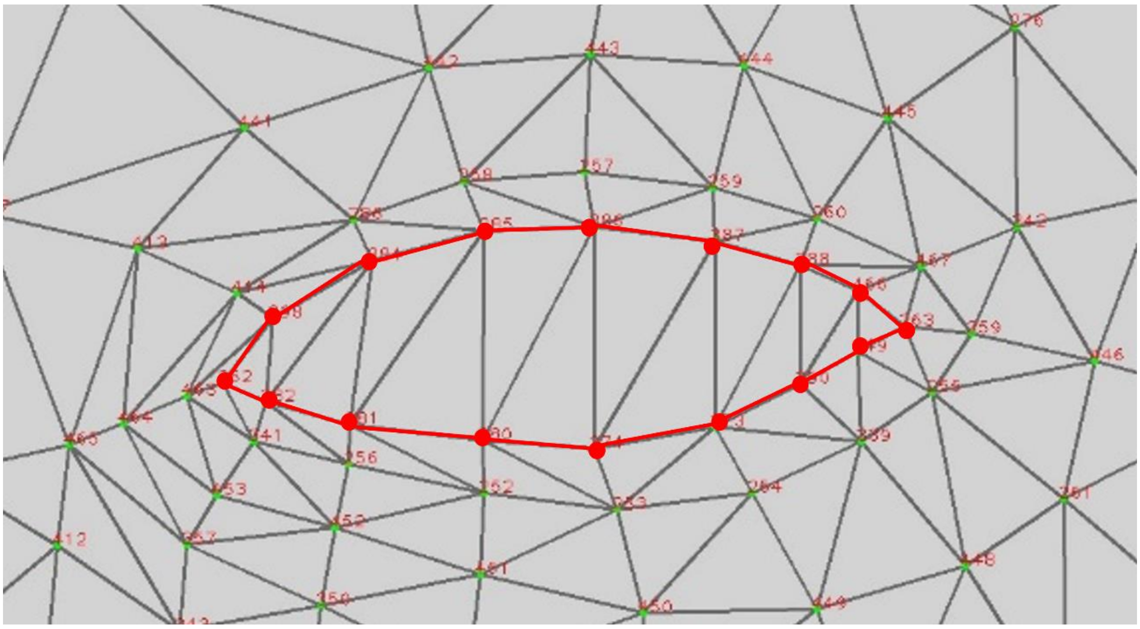

Figure 3.5 Landmarks of eye contour

When implementing the eye detection module, we first invoke the connected camera through the OpenCV method. The camera will stream the captured images at 60 fps. A MediaPipe recognition model is used on the captured frame to recognize the faces in the frame. In this system, we limit the number of faces recognized by the model and set the first face recognized as the user's face. Since the model detects each frame of the video stream, the generated face mesh map will be different according to each frame. To get the shape of the eyes accurately, the system lets the user save the mesh map of the current frame at the right moment. In this study, we only consider the shape analysis of eyes, so the system selects the landmarks of the eye parts when saving the mesh map and saves them into a list. In addition, we found that the angle of the camera often affects the detection results. To ensure that we can obtain a more realistic eye contour, we kept the user and the camera at a reasonable distance and allow the user to adjust the camera angle to get the correct eye contour.

3.1.2. Eye-shape Analysis

Before designing the function for eye shape analysis, we first reviewed the related works [12][13] about eye shapes . Based on this survey, we designed a series of rules to help us classify eyes. We reviewed the descriptions of several typical eye types (Figure3.6), such as round eyes: larger and more circular; close-set eyes: less space between eyes; downturned eyes: taper downward at the outer corner, and we found that the descriptions of eye shapes are always related to several features of eyes: the size of the eye, the angle of the eye outer corner, and the distance between the two eyes. Therefore, we set these three features as the classification conditions for determining eye classes.

Figure 3.6 Typical eye shapes
(http://manicarebeautyacademy.com.au/cat-2-tut-4/)

For the eye size, we consider that there is a significant correlation between the eye size and the aspect ratio of the eye. In our obtained eye contour landmarks, for example of the right eye (Figure3.7), we will define the leftmost and rightmost points *“p0, p8”* as the position of the head and tail of the eye. And we calculate the size of the perpendicular line from *p1-p7*, and *p9-p15* respectively, then find the maximum values of the upper part and lower part and sum them to get the *eye-height* up (Figure3.9). By connecting *p0* and *p8*, the length of this line is considered the *eye-width* of the eye; After obtaining the width and height, the ratio of *width/height* is calculated as the *eye-width* ratio "size-rate". After obtaining the aspect ratio, we start to investigate the margin of error and determine it. After testing, we obtained a relatively reasonable margin of error: "2.75~3.00", within which aspect ratios are considered average, those above 3.00 are considered small long eyes, and those less than 2.75 are considered big round eyes (Figure3.8).

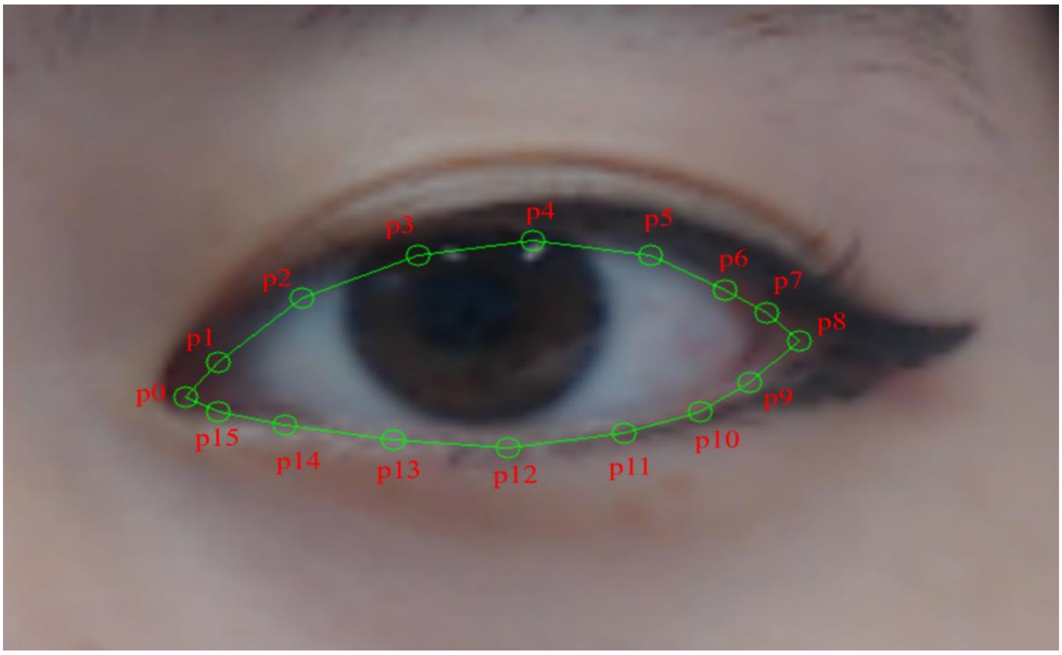

Figure 3.7 Eye contour marked with points

Figure 3.8 left: small-long eye; right: big-round eye

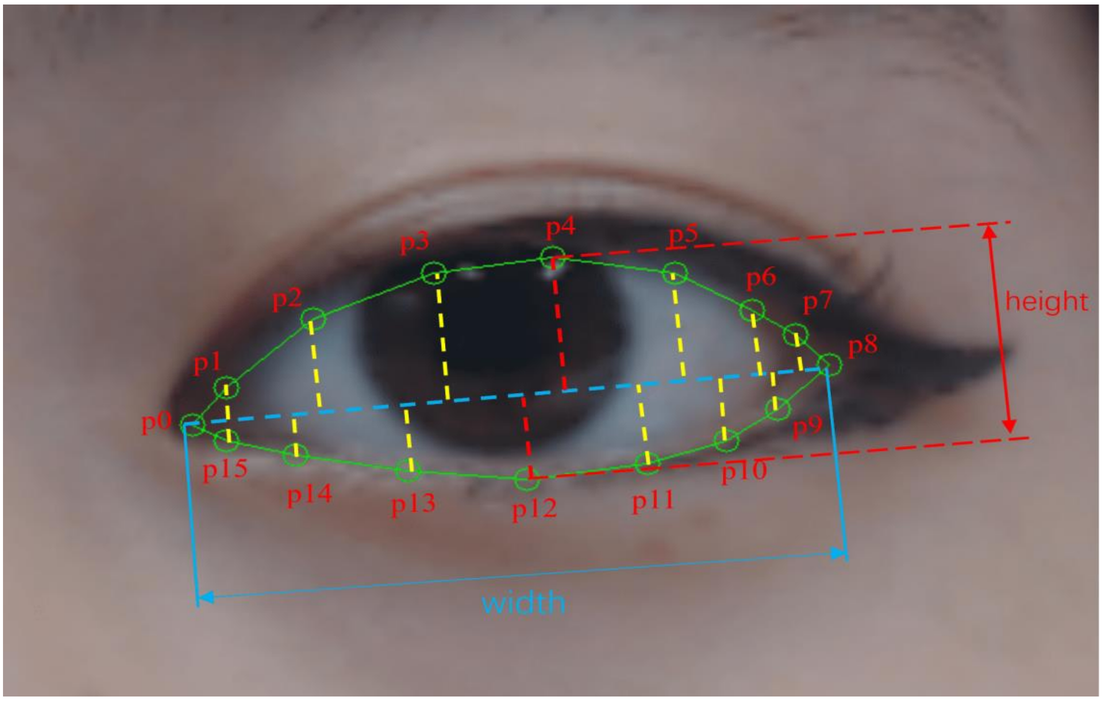

Figure 3.9 Calculate the width and height of eye

After observing the shapes of upturned and downturned eye types (Figure3.10) and referring to the description of these eye types, we found that the angle of the eye's outer corner can be used as a reliable reference, for determining eyes upturned or downturned. In the case of the right eye (Figure3.11), the *p4* and *p12* is the highest and lowest point as we calculated, we connect *p0* and *p8* as a line *p0-p8* for dividing the outer corner angle into two angels and connect *p8* with *p4* and *p12* as upper angel α and lower angel β. If the α is significantly larger than the β, the outer corner is determined to be down toward and the eye will be labeled as "downturned", on the contrary, is determined to be up toward and the eye will be labeled as "upturned".

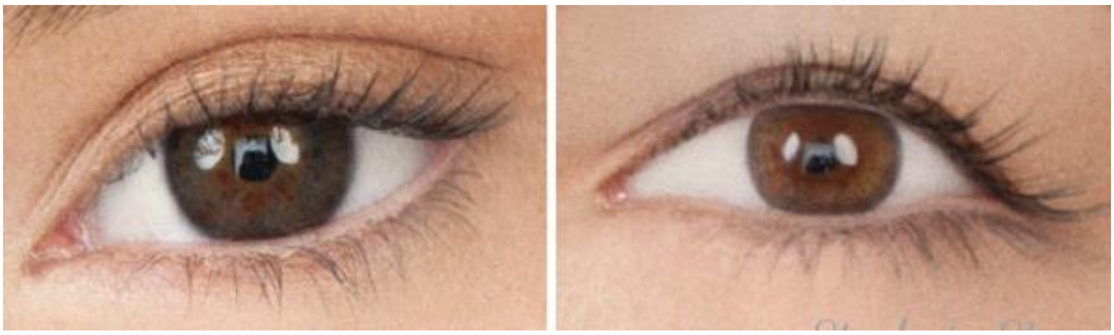

Figure 3.10 left: upturned eye; right: downturned eye
(http://stylesstar.com/makeup-upturned-eyes.html)

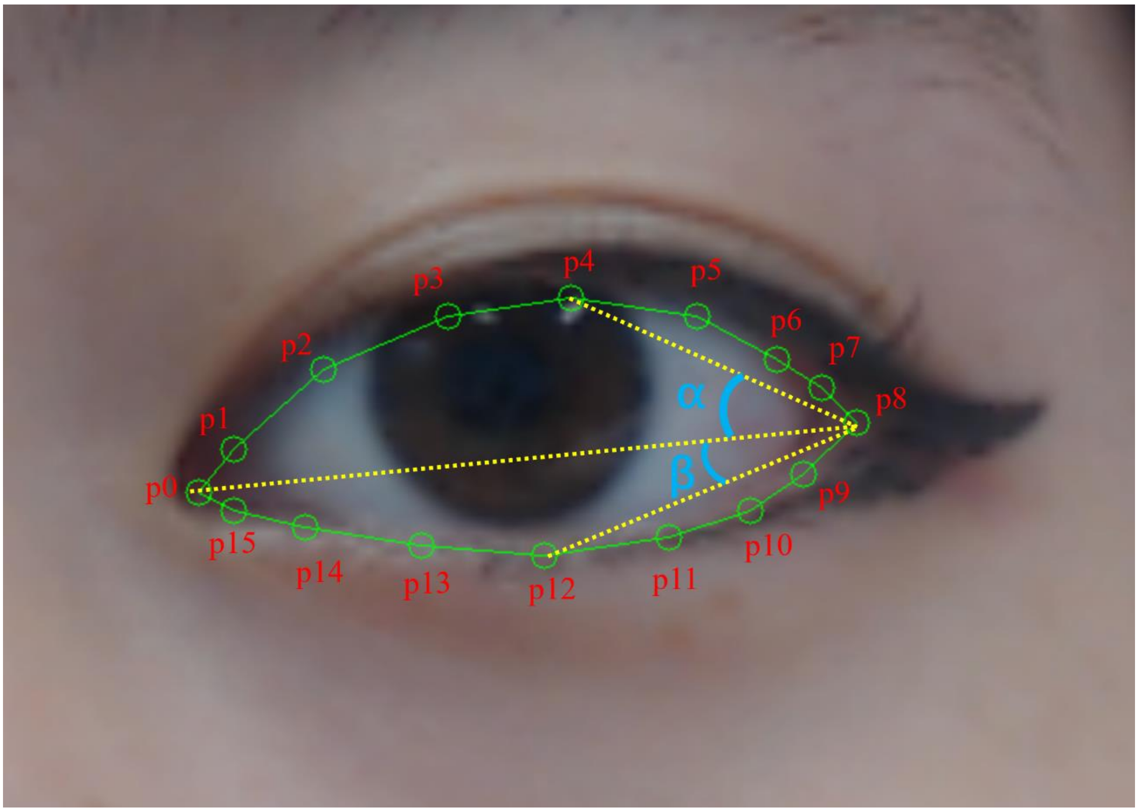

Figure 3.11 Calculate the toward of outer corner

In addition, we measure the distance between point "*lefteye-head*" and point "*righteye-head*" as "*eye-distance* " and calculate the average width of two eyes as "*average distance*" (Figure3.12). By testing the samples of open-set eyes and close-set eyes, we set the margin of error as 5%. Thereby, if the eye-distance is longer than *1.05 * average distance*, the eyes are considered as open-set and labeled as "open"; Conversely, if the eye-distance is shorter than *0.95 * average distance*, the eyes are considered as close-set and labeled as "close". Otherwise, the eyes are considered as having average eye-distance and labeled as "average".

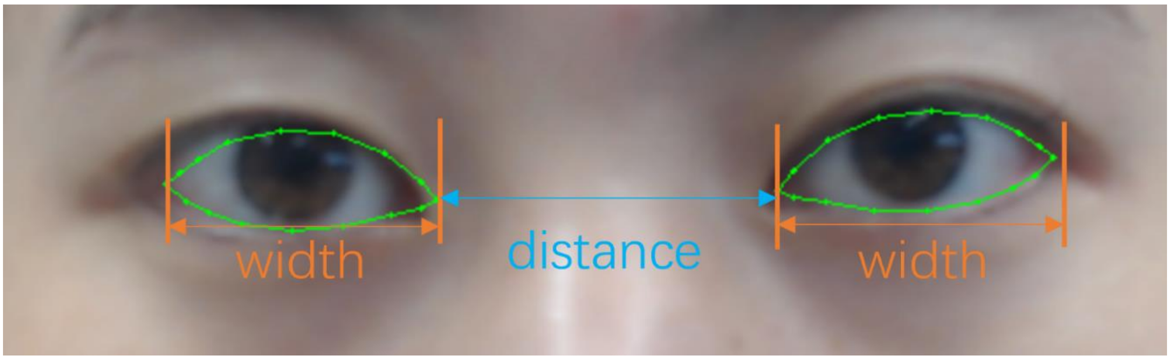

Figure 3.12 Calculation of Eye-distance

When the tags of the three features (eye aspect ratio, eye corner angle, and eye distance) are calculated, the system writes them into a list. And when the guidance module is running, the system calls the list of recorded features' tags, and the type of guidance is selected by reading the tags in the list.

3.1.3. Guidance Generation

Based on the research and experience of the main purpose of drawing makeup [3], eye makeup is categorized into making eyes look bigger and modifying the shape of the eyes. Therefore, eyeliner is a significant component for drawing eye-makeup. Generally, there are two typical eyeliner types: outer eyeliner and inner eyeliner. However, the inner eyeliner is applied in eyelashes roots, where is difficult to detect by current methods. Therefore, the eye makeup types generated in this system are all about the outer eyeliner.

According to eye makeup knowledge, we have defined and designed several typical styles of eyeliner related to eye shape features (Figure3.13).

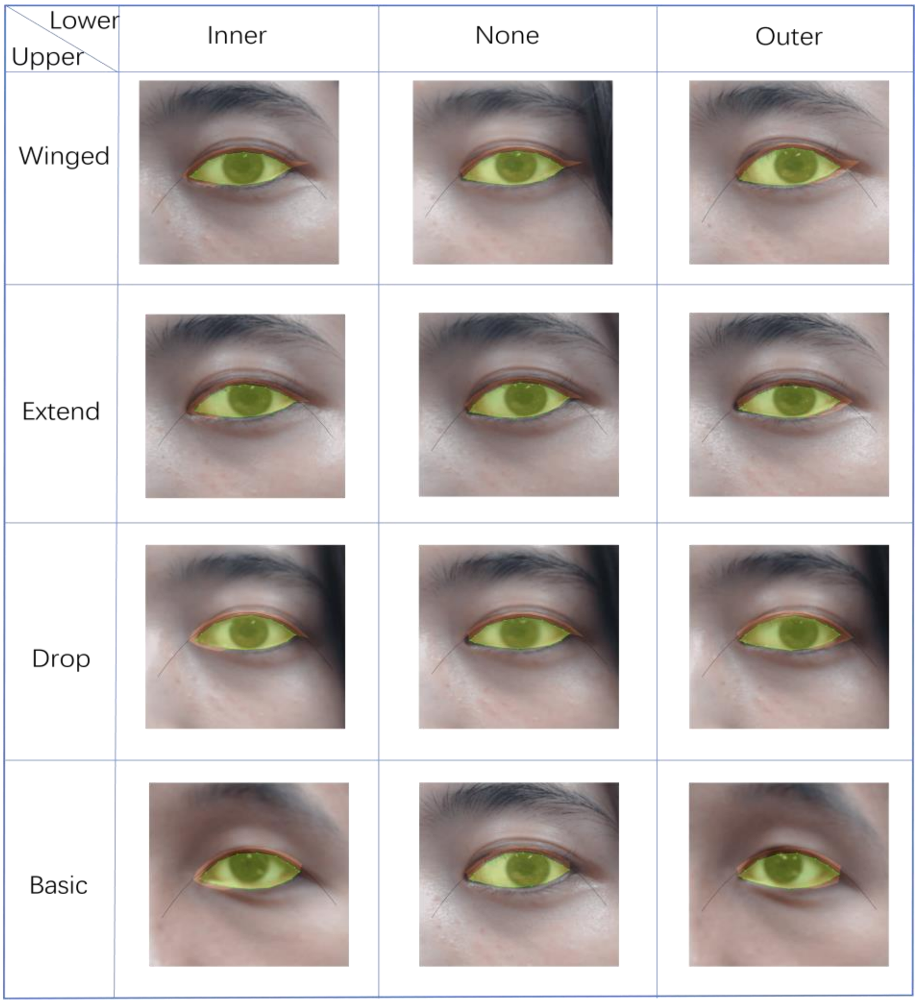

Figure 3.13 Eyeliner styles generated by system

Style-Basic is used to enhance the visual effect of the eyes and make them look bigger. *Style-Basic* is a thick line along the upper eyelid that starts from the inner corner of the eye to the outer corner of the eye (Figure3.14). Since the upper part of the eye contour consists of 9 points, we need to generate a thick line along with the shape of the upper eyelid. We calculate the mid-point for each line segment of the upper eyelid. Then set perpendicular line of each line segments from mid-point to *p0',p1'...p7'*, and the length of each perpendicular line is set as *h*. By connecting the serial of calculated *p'* and points of the upper eyelid, and the closed polygon is the basic upper eyeliner style as *Style-Basic*.

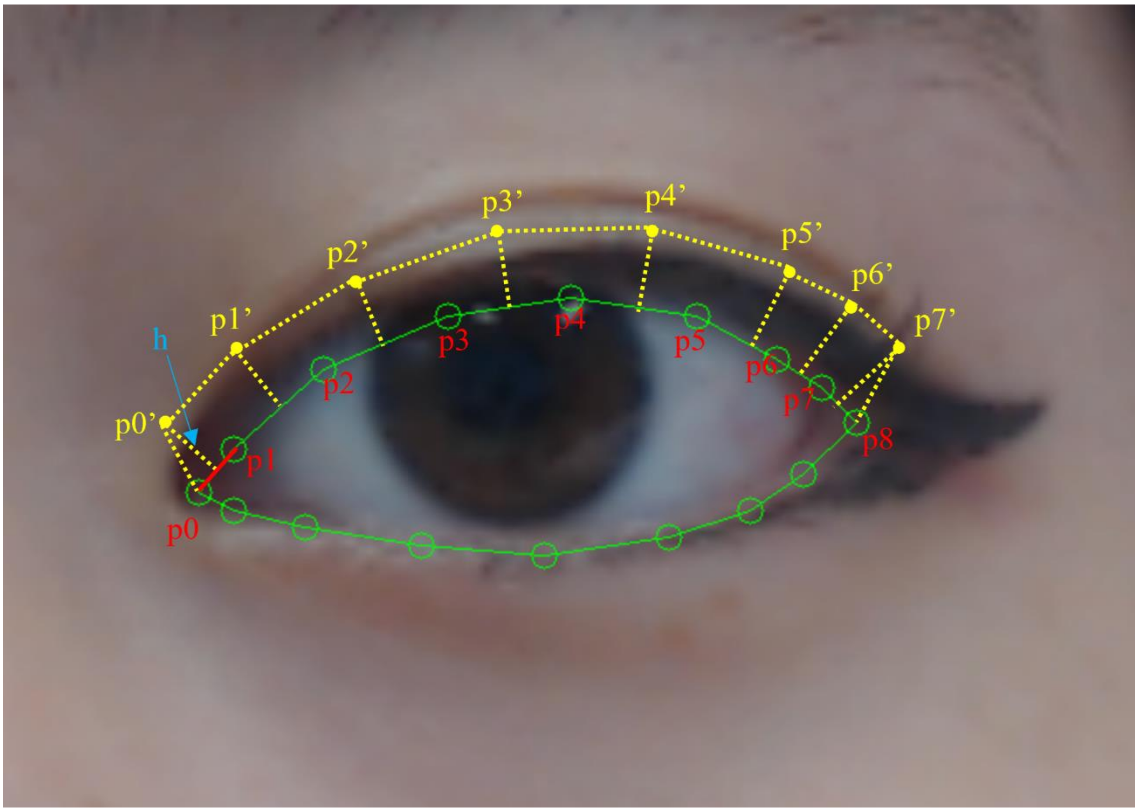

Figure 3.14 Generation of basic upper eyeliner

For the upturned-winged eyeliner pattern, we define an outermost point *E*. In the winged eyeliner pattern (Figure3.15), by measuring typical samples of winged eyeliner, the angle of the eyeliner tail is more natural when it is about 15 degrees, so we define the average angle between *E-p8* and *p0-p8* as 15 degrees. Then, we tested and found that the length of the wing is more natural when it is about 12% of the *eye-width*. The natural length of the wing (12% of the *eye-width*) is also applied for other wing eyeliner styles. Thereby, the coordinates of the point *E* can be calculated by trigonometric functions. By connecting the *Style-Basic* to the point *E*, forming a closed polygon, we get the upturned wing eyeliner *"Style-Winged"*.

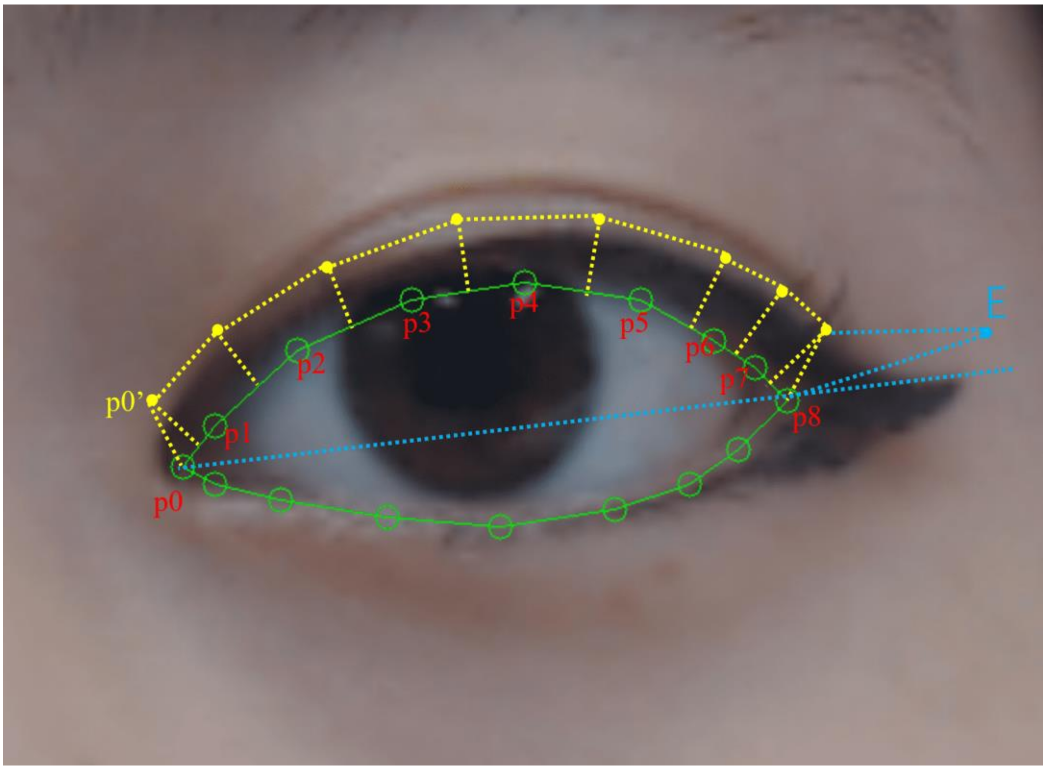

Figure 3.15 Generation of winged style

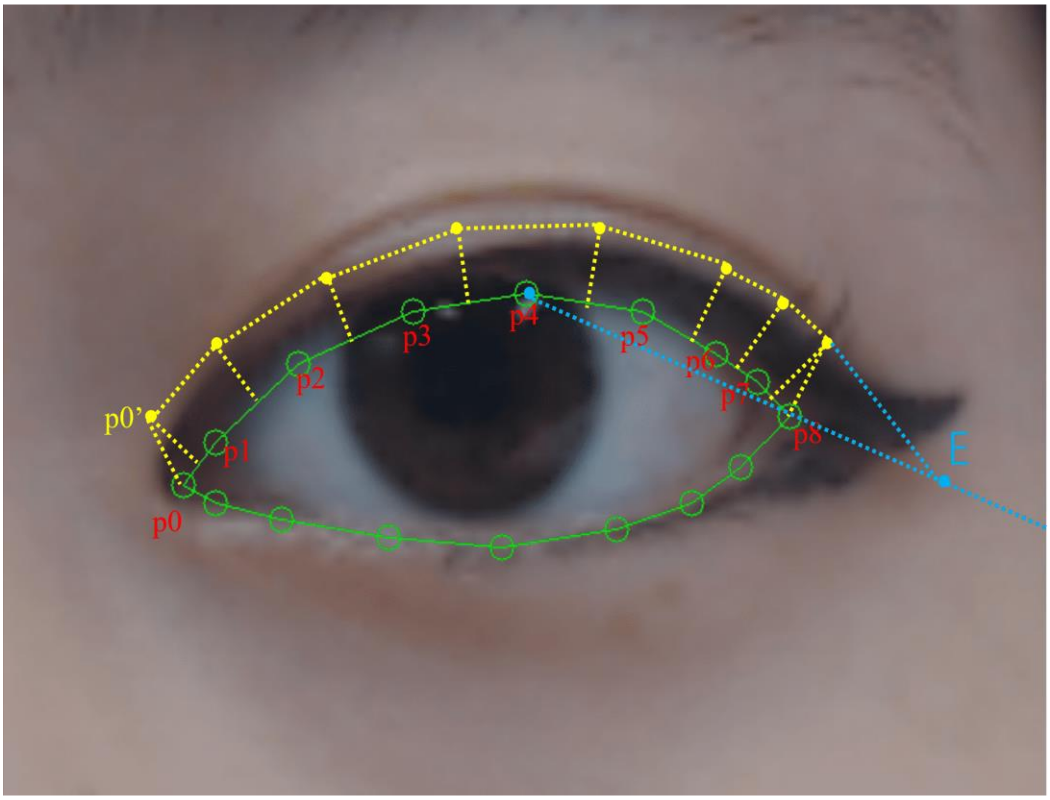

Figure 3.16 Generation of drop style

Style-Drop is designed in a similar way to Style-Winged (Figure3.16). We need to get a droopy eye-line style. By defining a point *E*, *p8-E* is the extension of *p4p8*, where the length of *p8-E* is 12% of the "*eye-width*" of the eye as we found in the previous test when we designed the *Style-Winged*. The closed polygon formed by connecting *Style-Basic* to point *E* is regarded as *Style-Drop*.

For *Style-Extend* (Figure 3.17), it is described as a style in which the end of an eyeliner extends out horizontally. We first define the outermost point of the eyeliner, point *E*. *p0*, *p8*, and point *E* are on the same horizontal line, and the length of *E-p8* is 12% of *eye-width*. Then connect *Style-Basic* with points *E* to get *Style-Extend*.

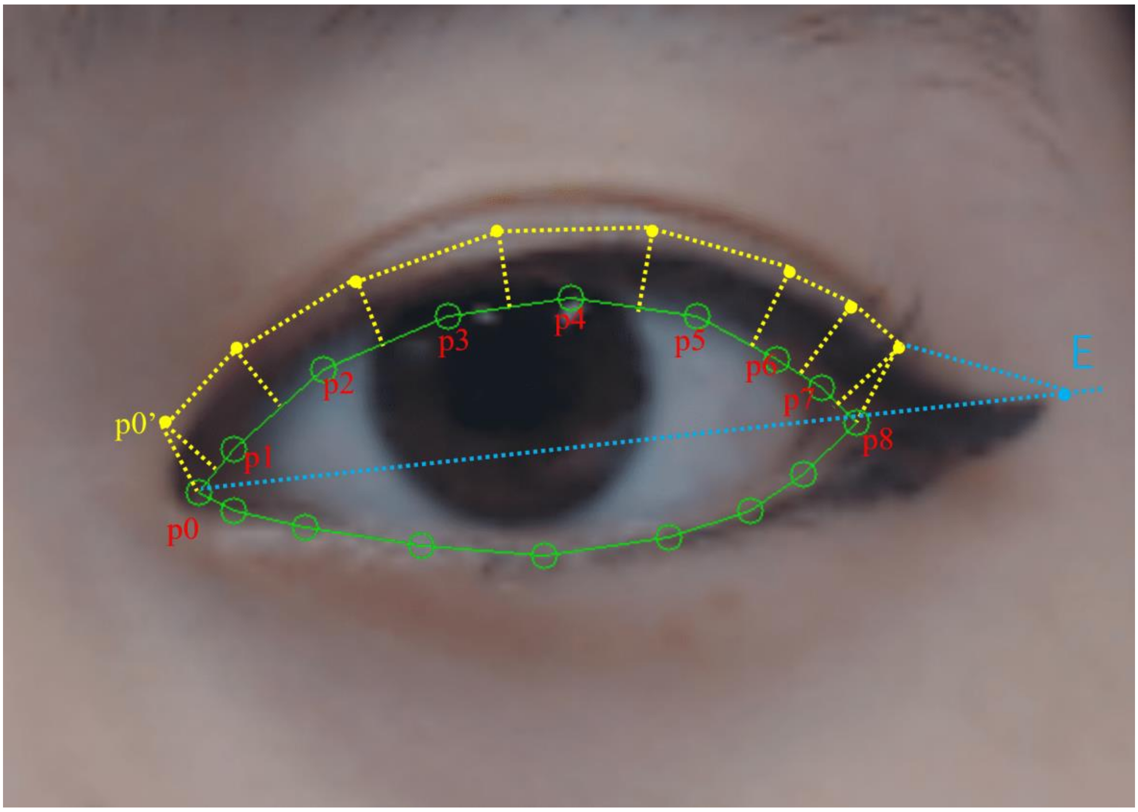

Figure 3.17 Generation of Style-Extend

In studying eye makeup styles related to eye spacing, we summarized two eyeliner styles used to close and widen eye distance (Figure3.18). We used a similar method as we used to design *Style-Basic*. As we found in previous work, the lower eyeliner is always thinner than the upper eyeliner and applied on corner sides.

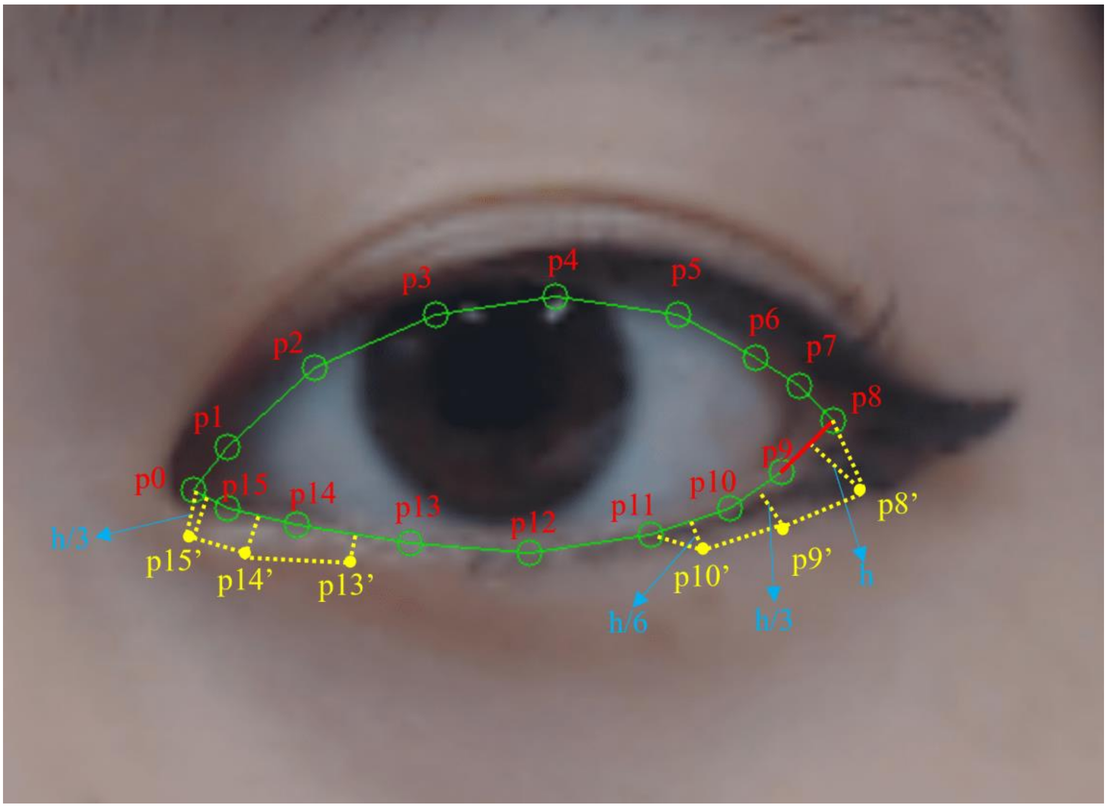

Figure 3.18 Generation of basic lower eyeliner

For lower eyeliner in outer corner side (Figure3.18), it is always used to connect the wing of upper eyeliner, therefore, we select *p8, p9, p10, p11* to create a lower eyeliner style on the inner corner side. We decrement the value of h from large to small in equal proportion, making the shape appear to be from big to small. For lower eyeliner in the inner corner side (Figure3.18), it is always used to connect the upper eyeliner and looks thinner, therefore, we select *p13, p14, p15, p0* to create a lower eyeliner style on the inner corner side. For that reason, by comparing the actual inner eyeliner and testing the visual effect of the pattern, we found that the value of *h* as *h/3* of the outer side could make this pattern looks thinner than the outer side . We defined these two lower eyeliner styles as "*Style-Inner*" and "*Style-Outer*"

When it is needed to apply the lower eyeliner styles, the system will select the recommended style and emerge it with upper eyeliner styles. In the case of emerging *Style-Outer* with *Style-Winged*, the system connects point *E* to lower *p8'*, and gets the closed polygon as the result for guidance (Figure3.19).

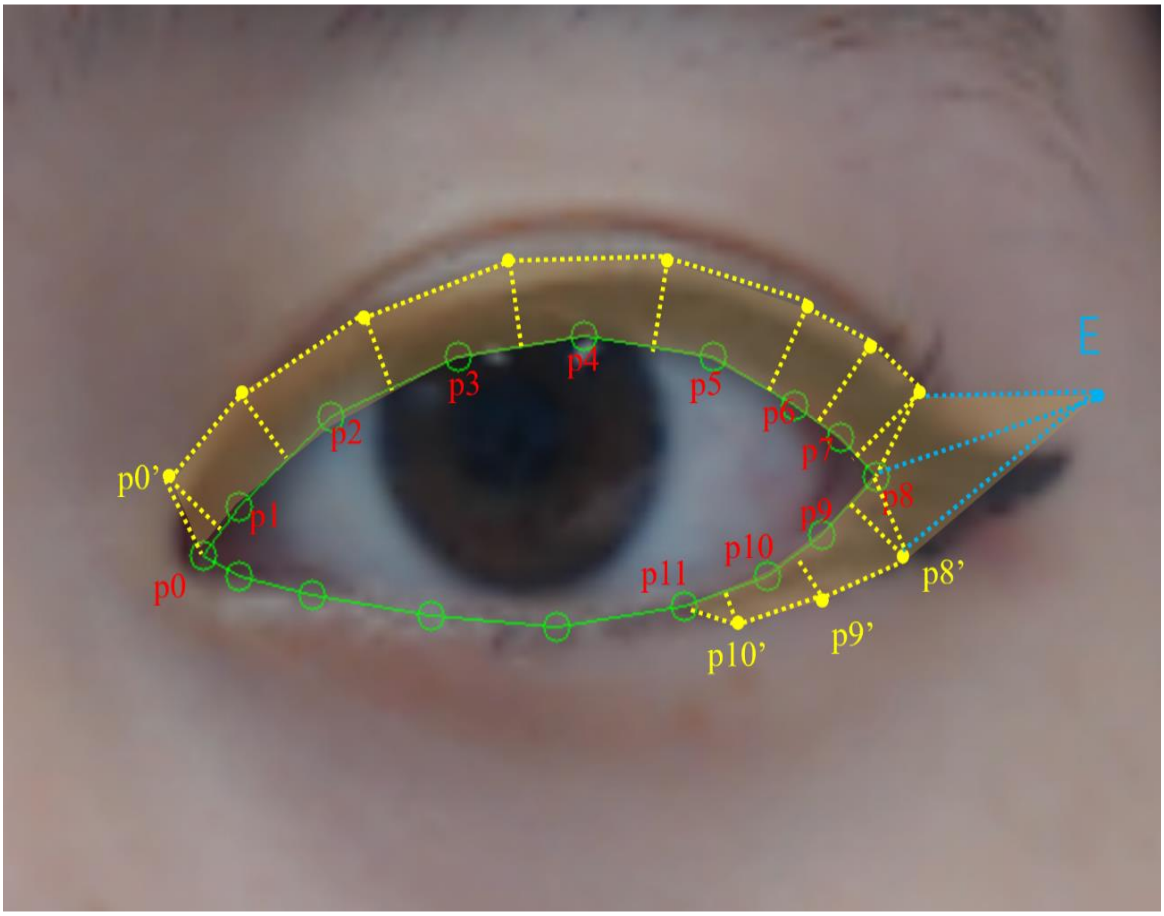

Figure 3.19 Result 1 of eyeliner styles

In the case of emerging Style-Inner and Style-Basic (Figure3.20), the system first calculates a fitting curve by *p0~p8* and *p0'~p7'*, then finds the cross-point *E* with line *p0-p8*. By connecting the point *E* and *Style-Basic*, *Style-Inner*, we get a closed polygon as the result (Figure3.21).

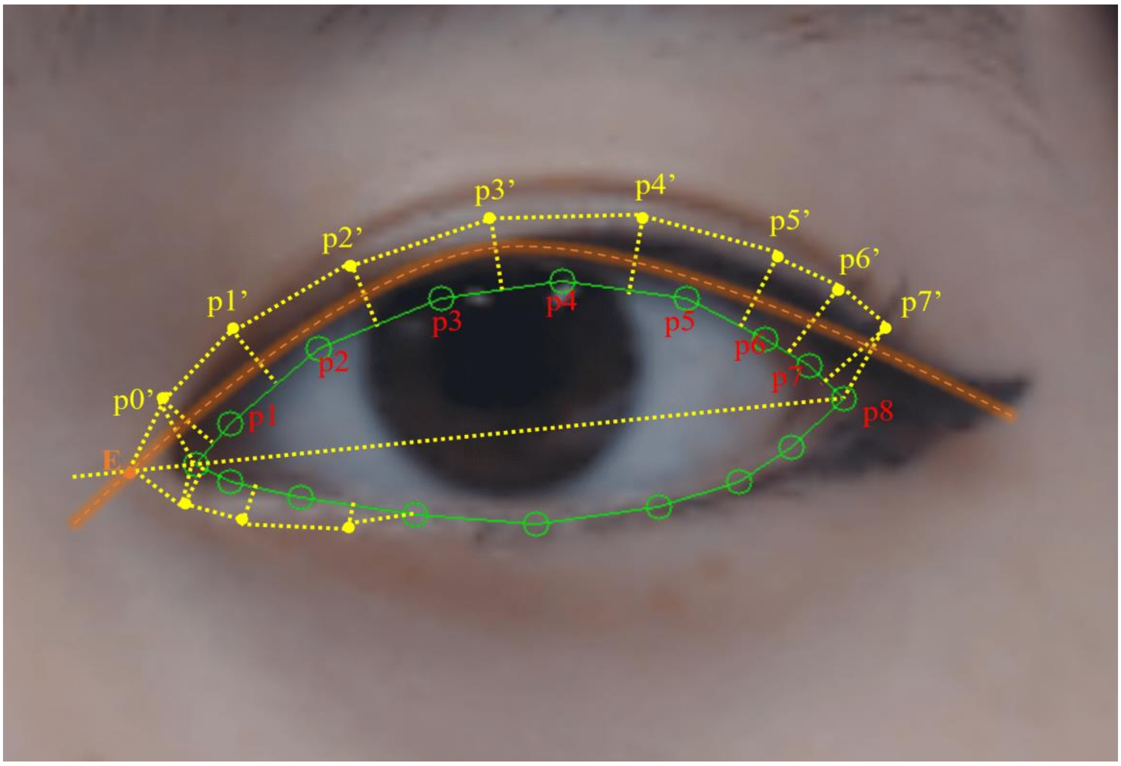

Figure 3.21 Calculate the recommend point of inner corner

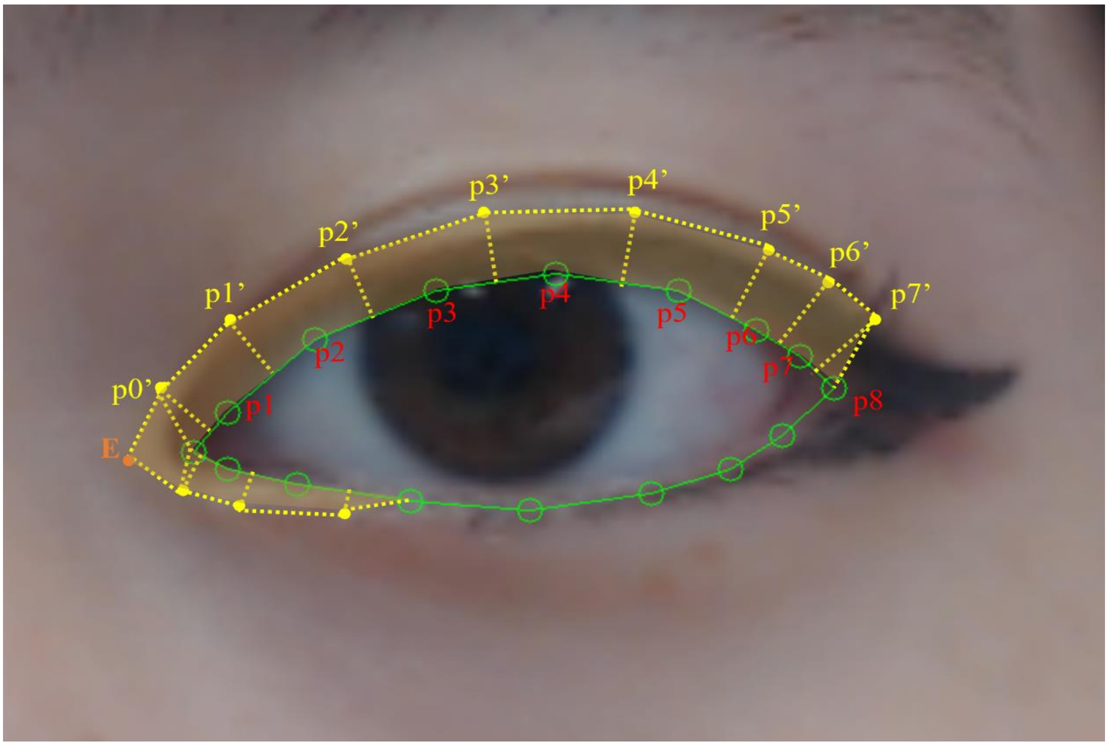

Figure 3.20 Result 2 of eyeliner styles

When the system analyzes the eye features for selecting which style to be applied, it will determine them in the order of eye aspect ratio, eye outer corner toward, and eye distance (Figure3.22). First, if the eye size is labeled with "small" or "average", the system will recommend the Style-Basic, and if the aspect ratio is labeled with "big", then the eye will also recommend the Style-Basic but with the lower parameter h. Next, the system will analyze the toward of the eye outer corner. Depending on the toward of the outer corner, the system will recommend Style-Winged, Style-Drop, Style-Extend. Finally, the system will recommend lower eyeliner styles: Style-Inner, Style-Outer, depending on the label of eye distance. When the whole process of selecting eyeliner styles has been done, the system combines all recommended styles to generate a polygon as a mask. The mask is filled with color and applied to the user's eyes image as guidance.

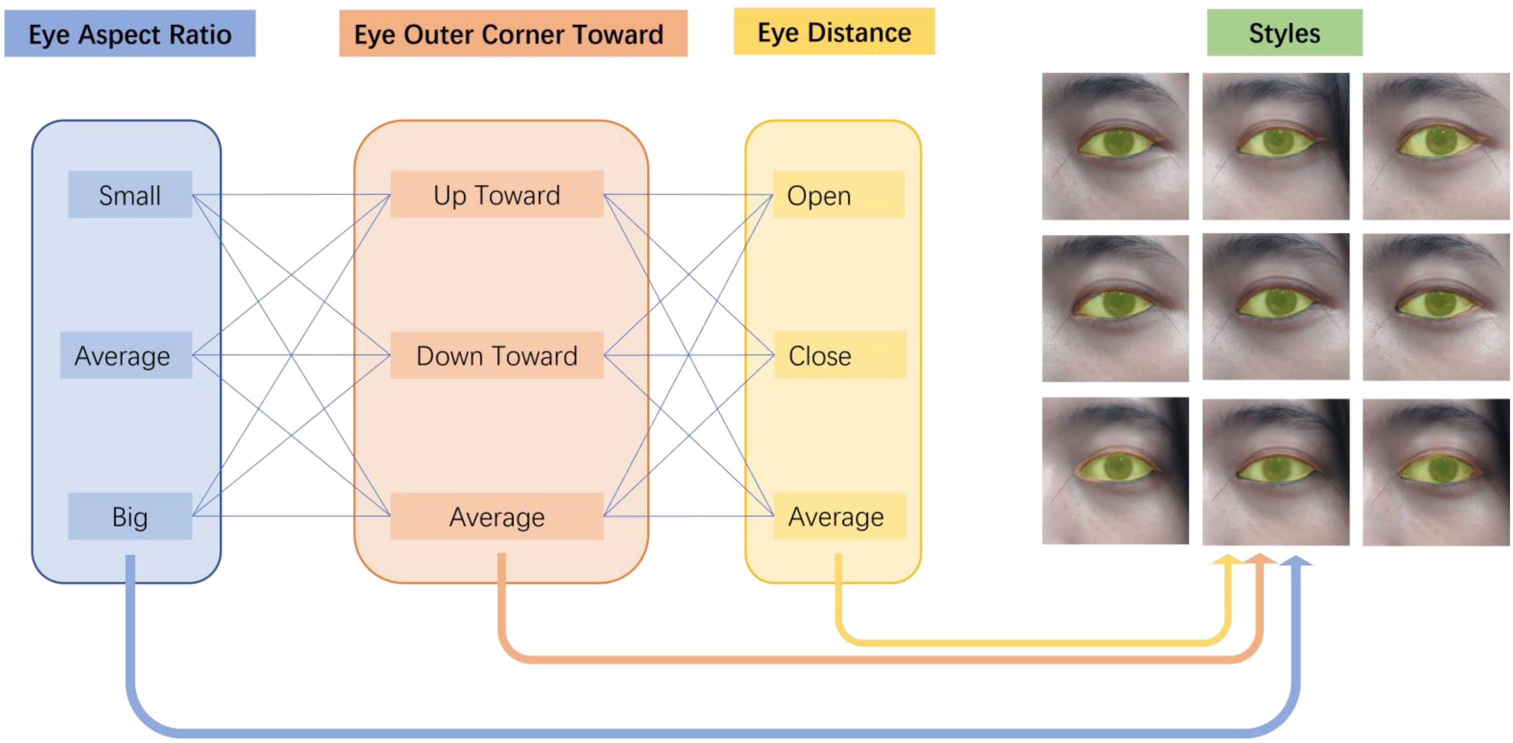

Figure 3.22 Workflow of recommendation function

In addition, we use the function "np.polyfit" from NumPy library to get a curve by inputting upper points *p0'~p8'* and *p0~p8* (Figure 3.23). The "np.polyfit" function is a least squares polynomial method for finding fit curves to inputting points. This curve describes the direction of the eyelid line. Users can refer to this curve to draw an eyeliner that fits the shape of their eyes more naturally.

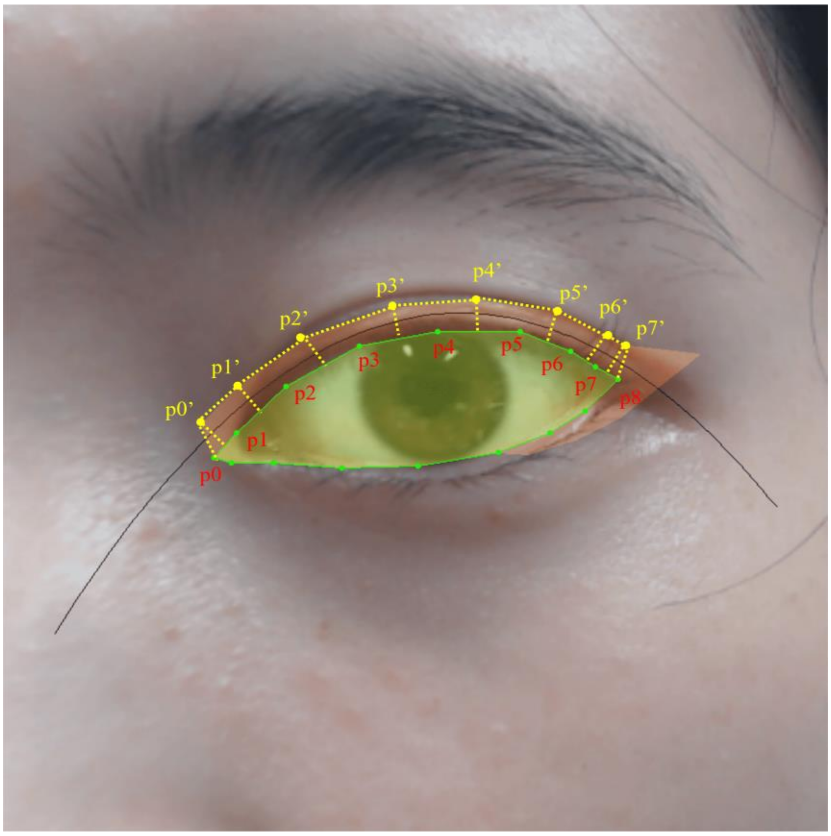

Figure 3.23 Fitting curve

3.2 User Interface

We developed this system using the Python language and OpenCV functions. The interactivity of the system is mainly implemented through the modules from OpenCV. In this work, we used a 27" monitor with 4K resolution, and the user can observe the guidance in the screen to draw eye makeup, while there will be a webcam set up on the table to capture the user's eyes. Since the webcam streams video at 1080p, the video will look too small on the screen, so we enlarged the captured image by 3 times to fit 4K resolution for the user to observe the face clearly.

Figure3.24 shows the User Interface of our system. Generally, people the user always draw makeup using a mirror means that users using our system need to see their eyes and the guidance pattern above their eyes through the monitor. Thus, the proposed system creates new windows of the left and right eyes separately and enlarges them to make the user observe the guidance and their eyes more clearly. At the same time, for the recognized eye contour, the system will stroke it and the user will be able to see how well their eyes are recognized.

In addition, the user can select one window to save the feature information of the current frame through keyboard input. Because the feature information of both eyes is saved at the same time, the recognized eye shape may be in error with the real shape due to the shooting angle and lens distortion of the webcam. Therefore, we need to let the user save the eye features at the correct angle while looking straight to the camera with one eye.

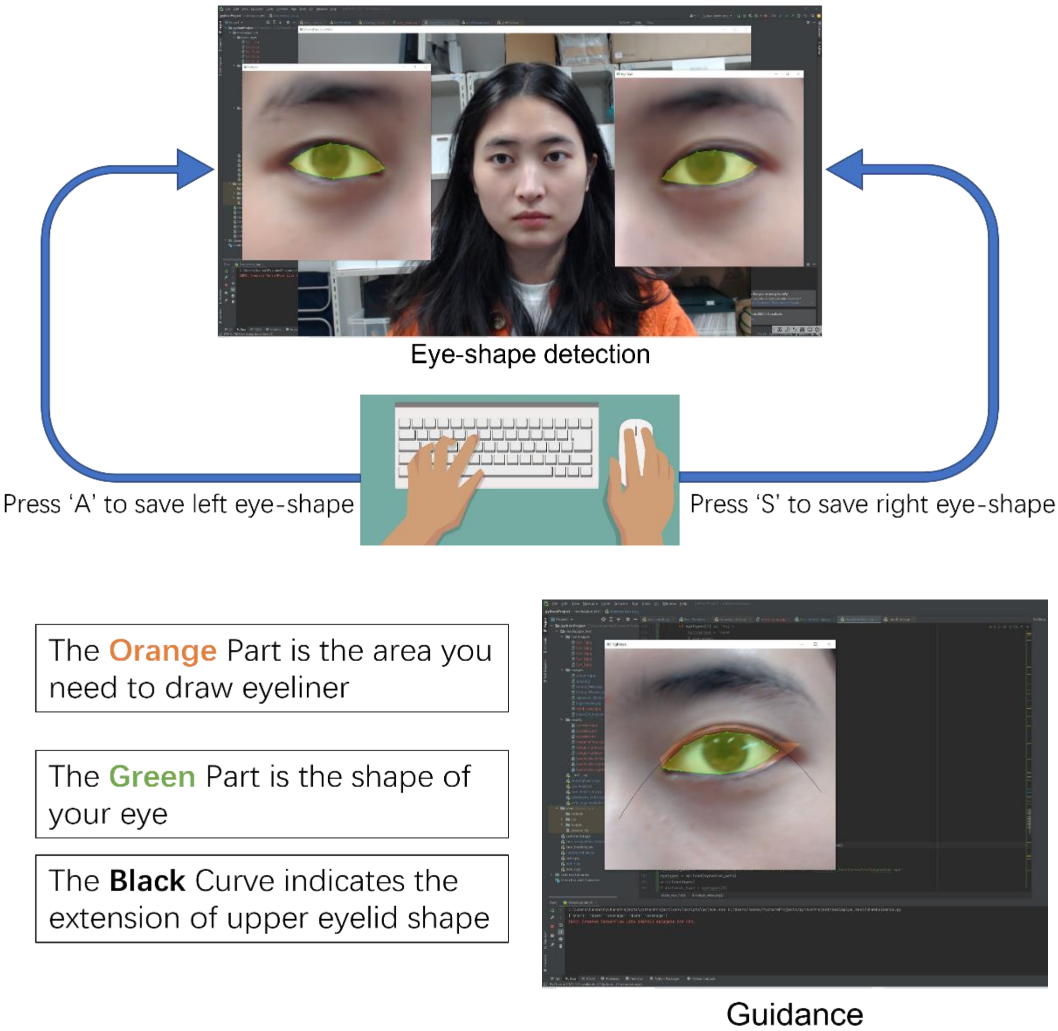

Figure 3.24 User Interface

Chapter 4 User Study & Evaluation

In this chapter, we will present our user study and verify the feasibility of our system. In addition, we will observe the user experience with using our system and show the results of the questionnaire for participants in this experiment.

4.1 User Study

In this section, we will introduce our system environment and describe how we design evaluation experiments.

4.1.1. Experimental Environment

The prototype was running in the follow system environment:

OS: Windows 10 Home x64
CPU: Intel(R) Core (TM) i7-9700 CPU @ 3.00GHz
GPU: Nvidia(R) GeForce RTX 2060 SUPER
RAM: 32GB
Tools: PyCharm, Python-OpenCV ver4.5.2, Python-MediaPipe ver0.8.6
Display Spec: Dell(R) U2718Q
Devices: Logitech HD Pro Webcam C920

The system was running in Python environment, and we set up webcam on the table to capture user’s face.

4.1.2. Experiment Design

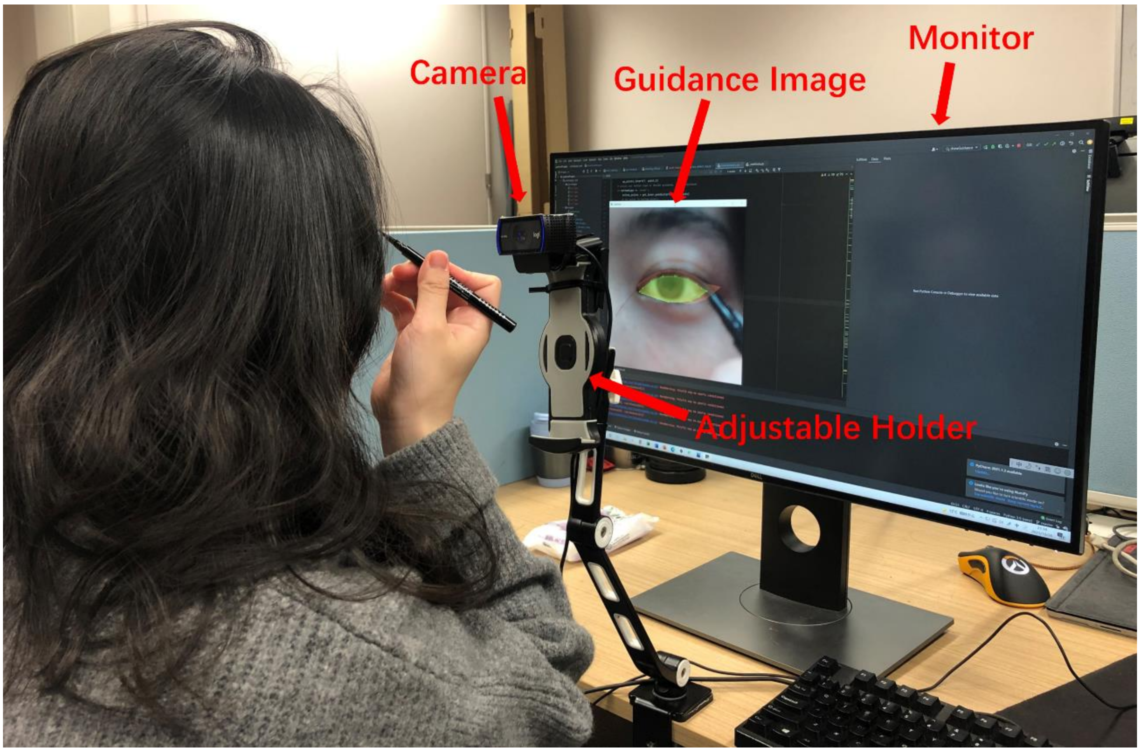

Figure 4.1 Experiment Environment

Figure 4.1 shows the experiment environment. At first, we conduct a comparison experiment, that participants are asked to draw eye makeup in their way, and we will count the completion time. After the eye makeup is finished, we will save photos of the eye-makeup for later comparison. After the eye-makeup is applied, we provide makeup remover for the participants to remove their makeup and start to draw makeup using system.

Before launching the system, we will introduce the workflow of our system and tell users to draw an eyeliner by referring to the orange guidance pattern. Then, we will ask the participant to look at the webcam, the monitor will display the participant's face and independent image of the two eyes, mark the recognized eye contour. The participant can adjust the angle of the webcam by himself/herself till the recognition effect in the screen is adjusted to the best. Then participant saves the current eye contour information through keyboard input. The analyzed eye features results are prompted to the participant in text. We provided participants with two eyeliners (one gel eyeliner and one liquid eyeliner) to draw eyeliner. When the system starts running the guidance program, the user is asked to draw eyeliner. In this progress, the analyzed eye makeup style is displayed in an eye window, and the user can follow the guidance on the screen. When the participant completes the eye makeup, we will count the cost time and save the image of makeup.

4.1.3. Evaluation Study Design

In this study, we used two types of evaluation, subjective evaluation, and objective evaluation.

Regarding the subjective evaluation, we designed a questionnaire to ask questions about the user experience and the feasibility of the system. In the first 4 questions, we investigate the user's makeup knowledge and makeup background. The rest of the questions focus on the experience and feasibility of our system. We present the questions of this questionnaire below, where we set a 5-point Likert scale for each question (1 means the lowest level and 5 means the highest level).

Gender： ， Age：

Q1: Do you wear makeup?

Q2: Do you watch makeup tutorials (videos, magazines, blogs)?

Q3: How do you evaluate the level of your makeup skill?

Q4: How do you evaluate the level of your eye-makeup skill?

Q5: Do you draw eye-makeup by considering your eye shape?

Q6: Do you consider this system describe your eye shape correctly?

Q7: Do you consider this system support you to draw eye-makeup?

Q8: Do you consider this system help you to draw better eye-makeup than by yourself

Q9: Do you think this system improve your eye-makeup skill?

Description: advice or idea

4.2 Observation

We invited students from our school to participate in our experiment. Considering that this system is designed for people who draw eye makeup, the participants will be required to have the ability to use eyeliner. Therefore, anyone who has experience in eye makeup can participate in this experiment, regardless of gender. In this experiment, we invited a total of 8 female students from JAIST, around 25-year-old. Participants were asked to sit on a chair and could not with eye makeup.

Participants were asked to answer the questionnaire after finishing the experiment, and the results of this questionnaire are shown in Table1.

Regarding the objective evaluation, we mainly compared the makeup completion time and makeup effect between using the system and not using the system.

We investigated the makeup habits and background of each participant in a questionnaire. The result showed that most participants did not wear makeup very often (Q1: average = 2.625) and were not confident in their makeup skills (Q3: average = 2.5; Q4: average = 2.25).

P	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
a	2	2	1	1	3	4	4	4	3
b	4	4	4	3	3	2	2	1	5
c	3	2	3	2	3	4	4	5	4
d	2	3	2	2	2	5	4	4	4
e	2	2	2	2	2	4	4	4	4
f	3	3	2	2	1	4	4	3	5
g	3	2	4	3	4	5	5	5	4
h	2	1	2	3	1	3	4	3	4
average	2.625	2.375	2.5	2.25	2.375	3.875	3.875	3.625	4.125

Table 1 Results of questionnaire by 8 participants

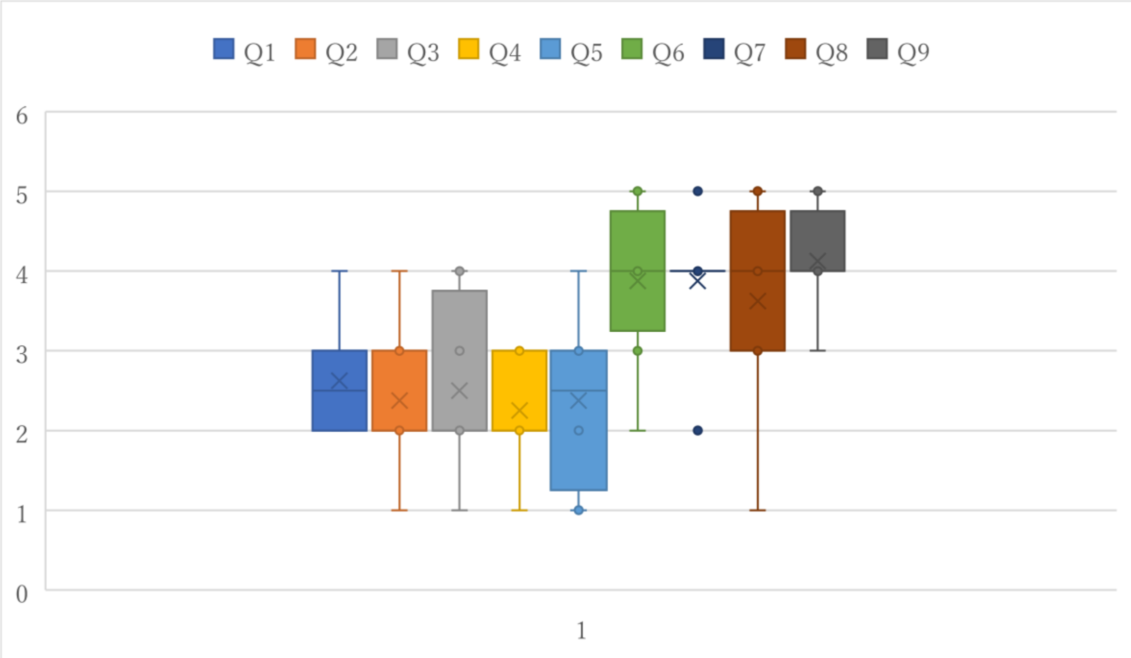

Table 2 Results of questionnaire (boxplot)

4.2.1. Objective Evaluation

In this experiment, we collected 8 valid answers as shown in Table 1and Table 2. First, we analyzed the correlation between participants' background of makeup knowledge and evaluation of the system.

We first calculated the average number of points from Q6 to Q9, where Q6: 3.875; Q7: 3.875; Q8: 3.625; Q9: 4.125. From these results, we can see that the overall rating of our system is above 3, which verifies that our system can help users to draw better eye makeup and improve their eye makeup skills to an extent. We noticed that participant (b)'s ratings on Q6, Q7, and Q8 tended to be lower. After discussing with her after the experiment, we confirmed that the eye makeup guidance and suggestions prompted by our system did not satisfy an experienced makeup artist well, who often already had a well-tested routine by their techniques and approaches for drawing eye makeup, so they would consider the basic eye makeup styles are insufficient and guidance is helpless.

We analyzed the Pearson correlation coefficients for Q1~Q5 and Q6~Q9 as shown in Table 3 and found a significant and positive correlation between Q1 and Q9 (p = 0.712). This means that the people who more wear makeup frequently can feel the more improvement brought by the system to their makeup skills. We believed that people who normally wear makeup are acquired with some experience and knowledge of makeup, and when they learn the exact contours of their eyes and their features, it can better help them to draw eyeliner afterward. In addition, one participant said that using our proposed system could have a better experience for improving makeup skills than watching tutorial videos because the system could describe and show the eye shape for users.

	Q1	Q2	Q3	Q4	Q5
Q6	-0.46	-0.26	-0.20	-0.36	0.19
Q7	-0.55	-0.68	-0.24	-0.18	0.06
Q8	-0.46	-0.58	-0.15	-0.35	0.32
Q9	0.71	0.64	0.52	0.55	-0.29

Table 3 Pearson coefficients for Q1~Q5 and Q6~Q9

4.2.2. Subjective Evaluation

In the objective evaluation, we first compared the participants' completion time (seconds) when using the system and without using as shown in Table 4.

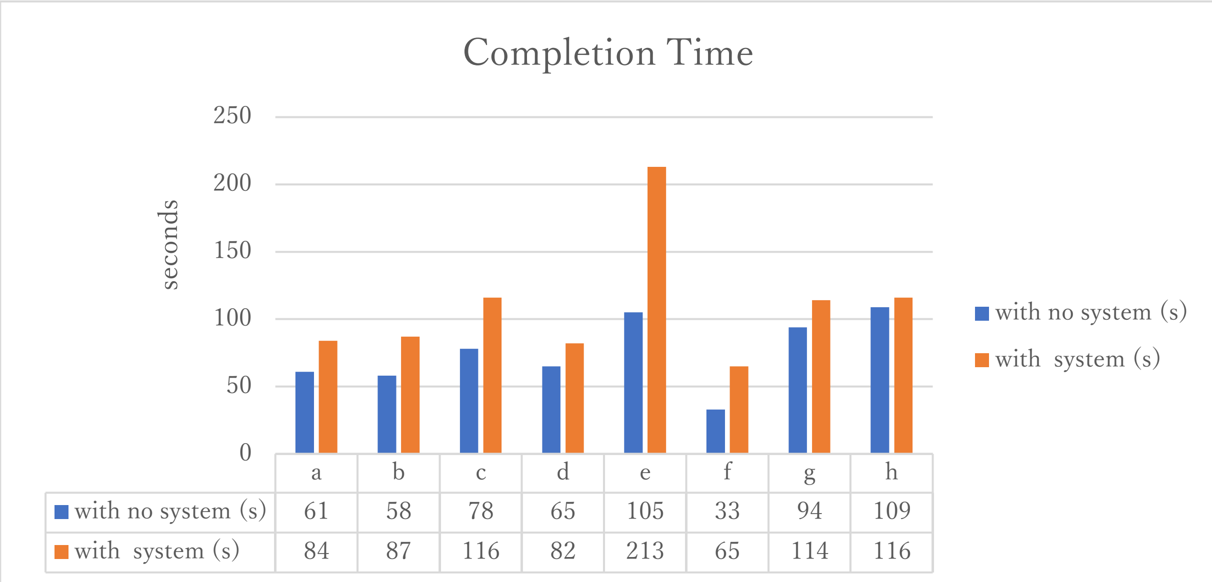

Table 4 Comparison of Completion Time

We found that after using our system, each user's completion time was extended. We reviewed the process of using our system, and we assumed that the users who take more time to find the location of the guidance pattern and consider how to reproduce the guidance pattern while using the system. In addition, we analyzed the correlation between completion time, and the questions in the questionnaire. We found a significant negative correlation between Q2 and completion time without-system ($p = -0.723$), meaning that the less frequently people watched makeup tutorials, the more time they spent on completing their eyeliner. This also implies that people can learn better makeup techniques by watching makeup tutorials to help them become more skillful at drawing makeup.

Next, we observed the eye makeup patterns drawn by participants in both conditions (Figure4.2), we found that the eye makeup which refers to the guidance prompted by the system was generally thicker and more clearly (Figure4.3) than those without using the system. After referring to Q6's response (average = 3.875), this can be considered that the eye makeup guidance given by our system is easy to understand and could be reproduced by the users.

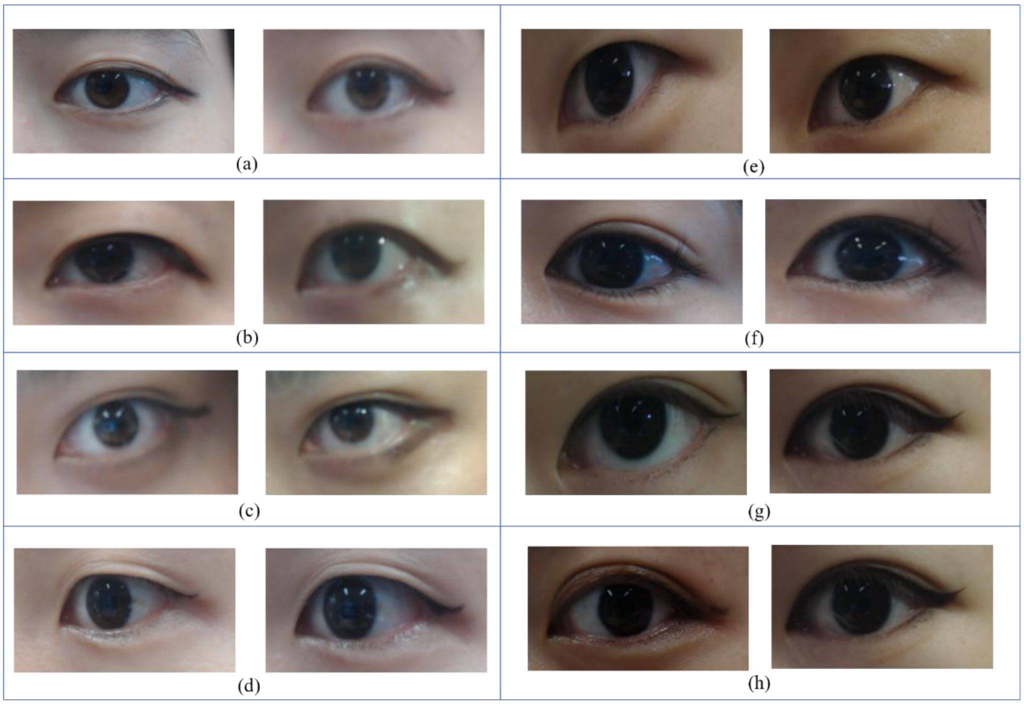

Figure 4.2 Comparison of makeup effect by participants
(Left is without-system; Right is with using system)

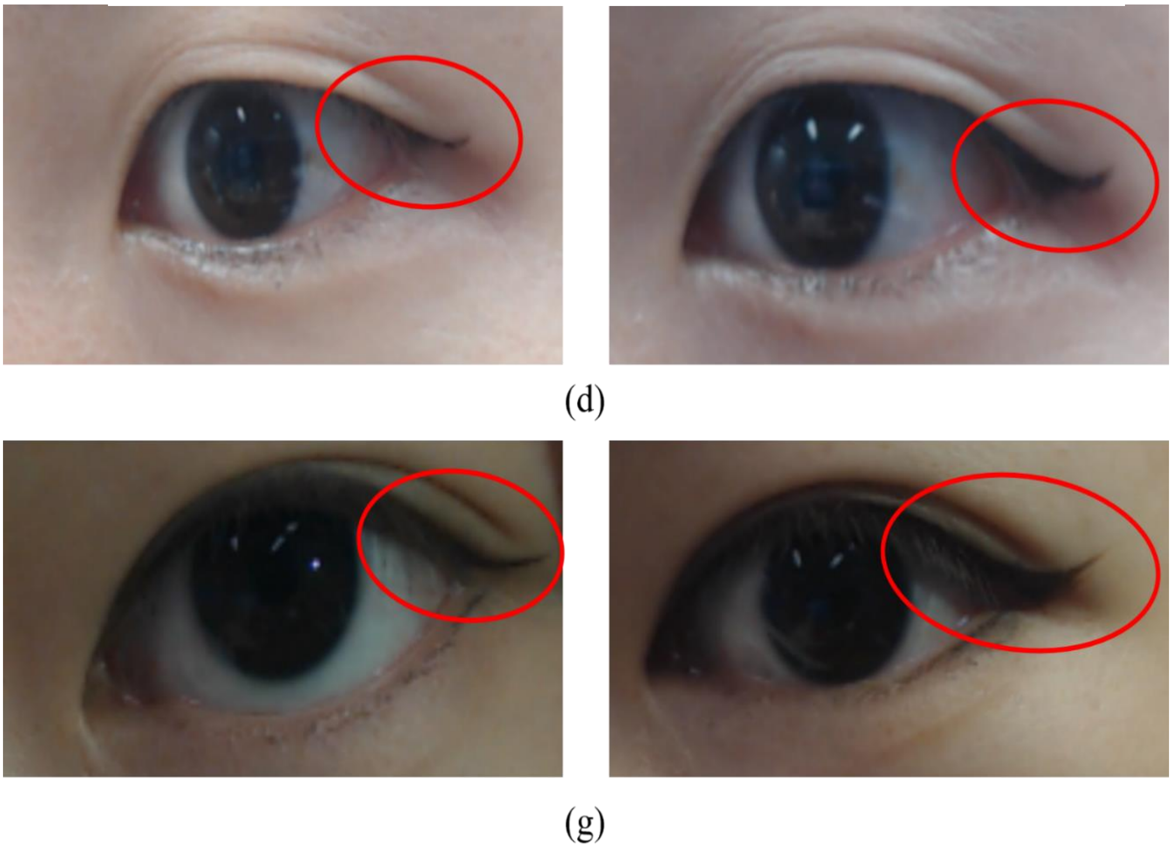

Figure 4.3 The difference of eyeliner's wing
(Left: without-system; Right: with-system)

4.3 Discussion & Limitation

From the results of this experiment, we can verify that the proposed system could support people who do not have good experience and knowledge of makeup to accomplish a better eyeliner by referring to the system's recommended eyeliner styles and guidance patterns. And for people who are not familiar with their own eye contours and features, this system can help them understand their own eye features and draw eye makeup by themselves afterward. However, in this experiment, most of the eyeliner styles recommended to the 8 participants were “Style-Wing”, “Style-Extend” and “Style-Outer”, which means that most of the experimenters had similar eye shapes. All the participants in this experiment were Chinese and Japanese, so we think this problem may be related to the human race, as East Asian people tend to have similar features in their eye structure, and some of the eye styles we set may be more easily applicable to other race people, and we also think that some eye features are too rare to find the matchable people under limited conditions.

About the recognition function of this system, we found that the camera would have difficulty in accurately recognizing the contour of the eyes at some angles, so we had to keep adjusting the camera angle to get accurate recognition results. Besides, the camera used in this experiment, it uses the fully automatic focus function, so it will often be in inaccurate focus, thus affecting the user to observe the guidance image.

After studying the results and evaluations of eye shape analysis by users, we noticed that although the system is accurate enough to describe the eye contour, the detection of eyelids is very limited, which means that the recommendations given by the system may not be suitable for users when their eyelids heavily affect the visual effect of their eyes.

With evaluating the process of using guidance for eye makeup work, we collected many comments and feedback from participants about this process as shown in Appendix1. Generally, people use a mirror to look at their eyes when applying eye makeup, but because this experiment used a monitor as the guidance display and a web camera as the image capture. Due to the filming angle of the camera, the user will keep a distance from the monitor, so that nearsighted user may be difficult to see the exact location where they need to draw makeup. Additionally, the system tracks the user's eyes and updates the guidance graphics on the user's eyes in real-time, which causes the guidance graphics to shake easily when the user is away from the camera and affects the user to observe guidance. We believe that although the system can recognize the eye position and detect the eye contour in real-time, the frame rates are too low in fact, which affects the smoothness of observing the guidance. Moreover，one participant indicated that it would be helpful if the system could give more recommended solutions for users to choose from. For example, she imagined that will be helpful if there is a scene-selecting function, which could recommend some makeup styles that match senses like the party, business, shopping, and allow users to preview those makeup styles applied on their face.

Chapter 5
Conclusion & Future Work

In this thesis, we proposed an eye-makeup guidance system based on an analysis of eye shape. This system captures the user's eyes by a camera and recognizes the eye contours for analyzing the eye shape of the user. As the result of the analysis, the eye shape will be described to the user and the system will provide a recommended eyeliner guidance to the user. Thus, users can draw better eyeliners by referring to guidance. We utilized a trained machine learning model from MediaPipe to recognize the eye contour. And we designed a rule model to classify the shape features of the eye based on analyzing samples of typical eye shapes. In addition, we designed and generated a serial of eyeliner styles related to eye shapes as guidance for the user to refer to.

We designed a user study and evaluation experiments to verify the effectiveness of our proposed system. We invited some women with makeup experience to test our system. From the test results, our system was able to effectively identify the user's eyes and recognize the contours of the eyes. The system was able to describe some specific eye features and the accuracy of the description results was satisfactory. Based on the analyzed eye shape results, the system recommends the corresponding eye makeup guidance, and the user can refer to it well and complete the eye makeup. Even though the participants' eye shapes are generally similar in this experiment, by concerning the results of completed eye makeup, we believed that the system provided an effective guidance function to help users draw better eye makeup. Besides, we noticed that the system has difficulty detecting the shape of the overall eyelids, which can make some users with more influential eyelids think that the type of eye makeup recommended by the system is not suitable for them.

In the evaluation experiment we conducted, we designed a questionnaire for evaluating the experience of using the proposed system. We investigated participants' knowledge and experience about makeup firstly and give some questions about evaluating the recommended eyeliner styles resulting from the system and benefit of our system. From the answers, to understand the relation between makeup experience and evaluation of our system, we analyzed the correlation of them. By observing the analyzed result, we found that users were satisfied with recommended guidance and the user with more makeup experience could obtain more improvement for their makeup skills.

For solving the issues found in this experiment, we plan to set further goals and do several works in the future. The possible future works are introduced as follows.

- By considering the limitation of our recognize-model for describing the shape of eyes, we plan to build a new dataset containing eyelid landmarks for further machine learning models to classify eyelid shapes and detect the eyelid contours. Furthermore, we want to improve the experience of using our system, so we need to optimize the workflow of our system increase the frame rates when performing the guidance graphics. If we develop a lighter and more efficient system, we can transplant it to portable platforms like iOS, Android.
- As mentioned in the evaluation and discussion, the eyelids always affect the visual effect of eye shapes and the process of drawing makeup. For that reason, we need to design and generate more eyeliner styles related to eyelid features that meet the expectation of people with influential eyelids.
- In the current stage, our system focuses on recommending eyeliner styles and supporting the user to draw eyeliner with guidance referring. By investigating previous related works [16][26], we found that many types of makeup are related to physical features like nose, face oval, skin color, etc. We noticed that eyebrows makeup is also a significant part of the visual effect of eyes, and it is related to itself features that can be analyzed. Therefore, we start to investigate the knowledge of eyebrow makeup as the next research goal in the future.

Acknowledgement

First of all, I would like to thank my main supervisor Professor Kazunori Miyata, and Senior lecturer Haoran Xie. They taught me much knowledge, offered me advice, and gave me the confidence to accomplish my research. Benefitting from Professor Miyata's rich research experience and vast knowledge, I was able to determine the direction and framework of my research. During the development of this system, Professor Miyata gave me a lot of advice on the development direction, which made my system more reasonable. During the writing of main thesis, he provided beneficial writing suggestions to make the structure of this thesis look more reasonable and logical.

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Appendix

Participants Advice and commends:

a) It is easier and faster for makeup novices, and the recommended eyeliner is more in line with the shape of their own eyes.

b) If the system could be improved a bit, that shape detector could detect the eyelid will be helpful. And it may be helpful for beginners who are just starting to learn makeup because they can clearly know what kind of eyeliner they are suitable for. Because you can know the contour of your eye shape, which can help you recognize your own eyes and help you draw eye makeup.

c) Compared to video tutorials, this system is more tailored to individual eye features, so it works for my eye makeup instruction.

d) For personal reasons, the guidance screen is always in motion, and it is a little difficult for people with inner double folded eyelids to follow their makeup.

e) If users can adjust the magnification level by themself. For near-sighted people, it is could be a good function.

f) My eyelashes are so thick that it's a little hard to see when I'm looking at eye makeup guidance.

g) Generally, monolid eyes use a different form of eyeliner. Currently it's more in favor of double folded eyelids.