Evaluating line drawings of human face

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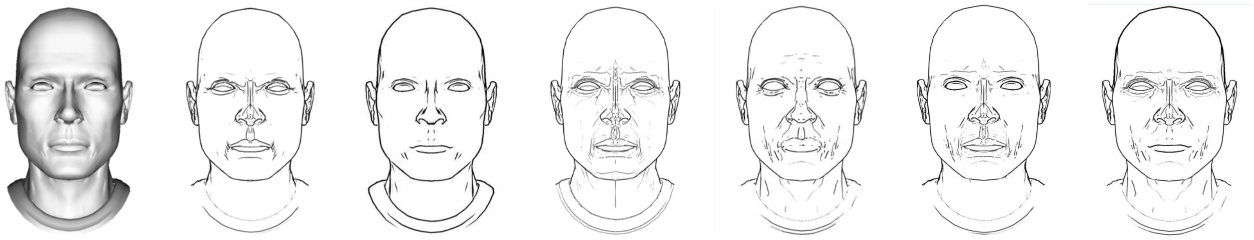


(a) (b) (c) (d) (e) (f) (g)

Figure 1: line drawing result. (a) Shaded image;(b) Apparent Ridges;(c) lines from shaded image;(d) Ridges and Valleys;(e) Suggestive Contours; (f) region & orientation based optimized line by our evaluation result; (g) region & expression & orientation based optimized line by our evaluation result.

***ABSTRACT*—This paper presents the results of a study in which type of line drawings intended to convey 3D faces by using the normal estimation method based on the face domain knowledge, including facial expressions, facial orientation and the regions of five senses. Estimated lines include occluding contours, suggestive contours, ridges and valleys, apparent ridges, and lines from shaded images. Our findings suggest that different style of line drawing has its own advantage in depicting different parts of human face，and that errors in depiction are localized in particular regions of human face. Our study also shows the result that which kind of lines can do better in depicting special parts of human face for different expressions, like eyes, nose, mouth and so on. Finally, we generate optimized line drawing results for different face models to illustrate the efficiency of our evaluation result.**

Keywords: non-photorealism, line drawings, head-poses, shape perception

I. Introduction

The line drawing which plays a very important role in the NPR (non-photorealism) [1] has been favored by a lot of researchers for a long time. The technology of NPR began to become one of the most hot spots of the computer drawing area. Compared with the photorealistic rendering technology which aims to do its best to simulate the real world, NPR focuses on presenting the art characteristics of an object in a particular style and simulating the art style of the art works. The line drawing is a very popular and important art form which is easy to create and is effective in presenting the art works. The line drawing emphasizes the characteristics of the object which is depicted by abandoning the redundant details, simplifying the shape of the object and revealing the sections hidden before, so it can transmit the visual information to the observer more effectively.

Using the computer to draw lines has become an interesting area since the birth of the technology of the computer graphics in the sixties of last century. Firstly researcher's works were based on the concerning of practical considerations, such as Bresenham's line rasterizing algorithm [2]. But as more and more other factors such as aesthetic sense has been taken into account, the computer line drawing technology developed gradually. Recently, the effectiveness of the line drawing technology of computer graphics in depicting the shape of the object is almost as powerful as the line drawings drawn by artists [3]. At present the assessment method which using an objective way to evaluate the effectiveness of different line drawing algorithms in depicting shape is based on normal information. However, the evaluation is only focused on general 3D models, considering no domain knowledge so far.

Because of the vast quantities of the detail features of the human face models and the definite domain knowledge of faces, the complexity in generating the line drawings for 3D face models by computers is highly increased. How to depict the features of the different part of the human face and the advantages and disadvantages of several main lines when they depicting face models is the main content of this paper. This paper mainly investigates the ability of sparse line drawings for depicting 3D human face models.

This paper mainly assesses four kinds of lines: lines from shaded image, apparent ridges, suggestive contours and ridges & valleys. Figure 1((b)-(e)) present the different line drawing results. This paper assesses the depicting and expressing ability of these four kinds of computer line drawings and the fully shaded image of the 3D human face models (Figure 1 (a)).

We perform a study in which people are shown an image of one of ten 3D head-poses (each pose contains front and side view) depicted with one of five styles and asked to orient a gauge to coincide with the surface normal at many positions on the head's surface, as shown in Figure 2. The user-estimated normal is compared with the ground truth of normal provided by each 3D head model to analyze accuracy and precision (for a visualization, see Figure 2).

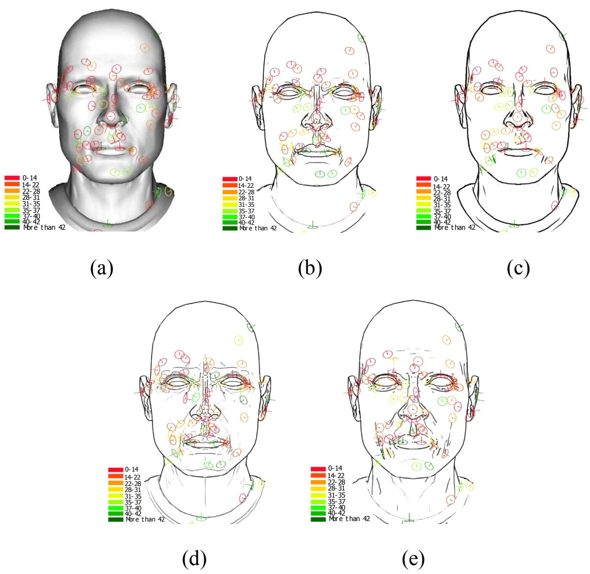


Figure 2: Gauge figure results. In our study, participants were shown one of five different renderings of a human facial expression: (a) a shaded image, (b) apparent ridges, (c) lines from shaded image, (d) ridges and valleys, (e) suggestive contours. Overlaid are representative "gauges"(the "pin" of the "thumb tack" revealing the surface normal) oriented on the images by participants in our study, colored by how far they deviate from the real normal.

II. Related Work

This paper is based on the theory that the normal information is an important factor to measure the object shape features, and draw upon a series of work in computer graphics, computer vision and the psychophysics of shape perception in our study.

A. Feature lines of 3D objects

We rely on the lines of the rendered image to convey the shapes and the features of face models. The most basic two lines of this type are occluding contours and sharp creases. These two kinds of lines are also classic elements in line drawings and universal elements in the non-photorealistic rendering system. In this paper, all the lines we study consist of the contours and one of the following three kinds of line: suggestive contours[4,5], ridges and valleys[6,7], apparent ridges[8]. In addition we assess one another kind of line drawing style: shaded image based line drawings by extracting the characteristics of the shaded image with the material of Lambert by using the image processing method[9].

B. How do people interpret line drawings

How do people find out the features of an object? How to translate these features of an object into a line drawing? It seems likely that the visual system can represent features explicitly since people can distinguish ridges and valleys from diffusely rendered surfaces in stereoscopic views successfully [10]. In addition, perceived shape can be treated as an interaction between the global organization of line drawings and the inherent biases of the visual system[11], such as preferences for convexity over concavity in certain kinds of imagery.

Forrester Cole et al.[3] investigated the ability of sparse line drawings to depict 3D shapes and gave us the results: the performance of the occluding contours alone was considerably worse than the performance of other drawing types, while the performance of other drawing types (apparent ridges, ridges and valleys, suggestive contours, and the human drawing) were roughly comparable, though still always statistically different. But its evaluation object is simple 3D objects that human face models are not included. Our study is designed to tease out general relationships between algorithms for depiction and the interpretation of human faces.

III. Evaluation Work Flow

The work flow of our evaluation system for the testing images is mainly divided into 4 steps:

(1) Set up evaluation system for participants to adjust the normal. Let participants log into the evaluation system and do the test they are required to do. This system has the functions as follows: Picking the testing image for participants, generating gauge figures on the testing positions, adjusting the gauge figure one by one and saving the results.

(2) Collect data. Assessment work needs a lot of assessment data. In order to get more assessment data so that the assessment result can be more accurate and universal, we mobilize more people to participate in this test by using some incentives.

(3) Process Data. In this step we need to process the collected result one by one. First we need to delete the data that has obvious errors and the data unregulated to reduce the impact of the erroneous data. Second, we need to compare the test result with the real normal and calculate the deviation. Then, for each picture, we get the average deviation of the line drawings of different styles. Also, we need to get the average deviation of all the pictures in each style so that we can get the best line drawing style that has the minimum deviation. Finally, calculate the deviation of each style line for different face areas and different facial expressions.

(4) Analyze the results. Analyze the processed results and get the line drawing style which has the minimum deviation as a whole. For each face expression and each area of the face, we also need to get the line drawing style that has the minimum deviation. Then we can get the conclusion that which line drawing style is more powerful than others in depicting the human's face. We can also get the conclusion that which line drawing style is more powerful than others in depicting different areas and different expressions of the face.

IV. Evaluation of line drawings of human face

Our study aims to determine how people interpret line drawings and shaded images of the same human face expression. Our study is also designed to assess that in each areas of human face, which line can do better in depicting feature. To achieve these goals, we should decide which kind of line drawing to choose to complete this study and how to gather a large amount of qualified data.

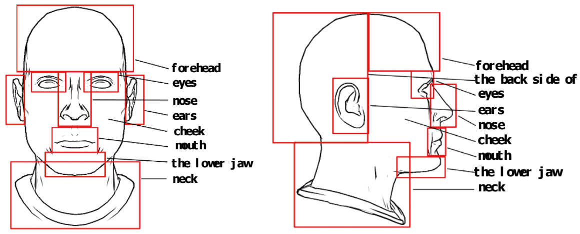
A. Face domain knowledge

We consider facial expressions, facial orientations and the regions of five senses as the main domain knowledge of human faces in our test.

(1) In this assessment we divide all the expressions of the face into ten kinds, including reference, anger, cry, fury, grin, laugh, rage, sad, smile and surprise.

(2) Each facial expression includes two orientations: frontal view and side view.

(3) In order to assess how these lines depict different face areas, we separate the human face into 8 regions for front view and 9 regions for the side view. All the regions include: the forehead, the nose, the eyes, the ears, the mouth, the neck, the lower jaw, the after brain and the region of the cheek. The regions are as shown in Figure 3.



(a) *(b)*

Figure 3: face areas (a) front view (b) side view

B. Face drawing evaluation method

By using the face domain knowledge, we do evaluation for ten 3D face models of the ten typical expressions under the front view and the side view by using an evaluation system. A good assessment system can improve the efficiency of evaluation greatly. So we need to take many aspects into account, for example, the interface of the system should be concise and beautiful, the operating process should be clear and easy to be understood, the interactive level should be high so that the participants can do the test flexibly and easily.

We follow the gauge placement protocol described by Koenderink et al.[12], also the method Forrester Cole et al. used. Participants are shown a large number of gauges in our study and are required to adjust each gauge correctly before moving on to the next. Each gauge is drawn as a small "thumbtack" which consists of a circle and a single line representing the normal of the point. The gauges overlap test points. They are superimposed over the line drawing images and are colored red for visibility. The initial orientation of the gauges is straight up.

In order to make the interface clear and easy to be understood, users will test the different expressions one by one. Each time the system shows the five images of different drawing styles of one expression. The participants can choose one they like to go on their test. After an image is chosen, related red points for testing will be shown on the image.

（a）good （b）bad

Figure 4: Instructional example. Images such as these were included in the instructions for the study. (a)good setting.(b)bad setting.

Before test participants were shown a simple human face model which is not included in our test models. The model had examples of good and bad placement (Figure 4). When the gauge has been properly adjusted, it seems like a "thumb tack" sitting on the surface, its base sits on the tangent plane, and its "pin" is aligned with the normal of the point. Participants should be trained to practice adjusting gauges on the example model before moving on to the real work.

Each expression of these five images has its unified set of test points while different expressions have different test points. The test points are generated randomly at a certain density on the face model at the time when the face models are rendered into different drawing styles. When practicing, participants are shown the total number of gauges to place in the task and the number they have placed. Each test image has at least 60 gauge positions, and we have 100 test images in total.

After the participants choosing one image, they can click on the "Create gauge" button, the system will show the gauge figure at the first test point. The participants can adjust the gauge interactively by using the mouse (move the mouse over the gauge, scrolling the wheel can adjust the degree of the circular flat, scrolling the wheel with the right button down can adjust the rotation angle of the drawing pin). After the adjusting procedure of one gauge is finished, click on the "Create gauge" button again and go on testing the next point, at this time the previous red gauge turns into green and unable to be changed again.

C. Data Collection

Our study is based on the theory that the normal information is useful to measure the object shape features. Rather than relying on the theory, we rely upon the robust statistics of many participants. The support of a large amount of data is the key to the success of the assessment in this paper. The more data we collect, the more accurate our assessment result are. When we are collecting data, we mobilized a lot of participants to test for us. In the later period when testers turned to be negative, we proposed appropriate incentives to encourage the participants to go on testing. The quality of the data we collected improved significantly.

The test based on web can be done by many testers that we do not know. Participants on the service are only interested in particularly attractive tasks which are usually completed within minutes. On the Mechanical Turk participants are always interested in work that takes around 5-10 minutes. So if we present too many gauges on one task to let the testers test, the result may be not good enough probably or even they can not finish it. We found finally that participants completed tasks at a satisfactory rate for up to 60 gauges in a session.

In order to avoid training effects, each participant is allowed to see only one style of line drawing of each face model. Each participant is randomly showed a line drawing from the available images each time they begin a test. There are 20 images across the 10 models (include the front view and the side view), each image with 60 gauges. The average time spent per image was 6 minutes, so every participant will spend at least 2 hours in our test.

Some participants did not understand the aim of our study, they did not treat it seriously. We could only exclude the obvious erroneous test results and data. But some other unobvious erroneous results we could not exclude. So there is still bad influence led by the bad data. Therefore, at the later stage of data collecting, we modified the strategy that we only found 50 skilled and conscientious participants to go on our test and they get paid for doing test. This strategy improved the accuracy of the test result.

After the data collecting period is finished, we got more than 1200 copies of data, 72000 gauges. Except some incomplete data and some obvious erroneous data we totally collected more than 1000 copies available. Each test image has 10 copies of data in average.

D. Data Processing

The data processing procedure can be divided into four stages:

(1) Compare user-estimated normal with the real normal for each testing point and calculate the deviation.

The real normals are generated from the 3D face models when we rendered the model to get the different line drawings. After projecting the 3D point *p* and its normalized 3D normal vector *n* onto the 2D projection plane, we record the projected 2D point as p' and the 2D normal vector as n'. Let the normal of *p* as:

$$N_r = (n'_x, n'_y, \sqrt{L^2 - |n'|^2}) \qquad (1)$$

where *L* is the maximum length of projected normal vector.

For user adjusted gauge on location p', let the 2D normal vector as vector of the pin starts form p', we can calculate the user-estimated normal N_e by equation (1), where *L* is the maximum length of the pin.

The deviation between the real normal and user estimated normal can be calculated as follows:

$$\theta = \arccos(\frac{N_r \cdot N_e}{|\mathrm{N}_r||\mathrm{N}_e|}) \qquad (2)$$

(2) We can not ensure that participants finish the work well. So the only way we can use to make the result accurate is filtering the obviously bad data. One kind of the obviously bad data is that all the gauges on one task were oriented in a single direction (usually towards the screen or the default direction). Usually we get this kind of data because the participants did not understand the meaning of the test or they just played tricks. We can distinguish this kind of bad data easily from all the results and then exclude it manually. Another kind of bad data is that the average deviation of one task is more than 42 degree. We exclude this kind of bad data using our experience and it suggests that we can remove the bad result and leave the good result un removed grossly.

(3) Divide the gauges into different face regions according to the coordinates range of every region, which is illustrated in Figure 3. For example, in the laugh-side image, the coordinates range of nose is: $1148 \le x \le 1248$, $326 \le y \le 436$.

According to the total deviation and each region's average deviation of each facial expression, we can figure out the best line of every facial expression and the best line in every facial region of this kind of expression.

(4) Calculate the average deviations in each face region for five different kinds of line drawings. We still need to average the deviation of all these expressions by different rendering styles and different facial regions. Using these data we can make the conclusions that whose ability of depicting is the best. We can even figure out the best line drawing style for each region. Because the regions of the front face is different from the regions of the side face, we get the whole average result of all the front-view face data and the whole average result of all the side-view face data. In this way we can improve the accuracy of the conclusion.

V. Evaluation Results

We can discuss some questions by our data results. First, when compared with a shaded image, how effective are the line drawings in depicting human face? Second, which kind of line is the most effective in depicting human face? Third, are errors in depiction localized? Forth, which line can do best in different region or different expression of face?

A. Do line drawing interpretations match the real face model?

Since the human face model is not a simple shape to depict, we want to see the accuracy between the shaded image and those line drawings. We can figure out that the deviation between different facial expressions is not too big from Table 1 and Table 2, and the deviation between different kinds of line drawings is small as well.

We can see that the shaded image is only a bit better than the line drawings, and there is no big difference between these lines.

We have known that the type of surfaces in the model has a large effect on the accuracy of interpretation from previous studies. Since the face models are all the same type, therefore, there is no big difference between the accuracy of different types of drawings and the models.

Model	S	AR	IR	RV	SC
anger-front	30	31	32	31	31
cry-front	27	30	31	32	32
fury-front	27	33	31	31	31
grin-front	30	31	33	33	31
laugh-front	30	31	32	30	32
rage-front	30	32	31	31	31
reference-front	30	32	33	32	31
sad-front	29	30	31	32	33
smile-front	29	31	30	31	32
surprise-front	30	32	32	31	32
average	29	31.8	32	31.9	32.1

Table1: Deviation in degrees from real normal for each expression and style from the front view. Columns correspond to styles: S, shaded, AR, apparent ridges, IR, lines from shaded image, RV, ridges and valleys, SC, suggestive contours.

Model	S	AR	IR	RV	SC
anger-side	30	31	33	33	32
cry-side	25	32	33	33	33
fury-side	32	34	33	33	32
grin-side	29	32	31	32	32
laugh-side	32	34	34	33	34
rage-side	30	32	33	33	33
reference-side	29	31	31	31	30
sad-side	31	33	32	31	31
smile-side	31	31	32	31	32
surprise-side	30	34	33	32	32
average	30	32.6	33	32.6	32.5

Table2: Deviation in degrees from real normal for each expression and style from the side view. Columns correspond to styles: S, shaded, AR, apparent ridges, IR, lines from shaded image, RV, ridges and valleys, SC, suggestive contours.

B. Which kind of line is the most effective in depicting human face?

According to the data from Table 1 and Table 2, shaded image has the smallest error in each expression of head model. It means that shaded image can depict human expression very well. But, our original question is which kind of line can depict human expression better? So we will mainly talk about four kinds of line drawings without shaded image.

From figure Table 1 and 2 we can find out that errors in the front view expression are smaller than the side view for all kinds of drawing styles. So we talk about the depiction ability of lines for different face orientation separately.

From the point of the evaluation data of the front view expression, we can see the errors in the apparent ridges stimulus and ridges and valleys is obviously less than the other two lines, lines from shaded image and suggestive contours have the equal ability to depict human face model without the shaded image.

From the point of the evaluation data of the side view expression, the errors in the apparent ridges, ridges and valleys and suggestive contours stimulus is obviously less than the lines from shaded image without shaded image.

Thus, we can conclude that in these four lines, apparent ridges and ridges and valleys have the best ability to depict human face model, suggestive contour is slightly less, lines from shaded image is a bit weak.

AR and RV in previous research has both shown their good capability of depicting object models, the evaluation results in this paper come to the similar conclusions, when come to the complex human face model, their ability of depicting is also quite high.

C. Are errors in depiction localized?

From the results of data processing, we can find out if error is localized in some important areas of human face or if it is evenly spread over the whole face model. If errors are highly localized, then we are interested in finding out those high error areas and the reason why the errors occurred.

From Table 3 and Table 4, we can see that errors are almost localized in the same areas in all the expressions of human face. Errors are high in the lower jaw, mouth, nose and eyes region at the front view and in the lower jaw, mouth, eyes and neck region at the side view. Because of the high complexity of mouth, nose and eyes region, it is difficult to convey all the details precisely, so that the errors are highly natural in these areas. On the contrary, lines in the lower jaw and neck region are too sparse to convey details, though the complexity of these two areas is much lower than other areas of human face.

D. Which line can do best in different regions of face?

Considering complex areas in human face, each line has its own advantages and disadvantages in depicting human face models, in order to accurately convey the facial features of each region, we try to find the best line of each region to depict human face.

Table 3 and Table 4 illustrate the average errors in each region of human face for front view and side view separately. In the front view, AR can depict the eyes better, the RV's performance is the weakest, but RV did best in the eyes from the side view.

Considering all the face knowledge, Table 5 lists out the best type of lines for different regions of face under different face expressions and different face orientations.

lines	*forehead*	*nose*	*eyes*	*ears*	*mouth*	*jaw*	*neck*	*cheek*
S	28	31	30	23	32	37	23	26
AR	30	33	32	24	35	42	23	30
IR	29	33	32	25	35	44	23	29
RV	29	33	33	24	34	42	25	29
SC	29.7	34.5	33	24	35.8	42.2	24.1	29.1

Table3: Deviation in degrees from real normal for each region of face and style at the front view.

lines	*Forehead*	*nose*	*eyes*	*ears*	*mouth*	*jaw*	*neck*	*cheek*	*Head back*
S	31	28	33	27	32	43	30	26	28
AR	33	31	35	29	33	43	35	27	31
IR	34	31	35	30	35	42	34	28	33
RV	33	32	34	29	33	41	35	29	32
SC	32.4	31	34.8	29.6	34.7	40.8	34.4	29	33.7

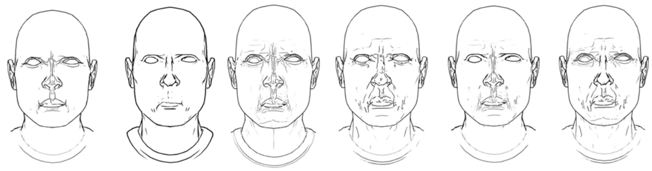
Table4: Deviation in degrees from real normal for each region of face and style at the side view.

model	*forehead*	*nose*	*eyes*	*ears*	*mouth*	*jaw*	*neck*	*cheek*	*head back*
anger-front	SC	IR	RV	AR	SC	RV	SC	SC	/
cry-front	SC	IR	AR	AR	AR	AR	IR	IR	/
fury-front	RV	AR	IR	RV	RV	SC	IR	AR	/
grin-front	SC	SC	AR	IR	RV	SC	AR	AR	/
laugh-front	IR	AR	RV	IR	RV	AR	IR	RV	/
rage-front	RV	AR	IR	RV	SC	AR	SC	IR	/
reference-front	IR	AR	RV	SC	IR	SC	SC	SC	/
sad-front	IR	AR	AR	AR	AR	RV	AR	RV	/
smile-front	SC	RV	IR	IR	IR	RV	SC	RV	/
surprise-front	RV	RV	AR	SC	RV	IR	AR	IR	/
anger-left	AR	SC	SC	AR	SC	IR	AR	IR	RV
cry-left	AR	AR	RV	RV	SC	RV	SC	AR	RV
fury-left	RV	SC	IR	SC	RV	SC	RV	AR	SC
grin-left	IR	SC	RV	AR	AR	AR	SC	RV	RV
laugh-left	IR	AR	RV	RV	RV	RV	RV	IR	AR
rage-left	SC	IR	AR	RV	AR	SC	AR	AR	AR
reference-left	RV	SC	SC	SC	IR	SC	SC	AR	RV
sad-left	SC	SC	RV	IR	SC	IR	IR	SC	AR
smile-left	RV	AR	AR	RV	SC	IR	RV	AR	AR
surprise-left	IR	IR	SC	SC	RV	SC	SC	RV	SC
front-all	RV	AR	IR	AR	RV	SC	AR	SC	/
left-all	SC	SC	RV	RV	AR	SC	SC	AR	AR

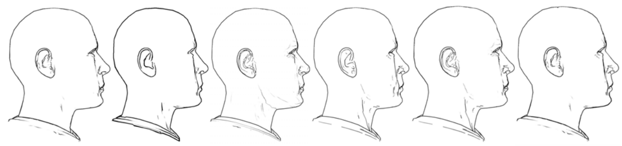
Table5: The best line (except shaded) in each region of each expression and of all.

E. Optimized line drawing results

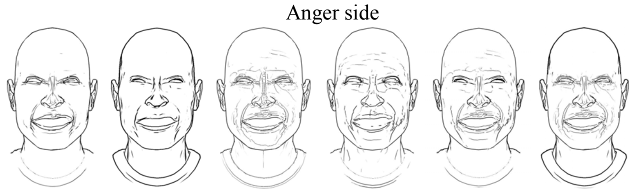
We use our evaluated results to re-depict the human face by these best lines of each region (See Table 3-5) to see whether it has better effect. And we even use our conclusion to apply to other face models which are not concluded in our test to verify our results. See Figure 5.



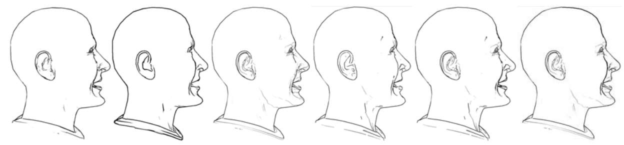
Anger front



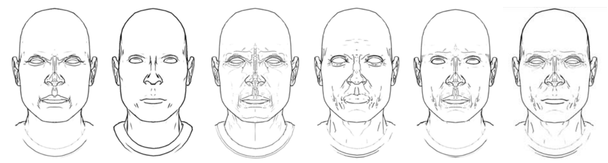
Anger side



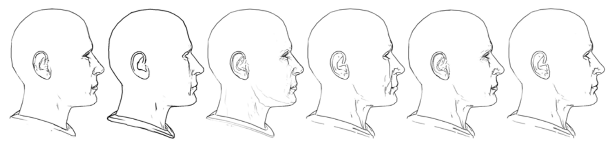
Laugh front



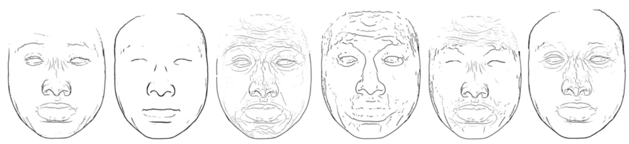
Laugh side



Reference front



Reference side



Face1 front

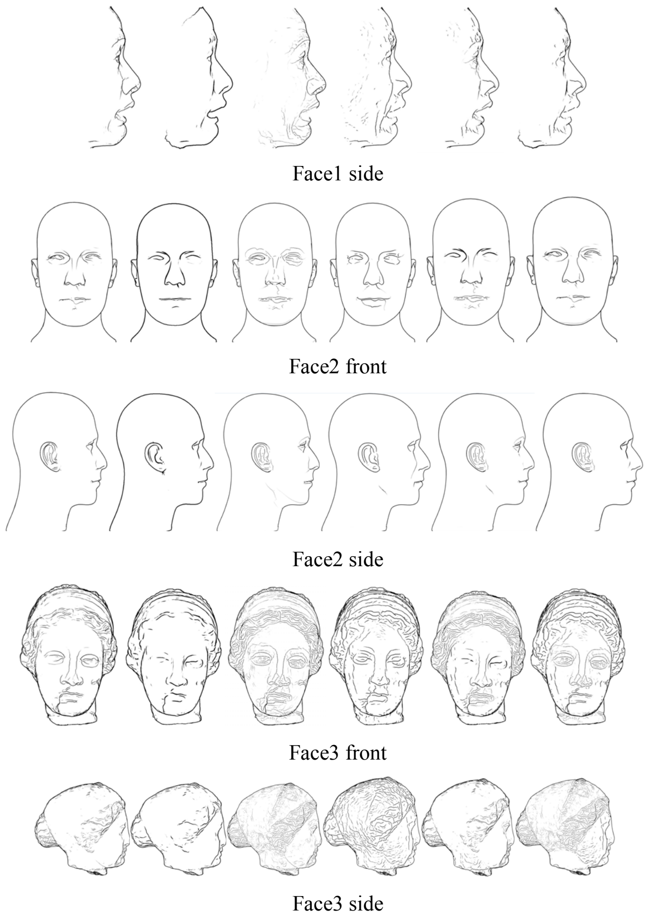


Figure 5: we use our evaluation results to generate optimized line drawing results for the test models (Anger, laugh, and reference model as exampple) and some other face models (face1-3). Each expression from left to right is: AR, IR, RV, SC, region&orientation based optimized lines by our evaluation results, region&expression&orientation based optimized lines by our evaluation results.

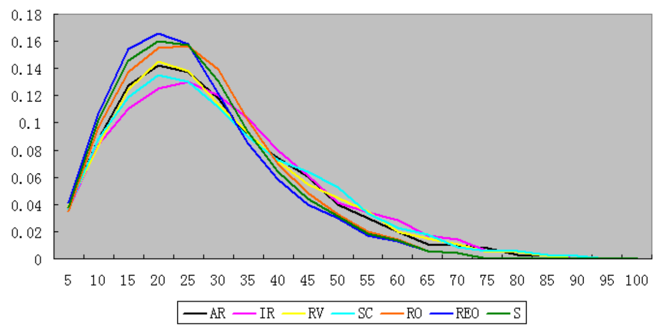


Figure 6: Angular error distributions (angle/frequency). AR, apparent ridges, IR, lines from shaded image, RV, ridges and valleys, SC, suggestive contours, RO, region&orientation based optimized lines by our evaluation results, REO, region&expression&orientation based optimized lines by our evaluation results, S, shaded image.

From Figure 6, we can see that the angular error distribution of region & expression & orientation based optimized lines of all the face models is concentrated in smaller angle than others. Also we can see that the result of region & expression & orientation based optimized lines is even better than the result of shaded image. Therefore, we can conclude that region & expression & orientation based optimized lines can do better in depicting human face.

VI. Conclusion

This study answers the question: how well do line drawings depict human face? Our normal-based testing shows that shaded image has the best ability to depict human face, while apparent ridges, lines from shaded image, ridges and valleys and suggestive contours has the similar level of ability. And compare these four lines, apparent ridges and ridges and valleys have the best ability to depict human face model. Considering the face domain knowledge, face regions, face expressions and face orientations are all important to find the proper kind of line to depict human face model. The optimized line drawings generated based on our evaluation results could depict face model better by showing more details.

In this paper we assess four typical kinds of line drawing styles while there are so many kinds of other stylized drawing styles have not been assessed. In the future, we plan to assess more other kinds of face drawing styles. In addition, in this paper we only take into account the function of the line drawing that whether it can present the shape of the human face model clearly, while we ignored the aesthetic capacity of line drawings. In the future, we will take both the aesthetic capacity and the functional ability into account to make the line drawing generated by the computer beautiful in appearance and accurate in depicting the human face model.

Acknowledgment

This work is supported by the National Natural Science Foundation of China under Grant No. 61003149, U1035004, the Natural Science Foundation of Shandong Province of China under Grant No. ZR2010FQ011.

VII. References

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