Facial Expression Editing in Face Sketch Using Shape Space Theory

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Facial Expression Editing in Face Sketch using Shape Space Theory

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***Abstract*—Facial expression editing in face sketch is an important and challenging problem in computer vision community as facial animation and modeling. For criminal investigation and portrait drawing, automatic expression editing tools for face sketch improve work efficiency obviously and reduce professional requirements for users. In this paper, we propose a novel method for facial expression editing in face sketch using shape space theory. The new facial expressions in the sketch images can be regenerated automatically. The method includes two components: 1) face sketch modeling; 2) expression editing. The face sketch modeling constructs 3D face sketch data from 3D facial database to match the 2D face sketch. Using facial landmarks, the "shape" of the face sketch is represented in shape space. The shape space is a manifold space which removes the rigid transform group. In shape space, the accurate 3D face sketch model is obtained which is consistent to the original 2D face sketch. For expression editing, we change the parameters of 3D face sketch model in the shape space to obtain new expressions. The expression transfer in 3D face sketch model can be mapped into the 2D face sketch. The advantages of our method are: full-automatic in modeling process; no requirements of drawing skills to user and friendly interaction; robustness to head poses and different scales. In experiments, we use the 3D facial database, FaceWareHouse, to construct the 3D face sketch model and use face sketch images from database: CUHK Face sketch Database (CUFS) to show the performance of expression editing. Experimental results demonstrate that our method can effectively edit facial expressions in face sketch with high consistency and fidelity.**

Keywords—face sketch modeling, face sketch editing, shape space, facial landmarks model,

I. INTRODUCTION

As a type of facial data, a face sketch has irreplaceable value in many applications such as law enforcement assist and portrait drawing. The face sketch images are obtained from professional painter or face photo based synthesis method in most cases. Once the sketch drawing process is complete, it will be difficult to edit the face sketch, especially to expression modification. The expression editing in face sketch by artist require repetitive and complex workload. For some users without painting skills, it is impossible to change expression in face sketch artificially. Therefore, the automatic expression editing tools for face sketch are required in practical. The tools improve the work efficiency of artist drawing and provide ability for nonprofessional users to edit the expression in face sketch to obtain the ideal face sketch image.

The auxiliary methods for face sketch drawing have been researched for many years. Basically, the methods can be divided into three parts: non-photo based sketch, photo based sketch and editable sketch. Non-photo based sketch methods were drawing face sketch independently of facial photos. It didn't mean that the facial photos couldn't be auxiliary information during the face sketch drawing. Basically, such methods collected multi-model information to generate the face sketch. Laughery[1] provided a system to achieve high-quality face sketches based on the artist drawings. Iwashita[2] proposed a face sketch generation method based on semantic descriptions. Sugimoto[3] provided a human interface to search a face sketch from a pre-defined sketch database. Onisawa[4] combined facial features by user input and subjective images to construct the face sketch. Such methods did not extract the facial features from the facial photos directly, the quality of sketch results didn't satisfy the requirement in face sketch recognition and accurate sketch representation. The methods cannot be used to expression editing in face sketch images.

Photo based sketch methods constructed the face sketch from real face photos. The largest advantage of these methods was the close connection between face sketches and real face photos. Using the connection, the transfer process between face sketches and photos was possible. It was useful to be applied in criminal investigations. Certain methods achieved face sketches directly from face photos. The face photos were transferred to non-parametric sampling[5], active shape model based facial features[6-7] and simple representation [8]. Other methods composed the face sketch from a face components network. The network constructed the correspondence between photos and sketches on different levels. The construction methods of the network included hierarchical compositional model [9], multiscale Markov Random Fields [10], Sparse Representation network [11], Bayesian model [12] and graphical structure model [13]. Although such methods had the ability to obtain accurate face sketches, the freedom to edit face sketches was lower. The facial expressions in face photos also affected the quality of face sketch generation, the methods were difficult to be employed for expression editing in face sketch.

The editable sketch based method provided editing tools for face sketches or face models. Such methods regarded the

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construction of face sketches as a dynamic process. The dynamic process technologies included fuzzy datasets and linguistic knowledge based [14], abstract graph structure based [15], morphing algorithm [16], multi-level animation model [17], 3D mesh active model [18], tensor based model[19, 20, 21], Convolutional Neural Network(CNN)[22] and video based model[23]. It was possible to generate dynamic face sketches and provided more freedom to face sketch editing. However, the quality of such methods depended on the diversity of the face samples. The accurate facial expression was difficult to reconstruct using these methods.

In summary, the facial expression editing method should satisfy several requirements: treat the face sketch generation as the dynamic process; provide accuracy matching method for expression representation; provide editing freedom for expression transfer. Non-photo based methods can't provide the high-quality facial drawing results. Photo based methods can't provide facial expression editing freedom for face sketch. The traditional editable sketch methods cannot reconstruct accurate facial expression and the face modeling process is complex. In our method, the shape space theory provides tools for shape match and regeneration. We propose an expression representation for face sketch which can be used to map the 2D face sketch into shape space, the facial expression matching and editing of face sketch are processed in the space. Using the shape space theory, we can achieve the reasonable facial expression editing results.

Our main contributions are as follows:

1. We propose an facial expression editing method for face sketch using shape space theory. In shape space, the facial expression editing process does not require complex operations and professional skills. The reconstruct new facial expression is more accurate.
2. We propose a method for 2D face sketch modeling using shape space theory. The 2D face sketch modeling is constructed by 3D face model, the modeling process is more convenient and robust to different head poses and scales.
3. We propose a representation of face sketch based on facial landmarks. The representation greatly reduces the complexity of facial feature extraction. Using the shape space theory, the representation can be used in face matching, face modeling and face synthesis with different expressions.

The remaining parts of the paper are organized as follows. In section 2, we introduce the methodology of our method. In section 3, we illustrate the process of face sketch modeling. In section 4, we illustrate the process of expression editing in a face sketch model. We present expression editing results in section 5.

II. METHODOLOGY

The expression editing tool for face sketch should provide two basic functions: expression representation and expression editing. In Euclidean space, the expression representation is limited by the coordinate system and the rigid transfer (translation, scaling and rotation). It is difficult to build a standard form for different expressions in face sketch. To solve the problem, we employ the shape space theory to build expression representation. The construction of expression representation and expression editing problem can be transferred into the shape matching process in shape space. In this part, we discuss the basic idea of shape space theory and the pipeline in our method based on the theory.

A. Shape space theory

Our method is based on the shape space theory. Shape is an important concept to describe the geometric information of object, especially for facial expression models which have complicated external form and contours. Comparing the similarity between different shapes is a challenging task. The shape should be invariant in some rigid transformations such as scaling, translation and rotation. For mathematic descriptions to shape, there is a theory which is called shape space. Shape space is a manifold space which removes the isometric Lie group actions. Different symmetric transformations such as scaling, translation and rotation are regarded as a Lie group acting smoothly on a manifold. Defining a metric in the manifold by geodesic distance, the similarity of shapes can be computed and the influence of symmetric transformations can be removed.

$$M / G = \{[p] \mid p \in M\} \quad (1)$$

$$d_{M/G}([p],[q]) = \inf_{g \in G} d_M(p, g.q) \quad (2)$$

$$\alpha(\gamma) = geodesic(q_o, q_1), \gamma \in [0,1], q_i \in M \quad (3)$$

In equation 1, G is a Lie group acting smoothly on a manifold M, which can be regard as a quotient space. For p in M, the orbit of p is defined as $[p]$. In generally, the metric in quotient space is hardly achieved, it should be computed in a more liberty space. In equation 2, the metric in quotient space is achieved by group acting process in M. The manifold M can be regarded as the shape space and the p and q are the units of "shape" in M. Once the representation of p, q and metric are determined, the shape space can be constructed completely. Once the shape space is established, the new shape unit can be regenerated. In shape space, the new shape unit can be obtained by geodesic path searching. In equation 3, we show the new shape unit generation process, $\alpha(\gamma)$ represents the new shape unit, the geodesic() means the path searching from q_0 to q_1, γ means the position in the path($\gamma = 0$, $\alpha(\gamma) = q_0$; $\gamma = 1$, $\alpha(\gamma) = q_1$).

To construct the shape space, the representation of "shape" and the metric should be provided. The shape unit have two different forms: discrete [24] and continuity [25]. The representation of face sketch expression in our method is based on facial landmarks which can be regarded as the discrete state.

B. The pipeline of facial expression editing in face sketch

Following the shape space theory, we propose the pipeline of our expression editing method in face sketch. The pipeline

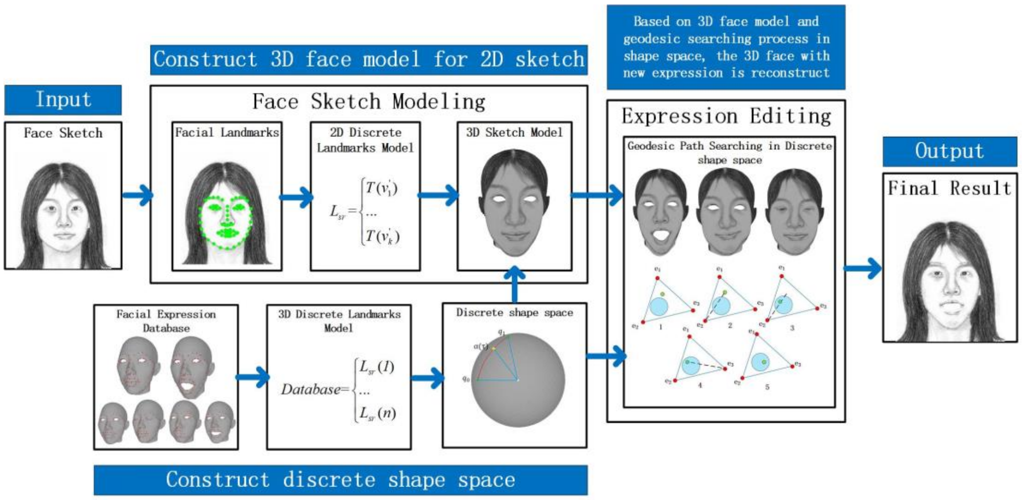

Fig. 1. The pipeline of facial expression editing in face sketch.

includes two parts: face sketch modeling and expression editing. The face sketch modeling generates a 3D sketch model from a 3D facial database to match the 2D face sketch. To represent the expression of 3D sketch model and 2D face sketch, a discrete landmarks model(DLM) is proposed which can be regarded as the "shape unit" in shape space. The 2D DLM can be regarded as the 2D counterpart of the 3D DLM and the matching between the 2D DLM and the 3D DLM can be computed directly. The metric between DLMs is consistent to the discrete shape measurement [24]. Then we provide the basic conditions to construct a discrete shape space. In the shape space, we obtain the best 3D DLM matching result from 3D facial database to match the 2D DLM from 2D face sketch. Using the 3D DLM, the 3D sketch model is regenerated.

For expression editing, we search the geodesic path in shape space to achieve new 3D DLM and the new expression can be obtained. The new 3D DLM is regenerated by the geodesic searching between different DLMs in shape space. Based on the new 3D DLM, the new 3D sketch model is obtained and the expression transfer is mapped into the 2D face sketch . In Fig 1, we show the pipeline of our method. In following parts, we will discuss the details of implementation steps.

III. FACE SKETCH MODELING

To edit a facial expression in face sketch, an editable face sketch model should be constructed at first. The basic idea of face sketch model construction in our method is mapping the source face sketch into the shape space and reconstructing a 3D sketch model. The whole process includes two parts: the construction of the shape space and 3D sketch modeling.

A. Construction of shape space

We have introduced that the shape unit and the metric should be defined in shape space construction. The shape unit in our method is represented by facial landmarks which is accord to the discrete form. Therefore the construction of our shape space is based on the discrete shape theory. In our method, we propose a discrete landmarks model (DLM) to represent the shape unit. The facial landmarks in face sketch are detected using [26]. The construction process of the DLM include three parts: 1. translation removal equation; 2. scaling removal equation; 3. rotation alignment equation. In equation 4 to equation 6, we show the construction of the DLM.

$$
\begin{aligned}
F &= \{x_1, ..., x_k\}, \quad B \in F \\
L &= \{v_1, ... v_k\}, v_i = x_i - B
\end{aligned}
\tag{4}
$$

In equation 4, F is the set of the facial landmarks, B is the benchmark of F. The benchmark is used to make the locations of the landmarks from different faces uniform. We select the nasal tip landmark to be the benchmark. L is the set of landmark vectors that are obtained by the landmarks minus the benchmark($v_i = x_i - B$). Thus we achieve the preliminary landmarks model.

$$
\begin{aligned}
s(L) &= (\sum_{i=1}^{k} \|v_i\|) \\
L_s &= \{v_1^{'}, ... v_k^{'}\}, v_i^{'} = \frac{v_i}{s(L)}, \sum_{i=1}^{k} \|v_i^{'}\| = 1
\end{aligned}
\tag{5}
$$

In equation 5, s is the scale of the L. Different scales of L influence the analysis of facial features' relative positions. The landmark model should have unique scale. To remove the scaling factor, we use each vector in L to divide s. The new landmark model L_s is constructed. The scale of L_s is unitized and the relative positions of the vectors in L are retained. In discrete shape space theory, the rotation is removed by the Singular Value Decomposition(SVD). In our method, we use a sample method in the process. The DLM is constructed by facial landmarks. The landmarks include semantic information. We construct a local coordinate system using certain landmarks to align the facial landmarks.

$$
L_{sr} = \{T(v_1^{'}), ..., T(v_k^{'})\} \tag{6}
$$

In equation 6, we achieve the L_{sr}, which is the final representation of the DLM. For the vectors in L_s, the rotation factors still exist. The influence comes from the different head poses of 3D facial data. We introduce the transform function T to remove the rotation from the landmarks model. The function T is a coordinate transformation based on a local coordinate system. We select the landmarks around the nose to build the coordinate system which are robust to facial expressions. In Fig 2, we show the instance of the local coordinate system. Based on equations 4 to 6, the face data in the facial expression database can be transferred to the representation of L_{sr}. Finally, we achieve the discrete shape space with facial data reflections.

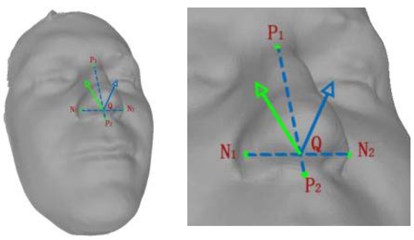

Fig. 2. Instances of local coordinate system by different landmarks. In the 3D scene, the points of P_1, P_2, P_3 and P_4 are landmarks around the nose area. The point Q is the pedal of vector P_1P_2 and vector(Q), which is computed by $P_1P_2 * N_1N_2$.

B. 3D Sketch Modeling

Based on the discrete shape space, we build the 3D sketch model. The modeling process searches the best fitting result from the shape space to match the source 2D face sketch image. The DLM of facial landmarks in the face sketch image is achieved in a 2D scene. To achieve the best fitting result in a 3D scene, we should solve the matching problem between the 2D DLM of face sketch image and the 3D DLMs in the shape space. Based on the best fitting 3D DLM, the 3D sketch model is recovered.

For 2D DLM and 3D DLMs matching, the simplest scheme is mapping the 3D DLMs into the 2D cases. The 2D counterparts of the 3D DLMs are affected by different head poses. To achieve the best fitting 2D counterpart of the 3D DLM, the different poses should be added in the 3D DLM and produce new 2D counterparts. The DLM matching problem is transferred in the 2D scene. The information of 2D counterpart have three dimensions: identity, expression and rotation angle. Using the certain step to rotate the 3D DLM, the new 2D counterpart data are obtained.

The final fitting result is selected from the 2D counterpart candidate set. The similarity measurement of the 2D DLM and the 2D counterparts should be provided. Based on shape space theory, the distance computation method has been proposed already. In equation 7, we show the distance computation process. The $L_{sr}(a)$ and $L_{sr}(b)$ represent the two DLM representations of the 3D sketch model a and b. The shape space in our method can be regarded as a hypersphere (the DLMs in shape space have same center and same scale). The distance of different DLMs in the shape space is equal to arc length in the hypersphere. Using the distance computation process in the shape space, we achieve the best fitting 2D counterpart from the facial database to 2D DLM in face sketch. Using the identity, expression and rotation information from the 2D counterpart, the 3D sketch model is obtained.

$$d(L_{sr}(a), L_{sr}(b)) = arccos(L_{sr}(a) \cdot L_{sr}(b)) \quad (7)$$

IV. EXPRESSION EDITING

Based on the 3D sketch model, we propose the facial expression editing method. The 3D sketch model has three degrees of freedom (identity, expression and rotation). If we change the index of expression, the expression transform result of the 3D sketch model can be achieved. Without any additional process, we can achieve 20 samples (FaceWareHouse has 20 different expressions) with different expressions of the 3D sketch model. However, the method cannot satisfy the requirement of expression editing. If the facial expression of the 2D face sketch does not exist in 20 samples or the target expression doesn't exist in 20 samples, the expression editing result will not be satisfactory.

To solve the problem, a new expression generation method based on facial expression samples should be proposed. We have introduced that the 3D sketch model is recovered from the DLM. Similarly, we construct new expressions based on the DLM in the shape space. First, we propose the new DLM generation method in equation 8 which is accord to equation 3. The parameter γ represents the position of the geodesic path in the shape space between a and b. Using equation 8, the new expressions from a to b are generated. Based on equation 8, the complete new expression generation method is proposed. We use an instance to show the process in Fig 3.

$$L_{sr}(\gamma) = \frac{1}{\sin(\theta)}(\sin(\theta(1-\gamma))L_{sr}(a) + \sin(\theta\gamma)L_{sr}(b)) \quad (8)$$
$$\theta = d(L_{sr}(a), L_{sr}(b)), \gamma \in [0,1]$$

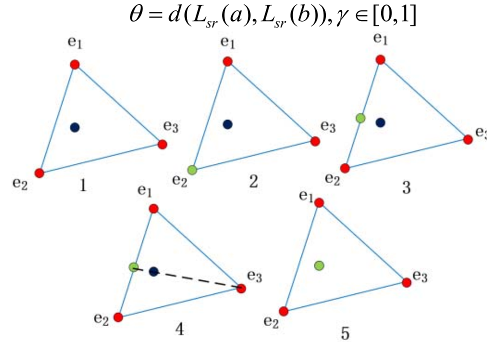

Fig. 3. Instances of the new expression generation process based on expression data.

The triangle area represents a small region in the shape space. The red points represent the 3D DLMs with different expressions in the shape space. The blue point represents the 2D DLM of the 2D face sketch. Based on the measurement in equation 7, we achieve the best fitting 3D DLM e_2 to 2D DLM, which can be regarded as the starting point in the expression generating process. In Fig 3, step 2 represents the initial state of the process. The green point represents the best fitting 3D DLM to the 2D DLM or the start point. In step 3, the green point walks in the geodesic path using equation 8. The direction of the geodesic searching is decided by the distance reduction speed to a different target 3D DLM. From the start point, the geodesic path from e_2 to e_1 satisfies the requirement. Walking a short range, the new direction should be updated. In step 4, the walking direction of the green point is changed to e_3. When the green point satisfies a stop condition (the distance between the blue point's 2D DLM and green point's 2D counterpart of the 3D DLM cannot be reduced by the direction update), the 3D DLM with the new expression is achieved.

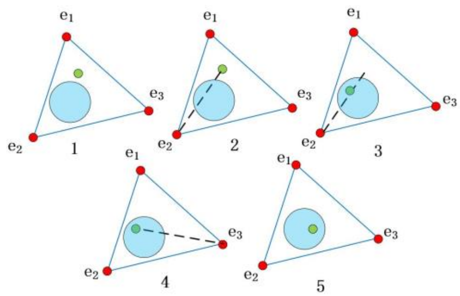

Fig. 4. Instances of the expression editing process based on expression data.

Based on the expression generation process, the expression editing can be processed by changing the record during the geodesic path searching. In Fig 4, we show an instance of expression editing. The green point represents the DLM with a certain expression. The blue region represents the range of the facial expressions we want to edit. Using the directional update with the different expressions: e1, e2 and e3, the facial expression of the DLM can be edited in the blue region. When we add the red points from the facial database, the triangular area is changed to a region with multi-vertices. The expression is regenerated and the edit will be more accurate. A convenient interactive way is provided in our method, the user can control the blue point's position (just like in Fig 4) in the region to achieve the new facial expressions.

The 3D sketch model with the new expression is recovered by the 3D DLM. The 3D DLM we have discussed is based on facial landmarks. Each 3D DLM represents a 3D face model with a facial expression in FaceWareHouse. To recover the 3D sketch model using the 3D DLM with a new expression, we rebuild the DLMs with all vertices, which are called the global DLM (GDLM). The start DLM and the walking geodesic path are stored from the new expression generation process. Following the record, we reproduce the new expression generated in the GDLM. Finally, GDLM with the new expression is achieved. The GDLM has complete geometric information of the face model. It can be regarded as the final result of the 3D sketch model with accurate expression of the 2D face sketch. The texture of the 2D face sketch is mapped into the 3D sketch model directly (The 3D DLM of the 3D sketch model has been aligned to 2D DLM of face sketch image).

V. Experiments and Analysis

We evaluate the performance of our expression editing method in this section through the experiments. The soft platform is constructed by Visual Studio 2013, OpenGL4.6.0 and OpenCV2.4.10. The hardware platform is constructed by Intel Xeon E5620 2.4GHz, 12G RAM and TITAN XP. The 3D face database (FaceWareHouse) is used to construct shape space in our framework. The database has 150 people and 20 expressions for each person. In our method, we choose a set of angles to rotate the 3D DLM in the database (rotation around by X:[-30,30], Y:[-30,30], step = 5, total samples: 13*13 = 169). Finally, we achieve a 2D counterpart candidate set of the 3D DLM with 150*20*169 samples. The vertices of the face data in FaceWareHouse are aligned. We manually label the 3D facial landmarks in one face data. The landmarks' positions can be automatically assigned to other face data. Using the 3D landmarks' positions, we construct the shape space with different 3D DLMs. For expression editing evaluation, we select the CUHK Face sketch Database (CUFS) to be the test data. It includes 188 faces from CUHK students. Essentially, the experiments can be divided to two parts: evaluation of 3D sketch model results and expression editing results.

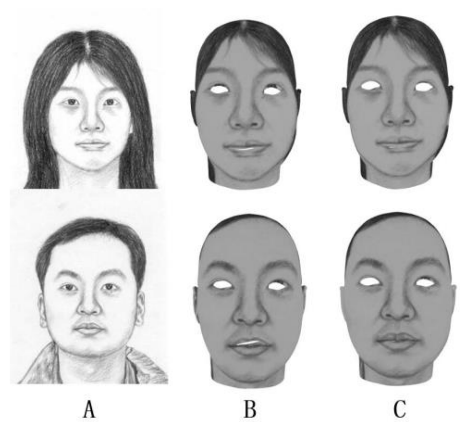

Fig. 5. Instances of 3D sketch modeling. A is the 2D face sketch, B is the 3D sketch model without a new expression generating process, C is the 3D sketch model with the new expression generating process.

A. 3D Sketch Modeling Result

The quality of expression editing in our method is dependent on the accuracy of the 3D sketch model. It can be represented by the similarity between the 2D DLM of face sketch and the 2D counterpart of the 3D DLM. Based on the new expression generation method, we achieve a more accuracy 3D DLM and 3D sketch model to match the source face sketch. In Fig 5, we show some instances of 3D sketch model with accurate regeneration expression. For further illustrate the accuracy of our 3D sketch modeling process, we compute the DLM distance between the 2D DLM of face sketch and the 2D counterpart of the 3D DLM by different iterations. We also select a classical face modeling method, the morph model [27], to be the comparison. In Fig 6, we show some instances of 3D sketch models and morph model results from the 2D face sketch images. Our modeling method achieve more accuracy 3D sketch model with head pose and identity features. In Fig 7, we show the DLM distance reduction curve graph using different iteration steps of the two methods for the modeling process. We can see that the convergence speed of our method is faster than morph model.

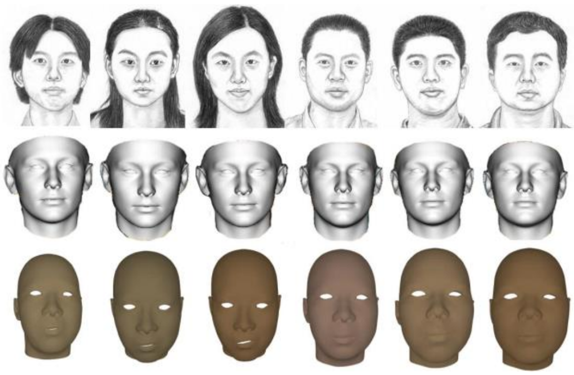

Fig. 6. Instances of the face sketch model using the two methods. The first row is the original face sketches, the second row is the face sketch model using morph model. The third row is the 3D sketch model by our method.

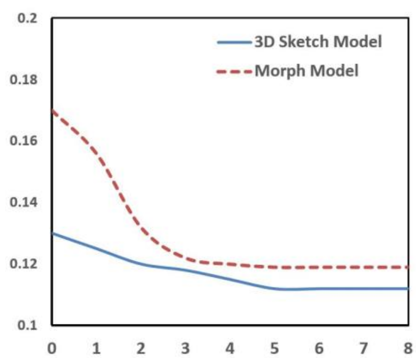

Fig. 7. DLM distance of different iterations by two methods. The horizontal axis represents the index of the iterations, the vertical axis represents the DLM distance value.

B. *Expression Editing Result*

Based on the 3D sketch model, we edit the expression and generate the new 2D face sketch. In Fig 8, we depict instances of the new 2D face sketch with certain expressions in FaceWareHouse. The expressions include a: closed eyes, b: crooked mouth, c: smile and d: surprise. In Fig 8, the expressions are transferred into the face sketch and the new face sketch images with different expressions are obtained. For expression editing, we show the expressions transfer process from one to another in Fig 9. We can see the animation between two face sketch images with different expressions. The animation shows the expression transfer from source to target. The parameter γ in equation 8 controls the intermediate frame in animation process. If we want to achieve a face sketch with new expressions, the expression transfer process provides a set of candidates when the end points' expressions data are fixed. To show the pose robustness of our method, we select some face sketch images with different poses (https://www.server110.com/game/201704/581322.html; https://www.16pic.com/photo/pic_755622.html; https://www.banbaowang.com/sumiao/144693/) and transfer the expressions in the faces. In Fig 10, we show the instances of expression transfer in face sketch with different poses.

C. *Summary & Analysis*

Overall, the quality of the 3D sketch model satisfies the requirement of expression editing in a 2D face sketch image. The number of expression samples in facewarehouse is sufficient to be used to achieve new facial expressions. Using the geodesic path searching to achieve target expression data, we can achieve the new expressions in any updating step. The expression editing process can be driven by certain expression samples from the present expression. It is friendly to the user without professional painting skills. Another advantage of our expression editing method is the robustness to the head poses in 2D face sketches. The influence of poses have been removed in the 2D counterpart construction of the 3D DLM. The expression editing can provide reasonable result in face sketch with different head poses.

VI. Conclusions

In this paper, we proposed a novel facial expression editing method for 2D face sketch drawing using the shape space theory. We construct a shape space by facial landmarks from a 3D facial database. Using geodesic searching in the shape space, a 3D facial sketch model is constructed from a 2D face sketch. The new expressions can be generated and transferred into the 2D face sketch by editing the 3D sketch model. The 3D facial sketch modeling in our method is robust to head pose and scale, the face feature extraction and representation are convenient. The reconstruct new facial expressions are natural and accurate. This approach provides a solution to users to change the expression information in a 2D face sketch. The method reduces the work for face sketch editing and reduces the professional requirements for the users. In future work, we want to apply the method to wider applications, such as facial animation and sketch recognition.

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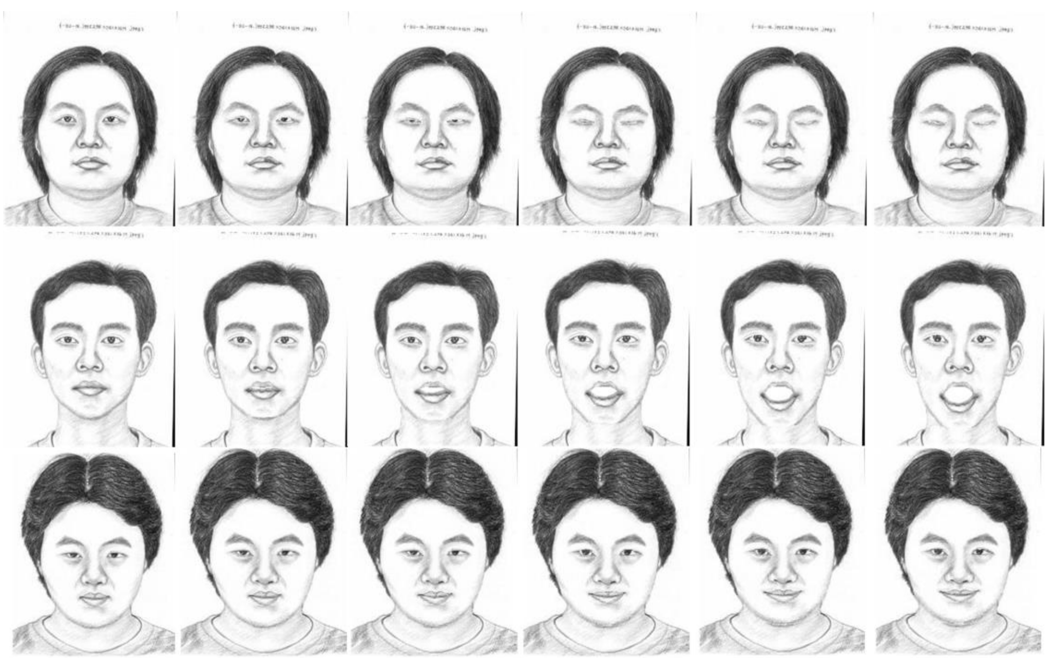
Photo **Face Sketch** **a** **b** **c** **d**

Fig. 8. Instances of new 2D face sketch with certain expressions. The parameters of a, b, c and d represent four kind of expressions.



Source **0.2** **0.4** **0.6** **0.8** **Target**

Fig. 9. Instances of face sketch expressions' animation. Form source to target sketch, the expresison is changed by A set of progressive parameters.

Fig. 10. Instance of new 2D face sketch with certain expressions in different head poses. The face sketch images in first row are original data. The face sketch imaged in other rows are regenerated sketch with different expressions.

REFERENCES

[1] KR. Laughery, RH. Fowler. Sketch artist and Identikit procedures for recalling faces.[J]. Journal of Applied Psychology, 1980, 65(3):307-316.

[2] S. Iwashita, T. Onisawa. A study on facial caricature drawing by fuzzy theory[C]. IEEE International Conference on Fuzzy Systems. 1997:933-938 vol.2.

[3] F. Sugimoto, N. Honda. A human interface to search and draw facial images in mind by using psychometrical space model of faces[C]. IEEE International Conference on Fuzzy Systems. 1999:1585-1590 vol.3.

[4] T. Onisawa, Y. Hirasawa. Facial caricature drawing using subjective image of a face obtained by words[C]. IEEE International Conference on Fuzzy Systems. 2004:45-50 vol.1.

[5] Chen H, Xu Y Q, Shum H Y, et al. Example-based Face sketch Generation with Non-parametric Sampling [C]. International Conference on Computer Vision(ICCV). 2001:433-438 vol.2.

[6] H. Wang, K. Wang. Facial Feature Extraction and Image-Based Face Drawing[C]. International Conference on Signal Processing Proceedings. 2002:699-702 vol.1.

[7] H. Wang. Image-based face drawing using active shape models and parametric morphing[C]. International Conference on Neural Networks and Signal Processing. 2003:1017-1020 Vol.2.

[8] S. Calinon, J. Epiney, A. Billard. A humanoid robot drawing human portraits[C]. IEEE-RAS International Conference on Humanoid Robots. 2005:161-166.

[9] Z. Xu, H. Chen, SC. Zhu, et al. A Hierarchical Compositional Model for Face Representation and Sketching[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence, 2008, 30(6):955-969.

[10] X. Wang, X. Tang. Face Photo-Sketch Synthesis and Recognition[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence. 2009, 31(11):1955-1967.

[11] X. Gao, N. Wang, D. Tao, et al. Face sketch–Photo Synthesis and Retrieval Using Sparse Representation[J]. IEEE Transactions on Circuits and Systems for Video Technology, 2012, 22(8):1213-1226.

[12] N. Wang, X. Gao, L. Sun, et al. Bayesian Face sketch Synthesis[J]. IEEE Transactions on Image Processing, 2017, 26(3):1264-1274.

[13] C. Peng, X. Gao, N. Wang, et al. Superpixel-Based Face sketch–Photo Synthesis[J]. IEEE Transactions on Circuits & Systems for Video Technology, 2017, 27(2):288-299.

[14] J. Nishino, T. Kamyama, Shira H, et al. Linguistic knowledge acquisition system on facial caricature drawing system[C]. IEEE International Conference on Fuzzy Systems. 1999:1591-1596 vol.3.

[15] Z. Xu, J. Luo. Face Recognition by Expression-Driven Sketch Graph Matching[C]. International Conference on Pattern Recognition. IEEE, 2006:1119-1122.

[16] Y. Luo, ML. Gavrilova, MC. Sousa. NPAR by Example: Line Drawing Facial Animation from Photographs[C]. International Conference on Computer Graphics, Imaging and Visualization. 2006:514-521.

[17] Y. Liu, Y. Su, Y. Yang et al. A Face sketch Animation Generator for Mobile Communication[C]. Iapr Conference on Machine Vision Applications. 2009:532-535.

[18] X. Li, J. Xu, Y. Ren, et al. Animating cartoon faces by multi - view drawings[J]. Computer Animation & Virtual Worlds, 2010, 21(3-4):193-201.

[19] I. Mpiperis, S. Malassiotis, MG. Strintzis. Bilinear Models for 3-D Face and Facial Expression Recognition [J]. IEEE Transactions on Information Forensics & Security, 2008, 3(3):498-511.

[20] C. Cao, Y. Weng, K. Zhou, et al. FaceWarehouse: a 3D facial expression database for visual computing [J]. IEEE Transactions on Visualization and Computer Graphics, 2014a, 20(3):413-425.

[21] D. Metaxas, J. Wang, E. Shechtman, et al. Facial expression editing in video using a temporally-smooth factorization[C]. Computer Vision and Pattern Recognition. IEEE, 2012:861-868.

[22] X. Han, C. Gao, Y. Yu. DeepSketch2Face: a deep learning based sketching system for 3D face and caricature modeling[J]. Acm Transactions on Graphics, 2017, 36(4):126:1-12.

[23] J. Chi, S. Gao, C. Zhang. Interactive facial expression editing based on spatio-temporal coherency[J]. Visual Computer, 2017, 33(6-8):981-991.

[24] DG. Kendall. Shape Manifolds, Procrustean Metrics, and Complex Projective Spaces[J]. Bulletin of the London Mathematical Society. 1984, 16(2):81-121.

[25] A. Srivastava, E. Klassen, SH. Joshi, et al. Shape Analysis of Elastic Curves in Euclidean Spaces[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence, 2011, 33(7):1415-1428.

[26] H. Yang, C. Zou, I. Patras. Face sketch Landmarks Localization in the Wild[J]. IEEE Signal Processing Letters, 2014, 21(11):1321-1325.

[27] A. Bas, WAP. Smith, T. Bolkart, et al. Fitting a 3D Morphable Model to Edges: A Comparison Between Hard and Soft Correspondences[C]. Asian Conference on Computer Vision. Springer, Cham, 2016:377-391.