Stylized Portrait Generation and Intelligent Drawing of Portrait Rendering Robot

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Abstract. In order to realize application in real time portrait rendering robot systems, a generating method of stylized portraits based on the triangle coordinate system is proposed to solve the problem of the dependence on training samples and the high complexity of the existing algorithms. The proposed algorithm automatically calculates the personalized facial characteristics of the input face and by exaggerating them, features of its stylized portrait are determined. Two triangle coordinate systems are established based on the features of the input face and the stylized portrait respectively, and the stylized portrait is generated by image morphing between the two systems. Besides, in order to improve the intelligence of the portrait rendering robot, a trajectory planning method is presented to imitate the drawing techniques of a real painter. Experimental results show that the stylized portrait generation algorithm can produce a vivid stylized portrait in less than 0.5 seconds. Finally, the portrait rendering robot imitates real painters to draw the generated stylized portrait based on the proposed trajectory planning method.

Introduction

Portrait drawing has always been a very popular form of artistic expression. With the development of machine vision, controlling robots to draw portraits gradually become a hotspot in the field of artificial intelligence research. A lot of automated portrait robots\cite{1-5} have appeared, which can generate a portrait based on a real face photo, create the drawing trajectory based on the face features, and finish portraits drawing automatically.

Recently, various stylized portrait generation methods have been proposed, among which, some need a large amount of training samples to learn the form of generating the stylized portrait\cite{6, 7, 8}, some need to analyze a large number of face parameters\cite{7, 8, 9}, and some need a lot of manual annotation works\cite{10}. Most of these algorithms are not efficient enough, which limits their application in real-time portrait rendering robot system.

In order to solve the problems of the dependence on training samples and the high complexity of the existing algorithms, this study proposes an efficient and effective method based on the triangle coordinate system\cite{11} to generate stylized portraits. Besides, we present a trajectory planning method to control the robot render the stylized portraits like a realistic painter. Based on these two methods, we implement an intelligent stylized portrait rendering robot system. Figure 1 shows the designed portrait rendering robot system.

The rest of this paper is organized as follows. We present the stylized portrait generation method in Section 2. Section 3 illustrates how to plan the trajectory that makes the robot draw like a real artist. Experimental results are depicted in Section 4. Section 5 provides a brief summary and comments on future developments.
Stylized Portrait Generation

Please refer to paper [11] to learn more about the definition and the properties of the triangle coordinate system. The overview of the stylized portrait generation algorithm based on the triangle coordinate system is shown in Figure 2. $S$, $S_{\text{ref}}$ and $S_C$ represent the feature points of the input face, the reference face and the stylized portrait respectively, and the reference face is a mean face calculated through over 2000 face images. $T_S$ and $T_C$ represent the triangle coordinate systems established on $S$ and $S_C$ respectively.

By the present state-of-the-art technologies of face feature points location, we can obtain the feature points of the face automatically, then we can establish the triangle coordinate system by the following steps. For any point of the feature points, connect it to other points. If the connection line intersects the existing line segment, delete it. For each point of the feature points, find all the pairs of points that are connected to it at the same time. If there are no other points in the triangle that is composed with the pair points, add the triangle to the triangle set. Finally, the triangle coordinate system is established. As the points of $S$ and $S_C$ are one-to-one, we map the connecting relation of $T_S$ onto $S_C$ to establish the triangle coordinate system of $S_C$.

Since there is offset between $S$ and $S_C$, it may cause cross connections of certain triangles, then some “black holes” will appear after the image morphing. In order to make sure that the triangles are independent to each other, based on the geometric structure of the human face, we set deformation constraint criterion: whatever the deformation mode is, the relative position of facial features remains unchanged, such as eyebrows are always on top of the eyes. Under the constraint criterion, the deformed face is reasonable and can conform to the face structure.

We first calculate the personalized facial characteristics by comparing the features of the input face and the reference face. By exaggerating the personalized facial characteristics, we can obtain the stylized portrait feature points. Then by the image morphing based on the triangle coordinate systems, we can finally generate the stylized portrait. The steps of stylized portrait generation are as follows.
Step 1. \( S = \{ S(i) | i = 1, 2, \cdots, n \} \) and \( S_{\text{ref}} = \{ S_{\text{ref}}(i) | i = 1, 2, \cdots, n \} \) are feature points of input face and the reference face respectively, where \( n \) is the number of feature points used in the image deformation. \( S_{\text{ref}}(i) \) is the corresponding feature point of \( S(i) \).

Step 2. Calculate the offset vector \( V_D = \{ V_D(i) | i = 1, 2, \cdots, n \} \) and the offset degree \( M_D = \{ M_D(i) | i = 1, 2, \cdots, n \} \) when moving the points from \( S_{\text{ref}} \) to \( S \).

\[
\begin{align*}
V_D(i)_x &= S(i)_x - S_{\text{ref}}(i)_x \\
V_D(i)_y &= S(i)_y - S_{\text{ref}}(i)_y
\end{align*}
\] (1)

\[
M_D(i) = \sqrt{(V_D(i)_x)^2 + (V_D(i)_y)^2}
\] (2)

Step 3. Calculate the personalized facial characteristics vector \( V_p = \{ V_p(i) | i = 1, 2, \cdots, n \} \) of the input face:

\[
V_p(i) = \begin{cases} 
V_D(i), & M_D(i) \geq T_p \\
(0,0), & M_D(i) < T_p 
\end{cases}
\] (3)

where \( T_p \) is the threshold which is used to measure the difference between input face and the reference face, and it determines the position of notable personalized facial characteristics.

Step 4. Set exaggeration degree \( W_C = \{ \omega_i | i = 1, 2, \cdots, n \} \) to exaggerate the personalized facial characteristics, and calculate the stylized portrait deformation vector \( V_C = \{ V_C(i) | i = 1, 2, \cdots, n \} \):

\[
\begin{align*}
V_C(i)_x &= \omega_i V_p(i)_x \\
V_C(i)_y &= \omega_i V_p(i)_y
\end{align*}
\] (4)

where \( \omega_i \) is the exaggeration degree corresponding to the \( i \)th feature point. \( \omega_i \) can be determined by the actual exaggeration demand in \([0.0, 2.0]\). The greater the \( \omega_i \), the greater exaggeration of the corresponding feature.

Step 5. Under the deformation constraint criterion, move \( S \) along \( V_C \) to obtain the stylized portrait feature points \( S_C = \{ S_C(i) | i = 1, 2, \cdots, n \} \):

\[
\begin{align*}
S_C(i)_x &= S(i)_x + V_C(i)_x \\
S_C(i)_y &= S(i)_y + V_C(i)_y
\end{align*}
\] (5)

Step 6. Establish the triangular coordinate systems \( T_S \) based on \( S \). Then we map the connecting relation of \( T_S \) onto \( S_C \) to establish the triangle coordinate system of \( S_C \). For each pixel \( P \) of the input face, calculate the triangle coordinate \( (x_{pa}, x_{pc}) \) according to \( T_S \). Then the new Cartesian coordinate is calculated by \( (x_{pa}, x_{pc}) \) and \( T_C \) to generate the stylized portrait.

**Robot Rendering Trajectory Planning**

In order to imitate real artists to draw a portrait and save the drawing time, we follow the drawing rules of real artists to propose the rendering trajectory planning method. Based on the features of \( S_C \) and the face structure characteristics, the stylized portrait is divided into six drawing areas and the major drawing sequence is determined: left eyebrow and eye, right eyebrow and eye, nose, mouth, left side of the portrait, right side of the portrait. The corresponding drawing direction of each part is also designed by simulating the real artists' drawing skills in Table 1. Parts of the drawing procedure by the robot end can be seen from Figure 3. When the robot drawing the portrait, it implements the rendering in accordance with the designed drawing mode, and it draws like a real artist.
Table 1. Drawing areas and their corresponding drawing directions.

| Index | Drawing Area            | Main Direction       | Secondary Direction |
|-------|-------------------------|----------------------|---------------------|
| 1     | Left eyebrow and eye    | From left to right   | From up to down     |
| 2     | Right eyebrow and eye   | From left to right   | From up to down     |
| 3     | Nose                    | From up to down      | From left to right  |
| 4     | Mouth                   | From left to right   | From up to down     |
| 5     | Left side of the portrait | From up to down    | From right to left  |
| 6     | Right side of the portrait | From up to down      | From left to right  |

Figure 3. Portrait drawing procedure of the robot end.

Experiments and Analysis

Figure 4 shows the stylized deformation results of different input faces based on the proposed method. With the values of $W_c$ becoming larger, the personalized facial characteristics are exaggerated more obviously. Especially when the personalized facial characteristics are very obvious, the effect will be more evident after exaggerating. In Figure 4, (a), (b), (c), (d) and (e) represent the input faces, the line portraits, stylized portraits with $W_c = 0.5$, stylized portraits with $W_c = 1.0$ and stylized portraits with $W_c = 1.3$ respectively.

The configuration of the experimental computer is processor Intel (R) Core (TM) i5-4460 CPU 3.20GHz, memory 12GB. The size of the stylized portraits is 300 pixels×450 pixels. From face detection of the input image to the generation of the stylized portrait, the whole process consumes less than 0.5 seconds. It shows that the proposed algorithm is efficient and effective. Figure 5 displays some of the portraits drawn by the robot. The average drawing time is about four minutes.
Summary
This paper presents a stylized portrait generation method based on triangle coordinate system. The method is simple, efficient, automatic, flexible. It can calculate the personalized facial characteristics by comparing the features of the input face and the reference image. The algorithm has good comprehensive performance, and can be applied in systems of real time portrait rendering robot. The robot rendering trajectory planning method also reflects the effectiveness, and finally the robot can draw the stylized portrait like a real artist. The future work mainly includes how to realize the stylized deformation of different states of the input face, like open or closed eyes and mouths to widen the scope of its application further.

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