Research and Application of 3D Face Modeling Algorithm Based on ICP Accurate Alignment

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Abstract. This paper focuses on 3D face modeling. First, the panorama is divided into faces. Then the segmented face depth map is filtered first and then registered. Finally, complete the process of modeling the human face. The face segmentation process is mainly to remove the background of the panoramic depth map, and then perform segmentation of the human head. In this paper, select the rough registration method based on SIFT feature point depth map. Use the optimized bidirectional matching algorithm to purify the matched feature point pairs. Then this paper uses the SVD algorithm to find the transformation matrix and complete the depth map rough registration. This paper mainly selects the improved ICP algorithm for accurate registration. The improvement strategy is mainly based on the search acceleration of the K-D tree. The experimental results show that the curvature of the human body changes greatly between the frontal and lateral surfaces of the human body. When the overlapping area is small, the face registration can be performed more accurately and complete face modeling can be performed.

1. Introduction

In recent years, virtual reality technology, digital multimedia technology, and internet technology have developed greatly. 3D face modeling has wide application prospects in face detection, face recognition. This makes it a hot research issue in the fields of image processing, computer vision and computer graphics. 3D face modeling is a process of constructing the face geometry. The shape information provided by the face geometry and the 2D texture data play a crucial role in building a 3D face model.

The traditional ICP algorithm proposed by Besl et al. and the Fast ICP algorithm proposed by Rusinkiewicz et al. are widely applied to various aspects of three-dimensional model registration. However, these traditional three-dimensional model registration algorithms may suffer from local optimality and false matching when the front and side curvatures of the face change greatly, and the overlapping area is small. It is difficult to accurately complete the point cloud registration and other issues.

Therefore, in this paper we propose a more effective 3D model registration method. Considering the speed of 3D reconstruction, controlling a certain number of point cloud frames, and the improved ICP algorithm requires the initial position of the two point clouds to be closer. In this paper, we first use the method of rough registration based on SIFT feature point matching to register the two point clouds closer to the initial position, and then use the improved ICP algorithm to perform fine registration, and finally complete a complete three-dimensional face modeling. Experiments show that
The proposed method can get better results.

2. 3D Face Modeling System Flow and Method
At present, the three-dimensional reconstruction technology is rarely applied to people's daily life, and the traditional three-dimensional registration algorithm has a large amount of calculation. To solve these problems, this article uses a low-cost Kinect device to perform three-dimensional reconstruction of the human body surface. The specific modeling process is shown in Figure 1.

The specific process of 3D face modeling proposed in this paper:
- **Data collection**: The system acquires the depth map and color map through Kinect at a certain moment. And complete the registration of depth maps and color maps.
- **Remove background and head segmentation**: The method of connected component analysis is used to segment the foreground region and the background, and the head segmentation is performed using fast head segmentation algorithm based on horizontal line in this paper.
- **Filter**: To ensure that the latter can be used efficiently, edge detection and removal of noise are required for the segmented depth image. This paper uses bilateral filters for depth map filtering.
- **From image to point cloud**: Convert depth maps into point cloud files in PCD format. Suppose the point in the image is \((u, v)\) and the corresponding 3D point position is \((x, y, z)\), then the conversion relationship between them is as follows:

\[
\begin{align*}
    x &= \frac{(u-c_x)z}{f_x} \\
    y &= \frac{(v-c_y)z}{f_y} \\
    z &= d e f(u, v) / s
\end{align*}
\]  

- **Rough registration**: This paper uses the method of SIFT feature point depth map registration to perform rough registration of depth maps. For the obtained correct matching feature points, the corresponding transformation matrix is calculated by the SVD method. Two-view rough registration can be implemented to provide an initial value for the following precise registration and to increase the registration speed.
- **Accurate registration**: This paper mainly uses the improved ICP algorithm to accurately register the 3D point cloud. Accurate registration mainly uses the least-squares optimal matching algorithm, and iteratively solves the optimal rigid-body transformation matrix. Until the error is less than the set threshold, an accurate registration model is obtained.
Draw and display the 3D model: In this paper, the color texture is added to the aligned 3D point cloud, and the reconstruction is performed by triangulating the point cloud. Finally, the model is smoothed. To show a more vivid and complete 3D face model.

3. Fast Face Segmentation Algorithm
Using the horizontal line-based fast face segmentation algorithm, find a horizontal line to divide the foreground region into the head region H and the body region. It can quickly segment the face of the depth map. Face segmentation using the panoramic depth map acquired from Kinect is generally divided into the following steps:

- Get the depth map closest to the point (tip of the nose): The extracted depth map has noise. Therefore, the obtained depth map is smoothed using a pixel filter method. Remove most of the point where the depth value is 0, so as to accurately find the distance from the nearest point of the depth map, that is, the position of the nose tip.
- Segmentation of the foreground area: First, the depth map is divided into a foreground area and a background area. The foreground area includes the user’s head and trunk. First get image binarization. The foreground area thus obtained is not accurate. Therefore, it is necessary to use the tip position information to determine the entire foreground area by using a connected area analysis algorithm.
- Horizontal line-based fast face segmentation algorithm: In order to determine the head area in the foreground area, a horizontal line is found to divide the foreground area into a head area H and a trunk area T, thereby determining the head area [1].

\[
D_r(u, v) = \begin{cases} 
D_r(u, v) & \text{iff } M_r(u, v) = 1, v \leq s \\
0 & \text{otherwise}
\end{cases}
\]  

(3.1)

s is a horizontal scan line. To obtain s, the paper uses the OPENCV built-in trained Haar method. After detecting the incoming face using the method, adjust the rectangle so that the user’s entire head is included in the rectangular box. And mark the height of the face s, s is the horizon. Fast Face Segmentation Image is shown in Figure 2.

![Fast Face Segmentation Image](image)

Figure 2. Fast Face Segmentation Image.

4. 3D Face Modeling Registration Process
In order to reconstruct a complete geometric model, multiple 3D point cloud data needs to be acquired from multiple angle scans. Then these 3D point clouds are transformed from the local coordinate system they belong to into a unified coordinate system. This process is called 3D Model registration.

4.1. Depth Map Rough Registration Based on SIFT Feature Points
The following is the introduction and implementation process of SIFT algorithm:

- SIFT algorithm introduction: The SIFT algorithm is Lowe [2], who summarized the existing feature detection methods based on invariant technology. Then he proposed a local feature description algorithm based on scale space.
The SIFT algorithm implements object recognition mainly in three major steps: 1. Extracting key points; 2. Adding detailed information (local features) to the key points, that is, the descriptors; 3. A number of matching feature points are found through the comparison of two-party feature points (attaching the key points of the feature vectors). As shown in Figure 3:

![Figure 3. Three major processes for object recognition using SIFT algorithm.](image)

- **Feature point detection**: Two depth maps were measured from different angles using the Kinect system, denoted as D1 and D2. Using S1FT algorithm to detect feature points on the feature image. As shown in Figure 4, the "o" position in the figure indicates the pixel position of the feature point.

![Figure 4. SIFT feature point detection.](image)

- **Feature point matching and registration**: In the search of matching relation, literature [3] proposes a bidirectional matching algorithm. The Euclidean distance between the matched feature points should be equal. Based on this principle, keep the number of votes exceeded by a certain number of matching relationships. According to the correct matching feature points obtained, the corresponding transformation matrix is calculated by the SVD method, and then the corresponding rigid transformation is used to register the two depth maps.

### 4.2. Accurate Registration Based on Improved ICP Algorithm

This paper adopts an improved ICP algorithm. Firstly, the curvature feature information of the point is calculated centrally at the target point T, and several feature points are extracted. Then use the K-D tree [4][5] index method to find the nearest point of these feature points in the reference point set S. Use it to achieve registration between two point clouds. The specific flow of the improved ICP algorithm is:

- Establish target point cloud T and corresponding reference point cloud S.
- In the target point cloud T, find m feature points based on the curvature feature of the point, and obtain a corresponding feature point set G.
- Data initialization: \( G_0 = G, q_0 = [1, 0, 0, 0, 0, 0]^T, k = 0 \).

  Use the K-D tree algorithm to find the nearest point \( F \) of the feature point set \( G \) in the reference point cloud \( S \):

  \[
  F_K = C(G_K, S)
  \]

- Calculate the best coordinate transformation vector (optimal translation vector and rotation vector) and error for the point cloud:

  \[
  (q_K, E_K) = Q(G_0, F_K)
  \]

- Coordinate transformation of feature point sets in the target point cloud:

  \[
  G_{K+1} = q_K(G_0)
  \]

- Determine whether the matching error \( E \) converges, if \( E_K - E_{K+1} < D \), \( D \) is the set value and \( D > Q \) errors converge, otherwise the algorithm flow jumps to the fourth step.

- If the error converges, the target point cloud \( P \) coordinate can be changed: \( T_K = q_K(T) \), the algorithm ends.

5. Experimental Results and Analysis

This article uses VS2015 and Kinect Xbox ONE as development tools. Use VC++ and OpenCv to register the depth map acquired by the kinect with the color map. Perform fast face segmentation transformation, bilateral filtering, and face registration based on SIFT algorithm for depth maps. Use PCL to convert the depth map to the point cloud file PCD file. Each PCD file contains a header. It identifies and declares certain characteristics of the point cloud data stored in the file.

5.1. Kinect Image Acquisition

Depth image and RGB image acquired with kinect, and align depth image with RGB image. The resulting depth, RGB, and alignment images are shown in Figure 5.

5.2. Depth Map Rough Registration Based on SIFT Feature Points

The SIFT algorithm is used to perform feature descriptor calculations on adjacent images. Afterwards, bidirectional matching algorithm is used to pair feature point pairs. Voting by the Euclidean distance equalization principle leads to a more accurate point pair. In this paper, the color map is first registered and then the registration of the depth map is completed through the mapping relationship. The experimental results are shown in Figure 6. The SVD algorithm is used to solve the matrix and then the depth map coarse registration is completed. As shown in Figure 7.
Figure 6. Color Map Mapping Depth Map Feature Point Detection and Matching.

Figure 7. Color and depth maps after rough registration.

5.3. Accurate Registration and 3D Face Modeling
Using a modified ICP algorithm for fine registration of face models. Figure 8 shows the left view of the image. Figure (a) and Figure (b) are the original images to be registered, and Figure (c) is the result of the registration. Figure 9 shows the right view of the image. Figure (a) and Figure (b) are the original images to be registered, and Figure (c) is the result of the registration. And complete the 3D face modeling, as shown in Figure 10.

Figure 8. Comparison of left view of original image and registered image.

Figure 9. Comparison of right view of original image and registered image.
6. Summary
This paper is mainly based on 3D face modeling of image and point cloud registration. This paper proposes a fast face segmentation algorithm based on horizontal lines. Secondly, this paper also proposes a combination of rough registration and accurate registration, using the SIFT feature point depth map registration and improved ICP algorithm to register depth maps, and obtain a complete, smooth face model.

First, use the Kinect device to obtain human RGB maps and depth maps at different viewing angles, and align the depth maps with the RGB maps. And use bilateral filtering to denoise.

Second, in this paper, rough registration based on SIFT feature point depth map is introduced and the experimental results are analyzed. A rough registration method using RGB image and depth image is proposed, and the image feature point information is introduced into a rough registration method. This article uses an improved ICP algorithm. For the traditional ICP algorithm, a K-D tree-based search acceleration improvement strategy was proposed for the accurate registration of point clouds.

Finally, design experiments verify the feasibility and effectiveness of the proposed algorithm. The experimental results show that the proposed algorithm can accurately complete the face registration when the curvature of the face and the side of the face change greatly and the overlap area is small. Then a complete 3D face modeling can be established.

7. References
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