Image Warping based on 3D Thin Plate Spline

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Abstract – This article has shown the simulation change after moving the landmarks within medical image by applying 3-dimension thin plate spline through the following 3 steps: The first step is to write the program to open and display 3-dimension medical images by using Borland C++ Builder 6 as the compiler along with OpenGL as the engine to display the images. The second step is to distort 3 dimension image by define the initial set of landmarks on the angle of the cube with the texture image constructed by using OpenGL and the set of final destination of landmarks. The last step is to apply the distortion algorithm on different corresponding points within the skeletal model in three-dimension such as the skull, limbs, and joints and display the result after distortion. The results from the experiment have shown that the distortion of three-dimension image by applying thin plate spline can simulate the results after moving the landmarks on the medical images.

Keywords: 3D Thin Plate Spline, 3D Image Warping, 3D Image Distortion, OpenGL

1 Introduction

This paper presents a technique for 3D image warping simulation based on thin plate spline. With this simulation, the users are allowed to see the movement of 3D structure, in the direction that they have been decided. Therefore, the users who needs to developed more complicated software; virtual animation or further study in 3D would find this technique more informative and useful.

3D Image warping technique use the 3D vertex or 3D coordinates as the data source. Although, there are a number of techniques for doing image warping such as the faster 3-dimension thin plate spline algorithm as shown in the research of Roberts et al. [1] as well as the fast reconstruction of 3D object by radial basis function on 3D thin plate spline algorithm by Carr et al. [2] to improve the performance of 3-dimension simulation.

However, the faster 3-dimension thin plate spline technique of Roberts has been applied to the 3-dimension head image implemented using MATLAB, which is difficult to exported as commercial product in the future. Furthermore, the application of radial basis function on thin plate spline algorithm of Carr would take longer to render 3D objects when the radial basis function algorithm has to manipulate the model data.

Therefore, our paper is another offer for someone who are interested to developed more research work in this field.

For the further research and development, this technique could be applied to the 3D Face Recognition with Vectors [3] and medical image registration in the same way as the registration of MRI images to find the exact position of breast cancer while reducing the motion artifacts [4].

2 Three-Dimension Thin Plate Spline

Thin plate spline (TPS) [5] is the technique for estimating the random data from 2 paring sets of data to construct spline map from the affine factor for linear distortion and weighting factor for nonlinear distortion for image registration. The first step of TPS is to solve eq. 1 to calculate both affine factor $A$ and weighting factor $W$.

$$
\begin{bmatrix}
K & \hat{P} \\
\hat{P}^T & O(4,4)
\end{bmatrix}
\begin{bmatrix}
W \\
A
\end{bmatrix} =
\begin{bmatrix}
V & O(4,3)
\end{bmatrix}
$$

$O(r,w)$ is zero matrix of 4x4 and 4x3 respectively.

$\hat{P}$ is a matrix $\hat{p}$ that has rows and columns switched (transposed $\hat{p}$ matrix).

$\hat{P}$ is an initial landmark position set matrix before moving with the additional value 1 in every row defined in eq. 2 while $P$ is a matrix of the initial landmark positions before moving without the additional value defined in eq. 3, and $V$ is an final landmark position set matrix after moving the landmarks defined in eq. 4.

$$
\hat{P} = [One(n,1); P] =
\begin{bmatrix}
1 & x_1 & y_1 & z_1 \\
... & ... & ... & ... \\
1 & x_n & y_n & z_n
\end{bmatrix}
$$
\[ P = \begin{bmatrix} x_1 & y_2 & z_3 \\ \vdots & \vdots & \vdots \\ x_n & y_n & z_n \end{bmatrix} \] (3)

\[ V = \begin{bmatrix} x'_1 & y'_1 & z'_1 \\ \vdots & \vdots & \vdots \\ x'_n & y'_n & z'_n \end{bmatrix} \] (4)

\[ K = \begin{bmatrix} 0 & U(r_{12}) & \cdots & U(r_{1n}) \\ U(r_{21}) & 0 & \cdots & U(r_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ U(r_{n1}) & U(r_{n2}) & \cdots & 0 \end{bmatrix} \] (5)

\[ U(r)_{i>0} = r_i, r = \sqrt{(P_{x1} - x)^2 + (P_{y1} - y)^2 + (P_{z1} - z)^2} \] (6)

\[ f_{x_i}(x, y, z) = a_{x_i} + a_{x_2}x + a_{x_3}y + a_{x_4}z + \sum_{i=1}^{n} w_i U(r) \] (9)

\[ f_{y_i}(x, y, z) = a_{y_i} + a_{y_2}x + a_{y_3}y + a_{y_4}z + \sum_{i=1}^{n} w_i U(r) \] (10)

### 3 Procedures

The experiments on three-dimension thin plate spline distortion on OpenGL [6] has been performed through the following procedures.

3.1 Creating 3D cube with texture bitmap image by using OpenGL according to the example 6 of Ne-He [7]

3.2 Draw landmark at the points according to the user’s demand, which is the 8 landmarks on the corners of the cube.

3.3 Control the mouse action to move the landmarks according to the article 13 of Ne-He. [8]

3.4 Add thin plate spline algorithm for 3D image warping mentioned in Section 2 [5] into the program.

The algorithm testing for 3D image distortion on a cube will be implemented as a program by using Borland C++ Builder 6 and OpenGL as shown in Figure 1.

Figure 1. 3D Distortion on a Cube with Texture Bitmap

The application in Figure 1 will be applied to perform three-dimension distortion will be as shown in Figure 2 and Figure 3.

Figure 2(A) is showing 3D thin plate spline distortion process on a cube with texture image mapping by rotating and applying the mouse to move all 8 corners (the red spots) to the new destination (the blue spots).

On the other hand, Figure 2(B) is showing 3D thin plate spline distortion process on a corresponding mesh cube without texture image by moving all 8 corners (the red spots) to the new destination (the blue spots) to display the distortion on the structure of a mesh cube.
Figure 2. Result from 3D Thin Plate Spline on the Cube

Figure 3(A) is showing 3D thin plate spline distortion process on a cube with texture image mapping by moving all 8 corners (the red spots) to the new destination (the blue spots) in similar ways as shown in Figure 2(A), but at different perspective angles.

On the other hand, Figure 3(B) is showing 3D thin plate spline distortion process on a corresponding mesh cube without texture image by moving all 8 corners (the red spots) by mouse to the new destination (the blue spots) and display the distortion on the structure of a mesh cube in similar way as shown in Figure 2(B), but at the different perspective angles.

4 Experiment Results

After finishing the 3-dimension thin plate spline distortion on the cubes with texture image mapping as shown in Figure 1 and Figure 2, the researchers are testing the algorithm on the 3-dimension skeletal models as well as other 3D images of the organs such as the lower part of the body and the left arm through the following procedures.

4.1 Morphing and loading 3-dimension object by using OpenGL according to the example 25 of Ne-He. [9]

4.2 Draw landmark at the points according to the user’s demand, which is 10 landmarks to be loaded along with the 3D object in 4.1.

4.3 Control the mouse action to move the landmarks according to the article 13 of Ne-He. [8]

4.4 Add thin plate spline algorithm for 3D image warping mentioned in Section 2 into the program.
The algorithm testing for 3D image distortion on a skeletal structure with landmark will be implemented as a program by using Borland C++ Builder 6 and OpenGL as shown in Figure 4.

Figure 4. Application for 3D Thin Plate Spline on a Skeletal Model with Landmarks

Figure 4(A) is showing the initial skeletal structure before performing 3D thin plate spline distortion and 10 pairs of landmarks started at the skull, left and right shoulder, left and right hand, the end of backbone, left and right femur, and left and right foot along with the new positions of corresponding landmarks. On the other hand, Figure 4(B) is the skeletal structure after performing 3D thin plate spline distortion which shows the distorted skeletal structure to fit the structure with the new positions of landmark pairs. The application in Figure 4(A) and 4(B) also show the coronal view of the skeletal structure on the upper small image and the sagittal view of skeletal structure on the lower small image.

More results from 3D thin plate spline on skeletal model can be shown from Figure 5 to Figure 7.

Figure 5(A) is showing the initial skeletal structure and 10 landmarks at the skull, left and right shoulder, left and right hand, the end of backbone, left and right femur, and left and right foot along with the corresponding pair of new landmarks. On the other hand, Figure 5(B) is showing the steps of skeletal movement from the initial positions to the defined destinations while Figure 5(C) is showing the result after performing 3D thin plate spline distortion to the new set of landmarks showing the distorted skeletal structure after moving the landmark set.
Figure 6 is showing the application of 3D thin plate spline on the lower part of the body along with the coronal and sagittal view of the object. Figure 6(A) is showing the initial structure of the lower body part and 10 pairs of landmarks with the initial points at both left and right size of hip, upper leg, knee, lower leg, and foot alogn with the new positions of corresponding pairs of landmarks respectively. On the other hand, Figure 6(B) is showing the results after applying 3D thin plate spline algorithm which is a render of lower part of body with bended knees.

Figure 7 is showing the application of 3D thin plate spline on the left arm along with the coronal and sagittal view of the object. Figure 7(A) is showing the initial structure of the left arm and 10 pairs of landmarks with the initial points near a shoulder, an upper section of arm, an arm pit, a lower section of the arm and a left hand respectively. On the other hand, Figure 7(B) is showing the results after applying 3D thin plate spline algorithm which is a render of lowering left arm.

5 Conclusions

The results from the experiment have shown that three-dimension thin plate spline distortion can be applied for simulating the change due to the change of positions within 3-dimension images such as the skeletal structure in Figure 4(B) and Figure 5(C) compared with the original structure in Figure 4(A) and Figure 5(A) respectively. Similar results can be applied to the bended lower body part in Figure 6(B) as well as the bended left arm in Figure 7(B) compared with the original lower body part in Figure 6(A) and the original left arm in Figure 7(A). However, the bended lower body part in Figure 6(B) and bended arm in Figure 7(B) have realistic form closed to the actual results from the movement due to the elasticity properties of the soft tissues.

Nevertheless, the researchers have to study more on the anatomy and real effects of the organ movements from the physicians, especially the structure with little elasticity such as bones, skulls and skeletons to ensure that the simulation results would become closer to the actual results performed by the physicians.
References


