Embedded Selforganizing Systems

A Novel Projection Distortion Correction Method on Patient's Body Surface

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***Abstract*—The fusion of augmented reality technology makes the surgical navigation system promote the safe, convenient and efficient development of minimally invasive surgery. On this basis, the researchers proposed that the body surface projection method provides a more convenient display form and operation mode for surgery, which not only expands the vision of doctors but also improves the quality of surgery. At this time, how to get the real projection display effect through the projector in the complex body surface environment becomes particularly important. Among them, the projection distortion correction method of patient's body surface is the key to its successful application. First, the applicability of four typical projection image distortion correction methods to different surfaces were compared. Secondly, Based on the correction method based on quadratic surface fitting, and a correction method based on point cloud mapping was designed, which uses structured light to extract the point cloud information on the surface of the projection screen for coordinate transformation. Combined with the depth information, it solves the distortion problem of complex surface projection images, expands the surface applicability of the correction method, and improves the correction accuracy and real-time performance. The projection distortion correction of different types of surfaces is realized by simulation, and the correction effect of the two methods is compared. The correction time is shortened from 67s to 7s by the correction method based on point cloud mapping. Finally, organ simulation experiment was used to verify the intraoperative feasibility, and the virtual "perspective" display effect was presented as a whole.**

Keywords—projection display, distortion correction, point cloud mapping, intraoperative organ projection

I. INTRODUCTION

As the key technology of body surface projection method [1], projection display technology is to directly project virtual organ information onto the skin surface of patients using projectors to achieve virtual transparent display effect for assisting doctors in surgical operations. However, it can not fully meet the requirements of surgical accuracy at present, mainly because of the distortion of the projection image. In order to observe the undistorted projection image for doctors, it is necessary to correct the image and project it onto the patient's body surface. In recent years, researchers have made some progress in the research of projection distortion correction for different types of surfaces.

According to the different surfaces of projection screens, the research of projection distortion correction methods has rapidly become a hot research field at home and abroad in recent years, from the initial plane to the parameterized surface such as spherical screen arc screen to the irregular surface,which has been widely applied to astronomical exhibitions, cinema projection, simulation training and other fields. In 2013, Majumder et al. [2] conducted a comprehensive investigation on projection display technology, studied the development direction of this technology, and laid a foundation for projection display technology applicable to the medical field. The characteristics of the four main projection distortion correction technologies are shown in Table I.

TABLE I. COMPARISON OF PROJECTION DISTORTION CORRECTION TECHNOLOGY

Correction method	Mainly applicable surface	Accuracy	Explain	Representative literature
Homography based correction method	plane	Depends on the density of point cloud obtained	Linear	Takahashi et al. [3]
Mesh based correction method	Parametric surfaces and irregular surfaces	Depends on the grid density	Piecewise linear	Yang et al. [4]
Correction Method Based on Bezier Function Fitting	Parametric surfaces and irregular surfaces	Depends on Bezier surface degree	Nonlinear fitting	Bhasker et al. [5]
Correction Method Based on Quadratic Surface Fitting	Quadratic surface	Depends on the density of point cloud obtained	Nonlinear fitting	Steimle et al. [6]

II. CORRECTION METHOD FOR MULTI TYPE SURFACE

The homography based correction method can achieve real-time and accurate correction of smooth planes, but the homography matrix for complex surfaces is no longer applicable to the coordinate relationship between "projector-camera-projection". In order to expand the applicability of projection screens, researchers continue to try to correct projection screens of types outside the plane, and propose grid based correction methods based on homography correction methods. However, at present, there is no research on such methods as surgical navigation projection display technology, and most of them have been used in large projection screens such as astronomical cinemas to obtain high correction accuracy, However, a small projection screen similar to a human body can not obtain a good correction effect. Similarly, on the basis of grid based correction methods, the correction method based on Bezier function fitting proposed by researchers can achieve the correction of projected images more smoothly. However, to achieve more complex surface correction, a higher Bezier surface is required, which is computationally complex and difficult to control. Therefore, this correction method is not applicable to the projection display of surgical navigation. To ensure the safety of surgery, For the complex body surface, the projection image correction accuracy is required to be high, which makes the calculation method too complex, and it is easy to delay the operation progress when updating the image in real time, so it is not suitable for the distortion correction method of projection display.

The morphology of the body surface of human abdomen, skull top and back is very similar to the common quadratic surfaces such as sphere [7] and cylinder [8]. The correction method based on quadratic surface fitting can better realize the projection distortion correction of quadratic surfaces. However, the morphology and structure of other body surface parts are too complex. Considering that the abdominal body surface and its microstructure (navel, nipple, etc.) are not quadratic surfaces, and the external surface of the skull cavity is more obvious, the correction method based on quadratic surface fitting cannot correct the distortion of the projection image according to the change of the depth information of the projection screen surface, and the fitting surface cannot accurately coincide with the actual surface, so there is a large error in the correction results, especially at the edge. Therefore, the correction method based on quadratic surface fitting cannot be applied to all projected images of body surface environment with high accuracy. In order to solve the applicability problem of body surface projection screen, this paper designs a correction method based on point cloud mapping, which eliminates the need for surface point cloud fitting process to improve the correction speed, and improves the correction accuracy by correcting corresponding points.

A. Correction method based on quadratic surface fitting

Different from the other three typical methods, the correction method based on quadratic surface fitting incorporates surface fitting technology into the projective geometric model, obtains the mapping relationship of its projection points under different viewing angles through the projection screen fitting formula, and predeforms the projection image to offset the geometric distortion caused by the projection screen [9]. This surface fitting method uses the quadratic transformation to express the mapping relationship between the corresponding points of the space points on any quadratic surface in the images from different perspectives. The cubic quadratic algebraic equation is usually used to represent the quadratic surface, and the symmetric matrix Q size of 4 × 4 represents its projection coefficient matrix. A series of known three-dimensional space points X can be substituted into the quadratic equations through this matrix, so that any space point on the projection screen is on the quadratic surface shown in equation (1):

$$X^T Q X = 0 \tag{1}$$

When the quadratic surface is beyond the origin, the constant term is not zero, let Q be 1, then the matrix Q is shown as follows:

$$Q = \begin{bmatrix} Q_{3\times3} & q \\ q^T & 1 \end{bmatrix} \tag{2}$$

Based on the classical view angle transformation principle, 3D reconstruction can be realized through the corresponding points of "camera projection" two views, and all unknown quantities can be obtained. The imaging relationship is shown in Fig. 1. The point P on the quadratic surface Q is projected on the camera and projector views ψ and ψ' respectively The intersection points are X and X' respectively, and their coordinates are $(x,y,1)$ and $(x',y',1)$ respectively.

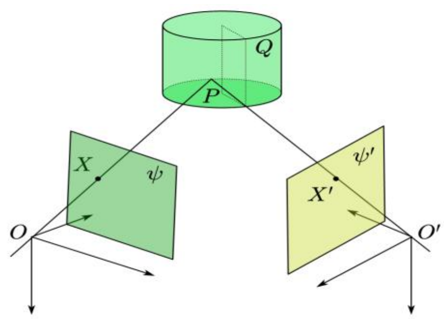


Fig. 1. Quadratic surface imaging relationship

According to the camera model relationship and projection matrix, there are:

$$x \cong \begin{bmatrix} E & 0 \end{bmatrix} P \tag{3}$$

$$x' \cong \begin{bmatrix} B & e \end{bmatrix} P \tag{4}$$

At this time, the coordinates of the image point X' which is point P corresponds on the projector view ψ' is:

$$x' \cong \begin{bmatrix} B & e \end{bmatrix} \begin{bmatrix} x \\ k \end{bmatrix} = Bx + ke \tag{5}$$

The coordinates of the image point X which is point P corresponds on the projector view ψ is $(x,y,1,k)$, abbreviated as (x,k), where k is the relative offset of the spatial position after the point transformation. P is a point on the space quadratic surface, then:

$$\begin{bmatrix} x & k \end{bmatrix} \begin{bmatrix} Q_{3\times3} & q \\ q^T & 1 \end{bmatrix} \begin{bmatrix} x \\ k \end{bmatrix} = 0 \tag{6}$$

Given the coefficient matrix of quadratic surface and the mapping transformation matrix of corresponding points, the transformation relationship of corresponding points is obtained:

$$x' \cong Bx - \left(q^T x \pm \sqrt{(q^T x)^2 - x^T Q_{3\times3} x} \right) \cdot e \tag{7}$$

According to this conversion relationship, the preobserved image can be corrected to obtain the precorrected image.

B. Correction method based on point cloud mapping

The correction method based on point cloud mapping is similar to the one based on quadratic surface fitting, but it does not need to parameterize the projection screen surface. After obtaining the calibration parameters of the "projector-camera" system, the projection surface point cloud X can be obtained by using the structured light 3D measurement method. Using the system parameter matrix and the pixel depth, the specific positions of each point on the point cloud X in the camera image and the projector image can be obtained respectively:

$$X_C = Z^c K^{-1} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \tag{8}$$

$$X_P = Z^p K^{-1} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \tag{9}$$

Since the coordinate mapping conversion is no longer carried out according to the fitting surface, it is necessary to establish the coordinate conversion relationship between corresponding points from the "projector-camera" system. The imaging relationship according to the principle of structured light is shown in Fig. 2.

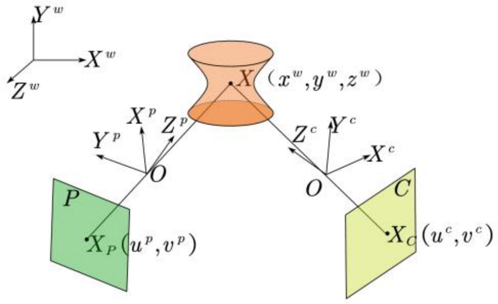


Fig. 2. Point-to-point imaging relationships

The rotation matrix R and the translation matrix T are constructed according to the parameters, where the rotation matrix is converted according to Rodriguez transformation, as shown in equation (10).

$$R = \cos(\theta) I + (1 - \cos(\theta)) r r^T + \sin(\theta) \begin{bmatrix} 0 & -r^z & r^y \\ r^z & 0 & -r^x \\ -r^y & r^x & 0 \end{bmatrix} \tag{10}$$

By using the rotation matrix R, translation matrix T and the three-dimensional space coordinates $X(X^W, Y^W, Z^W)$ of the point cloud on the surface of the projection screen, the coordinate conversion relationship between the space points on the surface of the projection screen, the corresponding points in the projector and camera images can be established. According to the principle of structured light, the following conversion relationship can be obtained. The conversion relationship between the projection surface point and the corresponding point of the camera image is shown in equation (11), and the conversion relationship between the projection surface point and the corresponding point of the projector image is shown in equation (12).

$$Z^c \begin{bmatrix} u^c \\ v^c \\ 1 \end{bmatrix} = \begin{bmatrix} (N^c/2) \cdot c \cdot \tan\beta_1 & 0 & u_0^c \\ 0 & (M^c/2) \cdot c \cdot \tan\beta_2 & v_0^c \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R^c & T^c \end{bmatrix} \begin{bmatrix} X^w \\ Y^w \\ Z^w \\ 1 \end{bmatrix} = M_c X \tag{11}$$

$$Z^p \begin{bmatrix} u^p \\ v^p \\ 1 \end{bmatrix} = \begin{bmatrix} (N^p/2) \cdot c \cdot \tan\beta_1 & 0 & u_0^p \\ 0 & (M^p/2) \cdot c \cdot \tan\beta_2 & v_0^p \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R^p & T^p \end{bmatrix} \begin{bmatrix} X^w \\ Y^w \\ Z^w \\ 1 \end{bmatrix} = M_p X \tag{12}$$

Where, Mc and Mp respectively represent the mapping matrix of camera and projector, Zc and Zp are the Z-axis coordinates of space point X under the camera and projector coordinates, which are usually constant, as scale factor offsets. Therefore, the conversion relationship between camera image and projector image corresponding points is:

$$M_p Z^c \begin{bmatrix} u^c \\ v^c \\ 1 \end{bmatrix} = M_c Z^p \begin{bmatrix} u^p \\ v^p \\ 1 \end{bmatrix} \tag{13}$$

According to the coordinate transformation relationship between the corresponding points, the points on the distorted image are transformed to obtain the precorrected image. Finally, the precorrected image is projected onto the projection surface to complete the correction process. This process breaks the surface limitation of quadratic surface, and is suitable for more complex projection screens, and can achieve higher accuracy according to the density of point clouds.

III. Multi type surface correction experiment

In this paper, the experimental system is built in the 3Dmax simulation environment, and the calibration experiment process is shown in Fig. 3:

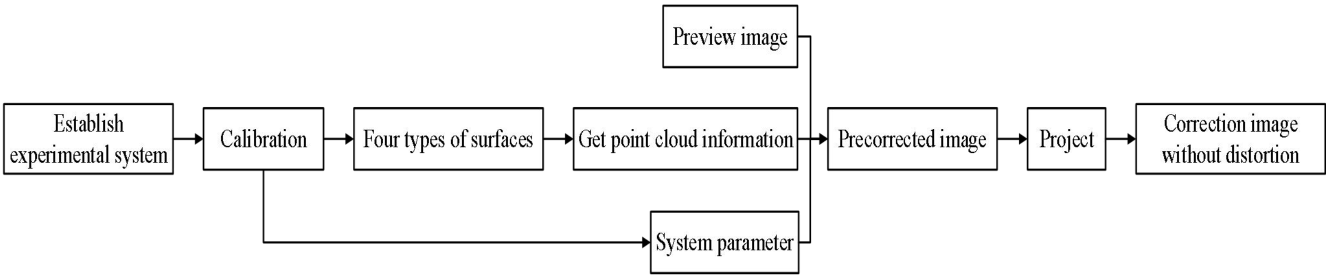
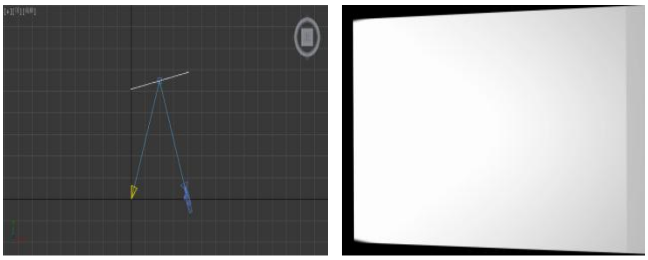
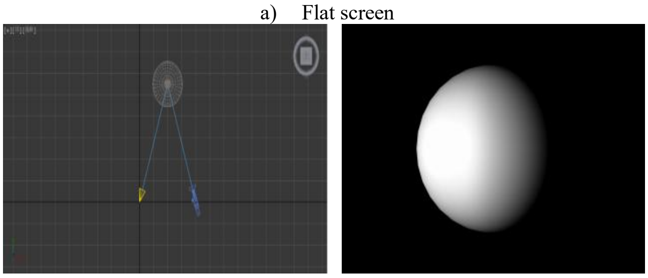


Fig. 3. Flow chart of calibration experiment

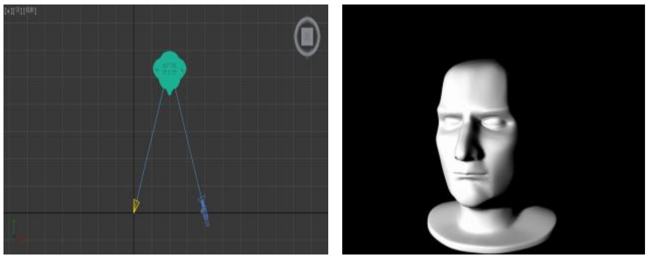
Set the projector (yellow module), camera (blue module), projector resolution and projection screen simulation parameters respectively, and then complete the position construction of the entire "projection-camera-projection screen" system through coordinate value setting and angle adjustment, that is, the experimental system is completed. Set the surface material of the plane screen as a chessboard to be used as the calibration board, and adjust three angles to project Gray code to calibrate the system and obtain the system parameter file. Select four types of surfaces to build simulation experiment scenes of different projection screens, including plane screen, spherical screen, plaster head, and abdominal body surface, as shown in Fig. 4.



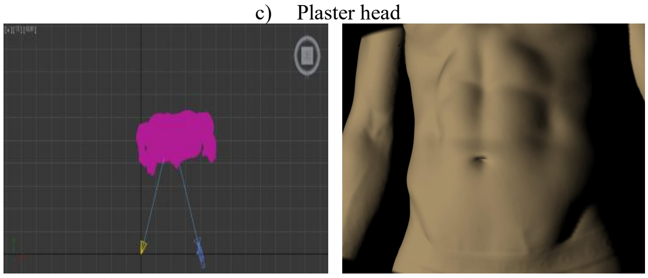
a) Flat screen



b) Spherical screen



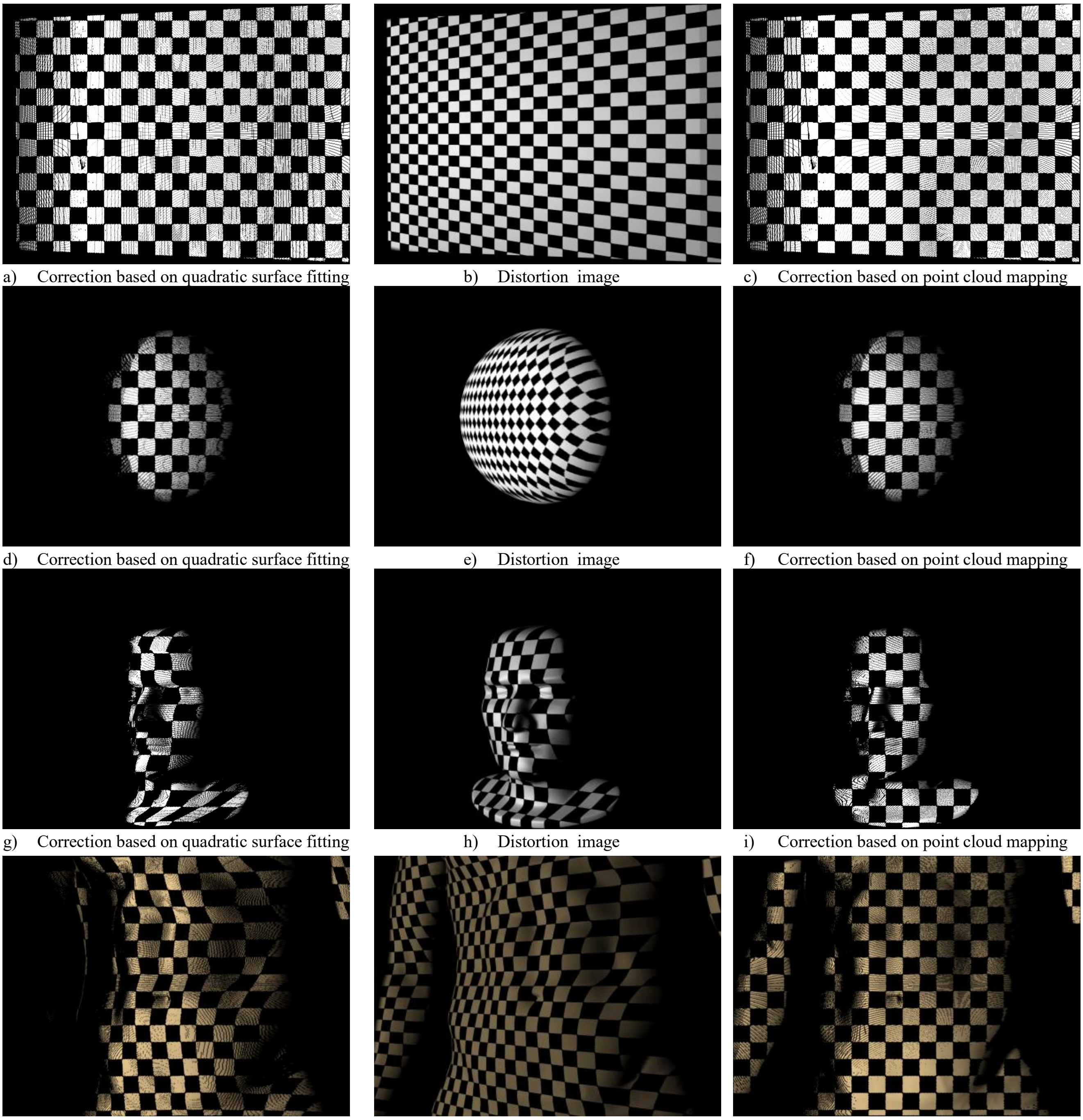
c) Plaster head



d) Abdominal body surface

Fig. 4. Calibration experiment scene

In each scene, the gray code is projected to obtain the point cloud information of four types of surfaces according to the system calibration parameters. In order to clearly observe the correction effect, the checkerboard is selected as the preobservation image, and the accuracy of the correction result can be clearly judged by the shape of the checkerboard. The system calibration parameters and point cloud data are used to precorrect the preobserved image. The precorrected image is projected into the scene, and the corrected image is obtained from the simulated viewing angle taken by the camera. As shown in Fig. 5 (left), it is based on the correction result of quadratic surface fitting, Fig. 5 (middle) is the distorted image before correction, and Fig. 5 (right), it is based on the correction result of point cloud mapping fitting.

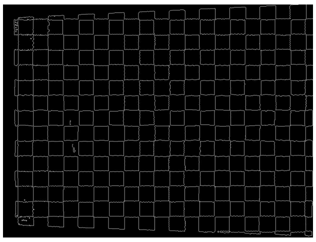


a) Correction based on quadratic surface fitting
b) Distortion image
c) Correction based on point cloud mapping
d) Correction based on quadratic surface fitting
e) Distortion image
f) Correction based on point cloud mapping
g) Correction based on quadratic surface fitting
h) Distortion image
i) Correction based on point cloud mapping
j) Correction based on quadratic surface fitting
k) Distortion image
l) Correction based on point cloud mapping

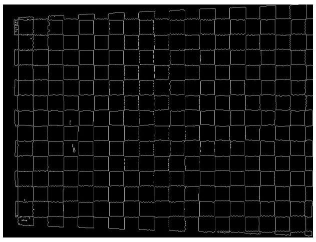
Fig. 5. Calibration results and distortion image

The experiment shows that, according to a) , c) and d), e) in Fig. 5, the two methods have better and more accurate correction effects for plane screens and spherical screens, and the chessboard with equal size and rules can be observed. Compared with the correction method based on quadratic surface fitting, the correction method based on point cloud mapping has more intensive visual effects for plane screens and spherical screens, especially at the edges. It can be seen from g), i) and j), l) in Fig. 5 that the correction method based on quadratic surface fitting is similar to the quadratic surface for the plaster head, which has obvious correction effect but is still inaccurate, and the correction effect of other organs is poor and the accuracy is not high; As for the surface of the abdomen, it is obvious that the lower abdomen is similar to a quadratic surface, which has obvious correction effect but is still inaccurate. Due to the relationship between the surface fitting, the shape of the checkerboard of the abdominal muscles is abnormal compared with the lower abdomen, and the correction image at the left arm has obvious displacement. The actual scene arm position is concave toward the back, and the correction image can not be displayed when projected into the gap. The correction method based on point cloud mapping is more accurate for gypsum head and abdominal body surface correction. There is no visual angle distortion of projection screen caused by complex structure, and accurate chessboard image can be seen without distortion caused by microstructure.

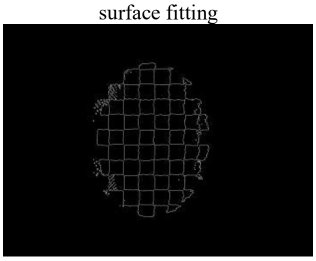
In order to compare the correction effects of the two methods more clearly, binary processing the corrected results after gray-scale smoothing. Canny algorithm is used to extract the checkerboard contour, and the threshold value is set to 10 to obtain clear checkerboard contours displayed under different surfaces As shown in Figure 6. For plane and sphere, the checkerboard outline is basically the same, and the correction method based on point cloud mapping has better details. For the plaster head and the abdomen surface, the correction method based on point cloud mapping has better results, and the edges of the chessboard are more even and more consistent with the human eye.



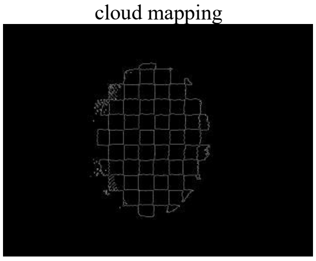
a) Correction based on quadratic surface fitting



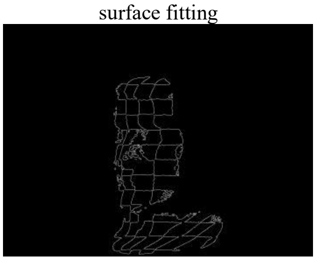
b) Correction based on point cloud mapping



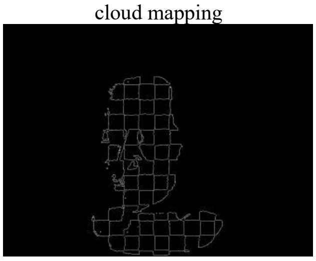
c) Correction based on quadratic surface fitting



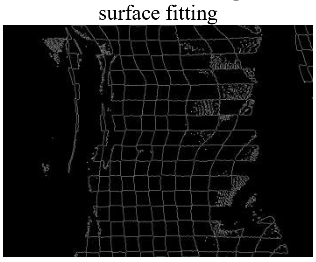
d) Correction based on point cloud mapping



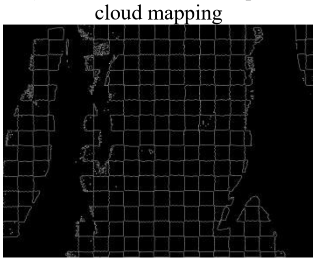
e) Correction based on quadratic surface fitting



f) Correction based on point cloud mapping



g) Correction based on quadratic surface fitting



h) Correction based on point cloud mapping

Fig. 6. Comparison of checkerboard contours

It can be seen that the image can be corrected according to the depth information of the projection screen surface, which improves the correction accuracy, and greatly shortens the correction time without fitting the projection screen surface, as shown in Table II., which improves the real-time correction. There are observable Moire fringes in the details of the four types of surface correction results, and the edges in the precorrection image are obvious, but the correction results after projection and the overall visual effect will not be affected.

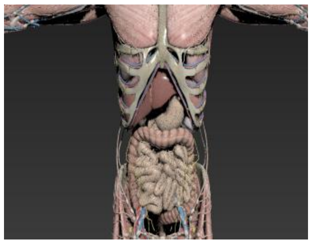
TABLE II. REAL-TIME COMPARISON OF CALIBRATION METHODS

Correction method	Correction time (s)
Correction method based on quadratic surface fitting	67
Correction method based on point cloud mapping	7

IV. SIMULATION EXPERIMENT OF INTRAOPERATIVE ORGAN PROJECTION

In order to simulate the scene of observing the "virtual" organ model on the body surface during surgery, according to the experiment in the previous section, build a scene where the human organ model is placed on the body surface, as shown in Fig. 7. The Fig. 7 a) is the body surface view of the human abdomen, and the Fig. 7 b) is the view of simulating the internal organs of the human body after removing the body surface. After the organs in the abdominal cavity are extracted and placed on the abdominal body surface, in order to facilitate experimental observation, the organs should be appropriately enlarged and displaced, so that the organ model in the pre observation image can be clearly seen and covered the entire view.

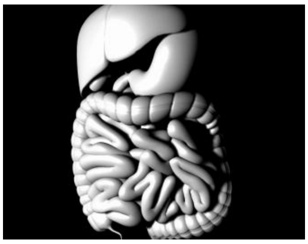
a) Abdominal body surface



b) Organ

Fig. 7. Experiment scene of intraoperative organ projection

Remove the body surface model, and use the camera to take the organ model as the expected observation image, that is, the surgeon expects the organ image observed on the body surface, adjust the material and projector multiplier to obtain the optimal pre observation image, as shown in Fig. 8 a). The Fig. 8 b) shows the distorted image before correction, and the organ position has obvious displacement and deformation.



a) Expected observation image

b) Distortion image

Fig. 8. Expected observation image(organ model)and distortion image

Correct the image and re project the precorrection result to the scene, adjust the multiplier value, and get the correction result as shown in Fig. 9.

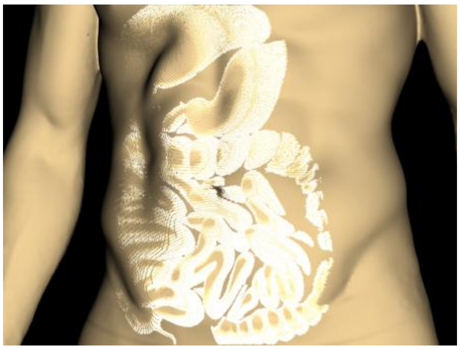


Fig. 9. Calibration image(organ model)

The experimental results show that when the multiplier value is 50 in the simulation environment, the organs on the abdominal surface are best displayed, with accurate positions, and can present a virtual "perspective" effect. Moire fringe has little influence, but the shadow display effect of left abdomen is poor due to the limited range of single projection light path at the edge, so multi projection display can be considered to compensate. On the whole, the correction method based on point cloud mapping can meet the application requirements of intraoperative display.

V. CONCLUSION

This paper mainly studies the correction methods of patient surface projection distortion. First, typical correction methods are analyzed and a correction method based on point cloud mapping is designed. The feasibility, accuracy and universality of the method are verified by experiments on different types of surfaces. The distortion problem of complex surface projection image is solved, the surface applicability of the correction method is expanded, and the correction time is shortened from 67s to 7s, so that a better visual display effect is obtained. In addition, through the simulation experiment of intraoperative organ projection, the experimental results show a virtual "perspective" display effect, and the organ position is consistent with the pre observed image, which verifies the intraoperative feasibility of this method.

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