15-862 Computed Photography - Final Project
Endoscope Exploration on Knee Surface

Chenyu Wu
Robotics Institute, Nov. 2005

Abstract

Endoscope is widely used in the minimally invasive surgery. However the size and distortion of endoscope images limit its use in the surgery planning and navigation. In this project, we stitch the endoscope video images up to get a large view of the knee surface, which actually enlarge the view of the surgeons thus enable them to explore the knee surface in the operation. We first correct the radial distortion by using camera sphere projection model. Then we calibrate the camera by estimating the intrinsic parameters of endoscope camera. With two trackers installed on the bone and endoscope, we can easily recover the transformation from the bone to the endoscope. For each vertex on the bone surface, we can compute the texture coordinates based on the bone to endoscope transformation. Finally, texture mapping technique is used to stitch the endoscope images onto the surface.

1 Introduction

The trend of computer assisted orthopedic surgery is to achieve true minimally invasive surgery (MIS). As a the diagnose tool of MIS, Endoscope and related research are attracting more attentions. Due to the small field of view (FOV) and big image distortion of endoscope, it is very difficult to connect individual images to the global anatomical shape. Especially for the bone surface, with less texture information, all the images look similar, we will get lost by looking through only one image. Why not create a big view for the object of interest based on these disconnected images? Is it possible to recover the 3D surface based on these images?

these questions have been explored for years and some important works are briefly described as follows. After that, our method is proposed and detailed.

1.1 Previous Work

Many people are interested in navigation across endoscope images [1], [4]. Dey *et al.* [2] map the endoscope images onto the 3D surfaces via a two-dimensional 2D to 3D mapping algorithm. They first register the position and orientation of the endoscope by an optical tracking system, so does the 3D surface model. An optical model is then used to identify and extract the surface patch which is visible to the endoscope. Finally a 3D to 2D transform is applied to generate a virtual endoscope image and texture map the real image onto it.

Some people focus on the 3D reconstruction. Quartucci and Tozzi [3] use only one endoscope image to reconstruct the 3D shape of anatomical objects. They model the camera as a spherical projection model and use shape of shading technique to recover the 3D shape after the camera calibration. A dichromatic model is used to obtain a lambertian surface.

1.2 Our work

We actually have proposed two applications of endoscope images in this project. Both are related to generating a bigger view of bone surface from endoscope images.

By fixing the center of projection of endoscope, we warp all the images onto a 2D plane to create a panorama. If we define the orientation of the endoscope by a ray passing through the head and the end of endoscope, fixing center of projection means all possible rays intersect at one point, which is the center of projection. Under this assumption, we can warp each image by computing a homograph based on the tracking information. However, without some important equipments, we have to postpone this experiment.

Without the above assumption, we have to use existed 3D surface to help stitch these images. After we correct the radial distortion, we can register each image to the corresponding 3D anatomical position based on the tracking information. We use texture mapping technique to patch the image onto the local surface. After using blending technique, a big 3D view will be generated.

2 Methods

In our work, we use camera spherical projection model to correct the radial distortion of endoscope camera. Then we calibrate the camera by estimating the intrinsic parameters from a set of control points. Finally we compute the texture coordinates for each vertex on the surface based on tracking information and use texture mapping technique to stich all the endoscope images up to a large 3D image map.

2.1 Calibration

2.1.1 Image Calibration

There are many kinds of lens for endoscope, such as fisheye, wide angle. The endoscope we use in our experiment has a fisheye lens installed. The resulting endoscope images have a large distortion. The deformation can not be recovered by computing a homograph. We calculate the deformation based on the camera spherical projection model.

In the camera spherical projection model, a 3D space point is firstly projected on a spherical surface of radius f with origin at the image projection center and then the obtained point on the spherical surface is projected onto the image plane. The model maps the 3D space points into a sphere with radius f. It covers 180^o field of vision [3].

Let (x, y, z) be the point coordinates in the 3D space with origin at the projection center, and the z axis along the camera optical axis. (u, v) the coordinates in the image plane (distorted). Thus we can easily get the following warping transformations:

$$u = \frac{f \cdot x}{\sqrt{x^2 + y^2 + z^2}} \quad (1)$$

$$v = \frac{f \cdot y}{\sqrt{x^2 + y^2 + z^2}} \quad (2)$$

By printing out different size of checker board images on the paper, we apply above warping transformations to the corresponding captured endoscope images to get corrected images by tuning the parameter f. Based on the visual judgement of correctness, we can find a series of f for different size of checker board images. Finally we use the average f as the distortion parameter. During calculation, we assume each pixel in the image has the same z value. We have also tuned this value to get best results.

Figure 1 and 2 show the results of correctness of radial distortion. The distorted checker board images and grid images are listed in the top row and the corrected images in the bottom.

2.1.2 Camera Calibration

Camera Calibration is a classical problem in computer vision field, where a camera transformation from the 3D view coordinates to the 2D image plane needs to be calculated. This 3D to 2D transformation is described by

$$\begin{bmatrix} \omega u_v \\ \omega v_v \\ \omega \end{bmatrix} = K \begin{bmatrix} x'_v \\ y'_v \\ z'_v \\ \omega'_v \end{bmatrix} \quad (3)$$

where K is a 3×4 transformation matrix defined by the camera intrinsic parameters. $(x'_v, y'_v, z'_v, \omega'_v)$ are the 3D homogeneous view coordinates of endoscope. $(\omega u_v, \omega v_v, \omega)$ are the projected 2D coordinates on the image plane. By labelling a set of control points with known $(x'_v, y'_v, z'_v, \omega'_v)$ and $(\omega u_v, \omega v_v, \omega)$, we can use least square to recover the matrix P.

2.2 Texture patching

2.2.1 Tracking System

We build a two-tracker optical tracking system by putting one tracker on the bone and the other one on the endoscope, in order to obtain the position and orientation of the endoscope and the bone. Moreover, we can compute the transformation from bone surface to the endoscope based on the registration. That means, we know the transformation from world coordinates to the endoscope view coordinates. By denoting this transformation as T, we will have

$$\begin{bmatrix} x'_v \\ y'_v \\ z'_v \\ \omega'_v \end{bmatrix} = T \begin{bmatrix} x_v \\ y_v \\ z_v \\ \omega_v \end{bmatrix} \quad (4)$$

where $(x_v, y_v, z_v, \omega_v)$ are 3D homogeneous world coordinates.

Figure 3 illustrates the tracking system.

2.2.2 Texture Mapping

By calculating the transformation T from world coordinates to view coordinates and the transformation K from view coordinates to image plane, we can project 3D scene to 2D image plane

$$\omega \mathbf{p} = T \cdot K \cdot \mathbf{P} \quad (5)$$

where $\mathbf{p} = (u, v, 1)$ is a point on the 2D image plane. $\mathbf{P} = (x, y, z, 1)$ is a point on the 3D space.

Endoscope images are 2D projections of 3D scenes. For each tiny patch on the surface, we use above transformation to compute the texture coordinates for each vertex on the surface. Then we can use texture mapping to patch the images onto the surface.

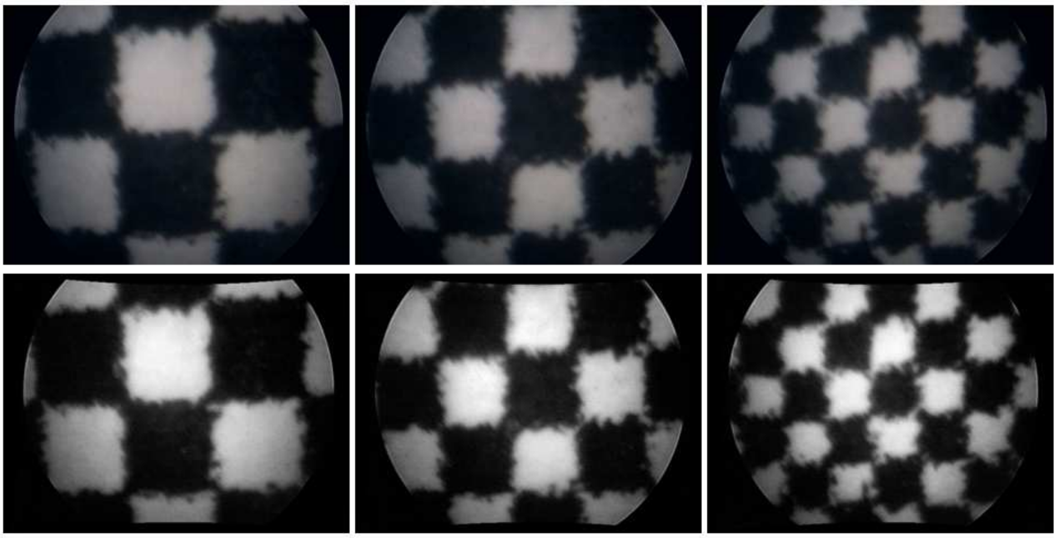

Figure 1: Radial distortion correction. Top row: test checker board images. Bottom row: corrected images

3 Experiments and Results

3.1 Experiments

We have captured 743 endoscope image frames for a knee model. Each frame consists of a 640×480 bit black-white image. We also build a 3D mesh for this knee model.

We have printed out 3 different sizes of checker board images and 3 different sizes of grid images for image calibration. We use $\bar{f} = \sum_i f_i/6$ as the distortion parameter, where f_i is the distortion parameter estimated from each test image i.

We have collected 100 control points (illustrated in Figure 4) for camera calibration.

3.2 Results

Figure 5 shows the 3D bone surface. Figure 6 shows the first 20 endoscope frames texture mapped onto the surface. (I only show the texture mapped triangles here since I still have trouble with displaying both the mesh and textured map at the same time.)

4 Summary

In this project, we have developed a framework to stitch a set of endoscope images together onto a bone surface, such that we can obtain a large view of bone surface. We use camera spherical projection model to correct the radial distortion. We build a two-tracker system to track the position and orientation of the endoscope and bone surface. Furthermore we compute the transformation from the world coordinates to the endoscope coordinates. After the camera calibration, we have the transformation from 3d space to 2D image plane. By computing the texture coordinates of each vertex on the surface, the endoscope image is mapped to the surface directly.

References

[1] L. M. Auer, D. P. Auer, “Virtual endoscopy for planning and simulation of minimally invasive neurosurgery,” *Neurosurgery*, vol. 43, pp. 529-548, 1998.

[2] D. Dey, D. G. Gobbi, P. J. Slomka, K. J. Surry, T. M. Peters, “Automatic fusion of freehand endoscopic brain images to three-dimensional surfaces: creating stereoscopic panoramas,” *IEEE Transcactions on Medical Imaging*, vol. 21(1), pp. 23-30, 2002.

[3] C. H. Quartucci Forster, C. L. Tozzi, “Towards 3D Reconstruction of Endoscope Images using Shape from Shading,”*XIII Brizilian Symposium on Computer Graphics and Image Processing*, pp. 90-96, 2000.

[4] A. J. Sherbondy, A. P. Kiraly, A. L. Austin, J. P. Herferty, S. Y. Wan, J. Z. Turlington, T. Yang, C. Zhang, E. A. Hoffman, G. McLennan, W. E. Higgins, “Virtual bronchoscopic approach for combining 3D CT and endoscopic video,” *SPIE Conference on Image Display*, vol. 3978, pp. 104-116, 2000.

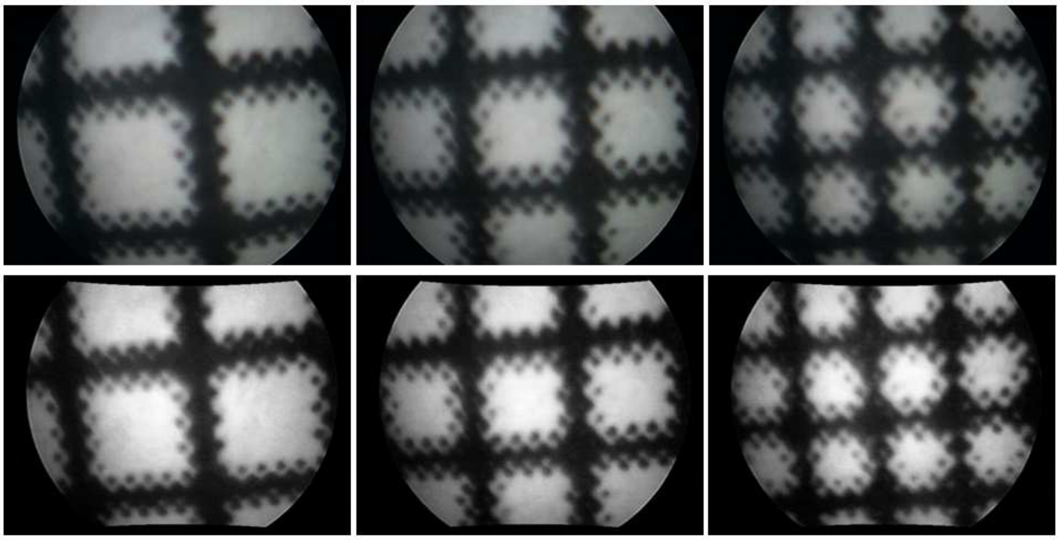

Figure 2: Radial distortion correction. Top row: test grid images. Bottom row: corrected images

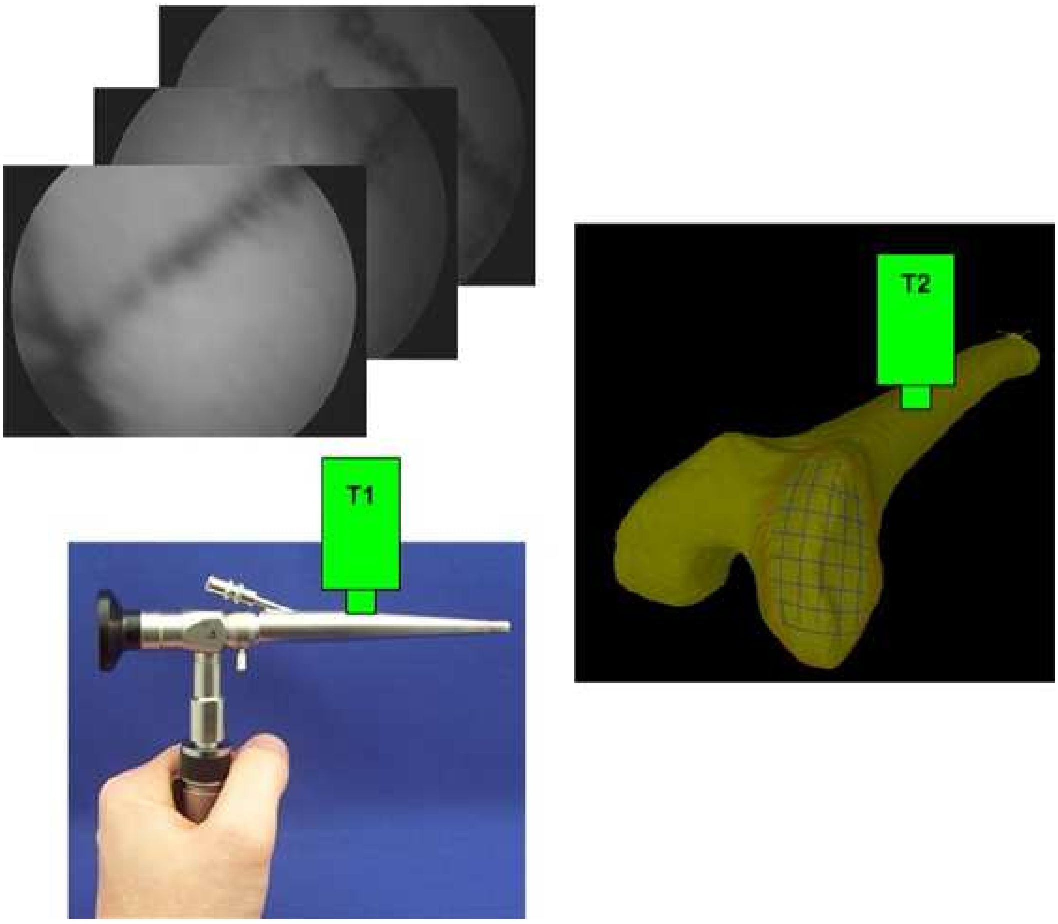

Figure 3: Tracking system

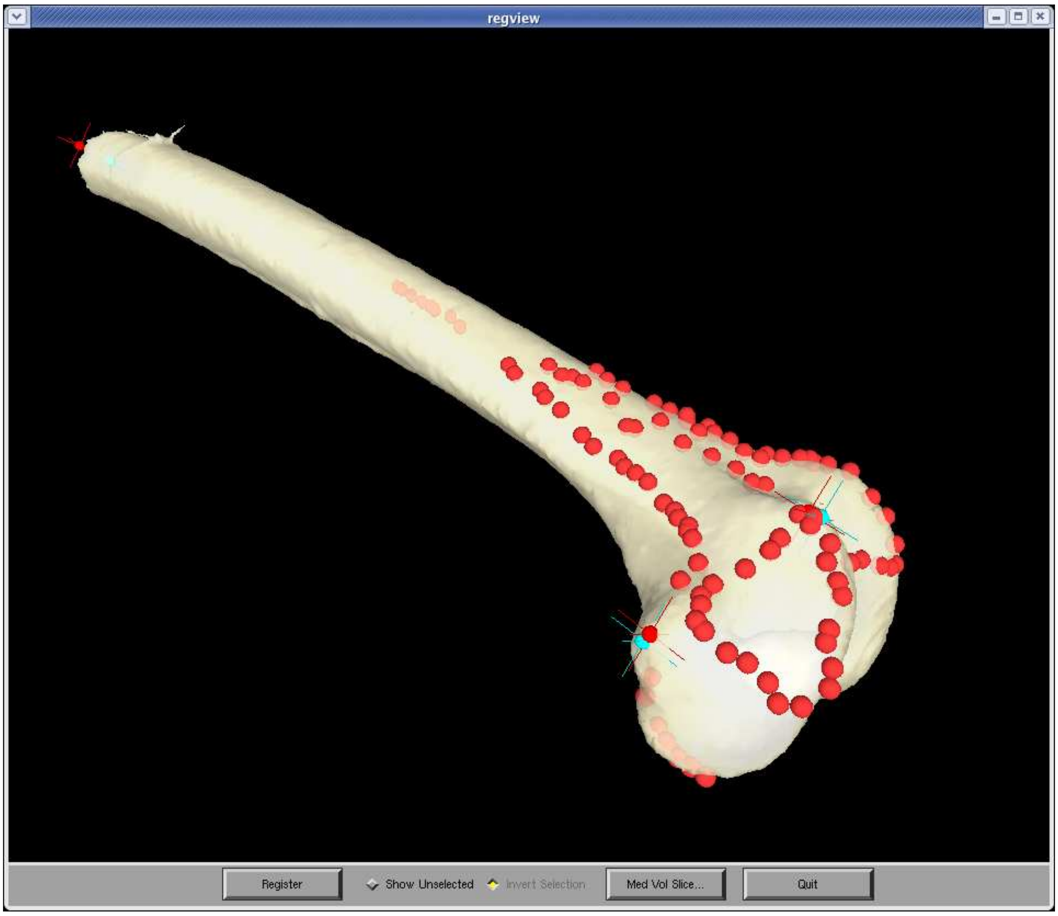

Figure 4: Control points for camera calibration

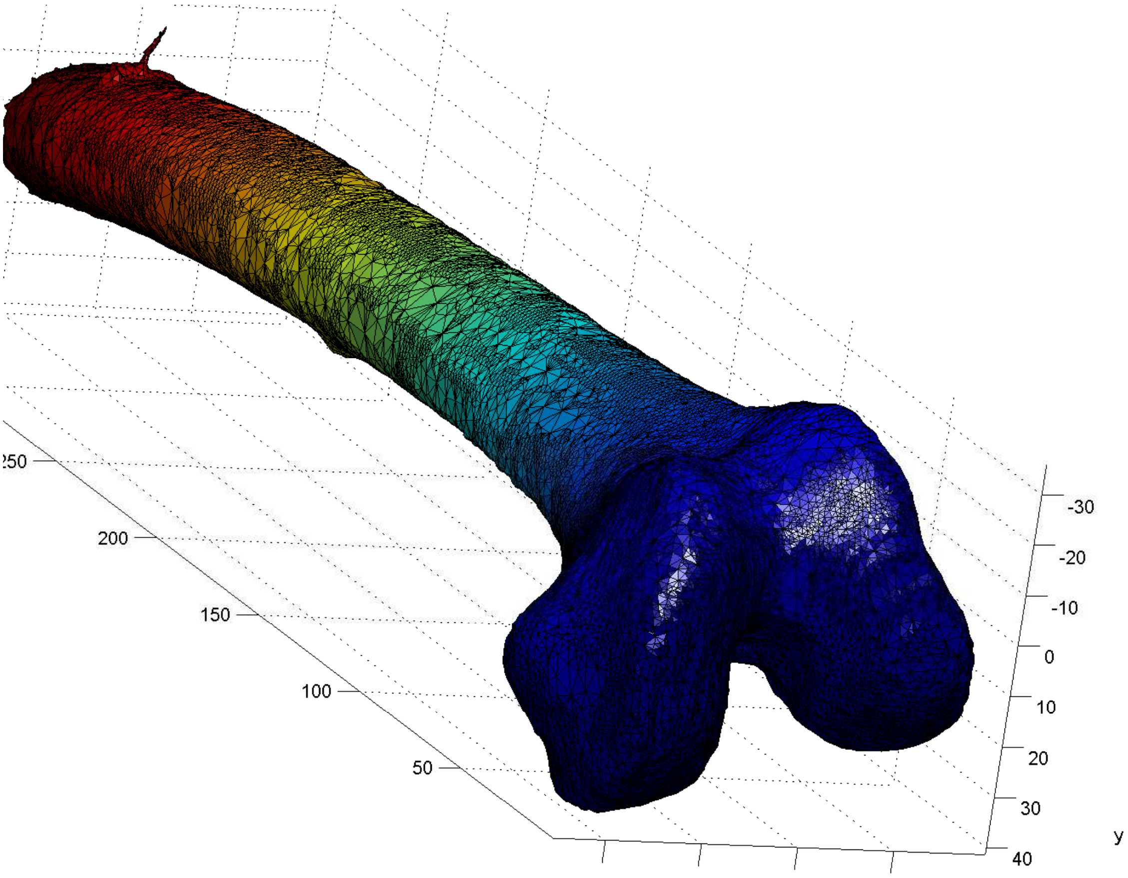

Figure 5: 3D bone surface

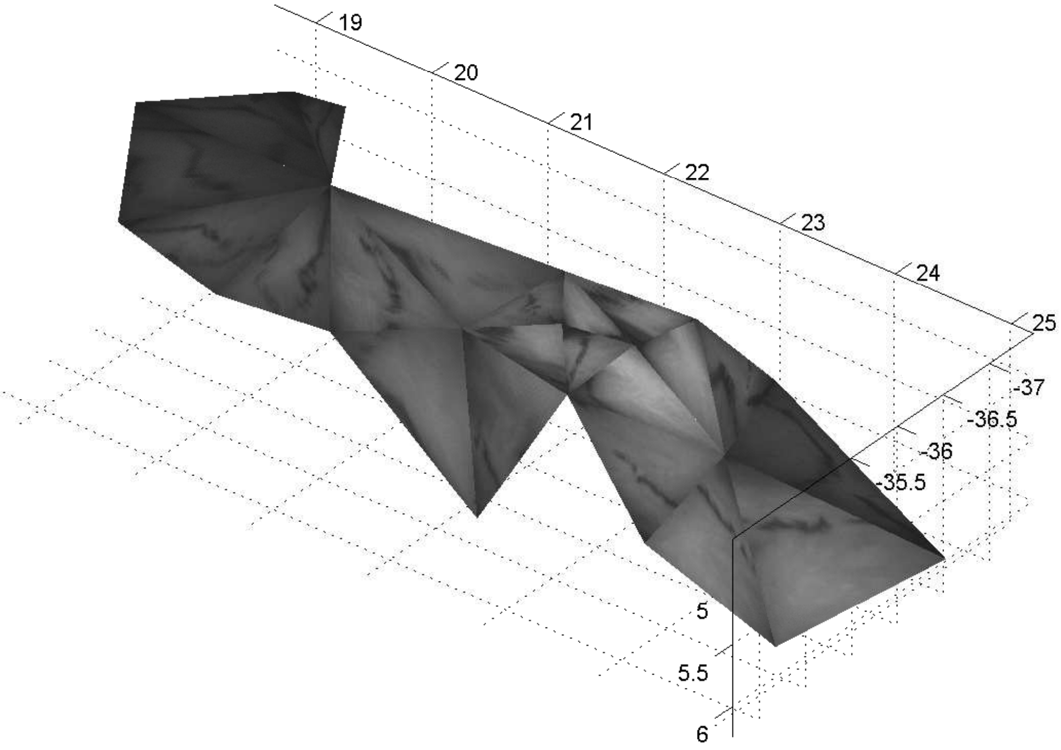

Figure 6: Texture mapped surface by the first 20 endoscope frames