Obtaining Shape from Endoscope Image Using Medical Suture with Two Light Sources

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***Abstract*—Obtaining polyp size and shape is important for the medical diagnosis. In this paper, a 3-D shape reconstruction of computer vision technology is introduced in the medical diagnosis for this purpose. Some approaches based on Shape from Shading have been proposed for polyp in endoscope image. Previous approaches need some parameters such as depth parameter Z from endoscope lens to the surface point and reflectance parameter C. In the endoscope image, it is important to obtain these parameters for accurate polyp shape recovery. This paper proposes a new approach for obtaining parameters Z and C from one endoscope image where a medical suture is taken. A medical suture is used to estimate the horizontal plane locally and an observation model of medical suture is used with the horizontal plane. Two light sources endoscope observation system is assumed based on the actual endoscope for improving the accuracy of the polyp shape recovery. Experiments are conducted to validate the proposed approach.**

Keywords–Shape from Shading; Endoscope; Point Light Source; Perspective Projection; Camera Calibration; Reflectance Parameter.

I. INTRODUCTION

The size of a colonic polyp is a biomarker that correlates with its risk of malignancy and guides its clinical management. Given this central role of polyp size as a biomarker, the precision and accuracy of polyp measurement is an important issue [1]. In addition, advanced adenomas are those that are larger ($\geq 1cm$) or that contain appreciable villous tissue or high-grade dysplasia [2]. Therefore, obtaining polyp size and shape is important for the precise diagnosis.

For these situations, it becomes more important to develop a medical supporting application of computer vision in the medical field, where the 3-D shape reconstruction is expected to be practically used in the medical diagnosis. As a 3-D shape reconstruction technology, Shape from Shading (SFS) [3] is one valuable approach of 3-D reconstruction. SFS uses the image intensity directly to recover the surface orientation of a target object from a single image. Based on SFS, some approaches [4] [5] have been proposed to recover polyp shape from endoscope images. The paper [4] proposes a polyp recovering approach using both photometric and geometric constraints, assuming an endoscope with one light source. Another approach [5] recovers polyp shape assuming a more actual endoscope, which has two light sources, and it uses a neural network to modify the obtained surface gradients.

These polyp shape recovery approaches based on SFS assume a Lambertian image and need some parameters such as a depth parameter Z from the endoscope lens to the surface point. To obtain the depth Z, paper [6] proposes an approach using two images using a medical suture between the movement of Z direction in endoscope video under the assumption of one light source.

To relax the constraint for shape recovery, this paper proposes a novel approach for obtaining depth Z and surface reflectance parameter C from a single endoscope image of medical suture. Medical suture is used to estimate its horizontal plane locally and observation model of medical suture is used with the horizontal plane. In addition, two light source endoscope is assumed to improve the accuracy of polyp shape based on the actual endoscope.

Experiments of polyp shape recovery are conducted with the estimated parameters and it is shown that polyp shape is recovered with its absolute size.

The rest of the paper is structured as follows. In section II, the logic of the proposed approach is explained. In section III, experiments are conducted to validate the proposed approach and the conclusion of the proposed method is referred in section IV.

II. PROPOSED APPROACH

A. Procedure

The proposed approach consists of the following steps. First, camera calibration is conducted to obtain the inner

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parameters of the endoscope and subsequent steps are based on these obtained parameters. Second, the horizontal plane of the medical suture for the lens plane is estimated locally. Third, depth Z and the reflectance parameter C are obtained by using the estimated horizontal plane and its observation model of horizontal plane of medical suture. Finally, the polyp shape is recovered using the obtained Z and C based on two light sources photometric constraint.

Step1 Estimating inner parameters of the endoscope by conducting camera calibration.

Step2 Estimating the horizontal plane of medical suture to the lens plane locally.

Step3 Obtaining Z and C using observation model of horizontal plane of medical suture.

Step4 Recovering polyp shape using obtained depth Z and reflectance parameter C assuming two light source endoscope based on the approach [5].

B. Camera Calibration

First, the inner parameters of the endoscope are obtained by a camera calibration assuming two light source endoscope for the subsequent approaches.

1) Observation System: The observation system of endoscope is assumed to be a point light source and perspective projection. According to the actual environment of the endoscope, two light point sources are assumed to obtain the accurate results in parameter estimation and shape recovery. The observation system of two light sources endoscope is shown in Figure 1. Here, let the coordinate of the center of lens be $(0, 0, 0)$, f be the focal length, $\mathbf{S_1}$ and $\mathbf{S_1}$ be the distances from the lens to the surface point and $\mathbf{n}$ be the normal surface vector.

2) Estimating Inner Parameters of Endoscope: Estimating inner parameters of the endoscope is performed using multiple images of checker board taken by the endoscope based on the camera calibration techniques [7] [8]. An example of checker board images used in the proposed approach is shown in Figure 2.

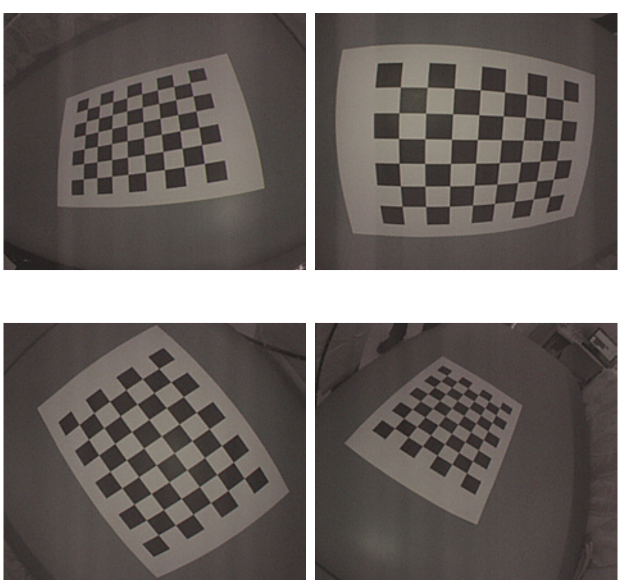

Figure 2. Examples of Checker Board Images

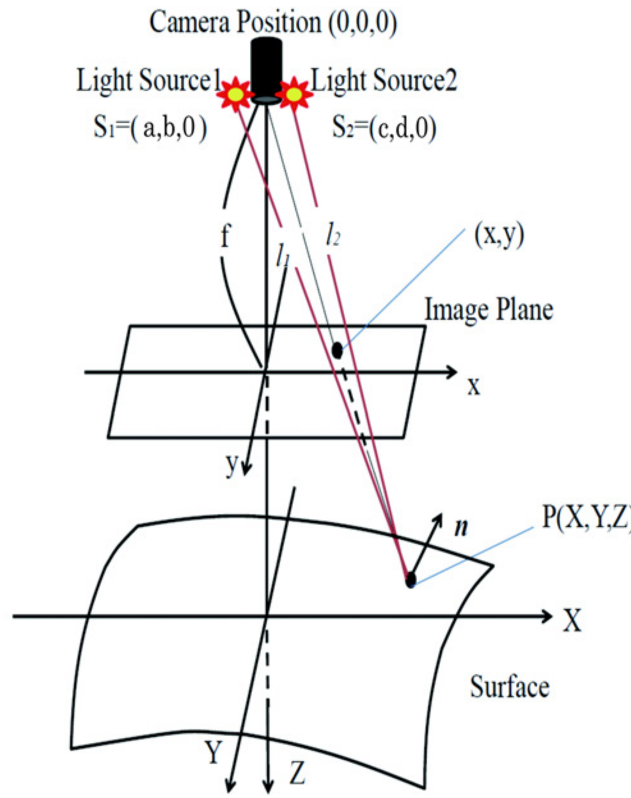

Figure 1. Observation System of Two Light Source Endoscope.

C. Estimation of Parameters Using Medical Suture

1) Estimation of Parameters: Parameters Z and C for shape recovery under SFS approach are obtained by estimating the horizontal plane of medical suture locally using its observation system. The procedures for obtaining parameters Z and C are shown in the following steps.

Step1 Estimating horizontal plane of medical suture locally from a single image.

Step2 Obtaining the depth Z using the horizontal plane of medical suture using its observation system.

Step3 Obtaining C using two light source photometric constraint.

The details of these steps are described below.

2) Estimation of Horizontal Plane: The horizontal planes of columnar forms against the lens can be obtained by considering the continuity of width from the columnar centerline to both end edges. The columnar width cut out by horizontal plane against the lens (as shown in Figure 3) continues while the cropped region is horizontal against the lens. The horizontal planes of medical suture can be obtained locally based on this property from one endoscope image.

The procedure of obtaining the horizontal plane is as follows.

Step1 Extract the medical suture region5 from original image4.

Step2 Extract the medical suture centerline by applying thinning processing as shown in Figure 6.

Step3 Extract medical suture edge using the morphology operation as shown in Figure 7.

Step4 Draw a line orthogonal to the centerline and crop the line by both end edges. Finally, extract regions where the cropped line continues the same width as shown in Figure 8.

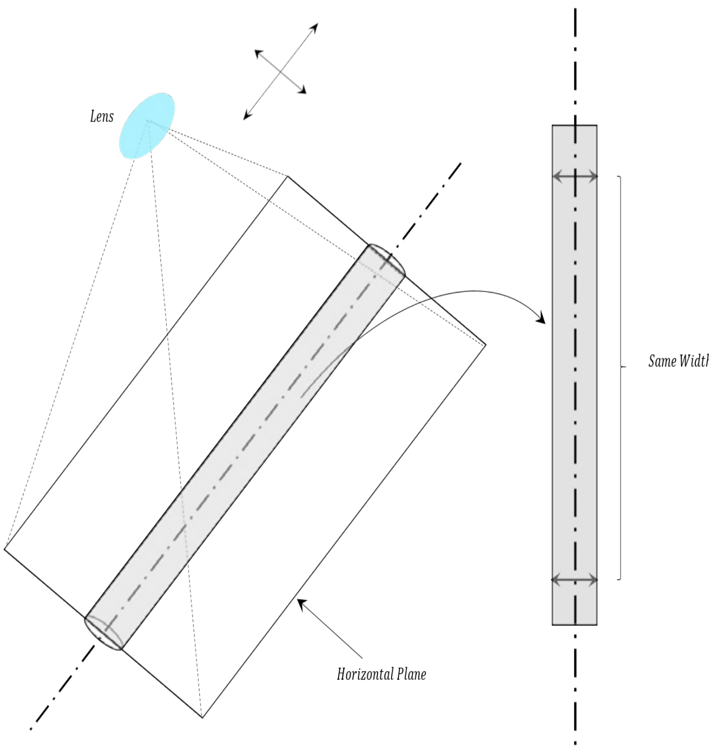

Figure 3. Horizontal Plane of Columnar against Lens

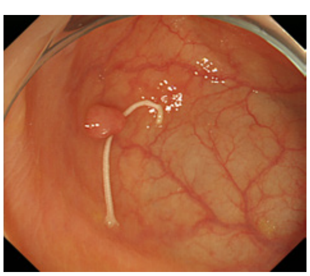
Figure 4. Original Image of Medical Suture

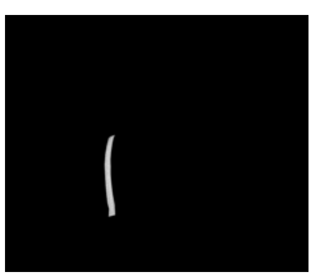
Figure 5. Example of Extracted Medical Suture Region

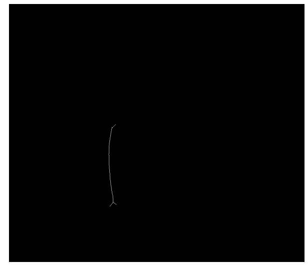
Figure 6. Example of Line Thinning Processing

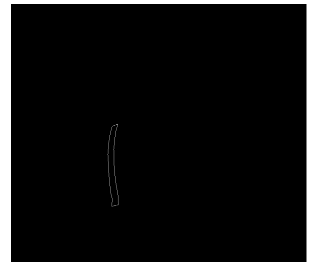
Figure 7. Example of Edge Extraction

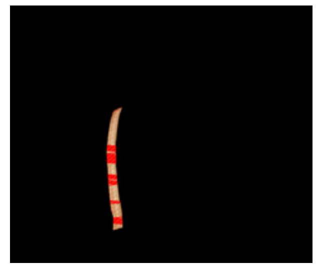
Figure 8. Example of Estimation of Horizontal Plane

3) Estimation of Depth Z: Here, an observation system of the horizontal plane of medical suture is proposed to obtain the depth parameter Z from the endoscope lens to the surface point. The observation system is shown in Figure 9.

Depth Z from the lens can be calculated using the model with respect to the estimated horizontal plane of medical suture. The procedure for calculating parameter Z is described below.

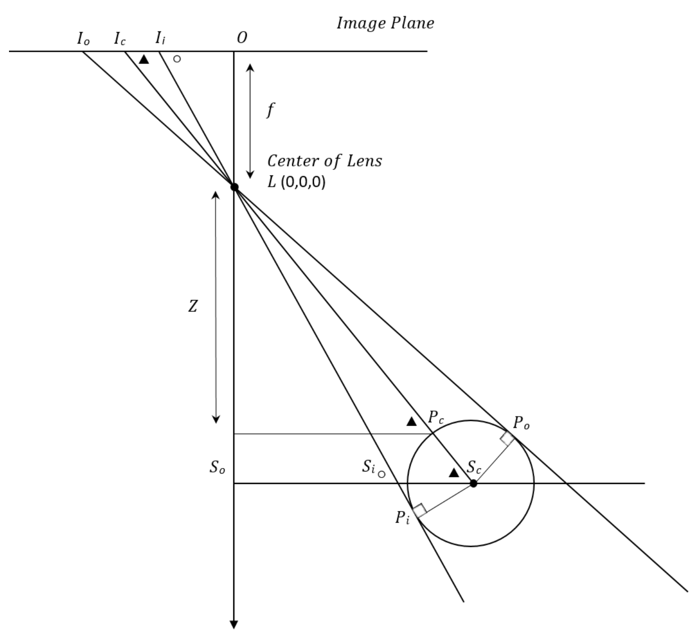

Figure 9. Observation System of Horizontal Plane

From $\triangle LOI_i \sim \triangle LS_oS_i$, $\angle LS_iS_o$ is an external angle of

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$\triangle LS_oS_i$, $\angle LS_iS_c$ is obtained by Equation (1).

$$\angle LS_iS_c = \pi - \angle LI_iO \tag{1}$$

From $\triangle LOI_c \sim \triangle LS_oS_c$, $\triangle LS_cS_o$ is given by Equation (2).

$$\angle LS_cS_i = \angle LI_cO \tag{2}$$

$$\angle S_iLS_c = \pi - \angle LS_iS_c - \angle LS_cS_i \tag{3}$$

Similarly, $\angle LS_cP_i$ can be obtained from Equation (4).

$$\angle LS_cP_i = \pi - \frac{\pi}{2} - \angle S_iLS_c \tag{4}$$

Focusing on the hypotenuse from the lens L to the center of the suture center S_i in $\triangle LS_cS_i$, distance LS_c can be obtained from Equation (5). Here, distance P_cS_c is the same as the suture radius.

$$LS_c = \frac{P_iS_c}{cos\angle LS_cP_i} \tag{5}$$

The distance from the lens L to the surface of the suture P_c can be obtained from Equation (6). Here, P_cS_c is the same as the suture radius.

$$LP_c = LS_c - P_cS_c \tag{6}$$

Finally, from $\triangle LZP_c \sim \triangle LOI_c$, the depth Z can be given by Equation (7).

$$Z = LP_c sin\angle LI_cO \tag{7}$$

4) Estimation of Reflectance Parameter C: The reflectance parameter C is calculated using the obtained Z and two light sources photometric constraint. Let the coordinate of the center of lens be (0,0,0) as shown in Figure 1.

The image intensity E can be expressed using the inverse square law of illuminance, as shown in Equation (8).

$$E = C\left(\frac{\mathbf{n}\cdot\mathbf{s_1}}{l_1^2} + \frac{\mathbf{n}\cdot\mathbf{s_2}}{l_2^2}\right) \tag{8}$$

Here, $\mathbf{n}$ is the normal surface vector represented using gradient parameters (p,q)=($\partial Z/\partial X$, $\partial Z/\partial Y$) as

$$\mathbf{n} = \frac{[p, q, -1]}{\sqrt{p^2+q^2+1}} \tag{9}$$

$\mathbf{s}_1$ and $\mathbf{s}_2$ are the light sources direction vectors for light sources 1 and 2, respectively. l_1 and l_2 are the distances from light sources 1 and 2, respectively to the surface point.

Let the light sources direction vectors be $\mathbf{s}_1$ and $\mathbf{s}_2$, and let the position of light source 1 be $(a, b, 0)$, let the position of light source 2 be $(c, d, 0)$. Light source direction vectors are represented by Equation (10) as unit vectors.

$$\mathbf{s}_1 = \frac{[a-x, b-y, -Z]}{\sqrt{(a-x)^2 + \sqrt{(b-y)^2 + Z^2}}}$$
$$\mathbf{s}_2 = \frac{[c-x, d-y, -Z]}{\sqrt{(c-x)^2 + \sqrt{(d-y)^2 + Z^2}}} \tag{10}$$

Distances l_1 and l_2 are represented using the coordinates of each light sources as Equation (11).

$$l_1 = \sqrt{(a-x)^2 + (b-y)^2 + Z^2}$$
$$l_2 = \sqrt{(c-x)^2 + (d-y)^2 + Z^2} \tag{11}$$

Substituting Equation (9), Equation (10) and Equation (11) into $\mathbf{s_1}$, $\mathbf{s_2}$, $\mathbf{n}$, $\mathbf{l_1}$ and $\mathbf{l_2}$ gives

$$C = E\left\{\frac{\left\{(a-x)^2+(b-y)^2+f^2\right\}^{\frac{3}{2}} Z^2\sqrt{p^2+q^2+1}}{f^2(-p(a-x)-q(b-y)+f)} + \frac{\left\{(c-x)^2+(d-y)^2+f^2\right\}^{\frac{3}{2}} Z^2\sqrt{p^2+q^2+1}}{f^2(-p(c-x)-q(d-y)+f)}\right\} \tag{12}$$

where f is the focal length.

D. Shape Recovery Using Obtained Z and C

Shape recovery is performed using the obtained Z and C based on the paper [5]. The procedure for shape recovery is as follows.

- Step1 Uniform Lambertian image is generated by the method [9] which is converted from the original RGB (red, green, and blue) color model endoscope image.
- Step2 Recover the initial depth by optimization using photometric constraints under the condition of two light sources and using obtained Z and C.
- Step3 Apply NN (Neural Network) learning using gradient parameters (p, q) of a Lambertian sphere, which is used to modify the obtained surface gradient (p, q).
- Step4 Update the depth Z using optimization by treating the obtained gradient parameters (p, q) as constants again.

III. Experiments

Experiments were performed to evaluate the proposed method using actual endoscope images. Here, a medical suture with size 1-0 silk suture and its diameter 0.33mm is used in the endoscope image.

A. Result of Camera Calibration

The result of the camera calibration is shown in Table I. The inner parameters of the endoscope are focal length, principal point and radial distortion and those parameters were obtained by the camera calibration.

Here, two parameters were obtained respectively based on the aspect ratio of image.

TABLE I. Result of Estimation

Parameter	*Result of Calibration*
Focal length (pixels)	[718.7447 + / - 0.8387, 718.3827 + / - 0.8654]
Principal point (pixels)	[879.0439 + / - 0.4669, 533.5813 + / - 0.4240]
Radial distortion	[- 0.3913 + / - 0.0010, 0.1178 + / - 0.0008]

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B. Result of Estimated Depth Z

Depth Z was estimated using the obtained inner parameters of the endoscope. The results of estimating the horizontal plane of medical suture are as shown in Figures 10 to Figure 17, respectively. Here, more than 6 continuous regions with same width are adapted as the horizontal plane section in tracing the suture center line.

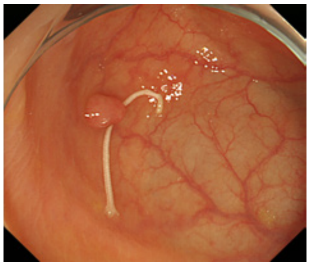

Figure 10. Scene1 Original Image

Figure 11. Scene1 Horizontal Plane

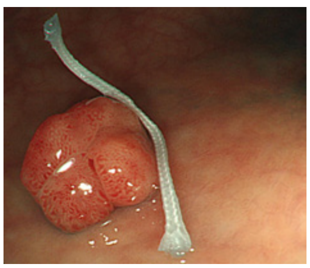

Figure 12. Scene2 Original Image

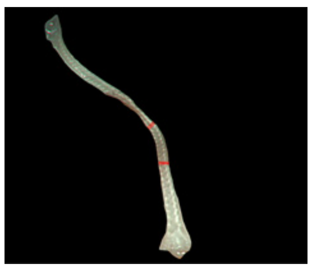

Figure 13. Scene2 Horizontal Plane

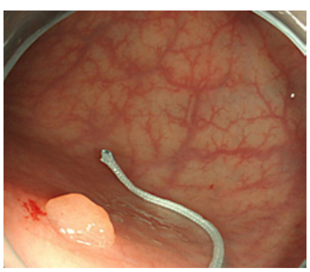

Figure 14. Scene3 Original Image

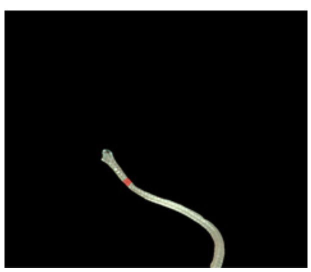

Figure 15. Scene3 Horizontal Plane

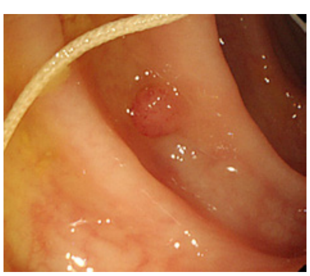

Figure 16. Scene4 Original Image

Figure 17. Scene4 Horizontal Plane

TABLE II. RESULT OF ESTIMATED Z

Scene	*Section*	*Estimated Z [mm]* MEAN	STD
1	1	34.3456	0.0000
	2	34.3424	0.0044
	3	34.2384	0.0051
	4	34.1847	0.0081
	5	34.9362	0.0086
2	1	30.8150	7.7443
	2	17.0185	0.0000
3	1	34.5360	0.0028
4	1	13.9666	2.6010
	2	15.1002	0.0000

The result of depth Z estimation for each scene and estimated horizontal section are shown in Table II. From these results, the horizontal section of medical suture within $[nm]$ level variation of the depth Z could be obtained in each scene. It is shown that the horizontal plane of the medical suture and depth Z were obtained with high accuracy in each endoscope image.

C. Result of Shape Recovery

Polyp shape recovery was performed using calculated Z and C. The results of polyp shape recovery are shown in Figures 18 to 21. Here, some regions which interfere with the shape recovery such as a hood cover of the endoscope were cut out. From the recovered shapes, it is confirmed that approximate polyp shape could be recovered using the calculated parameters Z and C of the proposed approach.

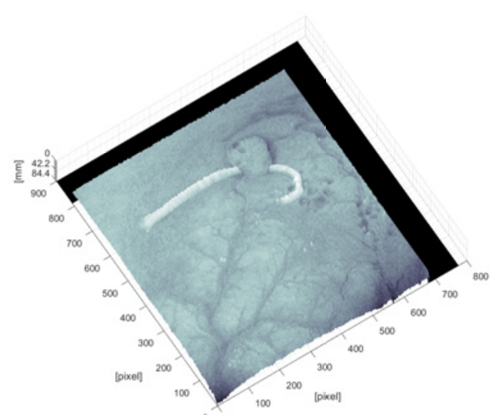

Figure 18. Recovered Shape of Scene1

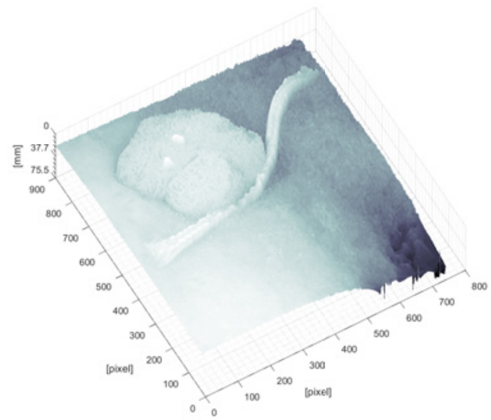

Figure 19. Recovered Shape of Scene2

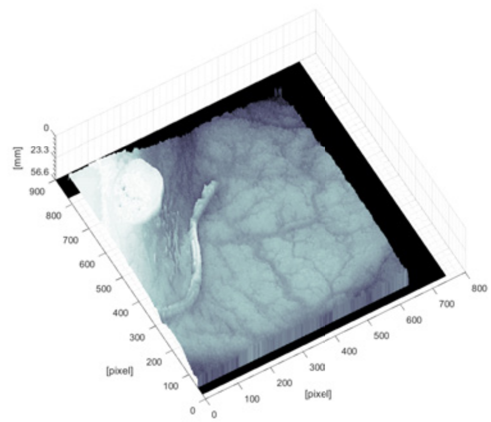

Figure 20. Recovered Shape of Scene3

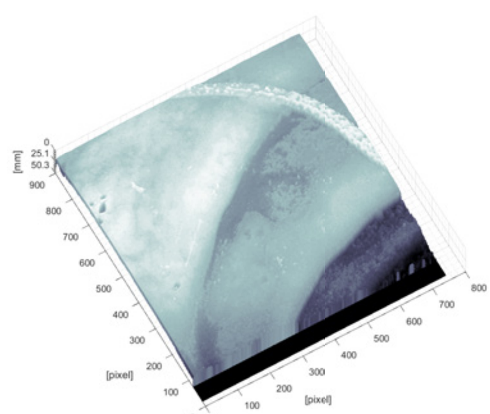

Figure 21. Recovered Shape of Scene4

IV. CONCLUSION

This paper proposed a new approach for obtaining depth parameter Z from endoscope lens to the surface point and reflectance parameter C from one endoscope image of medical suture by estimating the horizontal plane of medical suture locally and its observation model. The result shows that approximate polyp shape could be recovered using the calculated parameters Z and C. Applying this proposed method to the blood vessel for mitigating constraint conditions and improving the accuracy of shape recovery are left as future works.

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