# Estimating Reflectance Parameter of Polyp using Medical Suture Information in Endoscope Image

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Abstract: An endoscope is a medical instrument that acquires images inside the human body. In this paper, a new 3-D reconstruction approach is proposed to estimate the size and shape of the polyp under conditions of both point light source illumination and perspective projection. Previous approaches could not know the size of polyp without assuming reflectance parameters as known constant. Even if it was possible to estimate the absolute size of polyp, it was assumed that the parameter of camera movement $\Delta Z$ is treated as a known along the depth direction. Here two images are used with a medical suture which is known size object to solve this problem and the proposed approach shows the parameter of camera movement can be estimated with robust accuracy with correspondence between two images taken via slight movement of $Z$. Experiments with endoscope images are demonstrated to evaluate the validity of proposed approach.



## 1 INTRODUCTION

It becomes important to develop the medical supporting application of computer vision in the recent medical field, where the 3-D reconstruction technology is tried to be used in the medical diagnosis. Endoscopy allows doctors to observe the interior of hollow organs and other body cavities in a minimally invasive way. Sometimes, diagnosis requires assessment of the 3-D shape of observed tissue. To develop 3-D shape recovery from endoscope image is one example of medical application and it is hoped to obtain the geometrical shape of polyps from endoscope image.

Specialized endoscopes with a laser light beam head (Nakatani et al., 2007) or with two cameras mounted in the head (Mourgues et al., 2001) have been developed. Here, we consider a general purpose endoscope, of the sort still most widely used in medical practice. The problem considered is the recovery of the 3-D shape of tissue in view.

The challenge with stereo endoscopy (Thormaehlen et al., 2001) is to determine corresponding features in the two images while the shape of internal organs itself is changing. With a single camera endoscope, shape from shading can be applied.

Shape from Shading (SFS) is one valuable approach of 3-D reconstruction. SFS uses the intensity of images directly to recover the surface orientation of a target object from a single image. Horn (Horn, 1975) pioneered the development of shape from shading methods in computer vision, and many approaches have been proposed. In many cases, Lambertian reflectance is assumed under the condition that a known parallel light source direction and orthographic projection but most scenes are not Lambertian. To apply the Lambertian reflectance to the endoscope image, (Neog et al., 2011) is proposed. This approach tries to convert the actual scene to the Lambertian image based on clustering of plots in the normalized RGB axis and assigning the same reflectance parameter for any two points between the neighboring clusters.

Recent research (Tatematsu et al., 2013) (Iwahori et al., 2015a) proposes an approach to recover 3-D



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shape from one endoscope image. The optimization of the surface gradient parameters $(p,q)$ determines the depth $Z$ after converting the original image to Lambertian image. The reflectance parameter $C$ is treated as a known constant and estimating $C$ is remained as an important subject to recover 3D shape. While paper (Iwahori et al., 2015b) recently proposes an approach to estimate reflectance parameter $C$ using the small movement $\Delta Z$ of endoscope image. In this paper, treating $\Delta Z$ as known constant can estimate the reflectance parameter $C$ using optimization to recover the absolute size and shape of polyp.

This paper further proposes an approach to estimate $\Delta Z$ of the small movement using two endoscope images by using the image of medical suture treated in the medical operation. The assumption used in this paper is that the width of medical suture is known *a priori*. It is shown that treating the medical suture can perform the estimation the movement of *DeltaZ* of the endoscope and further the approach can estimate the reflectance parameter $C$ which can obtain the absolute size and shape of polyp.

## 2 ESTIMATING CAMERA MOVEMENT ALONG DEPTH DIRECTION AND REFLECTANCE PARAMETER

This section introduces an extension to estimate the reflectance parameter $C$ using two images with slight movement $\Delta Z$ of endoscope when the medical suture is observed in the endoscope images. By using the medical suture, the proposed approach makes it possible to estimate size and shape of polyp to be recovered.

### 2.1 Observation System

Observation system of endoscope image is shown in Fig.1 under the condition of point light source illumination and perspective projection. Note that it is assumed that the target object is continuous surface with Lambertian reflectance and original RGB endoscope image is converted to the uniform Lambertian reflectance.

Here the situation with using two images as shown in Figure 1 is considered. The movement of $\Delta Z$ is assumed from the correspondence of the observed medical suture between two images. Although triangle which forms the image coordinates $x$, $y$ and focal length $f$ of the lens becomes similar as the triangle of world coordinates $X$, $Y$ and $Z$, absolute shape cannot

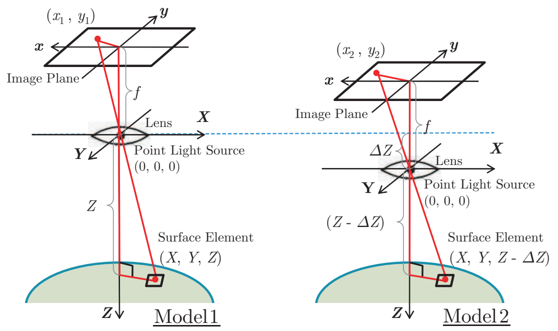


Figure 1: Observation System.

be obtained without any calibration object in the image. This paper uses the medical suture with known width and proposes a new approach to estimate the reflectance parameter $C$ and the absolute shape of polyp. Under the condition that the medical suture is used as the reference object of scaling. Here, a cylindrical model of the medical suture is used for its cross section as shown in Fig.1.

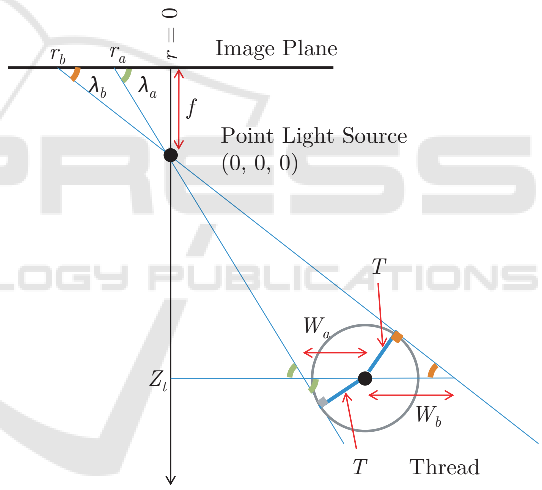


Figure 2: Observation Model of Medical Suture.

### 2.2 Estimation of Movement $\Delta Z$ of Camera along Depth Direction

Depth $Z_t$ is obtained for any point of the medical suture based on the radius $T$ of the medical suture width. As there is a similarity between a triangle of image coordinate $(x,y,f)$ and a triangle of world coordinate $(X,Y,Z)$, $W_a$ and $W_b$ are first obtained, where $W_a$ and $W_b$ are necessary to calculate $Z_t$. $\lambda_a$ is represented from a triangle of image coordinate and a triangle of radius of medical suture and tangent of circumference as follows.

$$sin\lambda_a = \frac{f}{\sqrt{r_a^2+f^2}}$$
$$sin\lambda_a = \frac{T}{W_a}$$

Solving this obtains $W_a$. $W_b$ is obtained in the same way.

$$W_a = \frac{T}{f}\sqrt{r_a^2+f^2} \tag{1}$$
$$W_b = \frac{T}{f}\sqrt{r_b^2+f^2} \tag{2}$$

The following relation is obtained using the similarity of a triangle of the base $(r_b - r_a)$ and the vertex origin and that of the base $(W_a + W_b)$ and the vertex origin.

$$|r_b - r_a| : f = |W_a + W_b| : Z_t$$

Substituting Eq.(1)(2) into this can derive $Z_t$ as follows.

$$Z_t = \frac{\sqrt{r_a^2+f^2}+\sqrt{r_b^2+f^2}}{|r_b - r_a|}T \tag{3}$$

Eq.(3) represents the depth estimation from one image and this equation can be applied to the depth $Z_{t1}$ of any point of the medical suture in image 1 and the corresponding depth $Z_{t2}$ in image 2. The movement of the camera should be $\Delta Z = Z_{t1} - Z_{t2}$. However this depends on the width of medical suture on the image plane and accuracy of corresponding point between two images. The proposed approach tries to obtain multiple candidate values of $\Delta Z$ using multiple corresponding points between images and estimates the best candidate value of camera movement parameter $\Delta Z$ along the depth direction. Let $C_1$ be a estimated reflectance parameter for image 1, and let $C_2$ be that for image2. The best parameter $\Delta Z$ is selected from the criteria which minimizes $C_r$ where $C_r$ is calculated from Eq.(4) with the difference between $C_1$ and $C_2$ which is estimated from each image 1 and 2, respectively.

$$C_r = \frac{|C_1/C_2| + |C_2/C_1|}{2} - 1 \tag{4}$$

### 2.3 Determining Initial Value $C_{init}$

Local brightest point is used to recover the 3-D shape of polyp as an initial point. This is because initial point has constraints where the surface normal vector is the same direction as the light source vector under the Lambertian reflectance. Here the approach first converts into Lambertian image to recovers the 3-D shape of polyp.

At the local brightest point under Lambertian reflectance, the relation of $\mathbf{n}$ and $\mathbf{s_1}$ is $\mathbf{n} = \mathbf{s_1}$ and $(\mathbf{s_1}, \mathbf{n}) = \mathbf{1}$.

Let the image coordinate of the initial point in image 1 be $(x_1, y_1)$, let the corresponding coordinate in image 2 be $(x_2, y_2)$, and let the image intensity at $(x_1, y_1)$ be $E_1$, then the initial candidate of reflectance parameter $C_{init}$ can be given by

$$\begin{aligned} C_{init} &= E_1(X^2+Y^2+Z^2) \\ &= \frac{E_1 Z^2}{f^2}\left(x_1^2+y_1^2+f^2\right) \end{aligned} \tag{5}$$

$C_{init}$ is derived by substituting $Z$ into Eq.(5) after deriving $Z$ geometrically using the corresponding points between two images.

$$C_{init} = \frac{E_1(\Delta Z)^2}{\{(1-k^{-\frac{1}{2}})f\}^2}\left(x_1^2+y_1^2+f^2\right) \tag{6}$$
$$k = \sqrt{(x_1^2+y_1^2)(x_2^2+y_2^2)^{-1}}$$

$C_{init}$ can be uniquely determined by Eq.(6) and it makes possible to obtain the actual scale of object to be recovered.

## 3 EXPERIMENTS

Actual medical endoscope image is used in the experiment. The original color image is converted into Lambertian image in advance. The assumption of observation system is point light source illumination and perspective projection. Image consists of 1000×870 pixels, the diagonal image size is 10mm, focal length is 5mm and image density is 8-bits.

### 3.1 Obtaining Depth of Camera Movement (Experiment 1)

Input images used in the experiment are shown in Fig.3 and Fig.4, respectively.

Although it is necessary to extract the medical suture region in the image, the region is manually extracted in this experiment (Experiment 1). The extracted result of medical suture region for Fig.3 and Fig.4. Thinning processing is applied for the medical suture region extracted and thinning process was used for obtaining the gradient parameter $\varphi$ of the medical suture. The results of thinning processing are shown in Fig.5 and Fig.6 with red part.

Next, the depth $Z_t$ of medical suture is derived using Fig.5 and Fig.5. Coordinate of corresponding

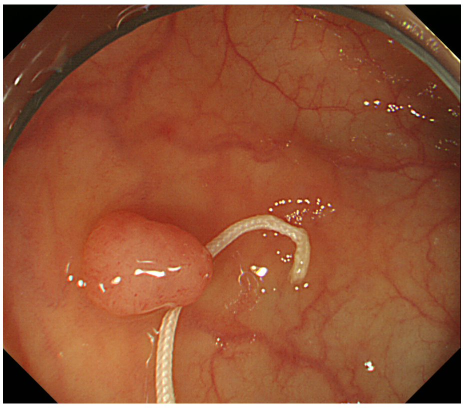

Figure 3: Input Image 1 (Experiment 1).

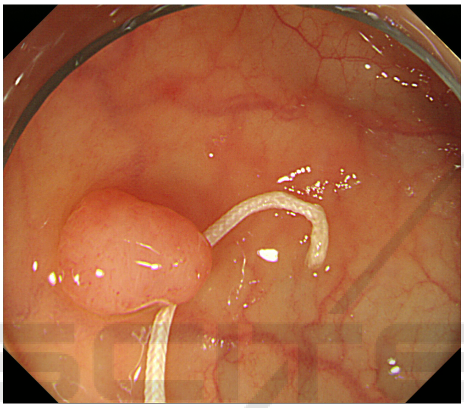

Figure 4: Input Image 2 (Experiment 1).

points (unit: pixel), depth $Z_t$ (unit: mm) and the error of $C_r$ between images obtained from Eq.(4) is shown in Table 1, respectively.

Table 1: Derived Parameter in Medical Suture Region.

| $(x_1, y_1)$ | $Z_{t1}$ | $(x_2, y_2)$ | $Z_{t2}$ | $C_r$ |
|---|---|---|---|---|
| (541, 685) | 6.17 | (581, 644) | 6.82 | 0.0099 |
| (453, 677) | 4.04 | (503, 644) | 5.13 | 0.2904 |
| (499, 462) | 5.75 | (528, 463) | 84.50 | 94.3704 |
| (452, 676) | 4.04 | (503, 644) | 5.13 | 0.2904 |
| (439, 570) | 7.77 | (484, 562) | 7.70 | 0.1505 |
| (414, 607) | 6.96 | (464, 586) | 8.24 | 0.1766 |
| (488, 681) | 3.20 | (533, 645) | 4.59 | 0.5474 |
| (439, 570) | 7.77 | (484, 562) | 7.70 | 0.1505 |
| (450, 543) | 7.65 | (488, 543) | 8.79 | 0.1410 |
| (544, 686) | 6.33 | (580, 646) | 7.41 | 0.0786 |
| (447, 670) | 3.95 | (497, 638) | 4.49 | 0.0736 |
| (431, 578) | 7.78 | (481, 546) | 8.79 | 0.0871 |
| (515, 692) | 4.25 | (557, 653) | 7.39 | 0.9982 |
| (454, 674) | 2.68 | (503, 641) | 4.93 | 1.2090 |

Here it is shown that $C_r = 0.0099$ gives the minimum value among 14 corresponding points between images in Table 1. From this estimation,

$$\Delta Z = 6.82 - 6.17 = 0.65$$

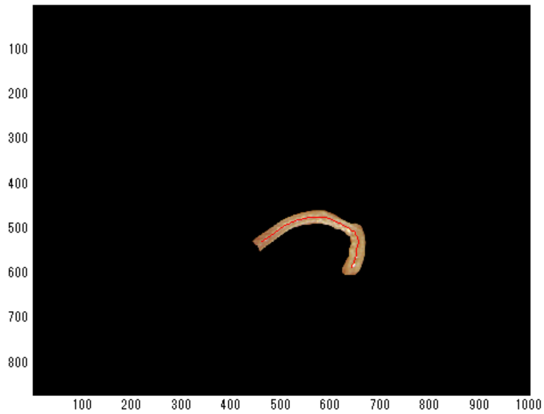


Figure 5: Medical Suture Region of Image 1 (Experiment1).


Figure 6: Medical Suture Region of Image 2 (Experiment 1).

is estimated. This $\Delta Z$ is defined as camera movement in the approach.

### 3.2 Result of 3D Recovered Shape (Experiment 1)

Shape recovery is applied based on the approach proposed in the previous papers (Tatematsu et al., 2013) and (Iwahori et al., 2015a). Fig.3 is trimmed for polyp region and gray scale image shown in Fig.7 is used as experiment. Region outside of recovery is masked with black and the object coordinates are kept for the shape recovery. Here, Fig.7 represents converted image to Lambert reflectance by removing specular components with uniform reflectance parameter. In the shape recovering process, surface gradient parameters $(p, q)$ are optimized by introducing both photometric and geometric constraints from the neighboring points starting from the local brightest point as an initial point. Local brightest point has the property that the light source direction vector becomes equal to the surface normal vector under the assumption of

Lambertian reflectance. See paper (Tatematsu et al., 2013) and (Iwahori et al., 2015a) for detail.

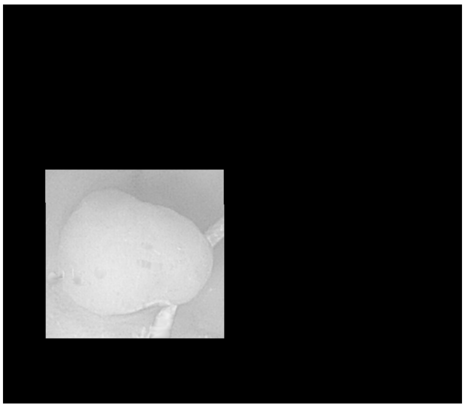

Figure 7: Test Object (Experiment 1).

Recovered results are shown in Fig.8 and 9. These results are obtained from the different viewing angle for the same 3D model and vertical size obtained is around 2.7mm and horizontal size obtained is around 3.5mm. Medical suture region is also recovered but there is no continuous region between the polyp region, and this region is not considered.

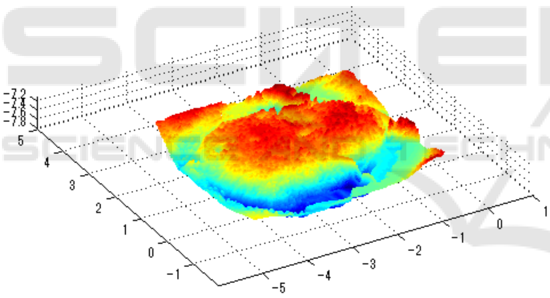

Figure 8: 3D Recovered Shape (Experiment 1).

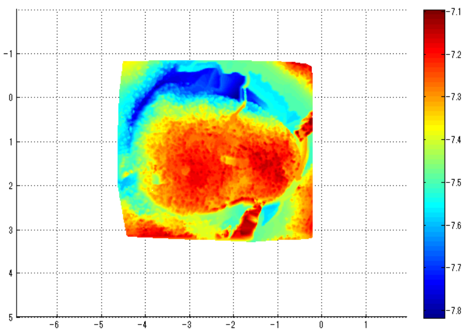

Figure 9: 3D Recovered Shape (Experiment 1).

### 3.3 Obtaining Depth of Camera Movement (Experiment 2)

Another experiment (Experiment 2) is done for the video sequence using the near two frames which includes the medical suture. Input images used are shown in Fig.10 and Fig.11, respectively. It is assumed that image 2 is taken after image1. The final purpose is to estimate the absolute size and shape of polyp in images.

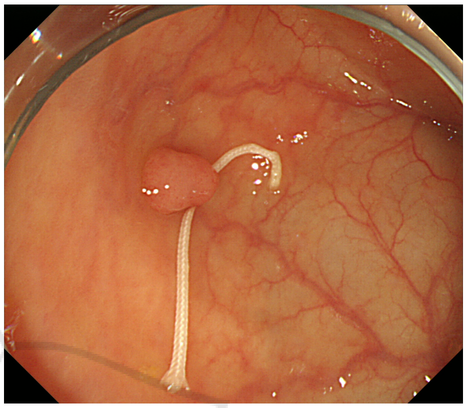

Figure 10: Input Image 1 (Experiment 2).

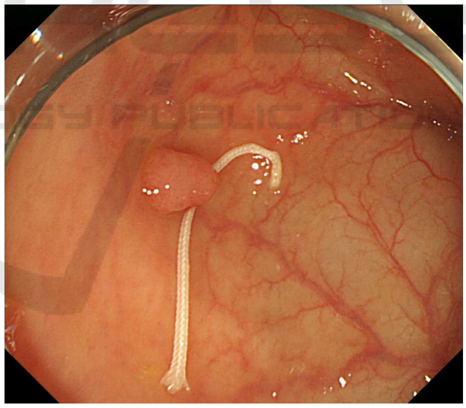

Figure 11: Input Image 2 (Experiment 2).

Difference of camera position of Fig.10 and that of Fig.11 corresponds to the camera movement $\Delta Z$ along $Z$-axis.

Extracted results for Fig.10 and Fig.11 and results of thinning processing are shown in Fig.12 and Fig.13 with red part, respectively. These extractions are done in the same way as Experiment 1.

Feature points are extracted by SIFT between two images for Fig.12 and Fig.13. The purpose of introducing SIFT is to obtain the corresponfing feature points between two images. After extracting feature points using SIFT, the depth $Z_t$ of medical suture is obtained for each extracted point.

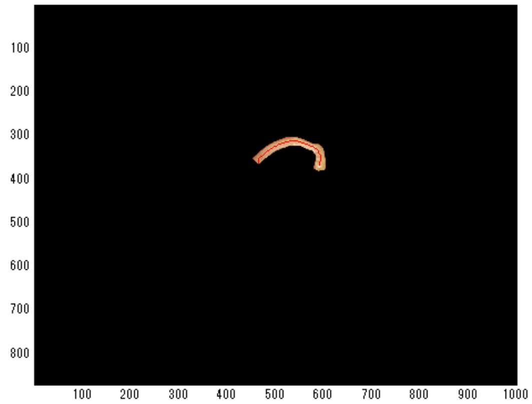


Figure 12: Medical Suture Region of Image 1 (Experiment 2).

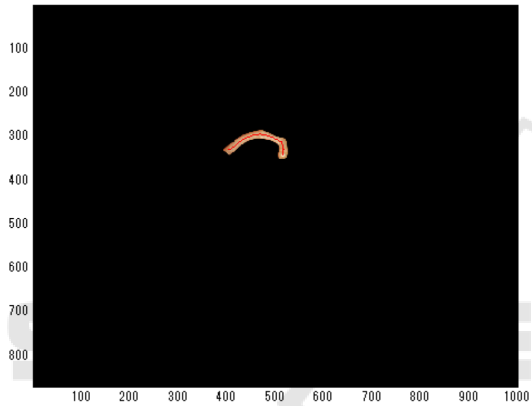


Figure 13: Medical Suture Region of Image 2 (Experiment 2).

Coordinate of corresponding points (unit: pixel), depth $Z_t$ (unit: mm) and the error of $C_r$ between images obtained from Eq.(4) is shown in Table 2, respectively.

Table 2: Derived Parameter in Medical Suture Region (Experiment 2).

| $(x_1, y_1)$ | $Z_{t1}$ | $(x_2, y_2)$ | $Z_{t2}$ | $C_r$ |
|---|---|---|---|---|
| (367, 592) | 9.69 | (341, 515) | 8.41 | 0.2943 |
| (345, 572) | 10.26 | (324, 500) | 7.46 | 0.6720 |
| (350, 468) | 11.81 | (328, 408) | 12.08 | 0.1724 |
| (329, 584) | 4.55 | (311, 511) | 5.51 | 0.3921 |
| (344, 573) | 6.49 | (324, 500) | 7.46 | 0.2948 |
| (353, 586) | 5.07 | (331, 511) | 5.51 | 0.1730 |
| (328, 507) | 11.28 | (307, 444) | 13.37 | 0.4406 |
| (336, 575) | 10.26 | (317, 503) | 7.46 | 0.6720 |

Here it is shown that $C_r = 0.1724$ gives the minimum value among 8 corresponding points between images in Table 2. From this estimation,

$$\Delta Z = 12.08 - 11.81 = 0.27$$

is estimated. This $\Delta Z$ is used in the experiment 2.

### 3.4 Result of 3D Recovered Shape (Experiment 2)

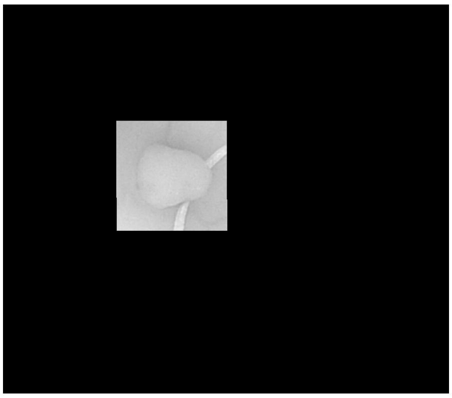

Figure 14: Test Object (Experiment 2).

Shape recovery was applied in the similar way as in the previous experiment. Recovered results are shown in Fig.15 and Fig.16. Similar values of horizontal width and vertical width were obtained and the result is almost close to the recovered result in experiment 1.

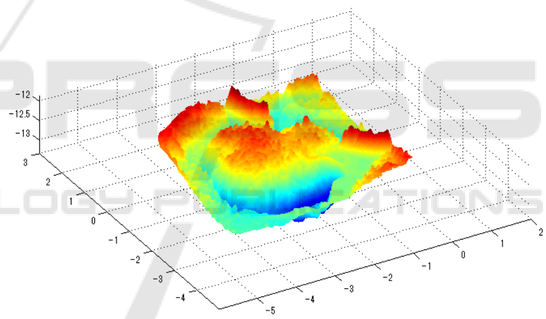

Figure 15: 3D Recovered Shape (Experiment 2).

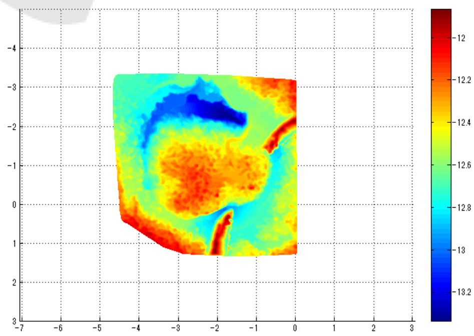

Figure 16: 3D Recovered Shape (Experiment 2).

## 4 CONCLUSION

This paper proposes a new approach to estimate the camera movement $\Delta Z$ along the depth direction by adding the medical suture as a calibration object with known size. The approach essentially solved the problem of treating the camera movement as known constant under the condition that the original image is converted to Lambertian image by removing specular reflectance with uniform reflectance parameter. Based on estimating $\Delta Z$, it makes possible to estimate the reflectance parameter $C$ and further to recover the absolute size and shape of polyp based on Shape-from-shading approach.

It is shown that the proposed approach is valuable in the recovery process of polyp and the evaluation is provided via experiments with real endoscope environment. Using the medical suture as a calibration object is not always useful but the paper extended the possibility to recover the absolute size and shape of polyp with further information. Further subject includes that another cue information instead of the medical suture is used and the entire purpose is done with usual endoscope environment.

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