Recovering Shape from Endoscope Image Using Eikonal Equation

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***Abstract*—This paper proposed a shape recovery approach from Endoscope Image using Eikonal Equation. Photometric constraint equation derived from the Lambert reflectance and geometrical constraint equation derived from the relationship between the neighboring points are used and these equations can make a new approximation equation of Eikonal equation under the point light source illumination and perspective projection. The original endoscope image is transformed and generated to the Lambertian image by removing the specular reflectance. Framework of Fast Marching Method using the derived Eikonal Equation can recover the 3D shape from endoscope image. Usefulness was confirmed using simulation and experiments.**

Keyword: Shape, Endoscope, Eikonal Equation, Fast Marching Method

I. Introduction

Endoscope is used in the medical diagnosis to detect polyps and the examinations are performed for the purpose of finding abnormal parts, such as bleeding, inflammation in the internal organs of the stomach and intestines (See Refs.[1][2]). Polyps found by endoscope have a variety of sizes and shapes. This paper proposed a new approach for a polyp shape and size recovery by solving Eikonal Equation under the condition of point light source illumination and perspective projection. Shape is recovered using an extended Fast Marching Method (FMM) approach. Proposed method is described in Section II. In Section III, experimental results are shown with absolute size and corresponding polyp shape. The approach provides overall good performance for the supporting system of medical diagnosis. Finally Conclusion is provided in Section IV.

II. Proposed Method

Endoscope image is obtained under the white light source. Procedure of the proposed approach is shown as follows.

A. Removal of Specular Reflectance Component and Generation of Lambertian Image

Our previous approach proposed in Ref.[3] is applied to remove the specular reflectance component and generation of Lambertian image with uniform surface reflectance from the original endoscope image. Converting the RGB (Red-Blue-Blue) to HSV (Hue-Saturation-Value) representation, classification for reflectance using the H histogram, then uniform reflectance image processing is performed using the ratio of V based on the difference of reflectance. Procedures are as follows.

- Step1. Classification using histogram of H
- Step2. Calculate the V ratio between interest color points and those neighboring points whose color is most frequent color.
- Step3. Equalization of reflectance using V ratio calculated in Step2 and using the points, which are not used in Step2 of interest color.
- Step4. Equalization of reflectance for all color groups by repeat Step2 and Step3.

B. 3D Shape Recovery

Photometric constraint equation and geometrical constraint equation derived should become the same depth value Z for both (See Ref.[4]). These equations can make a new approximation equation of Eikonal equation under the point light source illumination and perspective projection.

$$\sqrt{\frac{CV(-px-qy+f)}{E(p^2+q^2+1)^{\frac{1}{2}}}} = \frac{Z_k(f-p_kx_k-q_ky_k)}{f-p_kx_t-q_ky_t} \qquad (1)$$

Here, $t(trial)$ represents a trial point and $k(known)$ represents a known point of depth Z. C represents the reflectance

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factor, (p, q) represent gradient parameters, (x, y) represent image coordinate, f represents a focal length of the lens, E represents the observed image intensity and $V = f^2/(x^2 + y^2 + f^2)^{\frac{3}{2}}$.

Expanding Eq.(1) gives

$$\sqrt{p^2+q^2+1} = \frac{CV(f-p_kx-q_ky)^2(f-px-qy)}{EZ_k^2(f-p_kx_k-q_ky_k)^2} \qquad (2)$$

Approximation of $(f - p_kx - q_ky) \fallingdotseq (f - px - qy)$ derives

$$p^2+q^2+1 = \frac{C^2V^2(f-p_kx-q_ky)^6}{E^2Z_k^4(f-p_kx_k-q_ky_k)^4} \qquad (3)$$

Then the following equation is derived.

$$\sqrt{p^2+q^2} = \sqrt{\frac{C^2V^2(f-p_kx-q_ky)^6}{E^2Z_k^4(f-p_kx_k-q_ky_k)^4} - 1} \qquad (4)$$

Depth Z can be obtained by FMM algorithm developed in Ref.[5]. Here, it is possible to estimate the value of reflectance parameter C using two images and feature points matching to estimate the absolute size of polyp since absolute size is important and it depends on the value of reflectance factor C.

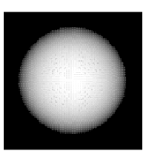
Step1. SIFT (in Ref.[6]) or ORB (in Ref.[7]) feature points extracted from blood vessels using two images and movement ΔZ of endoscope camera is estimated.

Step2. Parameter C is estimated using ΔZ (See Ref.[6]).

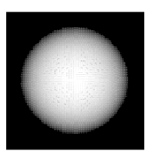
Step3. Shape recovery is applied for each uniform Lambertian image generated by Ref.[3].

III. Experiment

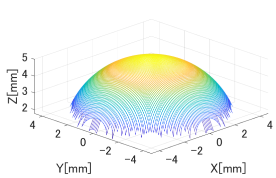
Simulation image for a hemisphere whose center is $(0, 0, 15)$ with the radius $R = 5$[mm], focal length $f = 10$[mm], reflectance factor $C = 22950$ is assumed and the result is shown in Figure 1. 3D shape are recovered for endoscope image as shown in Figure 2.



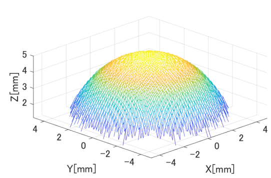
(a) Original Depth Map



(b) Recovered Depth Map

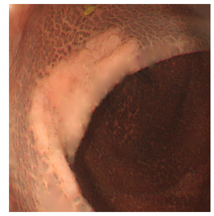


(c) Original Shape

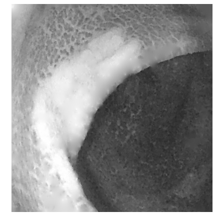


(d) Recovered Shape

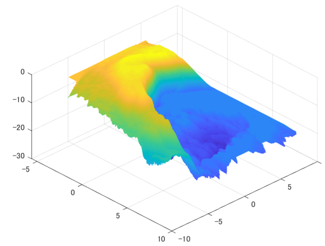
Fig. 1. Computer Simulation



(a) Input Image



(b) Uniform Lambertian Image



(c) 3D Shape

Fig. 2. Recovered 3D Shape

IV. Conclusion

This paper proposed a method to recover 3D shape and size from endoscope image using Eikonal Equation. Absolute size recovered from estimated C becomes also important from two images under endoscope motion. Further subject includes to use the recovered shape to the undetected or misclassification of polyp for the support of medical diagnosis.

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