Proposal on 3-D Endoscope by Using Grid-based Active Stereo

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***Abstract*— In this paper, we propose a novel 3-D endoscope system by using grid-based active stereo. In the proposed system, projection of a waved-grid pattern that consists of vertical and horizontal sinusoidal lines realizes accurate shape acquisition in sub-pixel accuracy. We develop a small pattern projector implementable to a head of a ready-made endoscope, and examine 3-D shape reconstruction by actual equipment. As the result of the measurement for a known-shaped object, which is a hexagonal cylinder, the error of length measurement is below 0.9% and the error of angle measurement is below 2.2%. We make a measurement of animal organ meat, and confirm that the system can reconstruct a 3-D shape of the organ surface.**

I. Introduction

With development of the esophagogastroduodenoscopy (EGD), the endoscope treatment of the alimentary canal cancer comes to be performed actively.

In the early gastric cancer, it is proved that the radius of tumor, the histological types, the invasion depth, and presence of the ulcer or the ulcer scar have causal connections with the lymph node metastasis. The indication in radical endoscopic therapy is said to be the lesion, whose size is below 2 or 3 centimeters. Therefore, the precision measurement of the radius of tumor is required, with check of such etiological factors as the histological types, the invasion depth, and presence of the ulcer or the ulcer scar.

In the therapy of the colon cancer, the American Society for Gastrointestinal Endoscopy set threshold of the polypectomy at 5 millimeters diameter. The calibrated forceps is currently used for measurement of the polyp in the EGD. But eye judgment by the calibrated forceps is less-accurate.

In the field of image measurement, a variety of researches about 3-D shape reconstruction is made. It is expected that the introduction of the 3-D shape reconstruction in the EGD provides a substantial improvement in inaccuracy in the size measurement of involved area.

3-D shape reconstruction from endoscope image by using shape from shading (SFS) is proposed as previous study [1]. The 3-D shape reconstruction by SFS is difficult. Because the problem is ill-posed, since the number of light sources is limited in imaging condition of endoscope. Also, 3-D shape reconstruction by the binocular stereo is proposed [2]. But, the shape reconstruction with high precision and high spatial resolution is difficult, because the image of internal organ, obtained by the endoscope, includes poor feature-points such as the edge and the texture.

The 3-D shape reconstruction called "active stereo" is proposed for solving this problem about the binocular stereo. The active stereo is the 3-D shape reconstruction by using a measurement system, which is consist of mono-/multi-projector and mono-/multi- camera. In the active stereo, the image of pattern light, which is projected on the target object from the projector, is obtained, and 3-D shape of the target object is computed by analyzing the distribution of the pattern light in the image. Some proposals to apply the active stereo to endoscope are reported [3], [4]. In these methods, a pattern to consist of multiple color is projected to measurement subject.

We previously proposed a grid-based active stereo with waved-grid pattern, which consists of vertical and horizontal sinusoidal lines, for 3-D measurement of moving object [5]. The method realizes one-shot 3-D shape reconstruction with a single-colored pattern and computation of accurate shapes in sub-pixel accuracy. Our method can be superior to spatial resolution of 3-D shape reconstruction in comparison with the above methods by multiple color. And, it is one of advantages in our method that there is no influence on the accuracy of 3-D shape reconstruction from deference of colors.

We consider that a high accurate measurement of involved area in EGD can be realized by applying the active stereo method to an endoscope device. In this study, we propose a new endoscope system, mounting the 3-D shape reconstruction with grid-based active stereo. And, we develop the prototype system and examine the validity of the system.

II. System Configuration

The system configuration of the endoscope system in this study is shown in Figure 1.

In the system, the projector-camera system is built by retrofitting the ready-made endoscope system to the pattern projector developed by us. The endoscope system applied in

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this work is VP-4450HD and EG-590WR, which are manufactured by FUJIFILM Corporation.

The pattern projector is attached to the external wall of the endoscope head, by using the Impact-shooter manufactured by Top Corporation. The Impact-shooter is the tube for fixing a treatment tool on the external wall of the endoscope head. Figure 2 shows the endoscope head with the pattern projector.

The laser source is a green laser module manufactured by Z-Laser Corporation. The wavelength of the laser source is 532 nm, and the output power is 40 mW. In the system, we do not apply a red laser, but a green laser, because the absorption and scattering of a green laser in the physiological tissue is smaller than a red laser.

The plastic optical fiber (POF) guides the laser beam, emitted from the laser source, to the projector head on the endoscope head. A pattern chip is set on the forefront of the POF. The pattern chip is a photo-mask substrate manufactured by photolithographic technique.

The projector head is assumed to be fixed at the head of the flexible endoscope. Therefore, the pattern-lens system of projector head is designed so that it is able to be installed in the housing, which is 2.6 mm diameter and 16.0mm length.

The light beam transmitted through the pattern chip is magnified by the aspheric lens, and projected on the target object. The endoscope camera images the pattern light projected on the target object, and the image data is transferred to the personal computer for 3D shape reconstruction processing. The diffuser is set at the output point of the laser source for removing the speckle noise of laser beam, for the speckle noise have negative influence on the process of 3D shape reconstruction. Figure 3 shows a projected pattern onto a plane.

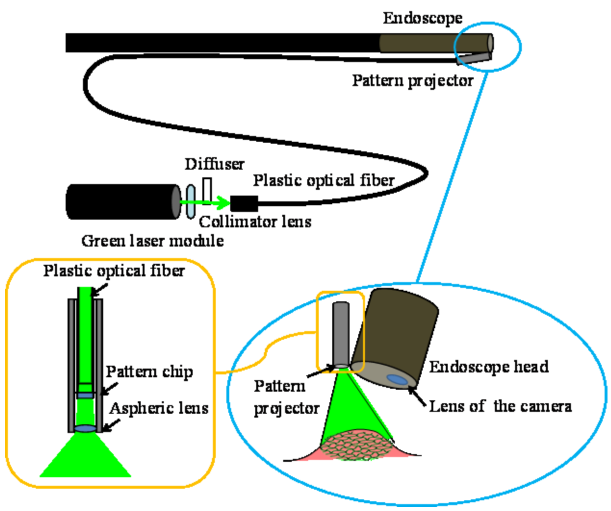


Figure 1. System configuration.

Figure 2. Endoscope head.

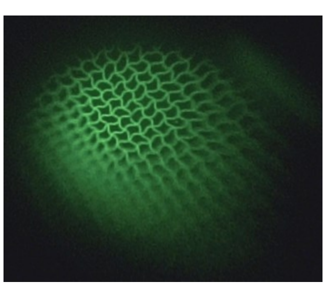


Figure 3. Projected pattern.

III. METHOD

A. 3-D shape reconstruction by using grid-based active stereo

In the 3D reconstruction method, by using a wave-shaped grid pattern as shown in Figure 4, the intersection points can be used as features for matching. Instead of explicitly encoding the positional information of a structured light, the proposed pattern implicitly gives information which can make the order on the candidates of corresponding points.

To obtain unique correspondences between the camera and projector images by spatial encoding, a complicated pattern of large window size have been required in previous methods [6]-[8]. Moreover, while the wider baseline is desirable to improve accuracy, the observed pattern will be more distorted, which makes it difficult to decode the pattern in practical cases. Therefore, we use a simple but informative pattern that is easy to detect and decode.

An overview of our algorithm is shown in Figure 5. Since the captured image of the endoscope is strongly distorted by a fisheye projection, the image is firstly undistorted. Then, we detect curves from the image. For the curve detection, we use a method based on belief propagation (BP) [9], where the image is segmented so that parallel line structures with a certain range of directions are emphasized by BP, and the parallel lines can be detected as borders of the segmented regions. With the method, vertical and horizontal lines of a single color are separated and robustly detected. From the detected curves, intersection points are calculated, and a graph structure of the grid is constructed from the connection of the points.

For each intersection point, candidates of the corresponding grid point are selected by using epipolar constraints and matching scores that compare an image patch around the intersection point and the grid points on the pattern image. For the epipoloar constraints, the lens distortion of the projector is accounted for.

Since multiple candidates of correspondences are usually found, one solution is determined by another BP algorithm.

Finally, the depths for all the pixels are interpolated by matching between the pattern and the captured image and 3D shapes are densely reconstructed.

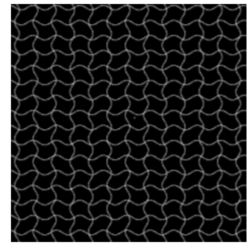


Figure 4. Wave-shaped grid pattern.

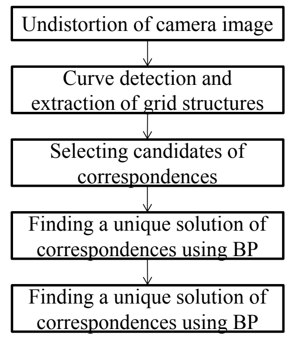
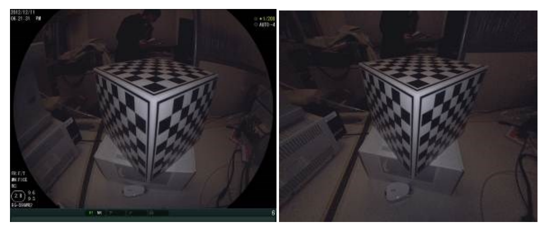
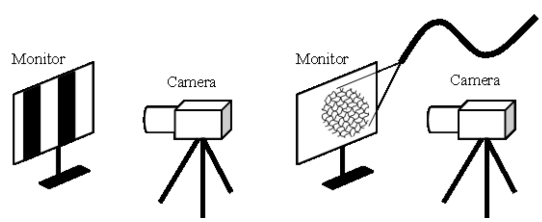


Figure 5. Algorithm of 3-D shape recontruction.



(a) (b)

Figure 6. correction of geometrical distortion:
(a) original image, (b) undistorted image.



(a) (b)

Figure 7. Projector calibulation:
(a) obtaining mapping from the camera image and the monitor plane, (right) capturing projected image on the monitor plane to calibrate the pattern projector.

B. Calibration of endoscope camera

To apply the method of Sagawa et al. [5], the camera of the endoscope and the projector should be calibrated.

For the fisheye projection model, we used parameter equisoid angle projection model (a model where all the pixels have equal solid angles). To obtain data for calibrating the projection, we used Grey Code patterns [10] that are widely used for projector camera systems. The Grey Code patterns were rendered on a PC monitor, and the patterns were captured from the fixed endoscope. This gives a large number of correspondences between the monitor and the endoscope-camera image. Then, mapping between those points were estimated as a parameterized composition mapping of an equisoid angle projection (represented by 3 parameters: 1 parameter for distortion and 2 parameters for distortion center) and a 2D homography (8 parameters).

Once the distortion is estimated, the camera intrinsic parameters are calibrated using a calibration object as shown in Figure 6.

C. Projector calibration

The calibration of the projector is more difficult than the camera, since we cannot obtain correspondences between the projected pattern and the 3D space from the projector itself.

To achieve this, we set the a normal USB camera in front of a PC monitor, and captured Grey Code patterns to obtain mapping from the camera image and the surface plane of the monitor (Figure 7(a)). Then, we project the wave-grid pattern on the projector, and the projected pattern is captured by the same camera (Figure 7(b)). By using the mapping from the camera image to the monitor surface, the captured grid pattern can be mapped to the physical plane of the monitor. By using this, we can obtain correspondences between the waved pattern and the monitor plane. This enables us to calibrate intrinsic parameters of the projector. We used projection and distortion model proved by OpenCV library [11].

Once the intrinsic parameters of the camera and projector are obtained, we can calibrate the extrinsic parameters by measuring planes and giving the correspondences manually.

IV. Experiments and Results

The experiment with an actual measurement system is carried out to examine the validity of the proposed method.

Firstly, the accuracy of the 3-D shape reconstruction is examined with the image data of known shape object. The known shape object is the metal hexagonal cylinder, which is 12mm on a side and 50 mm length. The surface of the object is colored as matt white as shown in Figure 8 (a). Figure 8 (b) is the pattern image obtained by the endoscope camera.

The 3-D shape reconstructed by the proposed method is shown in Figure. 9. The 3-D shape is two planes laying side-by-side in the hexagonal cylinder. The plane equations of respective reconstructed planes are calculated by principal component analysis. As the result, a side length is calculated as 11.89 mm, and the angle between two planes is calculated as 122.6 degrees. These values are nearly equal to the ideal values, 12 mm on a side and 120 degrees. The error of the length is 0.89% and the error of the angle is 2.17%.

Next, the in-vitro experiment with the animal organ meat, that is a piece of beef lever, is carried out as shown in Figure 10 (a). Figure 10 (b) is the pattern image obtained by the endoscope camera. Figure 11 shows the result of the 3-Dshape reconstruction.

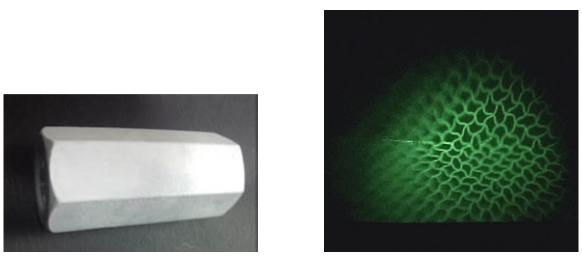
The missing 3-D data partly appears, because the projected pattern light is absorbed and the grid pattern in the obtained image has low intensity. However, we think that the basically 3-D shape of the animal organ meet is reconstructed. In near future, we will examine the optimization of the power and the color of the laser source.

V. Conclusion

We propose a new endoscope system mounting the 3-D shape reconstruction with grid-based active stereo.

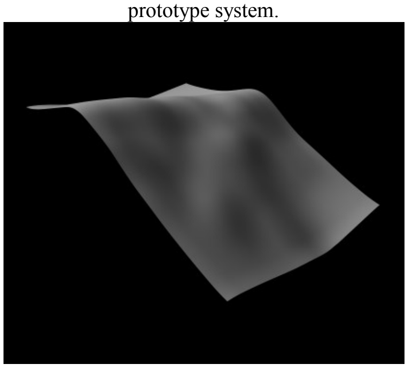
By applying the grid-based active stereo with wave pattern, which consists of vertical and horizontal sinusoidal lines, the proposed method realizes one-shot 3-D shape reconstruction with a single-colored pattern and computation of accurate shapes in sub-pixel accuracy. And, we examine the calibration of the endoscope camera and the projector.

In addition, we develop the prototype system and examine the validity of the system. As the results of the 3-D reconstruction to the known shape object, the error of the length is 0.89% and the error of the angle is 2.17%.

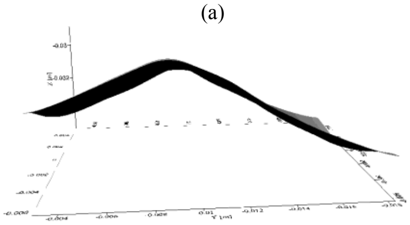


(a) (b)

Figure 8. (a) Known shape object and (b) pattern image obtained by prototype system.



(a)



(b)

Figure 9. Results of 3-D shape reconstruction: (a) overhead view, (b) cross-section view.

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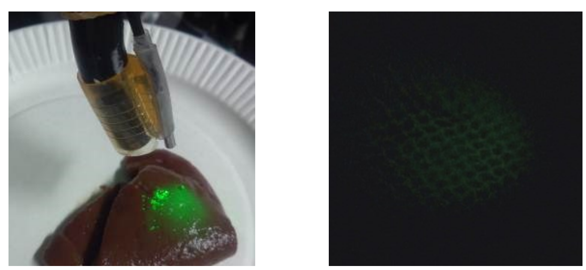

(a) (b)

Figure 10. Pattern image of animal organ meat.

Figure 11. Reconstructed 3-D shape of animal organ meat.