# 3D Measurement Using Line Laser and Stereo Camera with Background Subtraction

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***Abstract*— In this paper, we propose a method to improve the accuracy of three-dimensional (3D) measurement with stereo camera by marking the measured object with a line laser. Stereo cameras are often used for 3D measurement. However, the search for corresponding points in the left and right images depends on the amount of texture of a measured object. In addition, devices using a monocular camera and a laser or an optical projector are often proposed for 3D measurement by image processing. However, these devices require precise calibration. Therefore, we previously developed a measurement system that combines a stereo camera and a line laser. This measurement system improved the accuracy of 3D measurement with a stereo camera by marking arbitrary points with a line laser and measuring those points, independent of the texture amount of the object to be measured. In addition, the line laser could be moved freely, eliminating the need for calibration with a stereo camera. In accuracy evaluation experiments, measurements on the order of millimeters were achieved. However, this method has issues with robustness and processing time. Therefore, we propose a new method using background subtraction that solves those issues in this paper.**

## I. INTRODUCTION

In recent years, camera-based 3D measurement technologies have been widely used in many kinds of situations. Examples include infrastructure maintenance, inspection of components and measurement of the human body. Various methods are used for these situations, among which stereo methods are often used [1]–[3]. There are two types of stereo methods: passive stereo and active stereo. The former method uses two or more cameras of different viewpoints to calculate distances using the principle of triangulation [4], [5]. While this method has the advantage of high measurement density and large measurement area, it is generally computationally expensive and has the disadvantage of difficulty in finding correspondence points when measuring poorly textured objects. The latter method replaces one of the cameras in the passive stereo method with a light projection device such as structured light [6]–[8]. This method has the advantage over the passive stereo method that the search for correspondence points is easy and fast. However, the measurement density depends on the optical projection system and may require scanning or other manipulations. Active stereo methods are commonly used when highly accurate measurements of textureless objects are desired. Rui *et al.* constructed a 3D measurement system using a monocular camera and a line laser [9]. However, this system requires high-precision calibration of the camera and laser, which affects the accuracy of the 3D measurement.

Lingli *et al.* proposed a method using structured stripes as an optical projector [10]. This method can provide accurate 3D measurements of the object. However, the camera and light projection device need to be accurately configured and external parameters calculated in order to measure the overall shape. Another problem is that the positioning of the devices is fixed, and blind spots are likely to occur. We proposed a 3D measurement method using a line laser and a stereo camera as a solution to these problems [11]. In this method, an object captured by a stereo camera is irradiated with a line laser, and its location is extracted by thresholding. The threshold was set to R=255 because a red line laser was used, and experiments were conducted with the lighting turned off to facilitate extraction. Since the extracted line lasers had a width of several tens of pixels, the center coordinates were obtained by taking the center of gravity of the grayscale values. In this method, the stereo camera must be fixed, but the line laser can be freely moved. This has the advantage over the classical light section method that there is less blind spot problem and the camera and laser do not need to be calibrated. However, since the line laser is extracted with the R=255 threshold in this method, there are problems such as false extraction unless the lighting is turned off, and whether the line laser can be extracted or not depends on the color of the object. In addition, the processing speed was slow because processing was performed on the entire image captured by the stereo camera.

Therefore, we propose a 3D measurement method that uses the background subtraction method, which does not need to turn off the environment lighting and does not depend on the object's color. The difference between this method and the previous method is that the line laser is extracted using the background subtraction method, Region of Interest (ROI) extraction, and noise reduction. However, the method for calculating the center coordinates and obtaining disparity and 3D coordinates is the same as the proposed method.

The remainder of this paper is organized as follows. Section II describes the algorithm of the method. In Section III, actual experiments comparing the method with previous methods are presented. Finally, conclusions and future work are presented in Section IV.

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## II. PROPOSED METHOD

### A. Overview of Proposed Method

A flowchart illustrating the proposed method is presented in Fig. 1, while Fig. 2 provides a conceptual system diagram. The procedure begins with capturing the target object using a stereo camera. To reduce computation and eliminate the effect of ambient light surrounding the object, a rectangular ROI is manually extracted from the relevant portion of the object in both the left and right images. Subsequently, frames in the left and right images that are not illuminated by the line laser within the ROI are saved as base frames. The line laser is then projected onto the object, and the laser points are extracted by computing the subtraction from the stored base frame. To refine this extraction process and mitigate noise such as speckle noise and salt and pepper noise, a median filter is applied. This step ensures precise extraction of the line laser points. The width of the extracted laser region spans several tens of pixels. To determine accurate 3D coordinates, identifying the center coordinates along the horizontal axis of the extracted image is essential. This is achieved by calculating the center of gravity of the grayscale values within the extracted regions. Disparity is derived from the center coordinates obtained in the left and right images, enabling distance calculation through triangulation. By repeatedly executing these actions while systematically scanning the line laser, 3D points are constructed with each scan. The proposed method rests on two pivotal aspects. Firstly, there is no requirement for camera-laser calibration. The reason is that the line laser only needs to appear in the image taken by stereo camera. Secondly, measurements are not affected by ambient lighting conditions and object color. The initial extraction of the measured object's ROI serves to eliminate ambient light effect and decrease computational costs. Additionally, the line laser extraction relies on a threshold-free subtraction calculation, making it independent of object color. This makes for a highly robust measurement system.

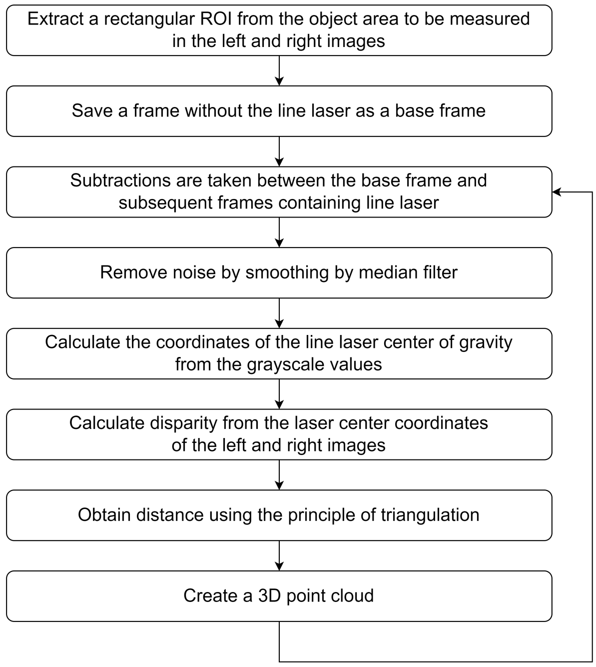


Fig. 1. Flowchart of proposed method.

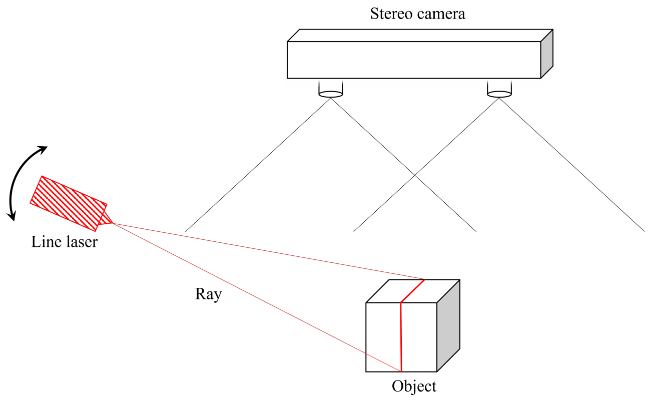


Fig. 2. System concept of proposed method.

### B. Region of Interest

Prior to the processing steps, ROI is extracted on both the left and right images. This entails manually enclosing solely the objects intended for measurement within rectangular boundaries. This process reduces the effect of ambient light on the measurement process. Furthermore, processing time can be reduced. The reason for manual ROI extraction is that in the case of automatic object detection, the accuracy of the 3D measurement is also affected by its accuracy. The process up to the calculation of the center coordinates is performed in the coordinate system of the ROI. The process of calculating disparity and 3D coordinates is then transformed back in the original coordinate system. Fig. 3 shows an example of ROI extraction.

### C. Extraction of Line Laser by Subtraction

From the RGB images captured by stereo camera, the points of the line laser are extracted by computing the subtraction between the base frame (absence of the line laser) and the laser frame (presence of the line laser). Fig. 4 shows an example of the line laser extraction.

### D. Noise Removal by Median Filter

When taking subtraction and extracting the line laser, speckle noise and salt and pepper noise may occur, as shown in Fig. 5(a). To remove these noises, median filter smoothing process is performed.

The filter's kernel size is configured at $3 \times 3$. Compared to other smoothing and Gaussian filters, median filtering does not blur the edges and has less effect on the points of line laser extracted by subtraction. This characteristic ensures that noise reduction can be executed without compromising the accuracy of measurements. This noise reduction process between frames is showed in Fig. 5 (b).

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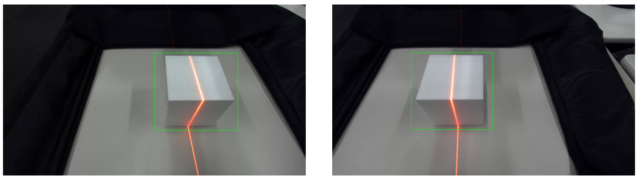
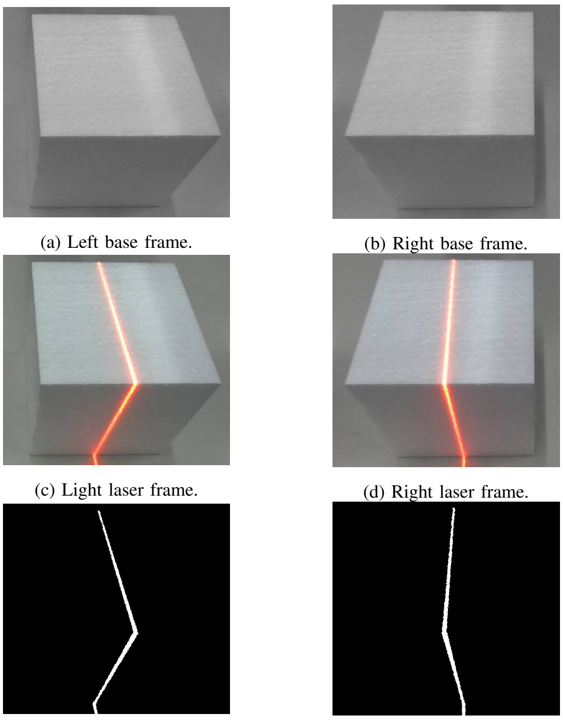


(a) Left image ROI

(b) Right image ROI

Fig. 3. ROI.



(a) Left base frame.

(b) Right base frame.

(c) Light laser frame.

(d) Right laser frame.

(e) Left subtraction image.

(f) Right subtraction image.

Fig. 4. Subtraction between base frame and laser frame.

### E. Calculation of Center Coordinates

The extracted laser region has a width of several tens of pixels. In order to calculate accurate 3D coordinates, it is necessary to determine the center coordinates of the extracted line laser region.

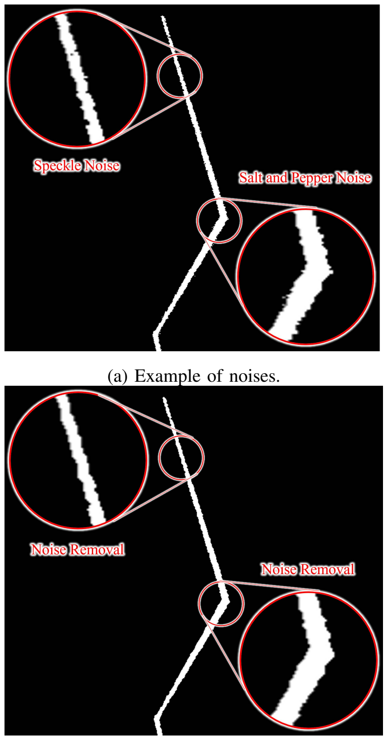
The method of calculating the center coordinates is by finding the center of gravity of the grayscale values. The extracted laser locations are output in grayscale and the grayscale center of gravity of the horizontal axis is calculated from the pixel values of all columns. Equation (1) is used to calculate the center coordinate $x_g$,

$$x_g = \frac{w_1 x_1 + w_2 x_2 + \cdots + w_n x_n}{w_1 + w_2 + \cdots + w_n} \tag{1}$$

where $w_n$ is the grayscale pixel value of the laser location and $x_n$ is its x-coordinate value. Fig. 4 shows the result of calculating the center coordinates in a certain frame and drawing them in red on the left and right binary images.

### F. Obtaining Disparity and 3D Coordinates

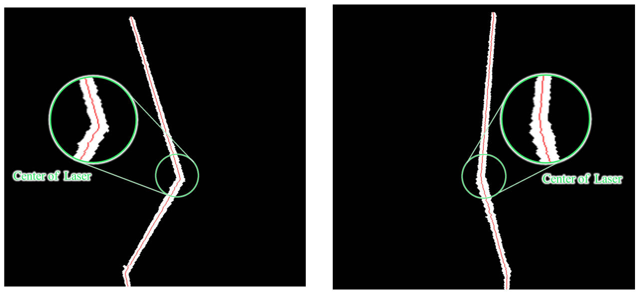
Disparity is calculated from the center coordinates of the line laser points calculated in the left and right images,




(a) Example of noises.

(b) Examples of noise removal.

Fig. 5. Noise removal by median filter.




(a) Left image.

(b) Right image.

Fig. 6. Calculation of the center coordinates.

and 3D information is obtained based on the principle of triangulation. Fig. 6 shows an example of disparity. In this case, because stereo rectification is carried out between the two stereo cameras, the disparity can be obtained in the same line in the left and right images.

The obtained disparity is then transformed to 3D coordinates. The transformation equations are shown in (2)-(4),

$$X = \frac{b x_{gn}}{s\left(x_{gn} - x_{gn}'\right)} \tag{2}$$

$$Y = \frac{b x_{gn}'}{s\left(x_{gn} - x_{gn}'\right)} \tag{3}$$

$$Z = \frac{b f}{s\left(x_{gn} - x_{gn}'\right)} \tag{4}$$

where $x_{gn}$ are the center coordinates of the laser in line $n$ of the right image coordinate system, $f$ is the focal length of the camera, $b$ is the distance between the cameras and $s$

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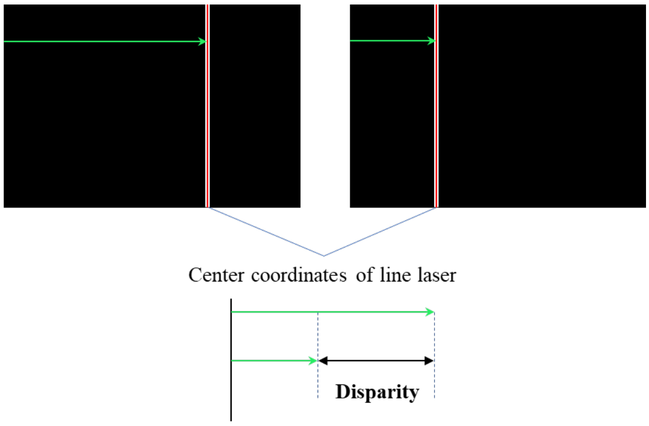


Fig. 7. Calculation disparity.

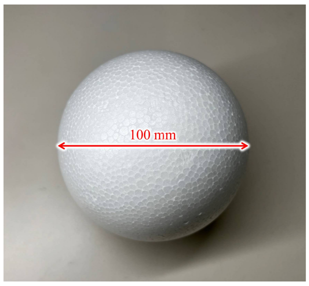


Fig. 8. Measured object.

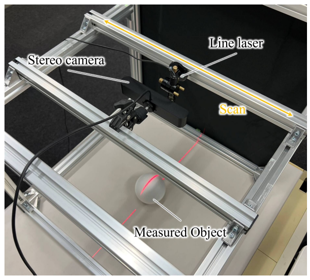


Fig. 9. Experimental device.

Fig. 10. Stereo camera.

Fig. 11. Line laser.

is the pixel size of the image sensor. The 3D coordinates $(X, Y, Z)$ of the laser are given on the coordinate system of the left camera.

## III. EXPERIMENT

### A. Comparative Experiment with Previous Method

Experiments were conducted to compare the accuracy and real-time performance of the proposed and previous methods by measuring a sphere. As a previous method, we used a method to extract and measure lasers by using a threshold value of R=255 [11]. The difference between this method and the previous method is that the line laser is extracted using the background subtraction method, ROI extraction, and noise reduction. However, the method for calculating the center coordinates and obtaining disparity and 3D coordinates is the same as the proposed method. The sphere was measured using each method, and the shape of the sphere was estimated using CloudCompare's RANSAC Shape Detection for the acquired 3D point cloud [12]. The accuracy was evaluated by determining the dimensional error. The frame rate of each point cloud was also evaluated for real-time measurement.

### B. Experimental Condition

As shown in Fig. 8, a sphere made of styrene foam with a diameter of 100 mm was used as the measured object. The Stereo Labs ZED2 stereo camera shown in Fig. 9 was used, and the line laser was the STS marking laser ML-7010 shown in Fig. 10. Table 1 shows the specifications of each device. The measurement environment is shown in Fig. 11. Experiments were conducted in an environment where measurement was taken from directly above approximately 500 mm. This assumed the inspection of parts in a factory.

The measurement methods of the proposed and previous methods are described below. The line laser was mounted on an aluminum frame, and scanning was performed on the aluminum frame. Note that the scanning time, scanning speed, and scanning interval were arbitrary. If only measurement is possible if the laser is captured by the camera, in this experiment, the laser was emitted perpendicular to the object to be measured as much as possible in order to make it easier to understand the acquisition of the 3D point cloud of the measured object.

To evaluate the 3D point clouds acquired by each method, shape estimation was performed using CloudCompare, a free 3D point cloud processing software. RANSAC Shape Detection was used for shape estimation. It uses the automatic shape estimation algorithm proposed by Ruwen *et al.* [13]. In this experiment, sphere estimation was performed. The dimensional error between the true diameter of the sphere and the estimated diameter of the sphere was used as a measure of accuracy evaluation. The frame rate at the end of point cloud acquisition was used as an evaluation index for real-time processing.

### C. Experimental Result

The point clouds at the top of the sphere acquired by the proposed and previous methods are shown in Fig. 12 and Fig. 13, respectively, and the model of the sphere estimated by RANSAC Shape Detection is shown in Fig. 14. The dimensional errors and frame rates for each method are shown in Table II.

### D. Discussion

Fig. 12 and Fig. 13 compare the 3D point clouds acquired by each method. Not a quantitative evaluation, the point cloud acquired by the proposed method seems to have less variation. This is because, when the line laser is extracted with a threshold of R=255, only a portion of the wide laser is extracted. On the other hand, the proposed method takes the subtraction between the base frame without the laser and the frame with the laser, so the laser points in the image can be extracted appropriately. This is thought to be the reason why there is little variation. In addition, Table II shows that the proposed method has a smaller dimensional error than the previous method, which means that the measurement is more accurate than the previous method. This is considered to be because the proposed method is able to extract the line laser

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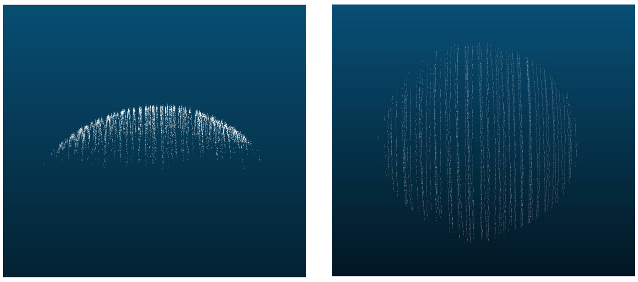
TABLE I Specification of experimental equipment.

| Used Equipment | Name | Specification |
|---|---|---|
| Stereo Camera | ZED2 | Image Resolution: $2208 \times 1242$<br>Frame Rate: 15fps<br>FOV: $110°(H) \times 70°(V)$<br>Baseline: 120mm<br>Focal Length: 2.12mm<br>Pixel Size: 2µm |
| Line Laser | ML-7010 | Wavelength: 635nm<br>Slit Width: approximately 5mm |



(a) Side. (b) Top.

Fig. 12. 3D point cloud by proposed method.

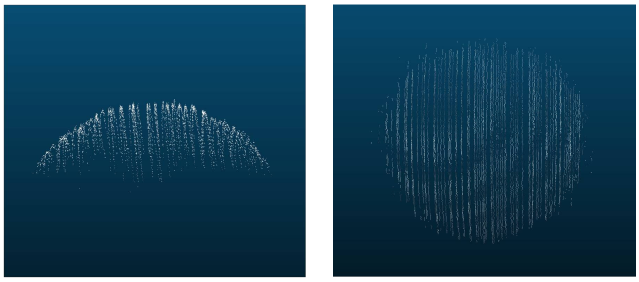
appropriately, as mentioned earlier. In addition, the proposed method is less prone to noise due to reflections of ambient light than the previous method, which is thought to be the reason for its more accurate measurement. Table Ⅱ shows that the frame rate of the proposed method is almost twice as high as that of the previous method. This is thought to be due to the fact that the proposed method performs processing only within the ROI, thus greatly reducing the amount of computation. The frame rate of the proposed method is lower than previous method, because the measurement of the points other than the object to be measured causes extra calculations not only in the line laser extraction, but also in the calculation of the center coordinates and point grouping process. The proposed method is more suitable for real-time measurement.

## IV. CONCLUSION

In this paper, we proposed a stereo method using a background subtraction method to realize real-time measurement using the line laser and stereo camera.

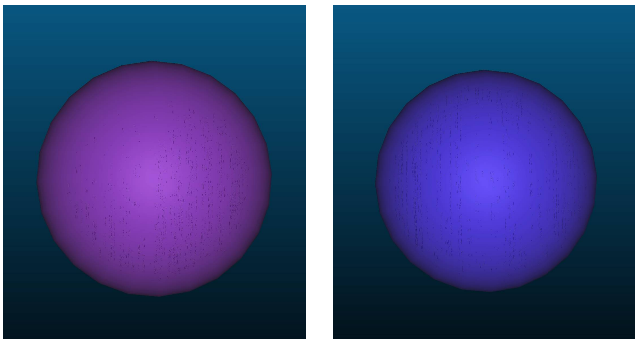
First, ROI extraction is performed on the left and right images taken by the stereo camera to enable measurement of only the object to be measured. The frame without the line laser is saved as the base frame, and the subtraction between the base frame and the subsequent frames with the line laser is used to extract the laser irradiation point. Since the image contains salt and pepper noise and speckle noises, a median filter is used to remove these noises. Next, the center coordinates are obtained by calculating the center of gravity of the grayscale values, since the noise-processed laser irradiated area has a width of several tens of pixels. The disparity is calculated from the center coordinates of each of the left and right images, and 3D coordinates are obtained and converted into a point cloud using the principle of triangulation.

The comparison experiment was conducted using the method that extracts laser with a threshold value of R=255 as the previous method. The results showed that the proposed method produced more accurate measurement than the previous method, and the frame rate was nearly twice as high. In the future, we aim to perform 3D measurement with higher accuracy. Future applications include inspection of parts and products manufactured in factories, measurement of the human body, and data collection of traditional crafts.



(a) Side. (b) Top.

Fig. 13. 3D point cloud by previous method.



(a) 3D model (proposed method). (b) 3D model (previous method).

Fig. 14. Result of RANSAC Shape Detection.

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TABLE II Comparison of dimensional error and frame rate.

| | Proposed Method | Previous Method |
|---|---|---|
| Dimensional Error [mm] | 1.980 | 2.249 |
| Frame Rate [fps] | 6.8 | 3.5 |

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