3-D Measurement of an Object by a Mobile Robot Equipped with a Laser Range Finder

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ABSTRACT
In this paper, we propose a 3-D measurement method of objects by a mobile robot equipped with a laser range finder. When a robot picks up an object, it is important to reconstruct its entire 3-D shape, in order to grasp it properly. Therefore, the robot is required to measure the object from different directions to integrate 3-D data. In our method, the robot is equipped with the laser range finder composed of a laser and a CCD camera, and measures an object using a light stripe projection method. Then the robot combines the range data of each view, considering errors in robot's positions and viewing angles, and reconstruct the shape of the object. An experimental result has shown the effectiveness of the proposed method.
KEY WORDS: Mobile robot, Light stripe projection, 3-D measurement

INTRODUCTION

It is expected for mobile robots to support man's works, not only in an industrial field but also in a public field, a medical field, and so on [1,2]. Places in which a mobile robot is working are expanded from factories to offices, institutions, and homes. Especially, it is important for a robot to perform transportation tasks instead of a man in an aging society with fewer children. Therefore, a mobile robot is required to understand the shape of various objects to pick up them for transportation. To satisfy this requirement, it is necessary for the robot to measure its shape and reconstruct it from the measurement results.

There have been a lot of studies about vision-based measurement of 3-D shape of an object. For instance, Arai *et al* proposed a mobile robot that measures its shape by scanning 2-D bar codes on the object [3], and Yamazaki *et al* proposed a method based on the motion stereo using a CCD camera equipped with a mobile robot [4]. However, there are problems in these techniques. In the former, it takes time and effort to put a bar code on every object. The latter requires that there is some texture on the object.

In this paper, we propose a method to measure the 3-D shape of an object for grasping it, using a mobile robot equipped with a laser range finder (LRF). Even if there is no texture on the object, LRF enables us to measure its shape. We measure an object in wide range from multiple views, and reconstruct its entire shape through the integration of the whole data acquired form multiple views. This study is a first step toward our final goal that a mobile robot can grasp an object automatically.

In the following, system configuration is given first, and then measurement principle is explained. Thereafter, an experimental result and its evaluation are shown.

ROBOT'S SYSTEM CONFIGURATION

We designed the following mobile robot, in order to measure the shape of an object from multiple views and grasp it (Fig.1). A wheeled robot is equipped with a CCD camera that has a pan-tilt function, a gripper with two degrees of freedom (TDF), and a laser which projects a slit light. The gripper is used in order to not only grasp an object but also scan the laser for the measurement. The robot also has a function of localization by dead reckoning that uses rotation information of the wheel. We calculate the physical relationship of the camera and the mobile robot beforehand. This makes it possible to integrate each measurement result obtained from multiple views. A host PC mainly executes time-consuming operations, such as image processing. The mobile robot only sends the image data to the host PC and receives the various commands from it.

MEASUREMENT PRINCIPLE

Outline of processing

Our processing procedure is shown in Fig.2. A mobile robot captures images for each view and a laser light in the image is extracted by image processing. We measure the object based on the image processing result. When the robot has measurement data at the previous view, the robot integrates measurement data in previous and present view. Then the robot changes the position for the next view. As a precondition, we measure the object of a polyhedron, and make the laser slit light project the object horizontally, which means that we consider the integration of measurement data on the 2-D plane in this paper.

Image acquisition

For each view, we capture two images, one of which is an image with laser light projection (on-laser image) and the other is an image without the projection (off-laser image) (Fig.3).

Extraction of laser light

The laser light is extracted from the images according to the following procedure.

<u>a) Image subtraction</u>

The difference image is created through subtracting the off-laser image from the on-laser image for each view. We extract the candidate area of laser light in the image (Fig.4).

<u>b) Noise removal</u>

It is necessary to removes noise from the difference image. This is realized by binarization and labeling that detects the size of individual connected areas (Fig.4). Small areas are removed as noises.

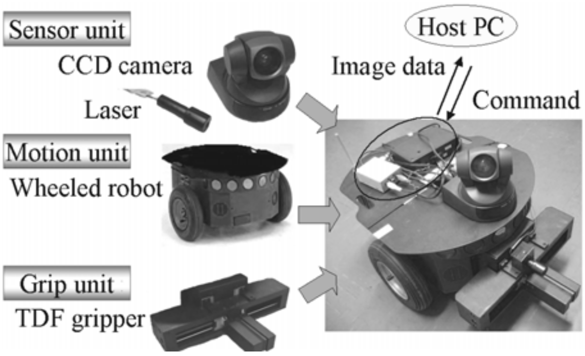


Fig.1: Mobile robot's configuration.

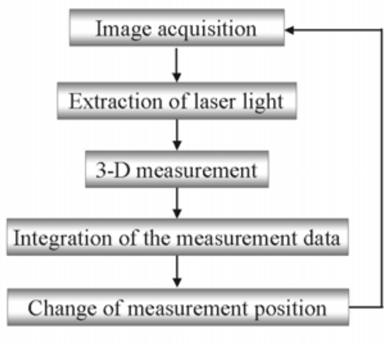
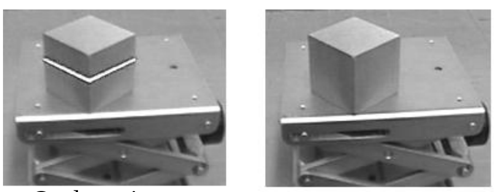
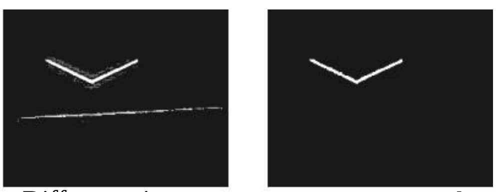


Fig.2: Outline of processing.



On-laser image Off-laser image

Fig.3: Input images.



Difference image Extraction result

Fig.4: Image processing.

Measurement of the object's shape

The 3-D coordinates of the laser light on the object are calculated using the principle of triangulation (Fig.5). It's because we know the position and direction of the camera and the plane of laser light in the world coordinates (X-Y-Z). The 3-D measurement point given is the intersection of the plane and the ray vector from the camera.

Integration of measurement data

In the integration of measurement data, each measurement data does not correspond to the others because the localization of the robot contains the error of dead reckoning. Therefore it is necessary to calculate the amount of a translation matrix *T* and a rotation matrix *R* between each measurement data (Fig.6). *R* and *T* are calculated from the correspondence of the vertices in each data. We calculate the correspondence of those vertices, using that the difference between each measurement data depends on the robot's motion direction. The corresponding result makes it possible to calculate *T* and *R*.

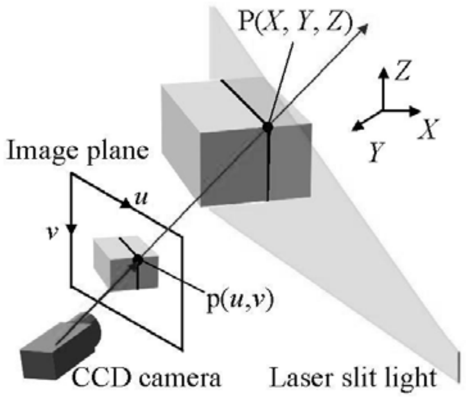


Fig.5: Principle of triangulation.

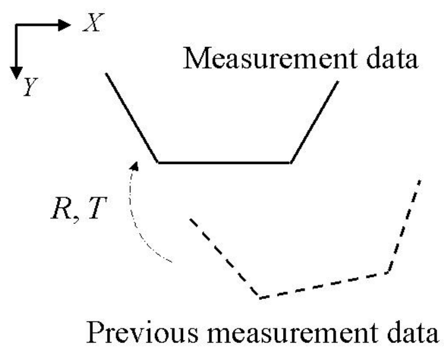


Fig.6 :Integration.

EXPERIMENT

Experimental setup

In the experiment, we measured the shape of a hexagonal prism as shown in Fig.7, and captured each image with the resolution of 640x482 pixels. 3-D measurement was performed from seven measurement positions, as shown in Fig.8, where the circle shows a mobile robot. The number is the index for the each robot's position in 3-D measurement. The robot moves about 100 mm when it changes the position. The distance between the hexagonal prism and the robot ranges from about 200 mm to 300 mm.

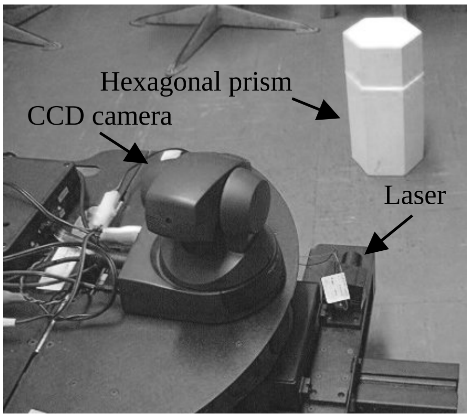


Fig.7: Experiment view.

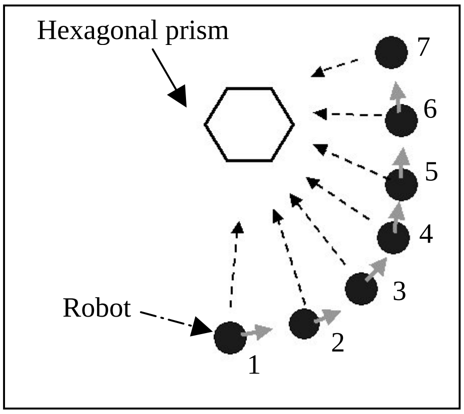


Fig.8: Outline of the experiment.

Experimental result

The measurement result is shown in Fig.9, which is a plane figure of the object. The number with each measurement data group in Fig.9 corresponds to the robot's position in Fig.8. We calculated the linear approximation of each measurement data by a method of least squares, and confirmed the linearity with standard deviation. In the experiment, there is about ±1.5 mm of standard deviation. On the other hand, the error of 1 pixel in the image causes the error of 1.64 mm in the measurement. So it can be said the sufficient stability against image noises is obtained in this 3-Dmeasurement experiment. We extracted the vertices of these measurement data, and matched the corresponding vertices in each data based on the robot's motion direction. The result of data integration is shown in Fig.10. We confirmed that measurement data was well unified in this figure although there remained a few mismatches between each data owing to the error in calibration of LRF.

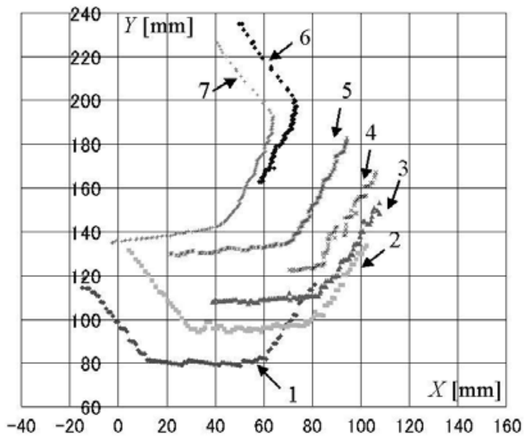


Fig.9: Experimental result.

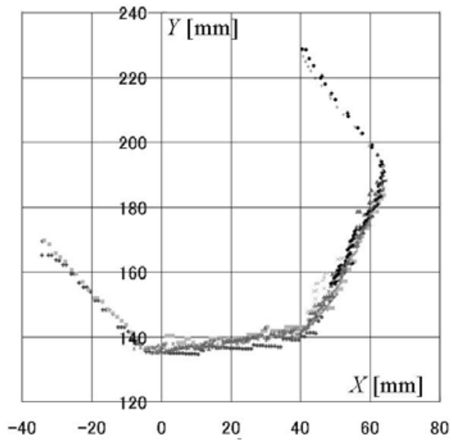


Fig.10: Integration result.

CONCLUSION

In this paper, we propose a 3-D measurement method for an object by a mobile robot equipped with a laser range finder. In the method, the shape of the object can be measured from multiple views, and integrated from measurement data for grasping the object. As future works, we should integrate the measurement data of an object with arbitrary shape, and confirm the validity of the integration result by grasping the object.

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