Effective 3D Data Extraction
for Multiple Structured Lights Projection Method

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Abstract: - Computer vision systems have been exploited to detect the three dimensional shape data of objects. Slit-laser scanning or pattern projection on the recording process is executed on these system. Generally, since the recording process takes a time, the temporally stop of physical movement is required for both of the measurement target and the measurement device during the recording process. In order to cope with this problem, the measurement system that projected the multiple structured light is introduced. Multiple structured light projection enables the quick measurement and three-dimensional data on these structured lights can be obtained by a few images. However, in the image processing, each structured light should be separated and identified properly for estimating the three-dimensional position by the triangulation.

In this paper, separation method of each structured light from the single recorded image is introduced, and this method improves the robustness of pattern recognition.

Key-Words: - Computer vision, Point Cloud, Multiple structured lights, Laser, Three-dimensional

1 Introduction

A point cloud is a set of vertices in a three-dimensional (3D) coordinate system. Point clouds are used in CAD data and robot vision systems. In recent years, inexpensive devices such as Microsoft Kinect[1–4] that detect 3D point cloud data have become available. Such devices are useful for capturing the motion or modeling systems that do not require high accuracy. Furthermore, there is no limitation on the measurement area size since individual 3D point cloud data sets recorded from different positions can be combined on the computer. The iterative closest point (ICP) algorithm [5–9] is often employed to combine data sets. This algorithm automatically determines the overlapping area between 3D point cloud data sets and constructs a single 3D image. Such devices are very attractive since they can obtain thousands of point cloud data sets in real time. However, the data obtained is not sufficiently accurate for industrial applications. Furthermore, for such systems to be utilized in industrial applications, an easy method is required for extracting the desired data from point cloud data. This is because automatic extraction of target objects requires very extensive computer processing since point cloud data includes much redundant data such as background data.

The slit-ray projection method [10–13] (i.e., shape from structured light) has been widely used in industrial applications and robot vision systems. It has high measurement accuracy. In this method, a laser slit is projected onto the surface of the target object and the laser streak generated on the surface is detected by a camera. The 3D position data of the laser slit is estimated by triangulating the orientation of the laser projector and the camera. The process of extracting valuable data from the huge amount of cloud data obtained is simplified as the slit-ray projection method detects pointed data from only the laser streak.

On implementing the slit-ray projection method, the laser slit should be swept to cover the whole surface of the object. Generally, since the sweeping takes a time, the temporally stop of physical movement is required for both of measurement target and measurement device during the recording process.

In order to cope with this problem, we developed the measurement system that projected multiple structured lights. Three dimensional shape data can be detected from a few images. On realizing the proposed method, each light has to be recognized where it is projected from. Coded pattern projections are used to recognize each slit. Using proposed system, both of the measurement device and object need not to be stopped during the measurement.

In this paper, separation and identification method of structured light from the recorded image is

introduced and this method improves the robustness of the measurement.

2 Measurement System

2.1 Multiple structured light projection

Fig.1 shows the principle of a general slit-ray projection method. In this figure, single slit is projected against the wall at different distances. The slit is displaced depending on the distance from the system. So, the distance can be measured by examining the displacement of the slit on the image. Fig.2 shows the schematic of shape measurement system. Points on the slit can be calculated by triangulation on considering the direction of laser slit. Therefore cross sectional shape at laser slit can be estimated. In order to measure the whole shape of the object, the sweeping of the slit is required.

Fig.3 shows the schematic of multiple slit-ray projection and Fig.4 shows the photograph of the system. The increase of the slit number increases the number of measurement cross-section. Though many data are included on the multiple structured light, it should be noted the difficulty to recognize the direction of the laser slit on the recorded image for a computer. Each slit has to be distinguished and the direction of the projection should be known for the triangulation. In the measurement image, many line segments that have different laser direction are existed and it causes the difficulty of the automatic image analysis.
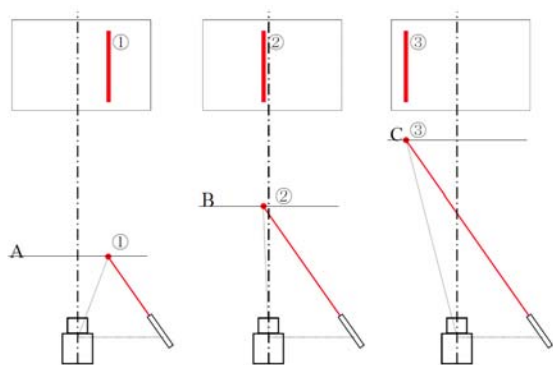

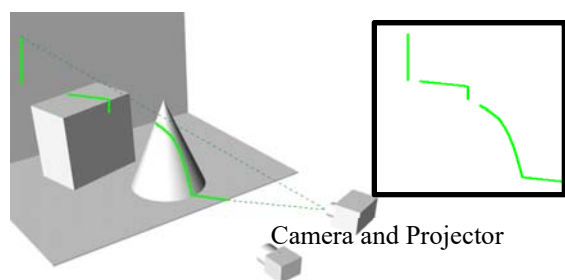Fig.1 Laser projection and recorded image by camera

Camera and Projector
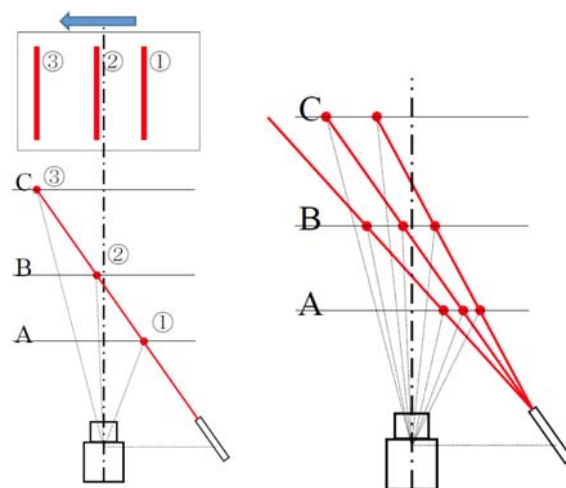
Fig.2 Shape measurement

Fig.3 Schematic of multiple slits projection

2.2 Strategy for the multiple laser projection

Each slit has to be distinguished and the direction of the projection should be known for the triangulation in slit-ray projection method but increases of the lights causes the ambiguity problem.

One of the method to distinguish the multiple lights is projection cording. The dots cording method has been developed in our study. The dots are programmed to blink on and off according to a predefined time series, synchronized with the camera capturing frequency. An example of the encoded 4-bit dot pattern is shown in TABLE 1. A total of 15 patterns are possible with 4-bit encoding, and 1023 patterns can be defined with 10 bits. The dots in the acquired images are labeled according to the pattern number, and cross-referenced to the predefined dot coordinates. This decoding is performed by processing consecutive images. The world coordinates in the scene and the corresponding image coordinates of the dots are then tabulated. Conversion functions for each local area in the image are determined, and a final conversion table for the entire image is constructed using the conversion functions. The constructed calibration table is used to convert positions from the camera image into world coordinates. Fig.5 shows the example of dots pattern displayed on the LCD. These patterns are exchanged on synchronizing with the camera capturing. First, thousands of measuring points can be recognized very quickly. The time required to capture 11 images is approximately 350 ms, and even with processing for decoding of the dot patterns, the total time is less than 1 s. Second, the number, size, and display interval of reference marks can be easily changed according to the measurement environment. Fig.6 shows the dots pattern recorded by the CCD and Fig.7 shows the enlarged dots pattern after labeling procedure by the computer. The positions of the each

dot are moved by the shape of the target but it is easy to be recognized and numbered using this proposed coding.

Fig.4 System setting for multiple structured lights projection.

TABLE 1
Encoded pattern on LCD (1:On 0:OFF)

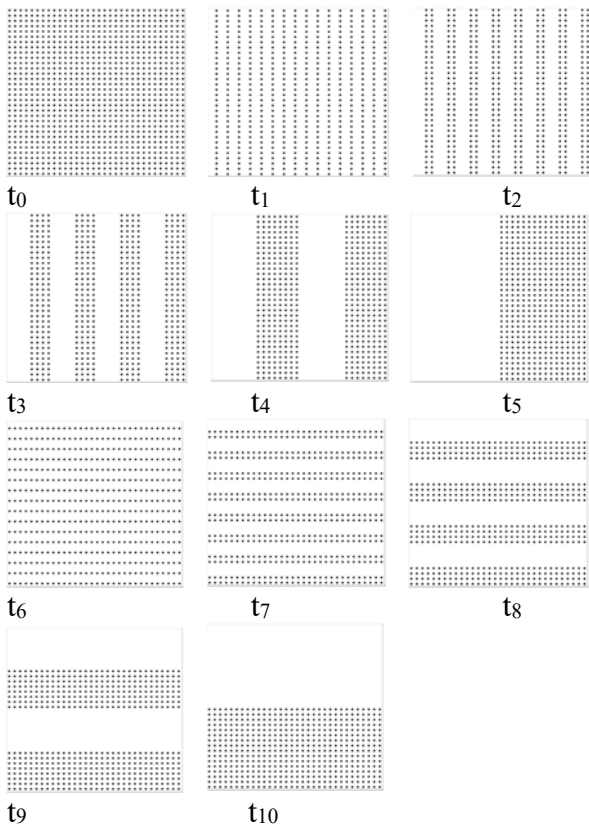|	t_1	t_2	t_3	t_4
Point 1	0	0	0	1
Point 2	0	0	1	0
Point 3	0	0	1	1
Point 4	0	1	0	0
Point 5	0	1	0	1
:	:	:	:	:
Point 14	1	1	1	0
Point 15	1	1	1	1

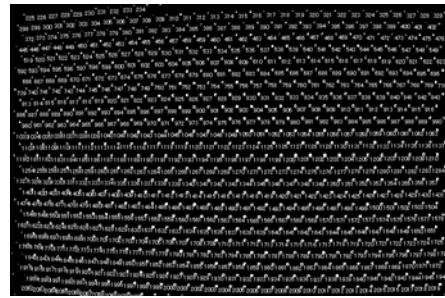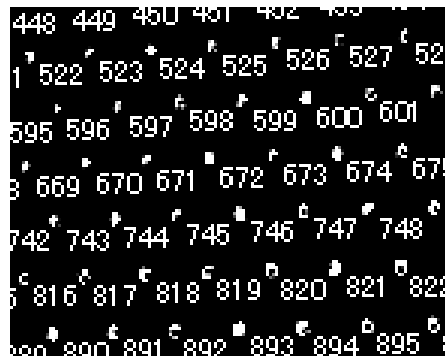Fig.5 Example of dots pattern

Fig.6 Dots pattern

Fig.7 Numbered dots (Magnified image)

The other method to identify the lights is to add the marker to the structured light. The example of the maker is a random dots pattern. Fig. 8 shows the image that multiple laser with random. Random dots are projected along the laser slit simultaneously and the random dots enable us to address each slit. Though LCD projector can be used to generate this pattern image, the use of laser projector is recommended in practical uses since the power of the slit intensity can be kept at high level.
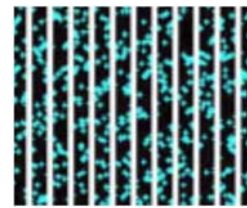
Mutiple slits with random dots
Fig.8 Random dots projected along the slit

In order to extract the laser slit and random dot separately, two kinds of method can be proposed. One method is executed by a physical control of laser projectors, and the other is executed by a software image processing.

Fig.9 shows the timing chart of a physical control for the slit projection and the camera capturing. Two images are captured while each slit is on and off. Consecutive image capturing is desirable, but the delay of the LCD should be considered on LCD system. Laser control is also executable instead of LCD use, but special device such as I/O interface is

needed. Since two images are needed for each multiple slits and dots image, the object should be stable while these two images are captured.
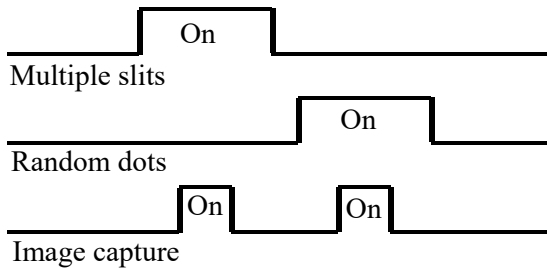

Fig.9 Timing chart of laser and camera control

The other method for the extraction of slit and random dots is executed by a software processing. Proposed system adopts this software processing method. Fig.10(a) shows the original image captured by the system. Multiple slits and random dots are recorded simultaneously in an image. First of all, median filter is applied to the original image. The image is changed as (b) by the median filter. By subtracting (b) from original (a), the slit and random dots are emphasized as (c). The random dots can be delated by applying the morphology processing. Generally, the morphology processing is applied for noise reduction but dots can be also delated properly as (d) using the morphology processing. Once the slit is extracted properly, the dots can be extracted easily by subtracting (d) from (c). The extracted dots are shown in (e). Separated two images of multiple slits and random dots are used for the line number allocation.

(a) Original image

(b) Median filter

(c) Subtraction (b) from (a)
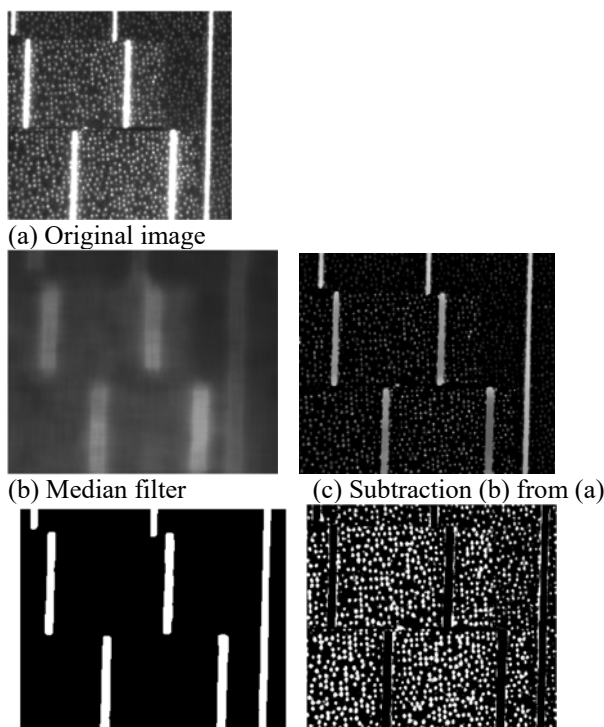
(d) Slit extraction by morphology processing

(e) Dots extraction by subtraction (d) from (c)

Fig.10 Extraction of slit and random dot

The initial setting is executed before the measurement. On the initial setting, basic image is constructed that indicates the position of the slit with random dots and slit line number. Slits and Dots are separated also in the basic image. The basic image is utilized to allocate the address to the slit. Slit laser and random dots are projected on the plain board. The image of the slit and random dots appeared on the board is recorded. After recording the image, the distance between the measurement system and board is changed. The recoding procedure of the basic image is repeated for three or four times. "Basic images" are recorded during this process. The slit-number (address) is allocated to each slit line by comparing with the basic image.

4 Slit recognition

Some points on the slit are randomly selected and the template area is set around the point. The random dots pattern is used to identify each slit. The area which has same dots pattern with the selected template is searched in the basic image.

Firstly, multiple slit laser and random dots are projected on the measurement target, and the image of it is recorded. Line segments are extracted from the measurement image by applying the labeling procedure. The allocation of the address is executed for each segment. Some dots on the line segment are randomly sampled. Template image is set surrounding the dot. The address of the each line segment is allocated by finding the corresponding line in the basic images. Template matching [14] is executed for the allocation. The evaluation value of matching is calculated on the template matching process. The selection of point on the line segment and the allocation procedure are repeated for f times. The best matching address is selected from f addresses candidates. The address is determined for the line segment on considering the matching evaluation value.

5 Experiment

Experiments of shape measurement were conducted using proposed method. Once each projected lights is identified, three-dimensional position on the light is estimated. The object in a water tank is measured for the application of coded dots pattern projection method. The object is deformed by the refraction of

water. Fig.11 shows the object deformed by the refraction. Fig. 12 shows the calibration setup to estimate the deformation. The dot pattern is corded using proposed method. By identifying each projected point, the magnitude of the deformation is estimated at each position. Fig.13 shows the reconstructed object on the computer and the deformation was corrected.
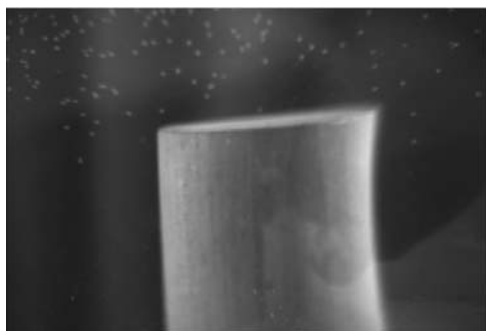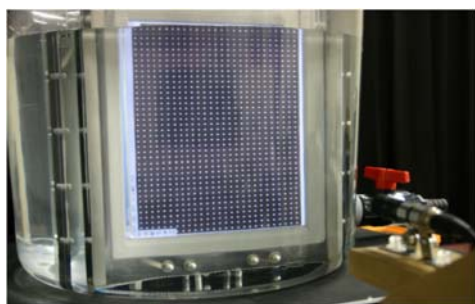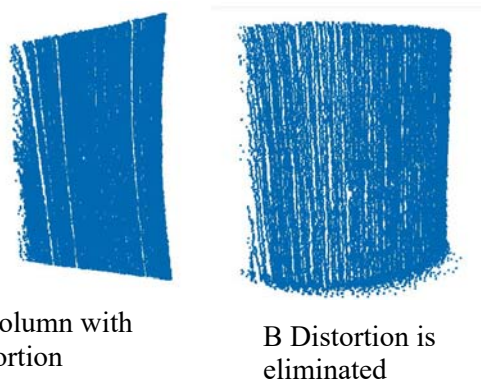

Fig.11 Wood column in a water tank

Fig.12 Photograph of calibration setup in a water tank

A Column with distortion

B Distortion is eliminated

Fig. 13 Reconstructed column by measured data

Fig.14 shows the photo that multiple slits with random dots are projected on the surface of the object. In this experiment 7 slits are projected.

Fig.15 shows the three-dimensional data displayed on the global coordinate systems.

Fig.14 Multiple structured lights on the object.

Fig.15 Calculated points on the global coordinate systems.

6 Conclusion

The three dimensional measurement system using multiple structured lights projection was introduced. Separating method of slits and identification method of light direction are introduced in this paper.

This paper is summarized as follows.
1) LCD projector and Laser projector can be selected for projecting the structured light.
2) Laser projector is adequate for the practical use.
3) Two kinds of method for laser separation are introduced. One is executed by physical control and the other is executed by software image processing.
4) Proposed image processing method is adequate for separation of slits and random dots.
5) Distortion reduction method is introduced by identifying the position of dots.
6) Experimental result shows feasibility of proposed image separation method.
7) Image separation of slit and random dots improved the allocation result of slit number

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