A Simple Surface Mapping Technique using Laser Triangulation Method

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Abstract: The system employs a solid-state laser with internal beam conditioning for range to a target by utilising the triangulation technique. The grating line was made from a transparent material with a width of one pixel set using a computer programme. A fixed black and white (B/W) camera together with a frame grabber DT-3135 was used to acquire the 2D image of the object. The triangulation angle was extracted from the difference in distance between the laser grating causing the line produced on the object and the B/W camera. The position between the B/W camera and laser grating was fixed at an angle of 30 degrees. The application of this system is as the visual input of a robot, so the robot can recognise images in near real time. The speed of recognition of the object would depend on the speed of scanning of the object and reconstruction. An efficient approach is presented for modeling 3D surface map of an object employing an uncalibrated camera. For surface mapping, the resolution is a function of range, which includes base line length measurement and proper 3D-model re-construction. A typical precision is 0.1% for a maximum range measurement of 30 cm. This vision system will be integrated with an automation system, which depends heavily on surface mapping information.

Keywords:
Triangulation, surface mapping, range measurement

I. INTRODUCTION

Techniques such as "laser surface mapping" and "range based vision" are systems that acquire depth information over an entire scene and use them for pose and distance determination. It provides 3D feature details at the cost of being computation intensive[1]. An efficient approach is presented for modeling 3D surface map of an object employing an uncalibrated camera. This technique employs a camera, which acquire a surround image of a rigid object. Total reconstruction of the overall shape of the object was conducted by collecting all the projected feature points around the object into a single measurement matrix [2], which is analyzed to yield an overall 3D model of the object. For constructing the 3D model, the triangulation theory was considered especially in obtaining the dynamic radius of the object. With laser line on the object, ample information could be gathered. The resolution is a very important parameter in acquiring an accurate surface map of the object. High-resolution means acquiring more information or matrix from the laser line for each positions. The surface map can be further improved by increasing the measurement position of the rotating table. But this also requires more processing power and proper matrix programming. The accuracy of the range and 3D coordinates of measured object point are determined by following factors:

- The calibration of the azimuth.
- The intensity of the laser.
- The accuracy of the matcher.

1.1. PREPROCESSING

The experimental set-up used a frame grabber (DT-Acquire 3135), a B/W camera, a laser diode, grating line, a moving table with 30 degree per step, Builder C++™ programming software and proper work-space. In the implementation described here, a laser diode with user adjustable focusing optics and the output wavelengths of 633nm and 670nm, and a camera with the width angle of 12 degrees was used.

II. STRIPED LIGHTING

Here the scene was lit by a sheet of light produced with a laser beam light source and cylindrical lens, but projecting a slit by using a standard slide projector is also feasible. This sheet of light is scanned across the scene, producing a single light stripe for each position. When the light source is displaced from a viewing TV camera, the camera view of the stripe showed displacements along a stripe which are proportional to depth, a kink indicates a change of plane and a discontinuity a physical gap between surfaces. In 1971 Shirai and Suwa[3] used a simple stripe lighting scheme with a rotating slit projector and TV camera recognize polyhedral shapes. In 1973, Agin and Binford[4] described a laser ranging system capable of moving a sheet of light of controllable orientation across the scene. A helium neon laser emitting 35 mW of red light at a wavelength of 6328 Å was thought adequate for use with the vidicon camera used. The work reported by Popplestone et al. [5] differs from Shirai's in that it deals with both cylindrical and plane surfaces and from both Shirai's and Agin's work in the development of body model specifically suited to solving juxtaposition problems in automatic assembly.
In 1975, Röcker and Keissling[6] discussed this problem along with difficulties associated with other

ranging techniques. In particular, they point out that, if more is to be extracted from a single image frame by using parallel grid illuminations, the strike identification problem causes a number of restrictions related to the following.

1) The image should contain parts of the supporting plane surface
2) Shadows cause line interruptions
3) Top surface lines should be distinguishable from ground plane lines
4) Scene with more than one object should not have hidden object planes

In 1985, Jeffrey A. Jalkio et.al [7] described a laser ranging system using multiple structured light. The simplest structured light project a single point of light from source onto an object for triangulation. In 1993, J. Kramer, P. Seitz and H. Baltes[8] used a spherical and a cylinder lens to convert a light sheet from diode laser.

III. EXPERIMENT

3.1. Triangulation theory

Many approaches can be utilised in this research, but due to the fact that the triangulation technique is a very familiar formulation to determine the distance of the images and also construction the images, it was chosen. Beside the triangulation technique, matrix technique was also used to draw the image in two-dimensional and three-dimensional format.

3.1.1. Camera and laser analysis

To simplify the analysis, a two-dimensional object system is considered. A camera and the laser with grating line are separated by a distance of *t*. The camera in-line with the object made an angle of 90 degree with the laser.

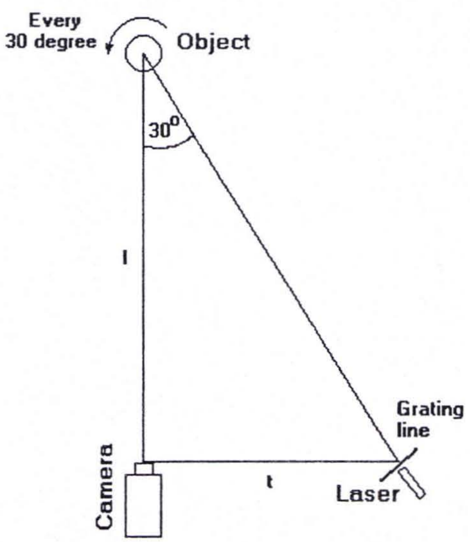

Fig.1: Camera and laser system

The length between the camera and the object is set to be 30 cm long. Fig. 1 shows such a camera and laser system. The camera and the laser grating line make an angle of 30 degree from the object.

With the triangulation techniques, the equation below is produced;

$$l = 30 centimeters$$

$$\tan 30 = \frac{t}{30} \quad (1)$$

$$t = \frac{\tan 30}{30} = 17,3 \quad (2)$$

3.1.2. Object analysis

The elegant techniques for object modeling is proposed here. Point P is an azimuth of the object and point L is the point, which the laser grating line makes a line in the object. Point C and Point L are separated by distance of Δt. Point P is tilted with an angle of 30 degree. The distance between point P and point L is *r*. For drawing the 3D image *r* is a radius. Fig.2 shows such an object system. With the triangulation techniques, the equation below is produced;

$$r = \frac{\Delta t}{Sin 30} \quad (3)$$

$$\Delta l = r.Cos 30 \quad (4)$$

Where:

Δt is calculated by the distance of point C and point L in the image.

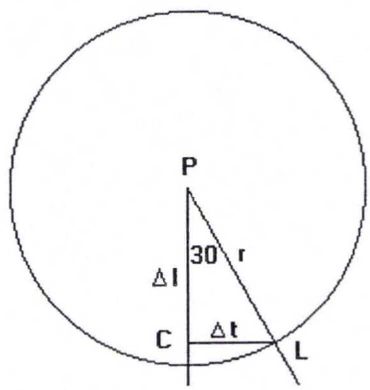

Fig.2: Object system

1.1.3. Distance of the image

The triangulation technique measures the distance from the object, which has a laser grating line to the camera. Fig. 3 shows such distance object system. After the program found the distance of Δt, With the triangulation techniques can get the distance of d. The equation is as shown below;

$$d = \sqrt{(\Delta t^2 + (30 - \Delta l)^2)} \quad (5)$$

Now the distance of the object is already known by equation (5).

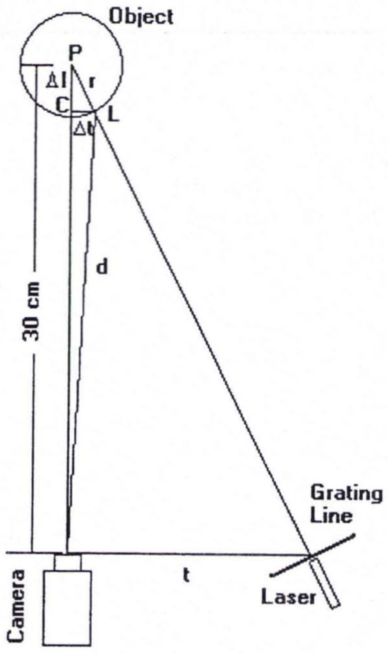

Fig.3: The distance object distance

3.2. The Three-Dimensional Theory

However, standard vision system provides only two-dimensional (2D) images of work area or finished product, unable to discern the distance to height of the object view. Recently, various 3D vision systems have been produced to alleviate this problem via several methods.

3.2.1. The Two-Dimensional Form

The two-dimensional pictures from rotation object describe about x-axis and y-axis. *r* is the radius of each point in the picture. Fig. 4 shows such points of the two-dimensional image.

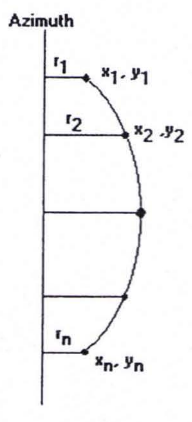

Fig.4. The points in two-dimensional form

3.2.2. The Three-Dimensional Form

It is possible to make the x and z magnifications independent of the z coordinate for a given laser grating line position by rotating the object and the azimuth of the object in the y plane. The length of the radius is calculated from the azimuth to the point in the laser grating line. From this calculation, the three-dimensional can draw to x-axis and z-axis. Fig.5 shows such three-dimensional drawing approach.

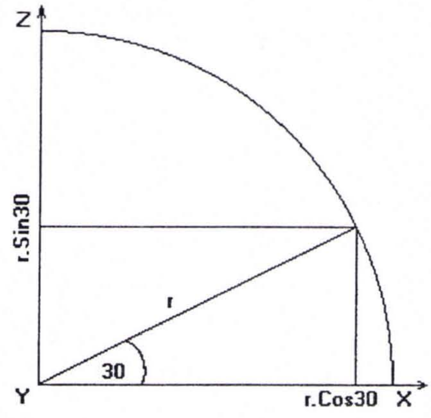

Fig.5: The three-dimensional drawing method

Here the calculation of the three-dimensional draws method.

$$x = r.Cos(n) \quad (6)$$

$$z = r.Sin(n) \quad (7)$$

3.2.3. The Matrix Technique

To develop an image produced by the triangulation, a matrix technique would be the best because the surface image can created by collecting all the projected feature points around the object into a single measurement matrix. To simplify the analysis, a two-dimensional system is considered. The camera and the laser grating line are separated by distance of t (shown in fig.1). The camera captures the image at the center of object, where the center of the object is also the zero coordinates between the camera and the laser grating line. This is shown in fig.6(a) where the laser grating lines are in the matrix form. The point of the matrix on the grating line object depends on the resolution of the image created. Many points on the matrices produced a much improved surface map. For constructing the image in the three-dimensional form, we need to turn the object. Fig.6(b) shows the turned object in a three-dimensional matrix.

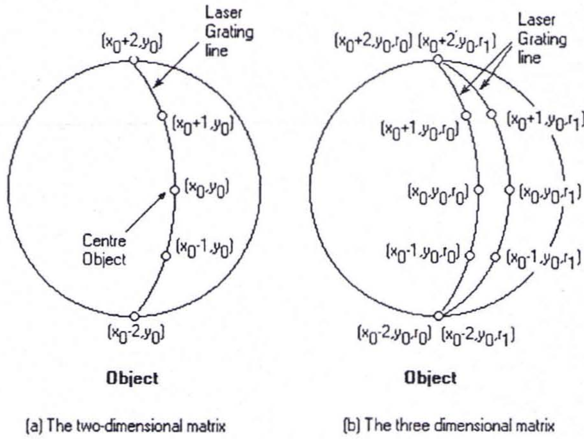

Fig.6. The matrix conversion

IV. RESULT

When the laser produces the outgoing beam, the beam passed to the grating line causing one line through to the object. The B/W camera with the width around 12^0 gets the object with the laser grating in-line. In the setup described above, the object field in the x-y plane depends on the turned angle (θ) and the distance Δt. For $\theta = 30^0$ and Δt measured by the image from the azimuth (point C) until the laser grating line is in the image (point L), in the software. To measure the distance Δt or point C to point L, the grey image must be converted into a B/W image. After converting the grey image to B/W image, the image was transformed into a black stripe. From this image, the distance Δt can measure from point C to point L with scale 1mm=10 pixels. After that, the distance of radius (r) of the object was measured. Hence, the radius of one point in the laser grating line was acquired, but to get the matrix of the object for drawing a perfect three-dimensional image, as many points as possible in one line. In the research conducted, the default of the number of point in one line is around 5, but it can be added until a perfect three-dimensional image is acquired. Fig. 4 shows such point in the two-dimensional image. After knowing the radius from the two-dimensional image, the radius in the x axis and z axis can be converted into a three-dimensional representation . The y axis never converts because the y axis is the azimuth of the object. Refer to the equation numbers [6] and [7]. From these equations, the matrix 5x12 for x, y and z axis was acquired as shown in table [1], [2], and [3].

Table 1. X-axis

357.0000	385.4100	391.5000	386.4310	357.0000
357.0000	381.6038	386.8779	382.4880	357.0000
357.0000	371.2050	374.2500	371.7155	357.0000
357.0000	357.0000	357.0000	357.0000	357.0000
357.0000	342.7950	339.7500	342.2845	357.0000
357.0000	332.3962	327.1221	331.5120	357.0000
357.0000	328.5900	322.5000	327.5690	357.0000
357.0000	332.3962	327.1221	331.5120	357.0000
357.0000	342.7950	339.7500	342.2845	357.0000
357.0000	357.0000	357.0000	357.0000	357.0000
357.0000	371.2050	374.2500	371.7155	357.0000
357.0000	381.6038	386.8779	382.4880	357.0000

Table 2. Y-axis

200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000
200.0000	240.4100	280.5000	320.4310	360.0000

Table 3. Z-axis

0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	14.2050	17.2500	14.7155	0.0000
0.0000	24.6038	29.8779	25.4880	0.0000
0.0000	28.4100	34.5000	29.4310	0.0000
0.0000	24.6038	29.8779	25.4880	0.0000
0.0000	14.2050	17.2500	14.7155	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	-14.2050	-17.2500	-14.7155	0.0000
0.0000	-24.6038	-29.8779	-25.4880	0.0000
0.0000	-28.4100	-34.5000	-29.4310	0.0000
0.0000	-24.6038	-29.8779	-25.4880	0.0000
0.0000	-14.2050	-17.2500	-14.7155	0.0000

These matrices gave the result from Mathlab™ program as shown in fig.7, i.e. the three-dimensional drawing. The three-dimensional mapping is not a very smooth drawing, because only the default point value of the program was used and furthermore, the angle of image rotation was fixed. If the default and the angle of the rotation are much smaller than 30 degree, e.g. 15 degree, a matrix of 5x24 matrix will be produced.

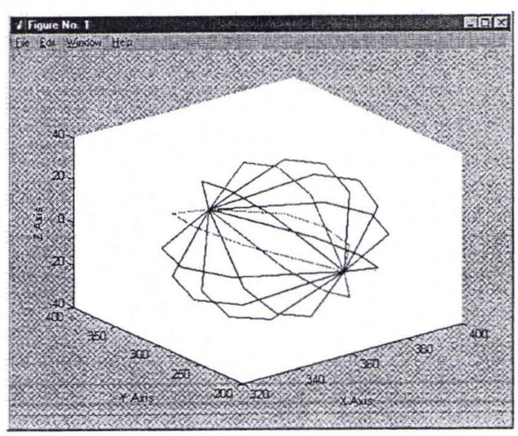

Fig.7. The three-dimensional drawing

The original image is shown in fig.8.

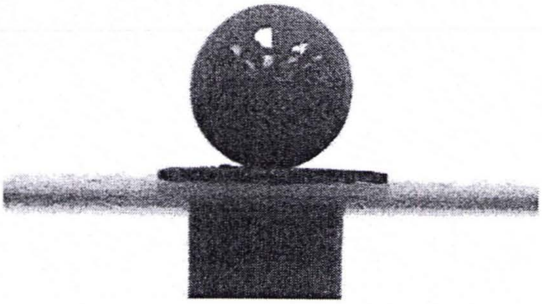

Fig.8. The original image

In three-dimension construction, the matrix will be draw like the image below. The shape of the image three-dimension will be smooth when the image are drawing with the many point of resolution, shown in fig.9. The three-dimension image will be seen from the X, Y and Z axis, shown in figure 10.

Fig.9a The Construction object sphere in 5-point resolution.

Figure 9b. The Construction object sphere in 100-point resolution

Figure 10. Recognition object sphere in X, Y and Z Axis.

In another example in this research, the object is totally different because the object is irregular (fig.11).

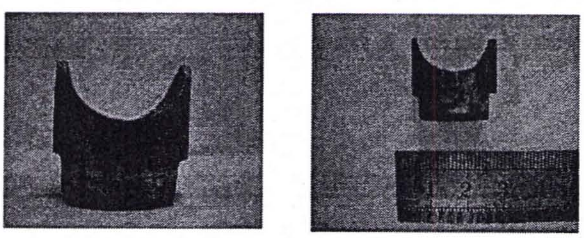

Figure 11. Irregular Object

The line and the resolution point will construct the three-dimension image. Like the sphere object, when the resolution point more than the default, the three-dimension will be smooth, shown in fig.12 and 13.

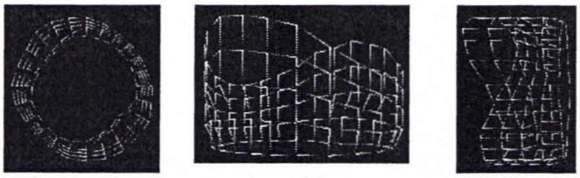

Fig.12. The Construction object Irregular in 5-point resolution

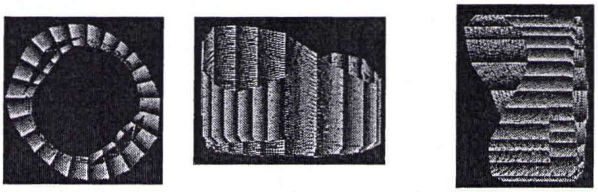

Fig.13. The Construction object Irregular in 100-point resolution

The recognition three-dimension image shown in X,Y and Z Axis in fig.14.

Figure 14. Recognition object irregular in X, Y and Z Axis

V. CONCLUSIONS AND FURTHER WORK

The B/W camera can measure the width of the object around 6.3 cm, this depends on the width angle of the camera. And the height of the image depends on the laser grating line. In this research, the height of the laser grating line was around 1.2 cm, since the optical lens where the beam diverge was limited by the laser. If a more accurate line is to be produced, the optical lens need to be re-arranged. The laser HeNe is sharper than the laser diode for getting a sharper and accurate line in the object. For getting a better surface mapping in three dimensions, the matrix must be larger than 5x12. This means, to produce a better quality surface map in three-dimension, the points which can be accommodated in the laser grating line must be larger than the default. And the angle of the rotation must be smaller than 30 degree. So from that result we got the matrix bigger than 5x12. The scale of the image around 1 mm = 10 pixel. Rendering the point of the image and putting some light to get a better shape illumination in the surface map can produce a better surface map. And for more perfect display, the surface mapping in the program should be able to rotate.

VI. ACKNOWLEDGEMENT

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