Laser Triangulation Based Object Height Measurement

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ABSTRACT

Today industries use manpower very wisely. More and more automation is adopted for tasks like inspection and measurements. Machine vision plays very important role here. Though two dimensions are captured by camera in form of image, it is not possible to cover third dimension by a single camera. This problem of finding height of object is addressed in this paper by using laser triangulation. In this paper, application of laser triangulation principle for height measurement is discussed along with related mathematics and geometry. Line extraction algorithms are discussed and implemented for this application, and results obtained are compared.

Keywords — Laser triangulation, height measurement, 3D measurement, machine vision, line extraction.

1. INTRODUCTION

Various measurement tools are available for different kind of measurements. Machine vision system provides great solutions for such purposes. Machine vision enabled industries to inspect various objects without human involvement. This results in saving manpower which can be utilized for better purposes. Still if a 3D measurement of some object is needed, then a single camera is not sufficient. Using a laser along with the camera this can be achieved. Principle of laser triangulation is used to measure elevation on or depth [3] in surface.

Laser source produces beam which seems thin when seen through naked eyes. When observed with camera, the line illumination has certain thickness. Crux of triangulation is finding the exact position of incident laser line. There are various algorithms available for line detection [2][4]. Few algorithms are discussed here. These algorithms are compared on the basis of results.

2. MEASURING PRINCIPLE

2.1. Laser Triangulation

Triangulation is technique to find distance of a point from fixed known line, provided that, angles subtended by endpoints of line to the point are known.

Same principle is used here to find height of object by using a laser and camera. Setup of laser and camera is shown in fig.1.

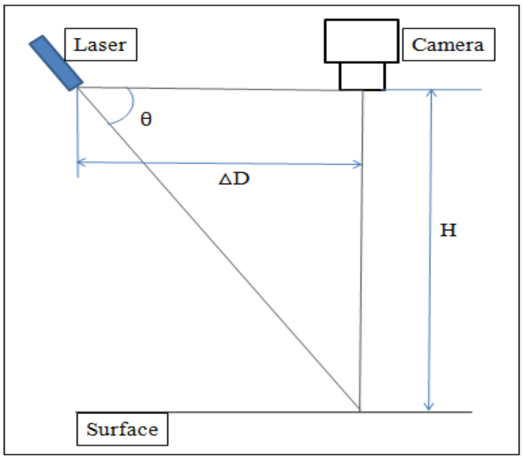

Fig-1: Laser triangulation geometry

Camera is perpendicular to the surface and laser is at an angle. Distance between laser and camera is 'ΔD', distance between camera and surface is 'H'. Laser is at an angle of 'θ' with the horizontal axis. From the geometry, following equation describes height (H) .

$$H = \Delta D \times \tan(\theta) \quad (1)$$

Similar geometry can be obtained if laser is setup vertical and camera is at an angle, but then it is tedious to retrieve 2D information from camera. Here, with this setup, 2D information taken from camera is untouched [1] [2] and is directly available for measurement.

2.2. Implementation

Equation (1) can be used for calculating height of object from the base surface. 'H' in fig.1.is height between camera and surface, when object is placed on surface, its height is less than 'H'.

Fig.2. shows height of object as 'H_{Obj}'. ΔD is not the distance between laser and camera but is distance between reference laser line and deviated laser line.(Henceforth in complete paper, ΔD represents laser line deviation). Fig. 1 and fig.2 present similar geometry, hence same mathematics is applied over fig.2.

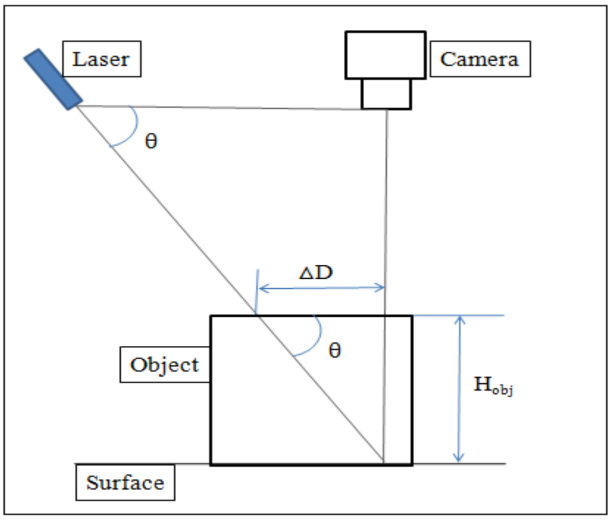

Fig-2: Laser triangulation geometry in presence of object

Object height can be given as

$$H_{Obj} = \Delta D \times \tan(\theta) \quad (2)$$

In this case, distance laser line deviation is measured with camera (Δd). But since camera returns this distance in terms of pixels, proportionality constant (K) is applied for conversion of Δd in pixels to ΔD in millimeters. Hence equation becomes

$$H_{Obj} = (K \times \Delta d) \times \tan(\theta) \quad (3)$$

For a given camera K is approximately constant over a distance. Also its exact value can be determined for a range of distances by calibration with known set of objects. Angle θ is constant for a given setup. Thus relation is,

$$H_{Obj} \propto \Delta D$$

$$H_{Obj} = \Delta D \times (C) \quad (4)$$

Where, C is constant.

Thus height of object is proportional to the deviation in laser line.

At the corners and at the edges of image in camera, straight line is seen curved due to lens distortion. Curve line can cause error in ΔD measurement. Hence, angle should be decided in such way that the deviation in laser line covers only limited area of image instead of covering complete image. Laser line deviation also depends on range of height to be measured. Thus, for a specific camera and lens, for a given angle, there is restriction on the overall height that can be measured.

3. IMAGE PROCESSING AND PARAMETER EXTRACTION

When an object is placed between camera and surface, as shown in fig.2, camera perceives deviation in laser line. This deviation can be seen in fig 3. Deviation depends on angle of laser. Lesser the laser angle with respect to horizontal axis more will be the deviation for the same height.

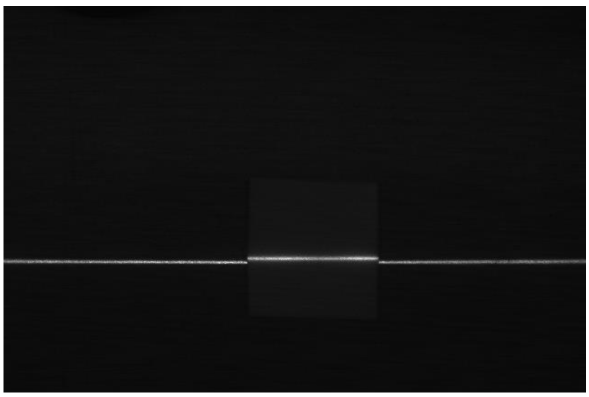

Fig-3: Deviation in laser line due to presence of object

From this image, ΔD should to be extracted for calculating height of the object. But image contains unwanted information including noise. Whole image therefore should be processed for removing unwanted information and thus extracting useful parameter.

3.1. Thresholding

Area covered by reference laser line to maximum deviated laser line is area of interest in image. That area is fixed by setting laser at corresponding angle. Since rest of the area is not useful for calculation purpose, intensity in that area is made zero.

Since laser illuminated area is brightest among all, thresholding is used for extracting image containing only laser illumination. Threshold image will look like fig.4.

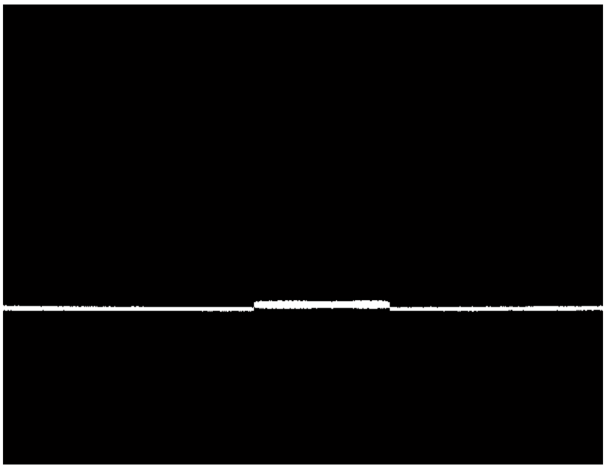

Fig-4: Image after processing

Thereafter important task is to find out deviation ΔD. For this task it is very crucial to consider thick laser line as a thin line so that every position on the line can be represented by point. This helps in positioning laser line accurately.

3.2. Laser Line Extraction

Title Finding impact position of laser line is a crucial in deciding the deviation due to object height. Incorrect estimation of laser line position is source of error. For accurate measurement, it is very necessary to find out precise ΔD.

Three line extraction algorithms are discussed below.

3.3.1. Midline Extraction

Fig.5. shows the geometry of laser beam projected on the surface. AB, CD and EF are laser line widths at height 3, height 2 and height 1.

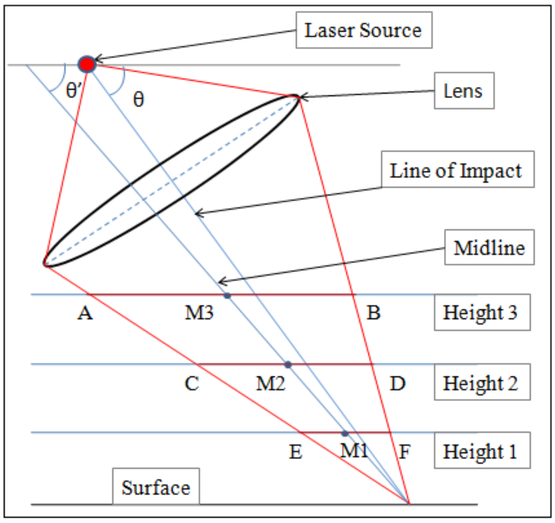

Fig-5: Illustration of laser beam geometry

Intensity profile of laser line is Gaussian fig.6. Hence maximum intensity lie on the central portion of line width.

In this method, for every column (j) of laser line, midpoint of laser line (M_j) is calculated.

$$M_j = (i_{min} + i_{max})/2………………(5)$$

With this, it is not possible to retrieve exact impact point positions of laser line. Since, laser is at an angle, midpoint of the laser line differs from impact point of laser (fig. 5).

Still, if, deviation in laser line (ΔD) due to object height, with midline extraction technique is calculated, it is possible to find height of object. This is because, the geometry remains same along with the equation, the only change will be in the proportionality constant. Following equations describe it well,

$$H1 = \Delta D \text{ x } \tan(\theta')$$

$$H1 = \Delta D \text{ x } (C1)…………………(6)$$

Where, C1 is constant.

Since here division is by 2, we will get midline point at the midpoint of pixel. So, maximum resolution of ΔD is half the pixel.

3.3.2. Intensity Maxima:

Fig.6. shows power distribution of laser beam around the centre of impact [6]. Since there is maximum power at the

centre, central portion has maximum intensity, which likely to be impact point.

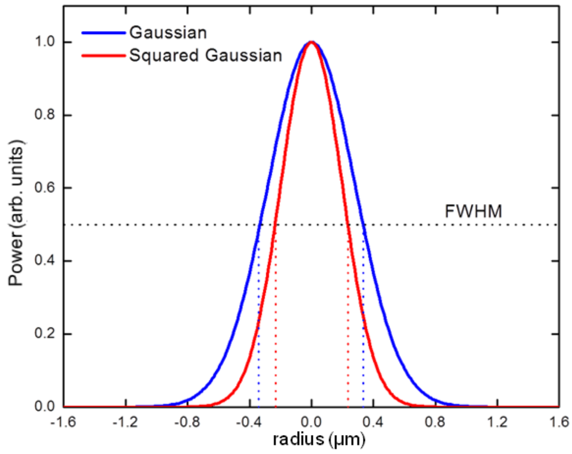

Fig-6: Power distribution profile of a laser

In this method maximum intensity pixel is considered as impact point of laser line. Algorithm scans intensities along the column and save their values with the respective locations. Then using sorting maximum intensity value is found out and corresponding pixel is considered as impact point for the column.

$$P_j = \text{position}\{\max(\text{intensity}(i\ ,\ j))\}$$

Though this method reliably finds impact point, resolution of (ΔD) is one pixel, which is even lesser than midline extraction. All the in-between values are approximated in this method.

3.3.3. Center of Mass:

In this method, weighted average of column vector is taken. Different pixel intensities are different weights. Every pixel in column is multiplied by its weight. Sum of all such multiplications divided by total weight gives centre of mass for particular column. Same procedure should be applied for all columns.

$$C_j = (\sum \text{Intensity}(i\ ,\ j) \times j) \,/\, \sum \text{Intensity}(\ i\ ,\ j)$$

Here in this method, resolution doesn't have any restriction. This is an advantage over previous two methods.

4. MEASUREMENT RESULTS

For implementation and testing of above methods, chips of 2 millimeter thickness are used. Experimental setup consists of line laser of 650 nanometer wavelength, camera with resolution of 640 x 480 pixels. Height of object from ground level is increased by stacking chips one above another. Calibration is performed with set of objects with known height [5]. Best linear fit function is used for system calibration.

Using three algorithms given above, different heights were measured and the errors are compared. Resultant readings of Δd are shown in Table 1 and corresponding calculated heights are shown in Table 2, errors in height measurement are tabulated in Table 3. Table 4 shows average of absolute errors.

TABLE I.

COMPARISON OF LASER LINE DEVIATION IN CAMERA

Actual Height (mm)	**Δd (pixels)**		
	Midline Extraction	***Intensity Maxima***	***Centre of mass***
2	5.50	5.0	5.309
4	10.0	10.0	10.273
6	15.0	15.0	15.553
8	20.5	21.0	20.968
10	25.5	26.0	25.905
12	31.5	31.0	31.711
14	37.5	37.0	37.411
16	43.5	43.0	43.072
18	49.0	48.0	48.673
20	54.5	54.0	54.53

TABLE II.

HEIGHT OBTAINED AFTER CALCULATIONS

Actual Height (mm)	**Calculated height (mm)**		
	Midline Extraction	***Intensity Maxima***	***Centre of mass***
2	2.427	2.203	2.233
4	4.047	4.033	4.040
6	5.847	5.863	5.962
8	7.827	8.059	7.933
10	9.627	9.889	9.730
12	11.787	11.719	11.843
14	13.947	13.915	13.918
16	16.107	16.111	15.979
18	18.087	17.941	18.017
20	20.067	20.137	20.149

TABLE III.

ERROR COMPARISON

Actual Height (mm)	Error in height measurement(mm)		
	Midline Extraction	***Intensity Maxima***	***Centre of mass***
2	-0.427	-0.203	-0.233
4	-0.047	-0.033	-0.040
6	0.153	0.137	0.037
8	0.173	-0.059	0.066
10	0.373	0.111	0.269
12	0.213	0.281	0.156
14	0.053	0.085	0.081
16	-0.107	-0.111	0.020
18	-0.087	0.059	-0.017
20	-0.067	-0.137	-0.149

TABLE IV.

AVERAGE ABSOLUTE ERROR IN HEIGHT

	Midline Extraction	***Intensity Maxima***	***Centre of Mass***
Average Error	0.17	0.121	0.107

5. COMPARISON OF METHODS

Out of above three methods of laser line extraction, midline extraction is easiest to implement. Minimum calculations are required for this method as compared to intensity maxima and centre of mass. Thus from implementation and processing point of view, midline extraction is most optimal algorithm.

From Table 1 it is seen that deviation Δd is rounded up in midline extraction. Hence due to lesser resolution of Δd, accuracy suffers in this algorithm. Intensity maxima have good capability to find impact point, but its resolution is limited to one pixel. Hence intensity maxima algorithm has better accuracy than midline extraction but still has limitations on accuracy.

Error is lesser when deviation is calculated using centre of mass method. Table 2 shows the error comparison. Centre of mass has minimum error, than intensity maxima and midline algorithm. Hence centre of mass algorithm is most reliable out of above three algorithms.

As the range of Measurement here is 20 mm. Average error in calculated height with midline extraction technique is 8.5%. For Intensity maxima and centre of mass, error is 6.05% and 5.35% respectively. As the range of measurement increases, maximum error will increase. Hence if measurement range is increased further more than 20mm, maximum error will increase.

6. CONCLUSIONS AND FUTURE SCOPE

In this paper, use of laser triangulation principle for height measurement is discussed. Implementation of the principle using camera and a line laser is described briefly. Image processing required for parameter extraction along with the line extraction algorithm is described and discussed. Comparison of the line extraction algorithms based on acquired results is done, which states that centre of mass algorithm is better from accuracy point of view and midline extraction algorithm is better from calculation point of view.

In future, 3D profile generation will be studied and implemented with the help of 2D image data and height at every profile point.

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