Laser-based non-contact dimension measurement of an object

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Abstract : This paper presents an optical technique to measure the dimensions of a hexagonal object having cylindrical cavity at the centre. A red line diode laser has been used as the light source which scans the object with the help of a manually operated mechanical arrangement. The images captured by a camera during scanning are subjected to preprocessing. 3-D coordinates of all the laser illuminated points on the surface of the object are calculated using optical triangulation method. Delaunay triangulation algorithm is applied for surface reconstruction from the acquired point set so that dimensions of the object can be extracted. The extracted features are compared with that of the original object and the results are found to be satisfactory.

Keywords: Laser, Dimension, Data acquisition, Optical triangulation, Surface reconstruction.

1. INTRODUCTION

Accurate measurement of dimensions of the final product is an important aspect in manufacturing industries. Optical techniques for dimension measurement are very much suitable in special cases because of their non-invasive nature [1]. Laser illumination is used in stead of incandescent or fluorescent light for the following reasons:

- Lasers can be focused tightly over long distances.
- Lasers have an extremely narrow radiation spectrum.

The first property allows to make very tight beams or narrow stripes to improve the resolution of the system. The second property allows to achieve relatively high immunity to ambient illumination in the environment [2, 3].

3-D reconstruction is the process of generating a three dimensional representation of an object or scene from the observations at lower dimensions. Multiple observations at lower dimension are combined together to generate complete 3-D view. 3-D reconstruction of an object usually takes place in three main steps. These are data acquisition, registration and integration [4]. A range sensor is used to acquire the geometric shape of the exterior of the object. Occlusions, as with most imaging systems, occur when surfaces of an object obstruct the full view of other surfaces of the same object. A single scan provides a range image that covers only part of an object. Therefore, multiple scans are necessary to capture the entire surface of the object. Objects of complex shape may require a large number of range images so that all of the surface detail is captured. In general, methods of acquiring 3-D data can be divided into passive sensing methods and active sensing methods. Passive approaches do not interact with the object, whereas active methods do, making contact with the object or projecting some kind of energy onto the surface of the object [5]. Registration is the process in which the multiple views and their associated coordinate frames are aligned into a single coordinate frame. The integration process eliminates the redundancies and generates a single connected surface model. Most commonly used algorithm to generate triangulated surface from an unstructured point set is Delaunay triangulation algorithm [6].

In this work, we present a technique using laser to obtain the dimensions of an object in 3-D space. Optical triangulation method is utilized to obtain the depth information of the object. Delaunay triangulation algorithm is applied on the acquired coordinate points to obtain a smooth surface representing the object. Lastly, structural features are extracted from the reconstructed model and a comparison with the original structural values is performed. The complete process algorithm has been implemented using MATLAB as programming tool.

2. EXPERIMENTATION DETAILS

We have taken a measuring weight that is hexagonal in shape having a cylindrical cavity at the centre for the experimentation purposes. The diameter of the hexagonal surface of the object is 8cm and the height is 3.2 cm. Radius of the cylindrical cavity is 2.7 cm and its depth from top surface is 1.1 cm. The original object is shown in Fig. 1.

Fig. 1: Original object

The object is placed on a horizontal and smooth platform. A red line diode laser (30 mW at 635 nm), which spreads the laser beam into a sheet of light with a cylindrical lens (Fig. 2) is placed on a mount.

Fig. 2: Laser source.

The sheet of laser is projected onto the object. The intersection of the laser plane and the object creates a stripe of illuminated points on the surface of the object. Part of the laser sheet falls on the platform on both sides of the object. A charge coupled device (CCD) camera interfaced with a Silicon Graphics machine acquires the image. The laser plane scans the object with the help of a manually operated mechanical arrangement on the mount such that entire object is covered. The series of images are captured by the camera during the scan. The experimental setup is shown in Fig. 3.

Fig. 3: Experimental setup.

3. OPTICAL TRIANGULATION

The method of optical triangulation is being used to in this work to acquire 3-D data of the object. The laser source, object and the camera form a triangle; hence, this method is called optical triangulation. It is also called structured light method because a special light pattern is projected onto the scene.

When the laser stripe falls on the object, several points on the object get illuminated. The laser line on the platform is considered as the base line for the particular scan. The displacement between the illuminated points and the points where the laser would have fallen in absence of the object (base line) is proportional to the depth of the object at that point. Fig. 4 shows relative position of object with respect to laser source and camera.
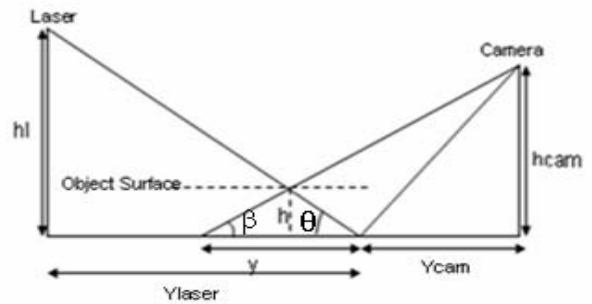

Fig. 4: Relative position of laser, object and camera.

Here hcam is the height of camera from the platform, Ycam is the horizontal distance of the camera from the laser line on the platform, β is the angle between camera view through the laser line on the object and the platform, hl is the height of laser source, Ylaser is the horizontal distance of laser source from the laser line on the platform, θ is the angle which laser line makes with the platform, h is the height of the object at the illuminated point and y is the displacement between the laser line on the object and that on platform.

From Fig. 4,

$$y = \frac{h}{\tan \theta} + \frac{h}{\tan \beta} \qquad (1)$$

and hence,

$$h = \frac{y \tan(\theta) \tan(\beta)}{\tan(\theta) + \tan(\beta)} \qquad (2)$$

It is clear from Eq. (2) that height h of a particular illuminated point is proportional to the displacement between the laser line on the object and that on platform considering the fact that θ and β are constant for the particular point.

4. PROCESS ALGORITHM AND RESULTS

The beam of laser is projected on to the surface of the object. The laser beam illuminates some points on the object. This pattern of illuminated points is captured by the camera. The scanning is repeated several times with known beam positions using the mechanical arrangement such that the entire object is covered. Complete setup is undisturbed through the whole process. A scanned RGB image is shown in Fig. 5.

Fig. 5: Laser scanned image

The captured RGB images are converted into a grayscale intensity images by eliminating the hue and saturation information while retaining the luminance. The gray image is being converted to binary image by defining a global threshold level to separate the desired laser illuminated pixels from the background. A grayscale image and its binary image are shown in Fig. 6 (a) and (b) respectively.
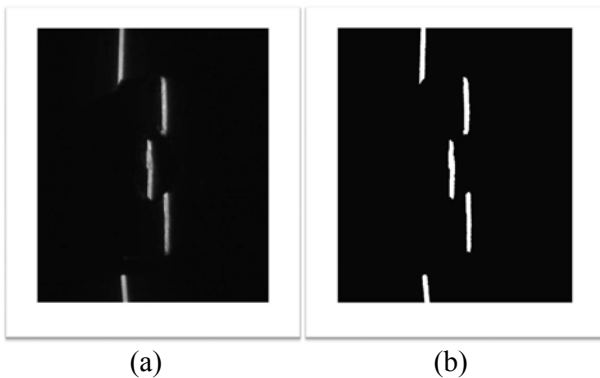

| (a) | (b) |
Fig. 6 (a) Grayscale image (b) Binary image

With the help of Eq. (2), the coordinate values in 3-D space (X, Y, Z) for all the illuminated pixels in the acquired images have been calculated and stored. The laser points on the platform have been removed as the points on the surface of the object are the desired points for 3-D reconstruction. All the points are considered to be a point cloud on the original object which is shown in Fig. 7. Color bar on the right side shows the Z values.
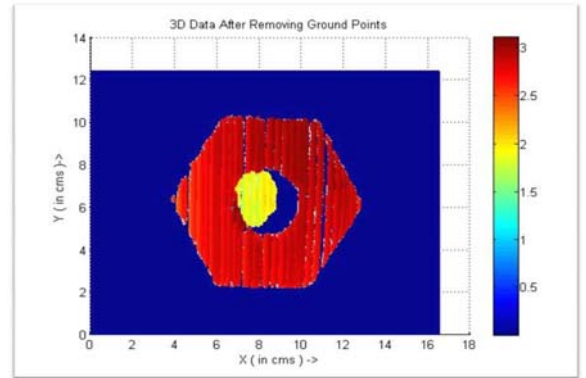

Fig. 7: 3-D point cloud

The cloud of 3-D points, thus obtained, need to be connected in such a way that it looks like a smooth surface. This requires interpolation, as there will be missing points on the surface of the object which are not collected by the laser scans. Delaunay triangulation is a very popular algorithm for this purpose. A Delaunay triangulation of a vertex set is a triangulation of the vertex set with the property that no vertex in the vertex set falls in the interior of the circumcircle of any triangle in the triangulation. Our algorithm uses triangle-based linear interpolation method based on Delaunay triangulation of data for surface fitting. A median filter of window size 5×5 is used to create a smooth surface. The median filter is used to reduce noise in the data set while still preserving the necessary details. It provides excellent noise reduction capabilities, with considerably less blurring than linear smoothing filters of similar size. The median filter considers each point in the grid in turn and looks at its nearby neighbors to decide whether or not it is representative of its surroundings. It then replaces the point with the median of those values. The mesh representing the surface of the object has been shown in Fig. 8.
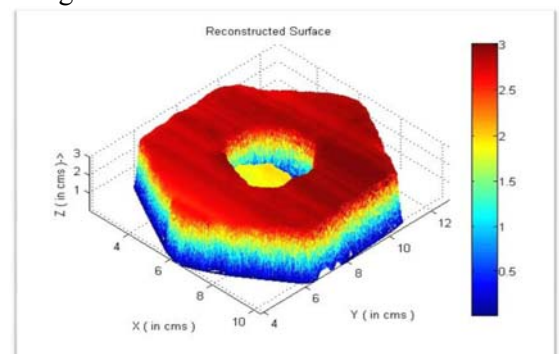

Fig. 8: Reconstructed surface of the object

Various structural features are extracted from the reconstructed model and compared with that of the original object. The comparison values are shown in Table 1. The dimension measurement results are quite satisfactory when compared with the actual values.

Table 1. Comparison of dimensions

Dimension	Original object (cm)	Reconstructed model (cm)	Error (%)
Diameter	8.0	8.8	-10.0
Height	3.2	2.9	9.3
Cavity radius	2.7	3.0	-11.1
Cavity depth	1.1	1.0	9.0

5. CONCLUSION

In this paper, a non-contact method of dimension measurement of an object is presented. A data acquisition system involving a laser source and a CCD camera interfaced with Silicon Graphics machine has been developed for this purpose. The optical triangulation method has been used for the data acquisition as it provides dense and accurate 3-D data. The acquired data points have been rendered into a smooth surface using triangle-based linear interpolation based on Delaunay triangulation algorithm. Smoothing of surface points has been done using a 5×5 median filter. Increasing the window size for median filtering can give more smoothness but at the cost of reduced accuracy in structural features. The dimension measurement results of the reconstructed model are quite satisfactory when compared with that of the original object. Accuracy in measurement can further be improved using high resolution camera and finer laser. Poor reflectance characteristics of the object can be a source of error in this technique.

The proposed approach can be applied for the dimension measurement of any other similar object with minor modifications in the algorithm.

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