



## Reconstruction of 3D Shape for an Object using Laser Scanning Triangulation

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(Received 4 April 2006; accepted 24 July 2008)

**Abstract:** This paper presents a method of designing and constructing a system capable of acquiring the third dimension and reconstructs a 3D shape for an object from multi images of that object using the principle of active optical triangulation. The system consists of an illumination source, a photo detector, a movement mechanism and a PC, which is working as a controlling unit for the hard ware components and as an image processing unit for the object multi view raw images which must be processed to extract the third dimension. The result showed that the optical triangulation method provides a rapid mean for obtaining accurate and quantitative distance measurements. The final result's analysis refers to the necessity of using laser light in the active optical sensing technique for its unique characteristics.

### Introduction

The need for non-contact three-dimensional (3D) data capture system capable of acquiring dense geometric data from complex surfaces has increased considerably over the past few years and this is due to their wide range of applications ranging from anthropometry to reverse engineering, including automatic control manufacturing, and robotics.

The vast majority of non-contact 3D data capture systems are optically based. They are based on any one of a wide variety of 3D optical sensing techniques, such as laser scanning triangulation, laser time-of-flight, phase measuring profilometry and digital stereo photogrammetry. Each method has its advantages and drawbacks and is therefore suitable for different applications [1]. In order to take full advantage of these vision systems, one must understand not only their advantages but also their limitations. In the last twenty years, many advances have been made in the field of

solid-state electronics, photonics, and computer vision and computer graphics. Non-contact 3D measurement techniques like those mentioned above are examples of fields that have benefited from all of these developments [2]. Optical sensing systems, especially those working with the principle of triangulation, have been an active area of research for decades in order to develop their techniques and reduce their disadvantages. The developed systems range from those that require many images to reconstruct a surface to those that require fewer images. Among these systems the swept stripe scanner is the most common one. A plane of light sweeps across a surface while a CCD array images the stripe reflection and triangulates to the light plane, scan line by line [3].

### Principle of Optical Triangulation

The basic geometrical principle of optical triangulation is shown in Fig. (1-a).

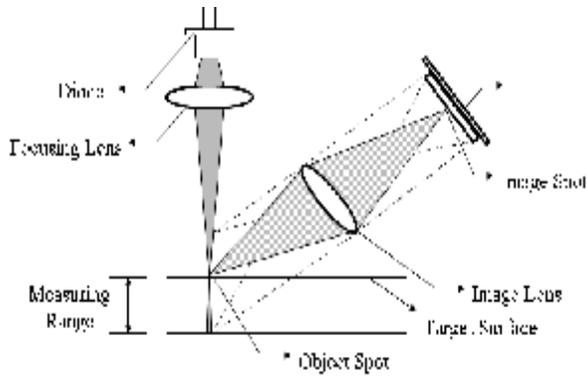


Fig. (1-a) Optical triangulation principal

A light source and focusing optics generate a collimated or focused beam of light that is projected onto an object surface. An imaging lens captures the scattered light and focuses it onto a photo detector. The collection of the scattered light from the surface of the object is done from a vantage point distinct from the projected light beam to acquire a full 3D image for that object. The photo detector may be either a lateral-effect detector for high-speed measurement, or a CCD for environments with high background light. As the target surface distance changes, the imaged spot shifts due to parallax. Knowing the angle  $\theta$  of the triangle relative to its base (baseline  $b$ ) determines the dimensions of this triangle as in Fig. (1-b).

To generate a three-dimensional image of the object surface, the object is scanned in two dimensions, thus generating a set of distance data that represents the surface topography of that object [4]. The current work aims to design and construct a laser scanning system working with the principle of optical triangulation capable of acquiring the third dimension and reconstruct a 3D shape for an object.

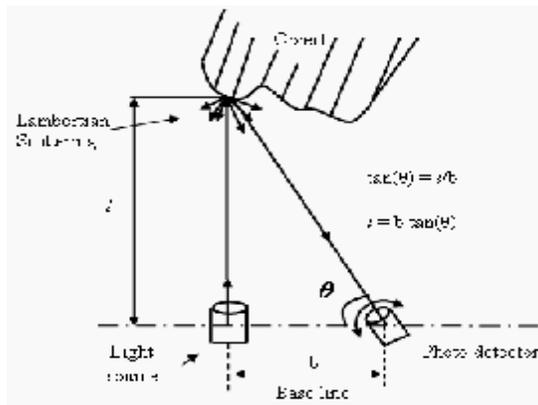


Fig 1-b: Optical triangulation geometry.

## System Design

The laser scanner device, which was designed during this study, is working with the principle of optical triangulation which is recommended because most of the optical sensors and probes for measurement and inspection employ it. The system consists of four main parts, as hardware components, including an illumination source which consists of a semi conductor laser (laser diode: Power=5mW; wavelength=680 nm) with a home made polygon mirror scanner which in turn consists of a polygon-shaped mirror mounted on a fast-rotating shaft, the sides of the polygon are polished to a mirror finish to sweep the light across the object and scan it vertically. The second part is a photo detector which is a CCD camera, 3.1 mega pixel from Mercury, model VQ 2220. Its focal length is 9 mm; the video capture resolution is 320\*240. The third part is a home made rotary table to place the object on during the test and scanned it horizontally. It consists of a circular flat table (10 cm diameter), stepper motor (24V DC, 1.8 degree step), and the stepper motor driver printed board. The last part is the controlling, operating and image processing unit which is a Pentium four personal computer. It employs four different programs as software components. The first one is the video capture program to operate the digital camera and capture the images, the second one is a quick basic program for driving and controlling the stepper motor, the third and the main program is for image processing and extracting the third dimension for the scanned object. Finally a 3D max program was used to display the result graphically.

## Scanning procedure

The operation is started by mounting the object on a fixed point at the center of the rotary table to maintain that an image of a small portion of the scene is focused upon the CCD camera. Then the laser source, which is laterally displaced from the camera and the polygon mirror scanner, should be turned on. A narrow beam of light swept over the scene and scanned the object vertically, while that the rotary table started to rotate, driven by the stepper motor, with a fixed angle to scan the object horizontally. The known directions associated with source and detector orientation at the

instant the detector sees the light spot on the scene are sufficient to recover range if the displacement between the source and the detector is known. The detecting system should be made to look at raster sequence of scene points then by sweeping the source beam in the suitable plane for each position and recording the relevant angles when a strike is detected a reliable range image can be easily constructed. To capture a 3-D scene for the object from these range images it is necessary to scan multiple views for at least tow different scene. Then these different set of images should be processed in order to extract the object third dimension. Figure (2) explains the system set up according to the scanning procedure.

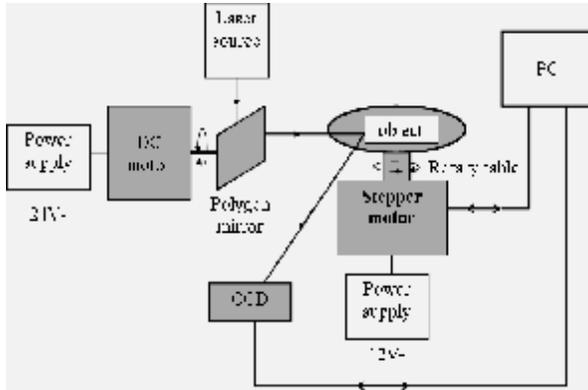


Fig. (2): Scanning procedure

### Image Preprocessing

The collected images during the test are digital images recorded in JPG, or BNP format. They should be reprocessed and then processed to extract the third dimension from them. The reprocessing step includes converting these raw images into another type in order to be ready to be processed; this type called IMG, which is the image of real matrix values.

The images dimensions were 340 in columns and 240 in rows with DN values expanded from 0 to 255. The images format is a colored (3-band) image, JPG or BMP. Due to the use of laser light, they were of a single band (red only) i. e. the values of red, green, and blue, were 255, 0, and 0 respectively. The image preprocessing algorithm consists of edge detection and noise removing done automatically in the same

program. The edge detection criteria can be summarized as follow:

1. Selecting a 3X3 window and compute the window mean value; this will be done for all image size sequentially.

$$Mean = 1 / 9 \sum_{i=1}^3 \sum_{j=1}^3 f(x_i, y_j) \quad (1)$$

2. Comparing each window value with mean, i.e. if pixel value > mean assigned its value as 255, else, write it as 0. The result will be binary image.

$$\sum_{i=1}^3 \sum_{j=1}^3 f(x_i, y_j) \leq Mean \Rightarrow f(x, y) = 0 \quad (2)$$

$$\sum_{i=1}^3 \sum_{j=1}^3 f(x_i, y_j) \geq Mean \Rightarrow f(x, y) = 255 \quad (3)$$

3. Constructing an edge image from the binary image to isolate the noise values. The noise isolating and removing criteria consists of the following steps:

- a- Selecting a 3x3 window for all image size sequentially.
- b- Detecting the isolated pixels, which are random noise, the decision for isolation state can be given as:

$$\sum_{i=-1}^3 \sum_{j=-1}^3 f(x_i, y_j) = 0 \text{ and } f(0,0) \Rightarrow f(0,0) \text{ isolated} \quad (4)$$

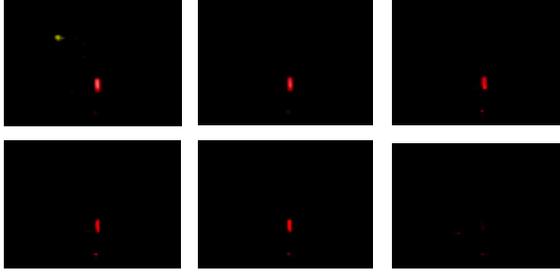
- c- Assigning the isolated pixel value as zero.

4. The above steps are done for the red band only (due to laser light), for the other bands (green & blue), rewrite all pixels values as zero. This process is to remove the random colors that appear in the collected images.
5. The final step is to enhance the target shape with respect to the high row and column number. Figures 3 and 4 show the images after and before preprocessing.

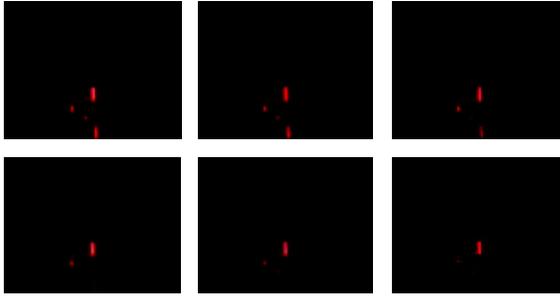
### Results

After preprocessing the raw data which is the primary result of the system they should be processed to extract the third dimension by an adaptive detection algorithm built by the researcher using computer program written in visual basic facility version 6.0. In fact, the

preprocessing and detection criteria will be run automatically according to this program. The whole detection steps can be given as follow:

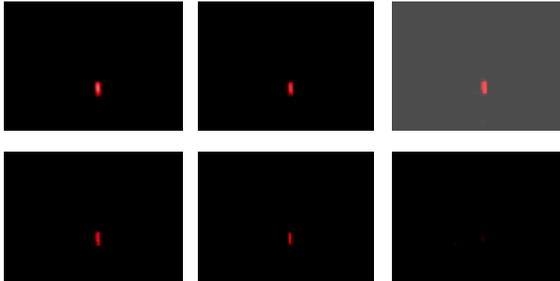


A- Raw data (first set of image).

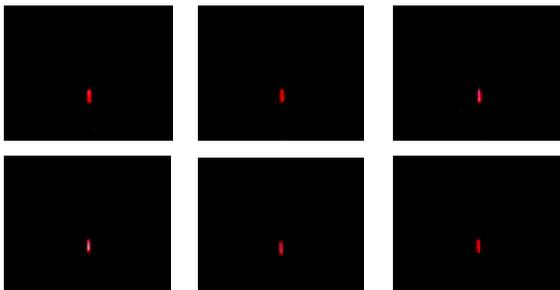


B- Raw data (second set of image).

**Fig. (3)** The Raw collected images.



A-First set of images



B- Second set of images

**Fig. (4)** The new images after Preprocessing.

1- The first step is reading the data sets as multi images (JPG or BMP), then converting them into (IMG) format. This will be accomplished by detecting the images values and saving them in a new binary file.

2- Applying the above preprocessing in order to remove the noise and prepare the images to the detection process.

3- For each image, the program searches for starting point of a target (target image), and fixing this point (xs, ys), this will be done according to the following condition;

$$\sum_i^{i+10} \sum_j^{j+10} f(x_i, y_j) \geq 200 \Rightarrow fix(i_s, j_s) \quad (5)$$

4- Starting from point (xs, ys) and for particular row, finding the number of column in that row, denoting this number for this i image. Then applying the same detection for other images sets, and finding the mean number of pixels for that dimension as in Eq. (6). (This process was easy to perform due to the using of monochromatic light, i. e. laser light).

$$\sum_{k=1}^l \sum_{i_s}^{i_s} \sum_{j_s}^{j_s+n} f(x_{i_s}, y_{j_s}) \geq 200 \Rightarrow fix(n_k) \quad (6)$$

where; l is the No. of images set, nk is the k number of pixel in that column.

5- Starting from point (xs, ys) again but this time for particular column, finding the number of row in that column denoted this number for this i image. Apply the same detection for other images set, and find the mean number of pixel for that dimension as in Eq. (7)

$$\sum_{k=1}^l \sum_{i_s}^{i_s+m} \sum_{j_s}^{j_s} f(x_{i_s}, y_{j_s}) \geq 200 \Rightarrow fix(m_k) \quad (7)$$

6- Transforming the coordinates from pixel values to real world values; this will be done using the resolution of image and the setup scale.

$$R = I * T \quad (8)$$

where R is the real image dimensions matrix, (x, y) in cm. I is the recorder dimensions matrix, (x, y) in pixel, and T is the transformation matrix as explained in Eq. (9)

$$[x_r, y_r] = [n_i, m_j] \times \begin{bmatrix} t_1 \\ t_2 \end{bmatrix} \quad (9)$$

7- At this point, two dimensions of the object will be detected. In order to detect the third dimension all these previous steps should be repeated for the second set of images for another object scene. The dimension detection algorithm is explained in the flow chart shown in Fig. (5).

At the end of the previous program the system managed to display the three dimensions numerically. Using these results and a 3-D Max program version-7 the results could be displayed graphically.

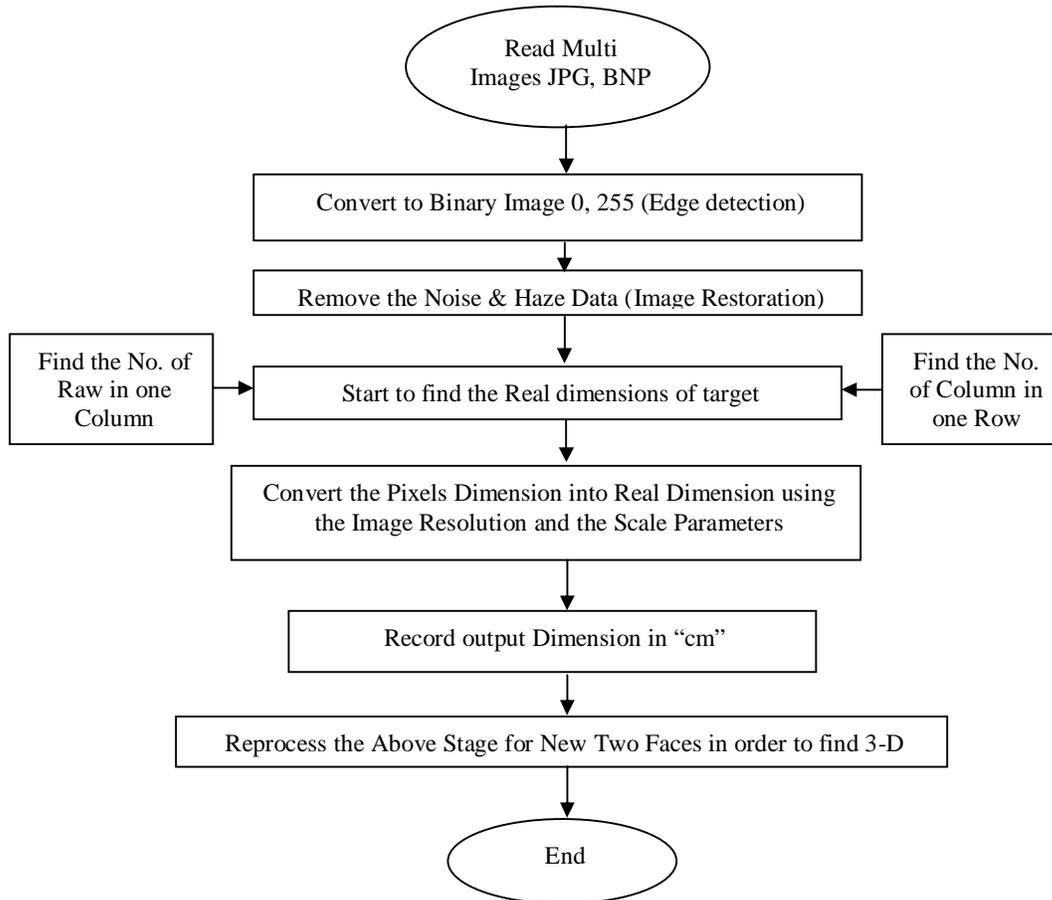
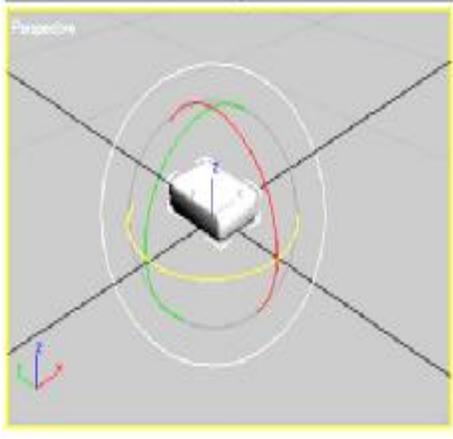


Fig. (5) Flowchart of dimensions detection algorithm.

### Discussion

By comparing the final reconstructed 3D shape with the original tested object, it is clear that the result is approximately identical as illustrated in Fig. (6). The accuracy of the designed system is affected by many parameters. First and most important one is the technical parameters of the hard ware components, such as the accuracy and resolution of the photo detector and the number of resolvable spots of the illumination source. The second parameter is that the material of the object has great influences on the quality of the collected images.

The best one among the tested material is the white rubber while the worst one is metallic shiny objects (the metallic shiny objects affected the result badly due to scuds refutation). Another important parameter is the position of each of the three main parts of the system (the object, the illumination source and the photodetector) and the angles between them which should follow the optical triangulation geometry. The larger the base line distance between the detector and the light source the more accurate the ranging but more prevalent the missing parts problem caused by directional occlusion. Also closer ranges can be more accurately measured.



(a) The final result.



(b) The original tested object

**Fig. (6)** Comparing the final result with the original object.

## Conclusions

The laser scanner is a versatile active non-contact device for 3D measurements and the Optical triangulation is a reliable and practical method to be used with such systems. It provides a rapid and simple mean for obtaining acceptable and quantitative distance measurements, as long as the system design following the geometrical conditions exactly and the object material is suitable. Using laser light with this method is so important and reduces the image processing algorithm complexity for the unique laser characteristics especially the Directionality and the mono chromaticity.

## References

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## أعادة بناء صورة لجسم ثلاثي الأبعاد باستخدام تقانة التثليث بالليزر الماسح

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**الخلاصة** يهدف البحث الى دراسة تصميم وبناء منظومة تقوم بتشكيل هيكل ثلاثي الأبعاد لهدف معين من مجموعة صور تلتقط عن بعد باستخدام تقانة التثليث البصري . تتكون المنظومة من مصدر أضواء وكاشف ضوئي وقاعدة متحركة وحاسوب يعمل كوحدة سيطرة والمعالجة الصورية للصور الملتقطة لاستخراج الشكل المجسم . أظهرت النتائج ان طريقة التثليث البصري توفر وسيلة سريعة لقياسات الأبعاد بشكل دقيق . وقد تبين من خلال تحليل النتائج بأن هنالك ضرورة لأستخدام الليزر في هذه التقانة نظراً لما يمتلكه من صفات جيدة .