

# Triangulation-based 3D image processing method and system with compensating shadowing errors

D.Costineanu, C.Fosalau, C.Damian, O.Plopa

„Gh.Asachi” Technical University of Iasi, Bd. D.Mangeron 53, Iasi, Romania,  
tel. +40 232 278680, fax +40 232 237627, e-mail costineanu\_dumitru@ee.tuiasi.ro

**Abstract-** The 3D points of a surface can be calculated from images achieved from two CCD cameras using stereoscopic methods. Classical procedures based on matching algorithms give errors at the highly curved or stepped surfaces. In this paper, we present a method to achieve a very high precision of measurement for surfaces with steps or holes, using a 3D multibeam scanner laser.

## I. Introduction

Generally, the vision measurement techniques may be grouped in two main categories: Active Vision, and Passive Vision. Active Vision refers to the techniques that use a controlled source of structured energy emission such as scanning laser source or projected pattern of light, and a detector, such as a camera. Alternatively, Passive Vision does not use a specific structured source of energy in order to form an image; hence, the light source may not be directly used in the range calculation.

The projection of the laser on the surface is used to measure the 3D surface with different methods. Of all known methods for 3D imaging, triangulation provides the most practical way for obtaining a high speed-accuracy product [1,2]. The triangulation method provides many advantages but it is not immune to certain types of errors provoked by occlusion or shadowing. The problem may be one of the two cases: either the laser light does not reach the area seen by the camera (Laser Occlusion, figure 1) or camera does not see the area reached by the laser (Camera Occlusion, figure 2).

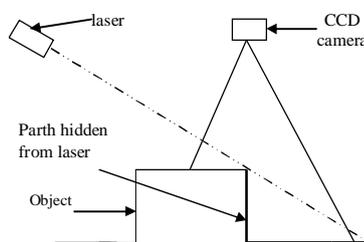


Figure 1. Laser occlusion

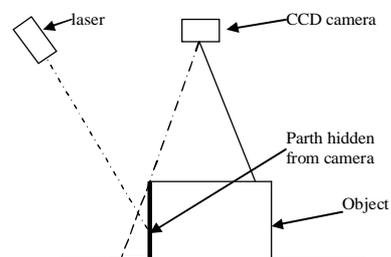


Figure 2. Camera occlusion

Laser occlusion is avoided by ensuring that laser reaches all areas seen by the sensor or that the optical center of the laser lens is further away from the scene optical center of the sensor. It can also be avoided with multiple laser sources or using a laser multibeam which has a great area of coverage (figure 3).

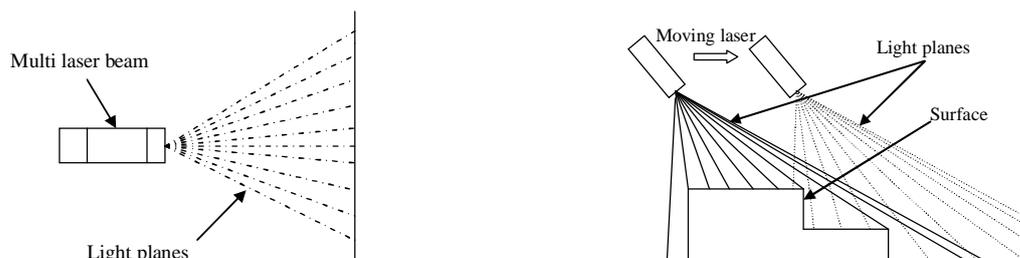


Figure 3. Illustration of a multi beam laser and the emitted sheets of light and its area of coverage

Sensor occlusion can only be avoided using multiple sensors. If two sensors are used, each viewing with baseline but separate sides of the laser, most of the sensor occlusion is avoided. The only remaining sensor occlusion comes from deep holes where both sensors are occluded.

## II. Description of the method

For image acquisition, we used two cameras equipped with CCD sensors, which capture the light in small photocells included in a matrix, and a multibeam laser (figure 4). The signals provided by the cameras are amplified and then applied to an ADC. After acquisition, pre-processing operations has been performed, having the role to eliminate the noise or unnecessary information from the image. For eliminating the noises and to distinguish the surfaces, we used filtering operation. After filtering, the image has been partitioned in more classes by attributing them individual pixels.

Our CCD cameras are mounted according to a “pinhole camera model” [2], in which the camera’s centre of projection is just in the centre of the coordinate system and the z-axis coincides with the optical axis of the camera, according to figure 4. The cameras are first calibrated [3-5].

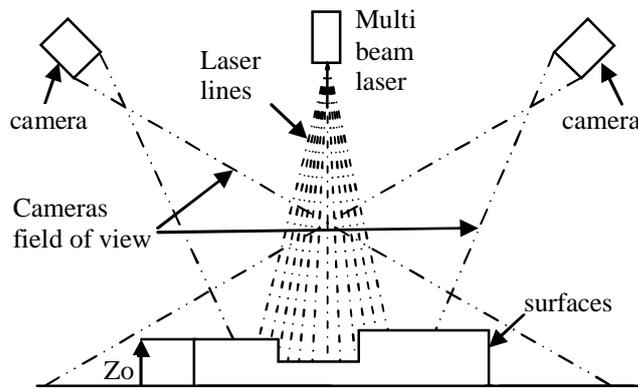


Figure 4. Basic configuration of the multibeam laser method

The laser projects on the surface 12 lines which we have to analyze which of them we are dealing with. For solving this problem, the real surface is approximated with a small plane section. From this, it will result that the images are not too different from each other. In this case, the coordinates of the features and the intensity distribution around the features are similar in both images, which allows to restrict the search range and to match features through intensity cross-correlation.

The measurement starts with an initial estimation of the position of the plane section. For each point, it is assigned a value of light intensity. The pixel position is calculated by bilinear interpolation in the image. The target center in image space is computed with sub pixel precision by least squares image matching. The 4-pixel neighbors of the target center are considered for computing a 3D point which approximately corresponds to the target center. Bilinear interpolation of the 3D points to the 4-pixel neighbors gives an initial 3D point corresponding to the target center. The precise extraction of the 3D points related to the targets uses three constraints: intensity of laser light, Euclidian distance of the 3D points from the two 3D target centers, distance between cameras and laser.

The reference height is calculated based on the baseline part of the projected line. It is assumed that the object doesn't fill the entire image and therefore a small part of the line is always guaranteed to be projected onto the ground. The depth to the point on the object is found as [6]:

$$Z = \frac{F \cdot L}{X + f \tan \theta} \quad (1)$$

where L is the baseline (triangulation distance) separation of the laser and the camera optical centres, f is the focal length of the camera lens, X is the image location within a row where a laser stripe is detected, and  $\theta$  is the projection angle of the camera central axis with respect to x axis. When laser stripe is projected, all the points along the stripe are digitized using a specific algorithm. With smaller triangulation angles, a reduction of shadow effects is inherently achieved and estimation of  $z_0$  of the object is done with good accuracy for a surface seen by the two CCD cameras and the laser.

### III. Results and errors discussion

In figure 5, an experiment with two CCD cameras carried out for analyzing a hole situated at a distance of 32.5 cm from the cameras is presented. This distance corresponds to the maximum possible distance between the cameras and object. We found that for an object with a volume of 30 cm x 40 cm x 50 cm, the measuring error is about 60  $\mu\text{m}$ :

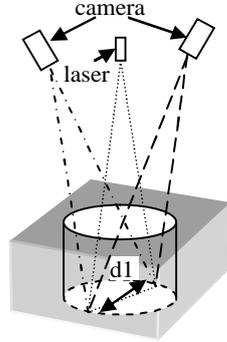


Figure 5. Measurement of the interior diameter of a hole. The figure illustrates one single beam laser

For holes with different diameters, the measuring errors are presented below:

Object	Measured interior diameter d1(mm) real	Reconstructed interior d1(mm) average value	Error in mm (mm) $\sigma$
1	1.960	1.920	0.005
2	1.680	1.643	0.008
3	1.590	1.550	0.012
4	1.490	1.432	0.026
5	1.300	1.245	0.029
6	1.100	1.162	0.036

The error was calculated as standard deviation for six objects with different diameters, but with the same height using the following equation:

$$\sigma = \sqrt{\frac{\sum (V_i - V_c)^2}{n}} \quad (2)$$

where  $V_i$  are the measured values,  $V_c$  are the real values and  $n$  is the number of the measured values.

As can be seen, this system and algorithm is capable of resolving with good accuracy the small surface deviations. This is especially significant when one considers that the width of the measured structure is in the order of a few millimeters. The distance between the cameras is smaller when the measured diameter is small. The measurement error is growing for small diameter.

Errors can occur at the boundary of the object where there are rapid changes of gradient information. Furthermore, error exists at the surface where discontinuities appear. Moreover, the computation of depth from surface is based on the assumption that the surface function is satisfied by the continuity condition. If there are some locations of the surface where integration is not possible, then the computed depth values are not accurate.

A thing that can be improved is the precision of the estimated center of the line. This estimation is very sensitive to the intensity variations of the line due to the speckle noise generated by the laser. If the speckle noise could be further reduced, the precision of the estimated center would increase. Especially in low-light conditions, intensity noise is observable in the stereo images. This noise can cause errors in the correlation process. To reduce the effect of this noise, both low-pass and median filters may be applied to the intensity values prior to further processing. We used a 5x5 Gaussian filter and a square mask median filter for the lowpass operations.

Many different problems arise when attempting dense stereo matching. The most notable problem is occlusions in the images, which simply means that points in one image have no corresponding point in the other one. Ambiguity is a problem when a point in one image can correspond to more than one

point in the other image. The intensity may vary from one image to another, making the same point in both images look different. The different heights of the hole need to adjust the camera's positions.

At a distance of 32.5 cm from the camera, which corresponds to the maximum possible distance between the camera and the object, one pixel corresponds to a diameter of 1.6 cm. The distance between the stripes projected by the laser on the surface is 2.5 mm. In such conditions, the line position can be estimated to an accuracy of roughly 0.4 pixels, meaning a height error of 0.06 millimeters.

#### IV. Conclusions

In the paper, a system capable to measure the surfaces having shadowing problems has been presented. The system is not able to measure surfaces with deep holes where the cameras are completely occluded, or the laser stripe is unseen. For deep holes, it is necessary to change the cameras position and to focus them into the hole. This system can be used in industrial environment where the product has complex structure and where the computing speed is critical.

#### References

- [1] Al Bovik, "*Handbook of image and video processing*", Department Of Electrical And Computer Engineering The University Of Texas At Austin, Pages 262-278.
- [2] Stefano Tubaro, Novara (it); Augusto Sarti, Seregno (mi) (it); Luca Piccarreta, Milano (it); Marco Marcon, Bollate (mi) (it), "Method for determining the three-dimensional surface of an object". *Pub. No.: us patent 2007/0229493*.
- [3] O. D. Faugeras and B. Mourrain "On the geometry and algebra of point and line correspondences between n images" In *Proc.ICCV*, pages 951–962, 1995.
- [4] Rosario Anchini, Consolatina Liguori, Vincenzo Paciello, and Alfredo Paolillo "A Comparison Between Stereo-Vision Techniques for the Reconstruction of 3D Coordinates of Objects", *IEEE Transactions On Instrumentation And Measurement*, vol. 55, no.5, october 2006.
- [5] R.K. Lenz and R.Y.Tsai, „Techniques for calibration of the scale factor and image center for high accuracy 3d machine vision”, *IEEE transactions on patten analysis and machine intelligence*, 10 (1988) (5), pp. 713–720.
- [6] M. A. Sid-Ahmed and M. T. Boraie, "Dual camera calibration for 3D machine vision metrology", *IEEE Trans. Instrum. Meas.*, vol. 39, no. 3, pp. 512–516, Jun. 1990.