Laser triangulation in three-dimensional scanners

Stanisław Mikulski
Poznań University of Technology,
60-965 Poznań, ul. Piotrowo 3a, e-mail: Stanisław.Mikulski@put.poznan.pl

Three-dimensional scanners are increasingly used in various fields of science (eg. medicine, computer graphics, architecture) and industry. There are a huge variety of methods to scan objects and their selection depends primarily on the type of the object and its location. Commonly used methods include branch laser triangulation methods. The objectives of this study is to provide a method for laser triangulation. It was described in the measurement system. In particular, this work examines triangulation methods based solely on the measurement system of the rotary motion of the object. The result of this measurement is a cloud of points is described in a Cartesian coordinate system. The work will be characterized examples of mathematical models of laser triangulation scanners.

KEYWORDS: triangulation, 3D Scanner, reverse engineering

1. Methods of engineering division reconstructive

In engineering, there is a large variety of reconstructive physical phenomena used to retrieve information about the shape of the object. The principle of measurement of three-dimensional scanner specific physical phenomenon does not specify the exact measurement method, since in practice each scanner uses a characteristic signal processing method for measuring the final result. That is why there is a large group of scientific papers dealing with the ordering of reconstructive engineering measurement methods.

The most general and basic division is the division of measurement methods for contact and contactless methods. The contact methods to determine the shape of the object using direct contact head contact with the object. Stand out here as destructive method by cutting the object into slices and consequently its destruction.

Much more important to have reconstructive engineering are the non-contact method. These methods are divided into candling and based on reflections. Candling methods were mainly used in medicine, where they are used for non-invasive examination of the internal organs of the patient. This is a computed tomography and magnetic resonance imaging [1, 3].

Optical methods, which include triangulation methods are methods-based contactless light reflected from the object and determine its geometry by means of light-sensitive detector. Further distribution of optical methods is dependent on the light source. The passive optical methods, is only used image analysis object from one or more cameras. For these methods can be included photogrammetry, which involves analysis of the shape of the image using multiple cameras, arranged in known positions. In order to increase the effectiveness of such a measure on the test object are applied to special tags that make it easy to locate points in common object on several different cameras. Active optical methods rely on projections to study the subject of a specific type of light and reflected light observations. The method is based on laser triangulation beam projection. Knowing the distance between the laser and the camera and the angle between the laser beam and the image plane of the camera, you can determine the distance of the measuring point from the camera lens. Procured in this way information about the third dimension of the object, which in conjunction with the coordinates, gives you a complete spatial information about the object. One way to speed up the measurement is displayed on the subject line of the laser, so that with a single measurement (a camera) measurement system can read information about measuring points within the entire measurement line [1, 3].

2. Laser triangulation method

The measuring system of any of the methods of laser triangulation source comprises a laser light (in the form of a point or line), and the measuring object light-sensitive receiver, it is mostly a camera. Depending on the object, in particular its dimensions, and the availability of the measurement system can be constructed in several different ways. The basic problem of the design of each measuring device is to determine the most appropriate way to move the laser beam on the object. You can distinguish between two basic types of scanner control. The first type of scanner is a device in which the beam moves along a stationary object. This method works best in cases where the image of the object we are interested in a particular page (such as mapping the face), but in situations where we are interested in a complete picture of the spatial object measurements to be made for several positions of the object. Example diagram of such a device is shown below (Figure 1). The measurement system consists of a laser line and the camera mounted on a movable stand. Knowing a constant distance between the light source and the camera and the angle between the plane of the laser beam, and the plane perpendicular to the camera image can be read about the subject at a depth reflection on the camera lines away.

The resulting image can be converted to the spatial coordinates by the following formulas:

$$\begin{cases} X = x' + x'' \\ Y = k_Y y_{pic} \\ Z = \mathrm{ctg}\alpha \cdot x'' \\ x'' = k_X x_{pic} \end{cases} \tag{1}$$

where: X, Y, Z - are the target coordinates Cartesian coordinate system, x'- the position of the measuring system for linear coupling, x"- the measurement in the direction of the X axis in units of measure, x_{pic}, y_{pic} - the coordinates of the laser line read from the camera pixels, k_x, k_y - calculators pixel camera units.

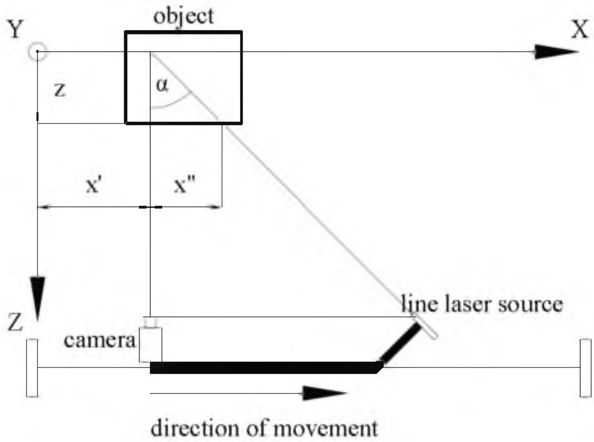

Fig. 1. Schematic three-dimensional scanner measures the object in Cartesian coordinates

The second type of three-dimensional scanner controls the position of the object relative to the laser. This approach is most often associated with the complication of the mathematical model of the facility and the mechanical positioning of the object, but also provides greater certainty for correct measurements

An example of such a scanner may be a measuring system composed of a laser line, the camera and the rotary tray on which the test object. The line is displayed vertically on the subject. Camera system and the light source is stationary, while moving the tray rotation. The measurement is performed by moving the tray rotation by a constant angle dθ. Knowing the inclination angle α between the camera image plane, and the plane of the laser line and the angle of inclination β of the image plane to the plane of the tray, it is possible to cast the coordinates object in the plane of the laser lines recorded by the camera, the image plane passing through the axis of the marking trays. This situation is shown on Figure 2.

Measurement points of such a system can be described using the following formulas:

$$\begin{cases} z" = y_0 - (y - (x' - x_0)) \tan\alpha \\ x" = x - x_0 + (y' - y_0) \tan\beta \\ y" = 0 \end{cases} \tag{2}$$

where y_0 and x_0 - are the coordinates of the pixel corresponding to the rotational center of the tray.

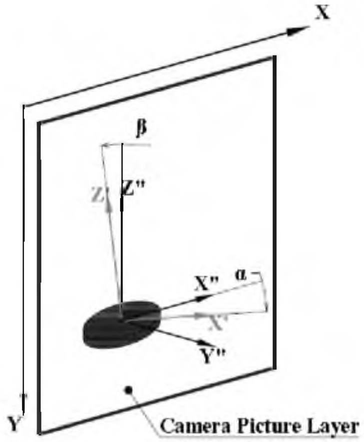

Fig. 2. Coordinate systems for the scanner with a fixed measuring system and the rotary tray [2] where: X, Y - coordinate system of the camera image (in pixels), X ', Z' - coordinate system lie in the plane of the laser line, inclined at an angle α to the image plane, X ', Y', Z '- target coordinate system tilted at an angle β to the plane of the image

Combining the results of measurements of the individual tray rotation is effected by rotation of the measurement points obtained as described above at an angle θ relative to the axis Z'. Matrix rotation axis Z" has the form:

$$M(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3}$$

hence the final models:

$$\begin{bmatrix} x''' \\ y''' \\ z''' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x'' \\ y'' \\ z'' \end{bmatrix} \tag{4}$$

In this way, the results make up the initial cloud of points representing the test object.

3. Line laser detection

The laser line detection is a vital component of the scanner. The first problem encountered in the identification process of the laser line is its width. Most mathematical models in the analysis assumes that the laser line is either infinitely thin, or in any case the width of one pixel. In real systems, all lines have a width of a few to several pixels and the size is variable. The difference in the width of the laser line due to two factors. The first (constant, regardless of the system under study) is the inaccuracy of the optical system of splitting the laser spot on a laser line. The second factor is the angle at which the laser light hits the surface of the object.

At the beginning of the line detection process should be determined the luminance of each pixel camera. Then the image is thresholded subject, it is the transformation of the image according to the formula:

$$B(x,y)=\begin{cases}1 & L(x,y)>t\\ 0 & L(x,y)\le t\end{cases} \tag{5}$$

where L(x,y) is luminance of the image pixels coordinated to xy.

This formula shows the thresholding of a single threshold, called binarization. Sometimes it is used multiple thresholding with a threshold such as the dual-threshold, as described by the formula:

$$B(x,y)=\begin{cases}0 & L(x,y)>t_2\\ 1 & t_2\ge L(x,y)>t_1\\ 0 & L(x,y)\le t\end{cases} \tag{6}$$

As a result, we get an image thresholding line composed of white pixels (pixels with a value of 1), and a background image made up of pixels black. So the resulting averaged laser line width of one pixel. Finally, the coordinates of pixels belonging to the average of the laser lines are calculated using the formulas (2) and (4) the coordinates of the object. The individual steps of detecting the line are shown in Figure 3 [4]

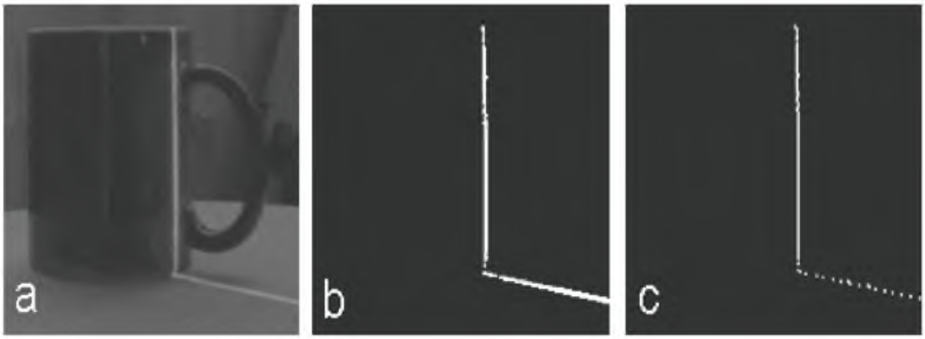

Fig. 3. Detection of the laser lines: a) the original image, b) Binarization image, c) averaging the laser line

4. Sample measurements made with the method of laser triangulation

Presented in Chapter 2, the mathematical model scanner employing laser triangulation method, was used to build the measuring system. This arrangement is shown in Figure 4. It includes a high-resolution camera (with a maximum resolution of 1920 by 1080 pixels), the red line laser, the tray with the propulsion system, and housing. To control the rotating tray uses a stepper motor for step 1.8°, which allows 200 measurements steps per full revolution. Such measurement resolution was not satisfactory because the motor control is used to control the distribution step by microstep 1/2, 1/4, 1/8, 1/16 and 1/32. This afforded the opportunity to increase the number of measurements per revolution tray up to 6400 measurements.

Fig. 4. The image measurement system [2]

The project contains also a computer program developed for controlling stepper motor and analyzing images from the camera. The program can also set the resolution of the camera, choose the number of steps and show the results, from the processing of images from the camera a points cloud of. Additionally, during the measurement is displayed in the preview image from the camera. The program was developed in Microsoft Visual Studio C # 2010 with the use of DirectX 10 library for presentation of the object.

Figure 5 shows a measurement example. Measurement results prove the correctness of the method of measurement.

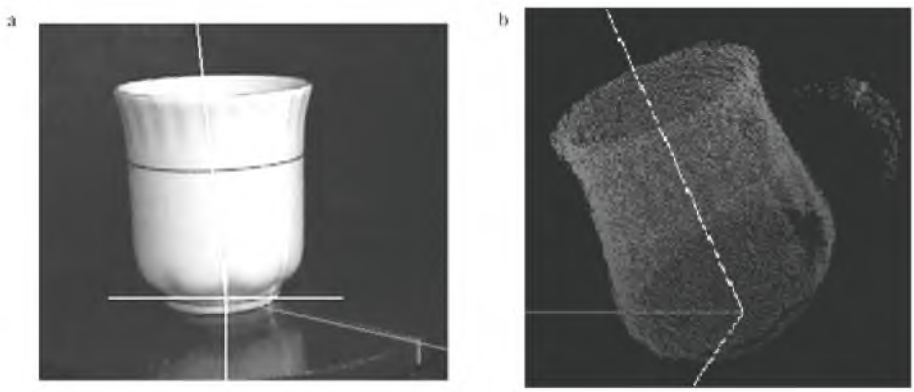

Fig. 5. Results of measurements a typical example) object b) point cloud created from measurements

5. Summary

This paper presents methods for scanning of the area. Classification of these methods is described and the basic physical phenomena in which the group is based measurement methods. In particular, the group focused on laser triangulation methods. Are examples of mathematical models using laser triangulation, the Cartesian XYZ system of rotation of the object.

In the following paper presents the results of measurements and analysis for position measurement based on laser triangulation method described in the article. The results attest to the accuracy of the method. Determined from measurements of the object model accuracy was 0.1 mm, the camera image resolution 1200 x 800 pixels.

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