Image Processing

DEVELOPMENT OF A COMBINED SYSTEM FOR INPUT OF THREE-DIMENSIONAL IMAGES

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Abstract: *A model of a mobile setup for shape reconstruction is presented. In this technique, the contouring is performed by laser scanning and image processing. The devices of this setup can be moved to examine occluded areas and small details. The algorithm of triangulation method computes the object dimensions from the deformation of a laser line and the camera position. This model improves the performance and the accuracy of the reconstruction system, because all steps of the contouring are performed by computer algorithms. In this manner, the errors of the physical measurements are not passed to the reconstruction system. This procedure represents a contribution to the methods of contouring based on laser scanning. To describe the accuracy, a root mean square of error is calculated with respect to a contact method. This technique has been tested with real objects. Also the new principle of the shaping the structured illumination suitable is considered for realization of pinpoint accuracy of the noncontact optical measuring systems for determination of the profile to surfaces greater object. Proposed method has no an analogue in Russia and overseas.*

Keywords: *three-dimensional model, 3D measurements, scanners, triangulation, phase shift method*

ACM Classification Keywords: *General Terms – Algorithms, Experimentation, Measurement, Theory*

Introduction

There are many different ways to obtain 3D measurements and the many types of scanners that are based on any one single way. Among the huge number of different methods to obtain three-dimensional model of the object can be identified several key: triangulation method, based on determining the time of the signal, the phase shift method. In practice, using the methods of determining the shape and topography of coherence and halftone images.

Three-dimensional contouring is an important research topic in industrial inspection, computer vision, navigation, rapid prototyping, reverse engineering, and object modeling. Nowadays, the contouring is achieved by noncontact systems based on lighting methods [Remondino, 2006]. These kinds of sensors use methods such as fringe projection, line projection, spot projection, time of flight, and interferometry. Many researches have been concentrated on these sensors, and new techniques are still being developed. Today, commercial solutions are available and used by the scientific community. And there is no, unfortunately, a scanning device capable of a three-dimensional model of the object immediately, without providing the necessary conditions, so any such system is narrowly applicable, and perfect. However, these sensors are still very expensive, and a long time is required to obtain the object reconstruction. Also, manual operations are required for the data collection in these sensors [Lin, 2004]. Therefore, there is a task to develop a new universal system that includes several methods for determining the topography and the construction of three-dimensional model of the object and does not depend on the conditions of scanning and the research is now focused on low cost, good accuracy, and fast processing.

Triangulation method for determining the relief image is key and fundamental method of my master's thesis. In collaboration with the other methods it`ll form a combined system of the input three-dimensional images.

Triangulation method and mobile setup for object contouring

In these researches, active triangulation has been used by the lighting methods to perform the contouring via image processing. In active triangulation, the distance between the image sensor and the laser projector provides the depth resolution. But in a static setup, holes in the surface occur due to the limitation of view field of the image sensor and to depth variation. Therefore, occlusions appear, and there are problems in detecting small details. In this case, the object reconstruction is not completed [Zagorchev, 2006].

To overcome these limitations, the object is profiled from different views to obtain the complete object. This is done by using multiple cameras or a mobile setup. Also, fringe projection, line projection, and spot projection have been applied to acquire different views of the object. In fringe projection, the object surface is retrieved by applying a phase detection algorithm. Then, the phase is converted to actual dimensions based on the setup geometry. In line projection and spot projection, the object depth is computed by triangulation using the position of the light pattern and the setup geometry. These kinds of optical sensors have been successfully applied to detect complete objects [Remondino, 2006].

A mobile setup uses a laser range scanner, and the captured object contains holes due to occlusions. In this method, the depth information is retrieved by triangulation, using the position of the laser line and the setup geometry. To fill in the holes, a weighted average is applied based on the surrounding surface data.

A mobile setup avoids occlusions and improves the resolution. However, a new equation must be deduced to compute the object depth in each modification of the geometry. This step includes a new measurement of the modified geometry and the determination of the parameters of the vision system. According to these considerations, modeling of the mobile setup is required to retrieve the object depth automatically at any camera position. Also, modeling of the mobile setup is necessary to improve its performance.

Modeling of a mobile setup is performed to achieve contouring of a complete object. The proposed model provides an equation that computes the object depth at any camera position. The mobile setup is implemented by an electromechanical device, which moves the camera and the object on an axis. To perform the contouring, the object is moved and scanned by a laser line. Based on the deformation of the laser line, the algorithm of triangulation method generates a model to compute the object dimension by means of the camera position. To detect the small details, the setup begins with a long distance between the laser line and the camera. When an occlusion of the laser line appears, the camera is moved toward the laser line to detect the occluded region. This is carried out by an electromechanical device and control software [Song, 2006].

For this mobile setup, the object dimension is proportional to the deformation of the laser line. Also, the deformation depends on the camera position. Thus, the algorithm computes the object dimension by means of the laser line deformation and the camera position. Also, this algorithm provides the intrinsic and extrinsic parameters of the vision system. In this manner, parameters such as the focal length, camera orientation, and distances in the setup geometry are deduced by computer algorithms. Thus, the mobile setup performs the contouring automatically.

In the reconstruction system, the produced information is stored in an array memory to obtain the complete object shape. This computational process improves the performance, the resolution, and the accuracy of the reconstruction system. This procedure represents a new contribution to laser-line projection methods. The experimental results are evaluated based on the root mean square error. The evaluation of these results includes measurement error, resolution, processing time, range of measurement, and limitations of the CCD array. In this evaluation, good repeatability is achieved.

Shape detection by means of multiple views is an important task in optical metrology and computer vision. In the mentioned methods, the vision parameters are computed to achieve the measurement of the object shape. Typically, these parameters are obtained by a procedure external to the reconstruction system. In the proposed mobile setup, the object contouring is performed by an automatic vision system. This means that the extrinsic and intrinsic parameters of the vision system are deduced by computational algorithms.

The mobile setup is shown in Fig. 1. This setup includes an electromechanical device, a CCD camera, a laser line projector, and a computer. In the electromechanical device, the object is moved along the *x* axis by means of a platform and control software. On the object, a laser line is projected to perform the scanning. In each step of the movement, the CCD camera captures the laser line. The camera is aligned at an angle to the object surface. This camera can be moved, independently of the laser projector, along the *x* axis. Every laser line is deformed at the image plane according to the object surface. The relationship between the laser line deformation and the object dimension is evaluated. Thus, the contouring of the object shape is performed.

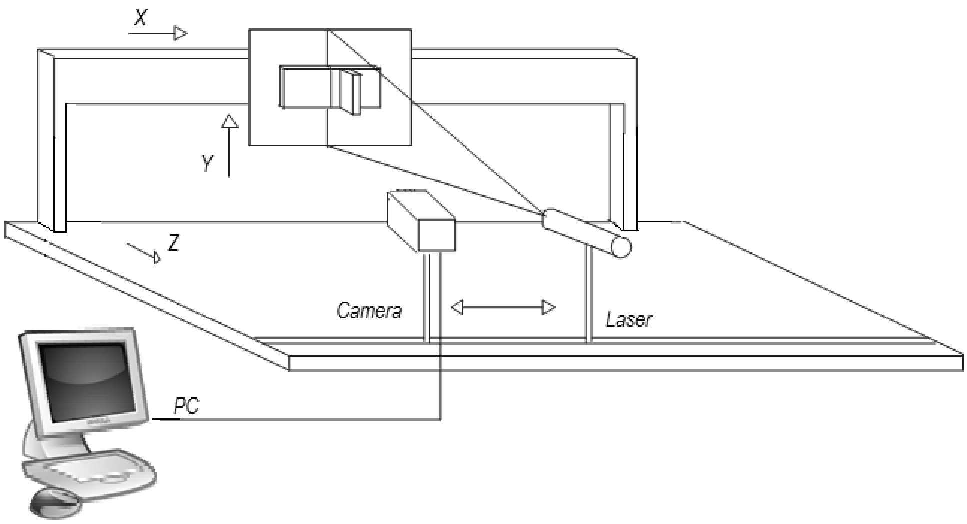


Fig. 1 Experimental mobile setup

The relationship between the position of the laser line and the object depth is described by the geometry shown in Fig. 2. For this geometry, the reference plane is the platform of the electromechanical device. In this reference plane, the three-dimensional Cartesian coordinates are defined. The coordinates *(x, y)* are on the reference plane, and the coordinate *z* is perpendicular to the coordinates *(x, y)*.The plane *(x, y)* is the reference from which the object depth is measured. The reference *z*=0 is obtained based on the projection of the laser line on reference plane. In this case, the coordinate of the laser line on the *x* axis is the same as on the *y* axis. In the geometry of Fig. 2, the *x* axis and *y* axis are located on the reference plane, and the object depth is indicated by *h(x, y)*. The points *A* and *B* correspond to the projections of the laser line on the reference plane and on the object surface, respectively. The laser line is deformed in the image plane due to the surface variation and the camera position. Thus, the coordinate of the laser line is changed from x_A to x_B in a step of the scanning. This displacement of the laser line is described by

$$s(x,y) = x_A - x_B \quad (1)$$

The object dimension is proportional to the displacement *s(x, y)*.

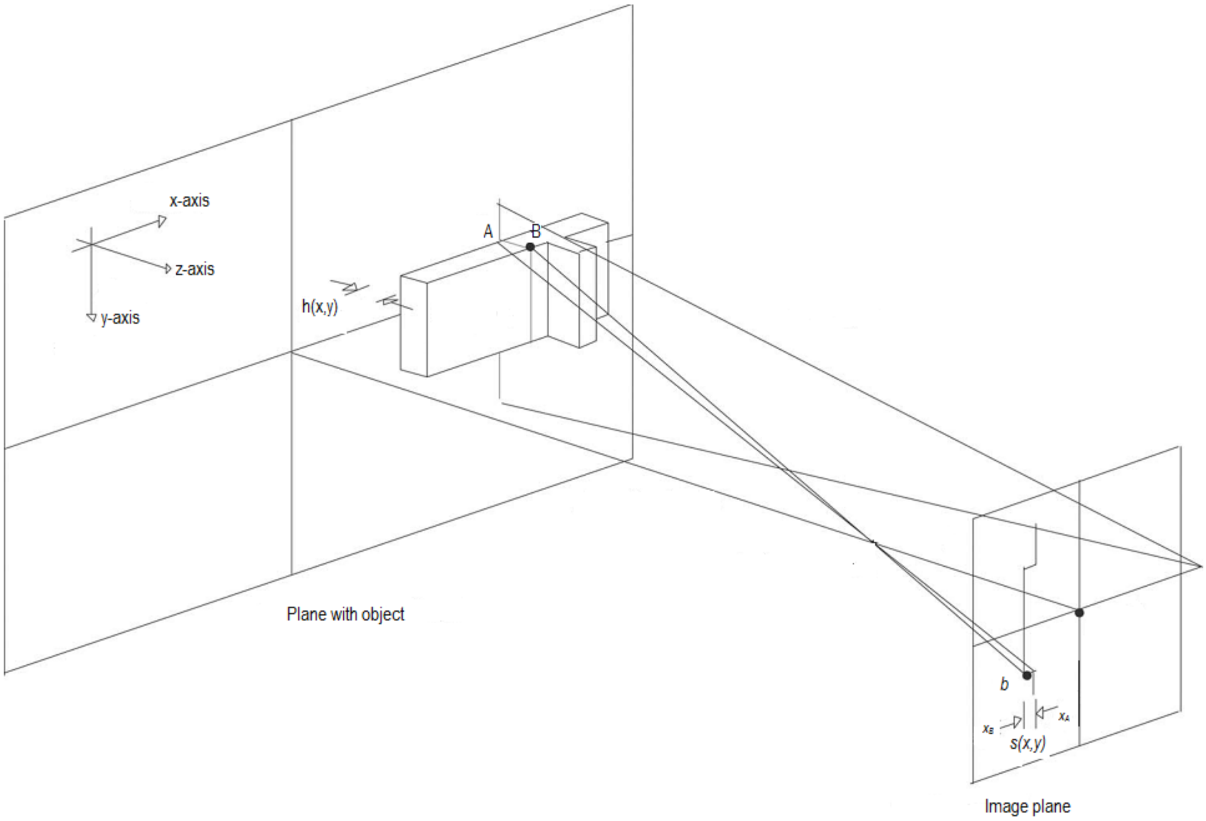
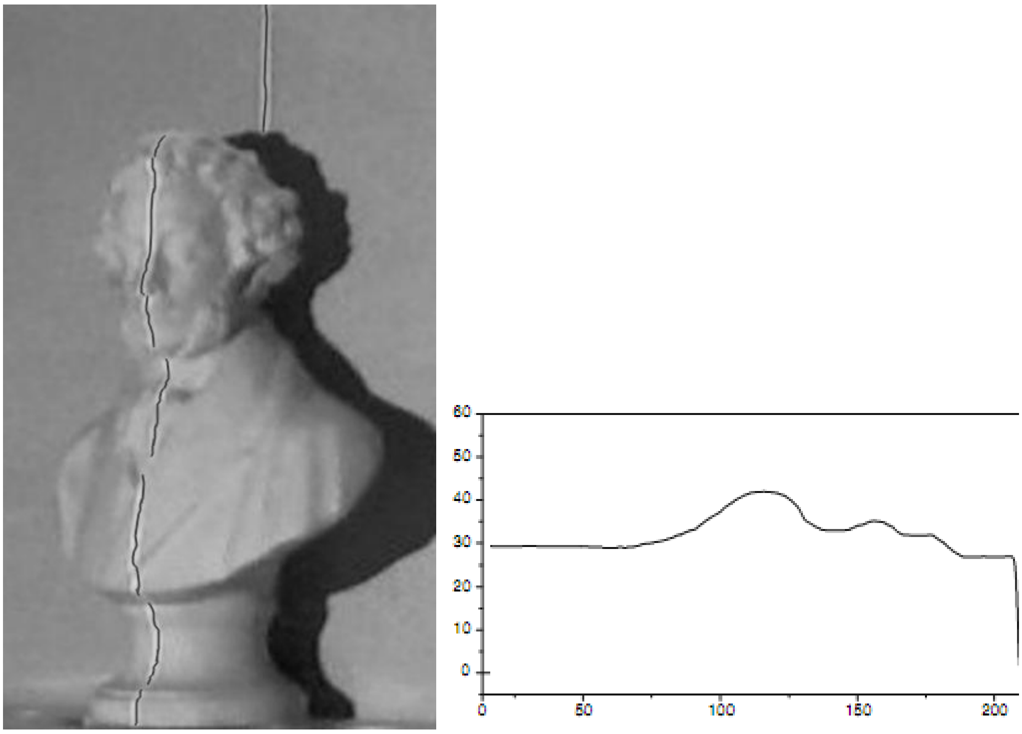


Fig. 2 Geometry of the experimental setup

To detect the displacement, the maximum of the laser line is measured in the image. To do so, the pixels of each row are approximated by a continuous function. The procedure to detect the maximum is applied to all rows of the images Fig. 3(a) to obtain the object contour. Figure 3(a) shows also the laser line. In this image, the position x_B is computed along the y axis. Then, the displacement s(x, y) is computed via Eq. (1) to obtain the contour shown in Fig. 3(b). Typically, occlusions of laser line appear in the initial configuration due to the surface variation. This lack of data is observed in the line occlusion and its broken contour. To avoid this occlusion, the CCD camera is moved toward the laser projector. In this manner, the occlusion is avoided and the object contour is completed. However, the scale factor of these contours is not the same. This is because the contours are computed in different camera positions. In the model of the mobile setup, the scale factor is corrected according to the camera position.



(a) (b)

Fig. 3 (a) Laser line projected on the Pushkin's bust. (b) Displacement s(x,y) extracted from a part of the image via Eq. (1).

Experimental Results

The model of the mobile setup is available to perform the contouring from different views of the object. Thus, occlusions are avoided, and small details are detected. Also, the vision parameters are obtained, and physical measurements on the setup are avoided. Thus, the contouring is performed automatically by the model of the mobile setup.

In the arrangement Fig. 1, the object is moved along the *x* axis in steps of 1.27 mm. This device can be moved 0.0127 mm as a minimum step along the *x* axis, *y* axis, and *z* axis. A laser line is projected on the target by a 15-mW laser diode to perform the scanning. The laser line is captured by a CCD camera and digitized by a frame grabber of 256 gray levels. The displacement of the laser line is computed based on the maximum intensity. The resolution in the *x* direction is deduced by detecting the laser line in two different positions. To do so, the laser line is moved 127.00 mm away from the initial position by means of the electromechanical device. Then the number of pixels between these two positions is 328.324. Thus, the resolution on the *x* axis is computed by the relationship resolution = (pixel number)/distance.

The resolution in the *y* direction is obtained by detecting the object on the laser line at two different positions on the *y* axis. To do so, the object is moved 95.00 mm away from the initial position on the *y* axis. Then the maximum displacement of the laser line is detected in each movement.

The resolution in the *z* direction is provided by the dis placement of the laser line along the *x* axis. The position of the laser line is measured with a resolution of a fraction of a pixel. Also, the displacement in Eq. (1) is achieved with a resolution of a fraction of a pixel.

The experiment was performed with one object. The object to be profiled was the Pushkin's bust shown in Fig. 3(a). An occlusion appears due to the surface variation. This occlusion was detected and recovered by the mobile setup. Thus, the contouring was performed completely. To do so, data produced was scanned along the *x* axis in steps of 1.27 mm. Data produced by the algorithm generate the complete object shape. The results of reconstruction of the Pushkin's bust is shown in Fig. 4.

Fig. 4 Three-dimensional shape of the Pushkin's bust

New way of phase shift method

The technology of projection methods (three-dimensional scanning) with high accuracy and speed shooting information on the object surface (depth), using the principle of structured illumination. All data are obtained by projecting the objects of the scene of the special lattice. Projection of the lattice distortion created by the geometry of objects allow us to calculate the exact position of each of its points in three dimensions. These systems can measure three-dimensional surfaces in video mode. Experience of using projection methods of measurement shows that the major source of measurement error is a distortion of the profile of the structured emission due to nonlinear processes: the illumination of the object (the nonlinearity of the luminance characteristics of the projection equipment), the reflection from the object (the nonlinearity of the reflection coefficient) and photo detection of radiation (non-linearity of the luminance characteristics of the photo - or a camcorder).

In the proposed approach to eliminate the effect of brightness distortion is invited to form a gray scale image as a structured sequence of bits (two gradational) fields. For a practical test of this approach was used projection measurement system consisting of a structured light shaper - a digital projector with a resolution of 800x600 pixels and streak - 8-Bit Web camera with a resolution of 1600x1200 pixels. The size of the projected image was 2x2 meters. Sequence of projected images and recorded eight bit fields of the sinusoidal grating image with 256 gradations of brightness, which are then reflected from an object shaped halftone pattern. Grating are perpendicular to the plane passing through the optical axis of the respective lighting systems and detecting optical system. Optical axis of the recording and lighting systems intersect at one point in the object. Angle between the recording and lighting system is 10º. The distance from the object plane to plane the registrar of 3m. The whole structure is mounted on a movable platform. Figure 5 shown formed a sinusoidal grating and a corresponding set of bit planes.

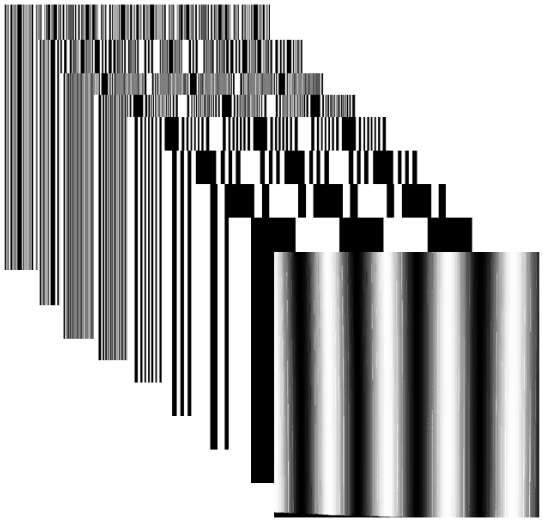


Fig. 5 Method of forming a structured image

In figure 6 shown the reconstructed profile of sinusoidal bands. It should be noted that the profile of the bands do not contain harmonic distortion inherent in projections of "analog" sine wave on the surface of the object.

For bad pixels due to the inaccuracy of the front fixing binary of images and can be eliminated by the introduction of additional redundant coding bit image corresponding to, for example, the code of the Reed-Solomon, Hamming or similar methods of error-correcting coding. Note that the proposed principle of forming a structured light can significantly improve another important characteristic of the projected image, the dynamic range of transmitted intensity levels.

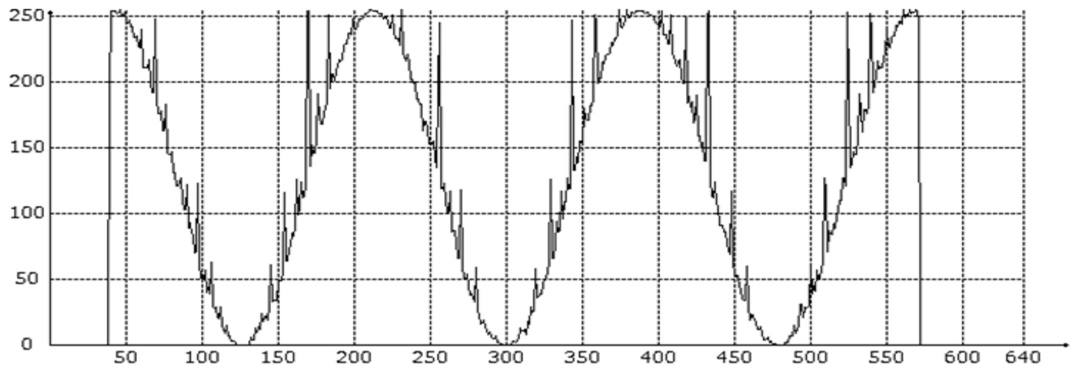


Fig. 6 Reconstructed profile of sinusoidal fringes

In real-world digital systems, this feature is limited to the projector and the digit streak. As a rule, used an 8-bit device coverage and 8-12 bit photo detection device. In our case, using a fairly cheap device, you can create a virtually unlimited dynamic range of brightness variation of structured light.

Conclusion

A technique of contouring performed by a model of a mobile setup has been presented. The technique described here provides a valuable tool for industrial inspection and reverse engineering. The automatic process avoids physical measurements on the setup, which are common in methods of laser line projection. This procedure improves the accuracy of the measurement, because measurement errors are not passed to the contouring system. This step is achieved with few operations. By using this computational-optical setup, good repeatability has been achieved in each experiment. A new principle of formation of structural coverage was developed. This method is suitable for implementing high-precision non-contact optical measurement systems for determining the surface profile of large objects. High accuracy allows the use of such systems for the analysis of the stress-strain state of objects, as well as the instantaneous three-dimensional model of a large number of objects. At this point, unfortunately, no satisfactory results of our new way of phase shift method, but now implement the software part of the method. In the future we plan to combine the two above-described method of obtaining information about relief to improve the accuracy of scanning up to 10 microns.

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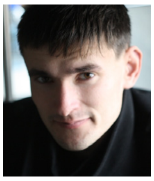
Authors' Information



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Major Fields of Scientific Research: Computer vision and image processing

METHODS OF IMAGE RECOGNITION AS A TOOL IN ANALYSIS OF INTERNAL COMPOSITES STRUCTURES

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Abstract: *The theme of the article is to discuss the suitability of image recognition software to study the structure of composites. These materials are already used for many years as an alternative to many higher-priced used in the aerospace industry and beyond. Research of composite structures are conducted on a regular basis. Application of pattern recognition methods can give a new perspective on analysis and measurements in the features of the composites.*

Keywords: *foam composites, image recognition*

ACM Classification Keywords: *I.3.3 Picture/Image Generation*