Mechanics Transport Communications
Academic journal

ISSN 1312-3823
volume 10, issue 3/3, 2012
article № 0721
http://www.mtc-aj.com

OPTICAL SYSTEMS FOR 3D SCANNING

(Introductory article)

Nebojsa Bogojevic
bogojevic.n@mfkv.kg.ac.rs

Faculty of Mechanical Engineering Kraljevo, University of Kragujevac
Dositejeva 19, 36000 Kraljevo,
SERBIA

***Key words**: Optical scanners, 3D scanning, rapid prototyping*

***Abstract:** Rapid prototyping is a powerful tool for quick creation of new models and prototypes. As the first step in the process of rapid prototyping is usually used process of 3D scanning. 3D scanners are devices for non-contact transformation of a real object into the virtual world–the process is also known as digitalization. The collected data may be used for creation of the CAD model, for drawing of technical documentation or for reconstruction of 3D objects. In the industry, 3D scanning may be used for measurement and inspection, measurement of deformations, analysis of dynamic behavior of parts and assemblies. This paper presents various types of optical scanners, explains principles of digitalization techniques used for optical 3D scanning and its application in industry.*

Introduction

Today, there are a lot various devices which may be considered as 3D scanners. Generally, any device with possibility to digitize objects from real world to virtual world using laser, x-ray or light may be considered as a 3D scanner. The digitalization means representation of the geometrical characteristics of a solid object in virtual world by numeric values of coordinates of a cloud of points or polygonal meshes.

For decades, devices for 3D scanning were designed primarily for needs of research and academic institutions. Through the years, improvement of optical devices and sensors, as well as development of accompanying software made 3D scanners available for commercial usage. Development of optical sensors increased the accuracy of the devices, the scanners became to be lighter and portable, and the price of the scanners became lower.

A very important role in the process of the digitalization has accompanying software packages for scanners. High speed of digitalization process and possibility to save, edit and manipulate huge number of data points is the main task of the software packages for 3D scanners. Some of the software packages may save a cloud of points in several CAD formats such as IGES, STEP and DXF for CAD applications, or in STL format for rapid prototyping machines.

3D scanning technologies

The optical 3D scanners may use several different technologies to digitize objects from real world. According to Giovanna Sansoni et al. [1] the optical methods for 3D scanning which are used in recent years may be categorized as following: laser triangulation, structured light, stereo vision, photogrammetry, time of flight, interferometry, Moiré fringe range contours, shape from focusing, shape from shadows, texture gradients, and shape from photometry. In the following text are explained the most common technologies which are used for 3D scanning today.

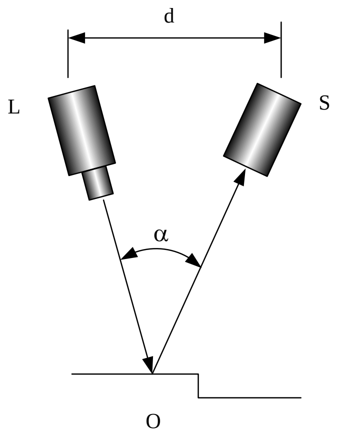


Figure 1: Principle of work of laser scanners

Laser triangulation scanners

Laser triangulation scanners use either a laser line or single laser point to scan across an object. These types of lasers are based on triangulation which is described in [2]. Figure 1 shows a configuration of the measurement system. Sensor *S* picks up the laser light *L* that is reflected from the surface of the object *O*. Using trigonometric triangulation the system calculates the distance from the object to the scanner. The distance *d* between the laser source and the sensor is known very precisely, as well as the angle α between the laser and the sensor. As the laser light reflects from the surface of the scanned object, the system can calculate the angle is returning to the sensor, and therefore the distance from the laser source to the object's surface.

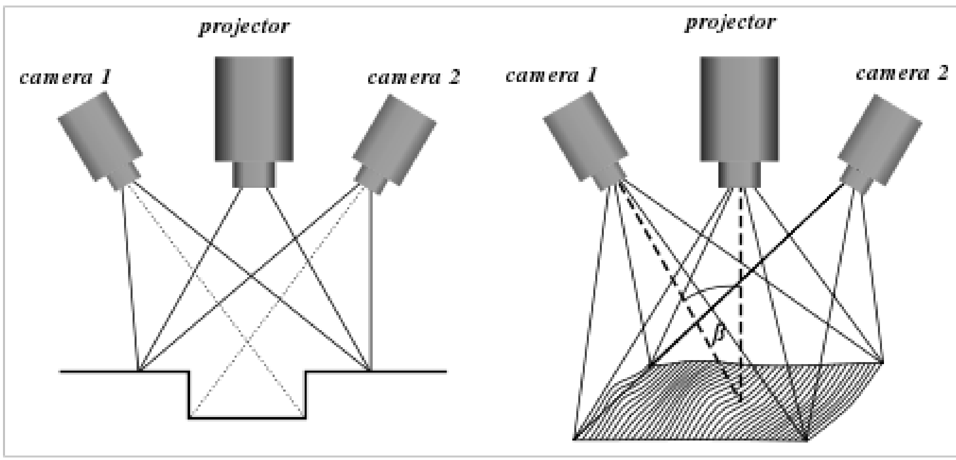


Figure 1: Fringe pattern recording system with two cameras

The main advantages of the laser triangulation are accuracy and insensitivity to the environment light and texture of the surface. Single point laser triangulation is used in industry applications for measurements of the distance, diameters, thickness and quality control.

Structured light scanners

Structured light 3D scanners, like laser triangulation scanners, are also based on the triangulation. Unlike laser scanners, the structured light scanners project bi-dimensional patterns of non-coherent light. By projecting a single or multiple patterns on the object the coordinates of points at object's surface may be calculated. In order to increase the accuracy and speed of scanning techniques, different projection strategies has been studied [2,3]. In recent years the grid patterns of dots [4], multiple vertical slits [5] and multi-color patterns [6] have been developed. The fringe patterns [7,8], shown in Figure 2, have been used to maximize the accuracy and to increase the measurement resolution of 3D scanners. Typical measurement assembly consists of a camera and a pattern projector. The other configuration of measurement assembly consists of two cameras and a pattern projector between them, as shown in Figure 3.

Figure 2: Optical system Atos compact scan with two cameras and blue light

According to the type of light used for pattern projecting, the scanners with structured light are divided into white light and blue light scanners.

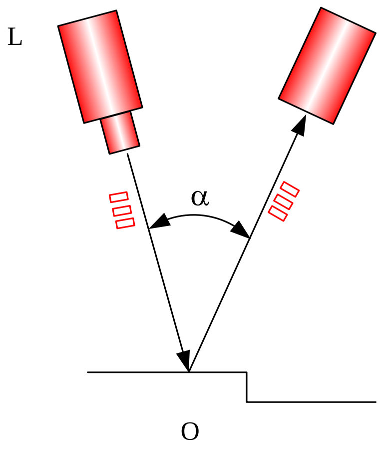


Figure 4: Principle of work of the laser pulse scanners

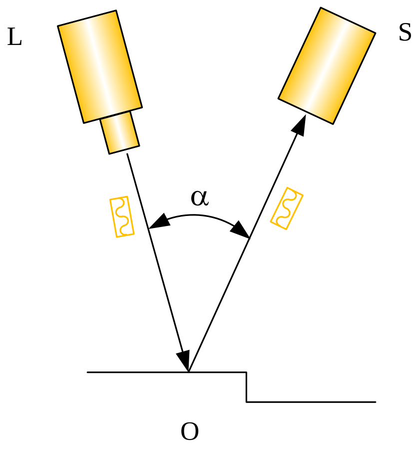


Figure 5: Principle of work of the phase shift laser scanners

Laser pulse scanners

Laser pulse scanners are based on the time-of-flight principle. This principle is widely used in radar systems. The emitter generates a laser pulse and sends it to the surface of the scanned object. On the basis of the time needed to laser pulse travel from emitter to the object surface and back to the sensor, the position of the distance of each point may be calculated. Single-point sensors mainly perform distance measurements, and scanning devices are combined with optical devices to cover bigger scenes.

Table 1.Strengths and weaknesses of the 3D scanning techniques

Technology	Strengths	Weaknesses
Laser triangulation	Relative simple High acquisition data rate Independent on ambient light	Low accuracy Low resolution High noise
Pattern fringe triangulation	Lower noise High resolution High accuracy	Intermediate measurement volume Dependent on ambient light
Laser pulse	Medium and long measurement range Independent on ambient light	Less accurate Slow data acquisition
Laser phase shift	Higher accuracy Lower noise Fast data acquisition	Short and medium measurement range only

This type of scanners may be used for scanning in the different ranges. However, the scanning range has big influence on the accuracy. In the long range measurements, from 15 m to 1000 m, this type of scanners may be used only for measurement of distances. In the medium range, between 5 m and 15 m, the scanners may acquire the 3D data from objects. In the short range, for distances less than 5 m, these scanners have low accuracy.

Figure 5. 3D scanning –cultural heritage application

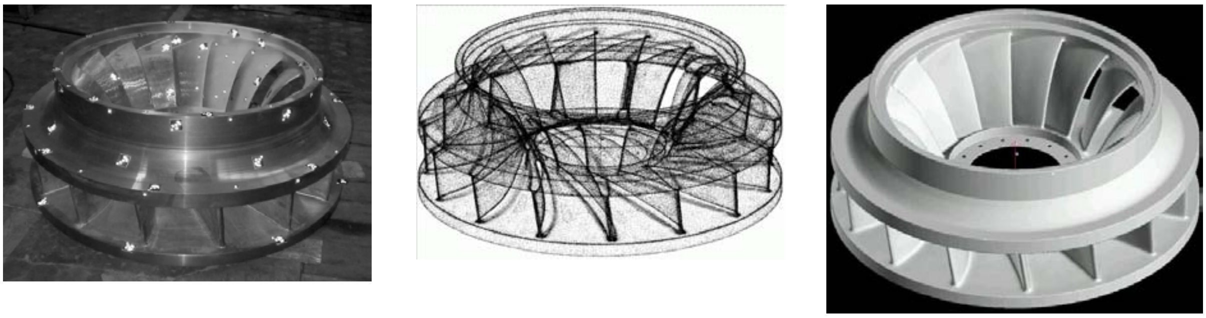
Figure 6. 3D scanning – archeological application

Laser phase shift scanners

Laser phase shift scanners belong to the laser pulse scanners because they have a same principle of work. In order to increase the accuracy of the laser pulse scanners in short range (2 m−5 m) is introduced the modulation of the frequency and/or amplitude of the laser beam.

Applications of the 3D scanning

Due to its lower prices, better accessibility, better accuracy and higher speed of scanning 3D scanners are represented in various fields of research and industry. One of the benefits of the 3D scanning is possibility for virtual investigation and research. The object can be examined in the virtual world without any impact on the physical object. This may be very important for objects which are very sensitive such as objects which presents cultural heritage or archeological objects.



a) b) c)

Figure 7. Process of digitalization of object, a) turbine, b) point of clouds, c) CAD model (source Topomatika)

Reverse engineering is the process of creating digital models using measurements and inspections of an object from real world. On the basis of the data collected during scanning process, it is possible to create a CAD model or STL file for creating parts on 3D printers. The CAD model may be used to decrease the number of prototypes or as a reference which is describing the limitations during the process of creation of new parts of assemblies.

Figure 8. Dimension measurement

In metrology, the optical methods for product analysis and control are already present for several years. The process of control in the industry is usually based on contact measurements, but some optical methods are also presented. Considering that in the process of 3D scanning large amount of data is collected, non-contact measurements may be carried out with 3D scanners. Depending on the technology which is used in the optical devices, the achieved accuracy may be of order of magnitude of microns. High accuracy and data acquisition give possibility to 3D scanning techniques to be used in processes of surface control, dimension measurements and quality control.

Due to possibility to determine large numbers of the points on the object in relatively short time 3D scanners are able to be used to analyze the motion of objects in time, such as analysis of the object motion, measurements of vibrations or measurements of the object deformation in exploitation.

In civil engineering the 3D scanners may be used for collecting data from construction sites or from buildings or parts of buildings–rooms. The collected data may be used for creation of virtual construction sites, creation of virtual reality, or crime scene investigation and documentation.

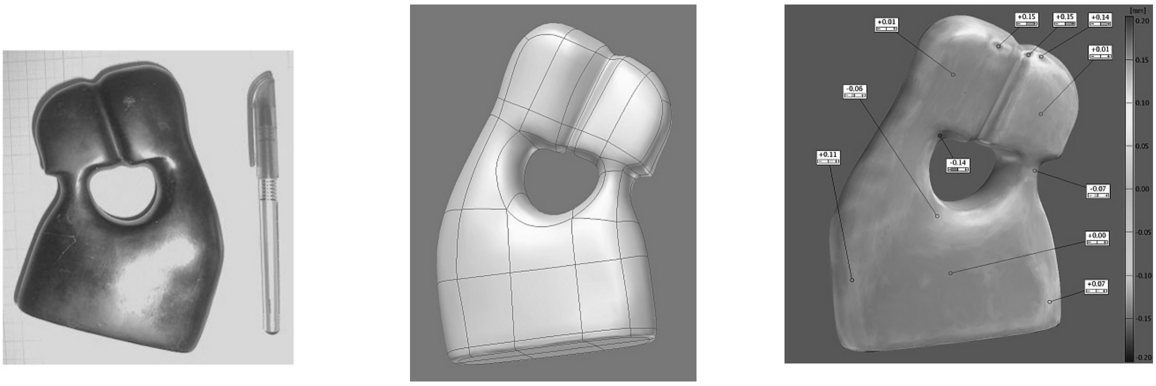


Figure 9. Quality control with 3D optical scanners by comparing the scanned data with CAD model

Conclusion

This paper presents the review of the optical systems for 3D scanning which are based on active triangulation and time–of–flight method, gives their characteristics, strengths and weaknesses. The aim of this paper was to present the various problems which may be solved using 3D scanning devices.

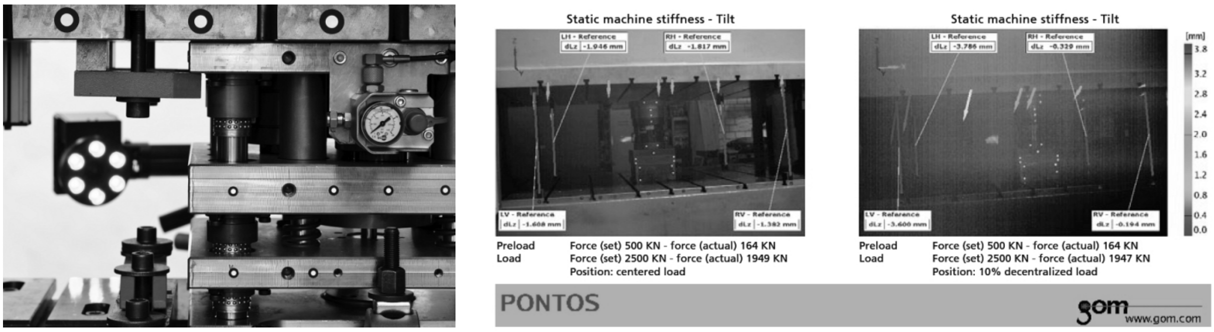


Figure 10. Measurement of deformation

The development of the optical sensors and software packages will lead to future developments of 3D scanning devices. The accuracy and data acquisition will increase while the price of the scanning devices should be lower, which will give possibility for wide application of 3D scanning devices.

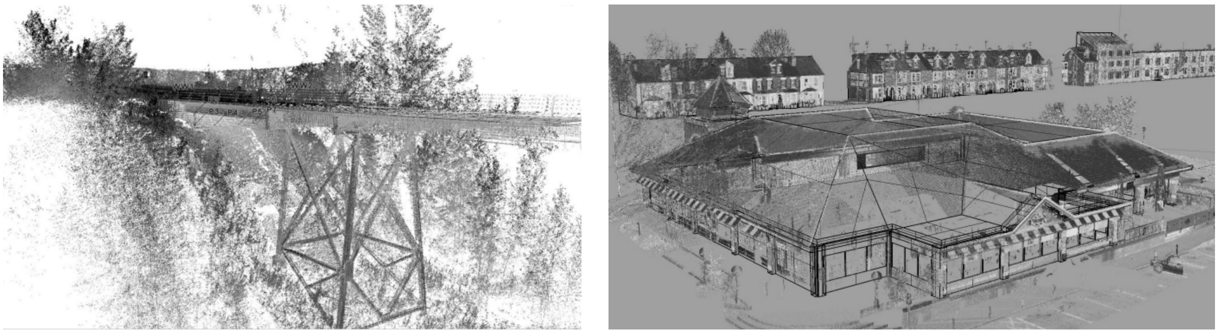


Figure 11. Digitalization of construction sites

Today there is no single 3D scanning device which fulfills all requests and demands. Requests for high accuracy or fast data acquisition as well as scanning range force users to make compromises when choosing 3D scanning device.

Despite user friendly software packages and new optical sensors, 3D scanning devices are still complex and require skilled personnel to operate them. The future development will give the more automated process of scanning, data manipulation and transfer to CAD model.

Acknowledgement

The author wishes to express his gratitude to Serbian Ministry of Education and Science for support through project TR37020.

References

[1] Sansoni, G; Trebeschi M.; Docchi F. State-of-The-Art and Applications of 3D Imaging Sensors in Industry, Cultural Heritage, Medicine, and Criminal Investigation, Sensors 2009, 9, 568-601; doi:10.3390/s90100568

[2] Rainer G. Dorsch, GerdHäusler, and Jürgen M. Herrmann, Laser triangulation: fundamental uncertainty in distance measurement, Applied Optics, Vol. 33, Issue 7, pp. 1306-1314 (1994), http://dx.doi.org/10.1364/AO.33.001306

[3] Blais, F.; Rioux, M.; Beraldin, J.A. Practical considerations for the design of a high precision 3D laser scanner system. Proc. SPIE 1988, 959, 225-246.

[4] Le Moigne, J.; Waxman, A.M. Multi-resolution grid patterns for building range maps. Proc. Vision Conf. 1985, 8, 22-39.

[5] Morita, H.; Yajima, K.; Sakata, S. Reconstruction of surfaces of 3-D objects by M-array pattern projection method. Proc. Int. Conf. on Computer Vision, Annapolis, March 1988; pp. 468-473.

[6] Maruyama, M.; Abe, S. Range sensing by projecting multiple slits with random cuts. IEEE Trans. Pattern Anal. Mach. Intell. 1993, 15, 647-651.

[7] Boyer, K.L.; Kak, A.C. Color-encoded structured light for rapid active ranging. IEEE Trans. Pattern Anal. Mach. Intell. 1987, 9, 14-28.

[8] Tang, S.; Hung, Y.Y. Fast profilometry for the automatic measurement of 3-D object shape Appl. Opt. 1990, 29, 3012-3018.

[9] Srinivasan, V.; Liu, H.C.; Halioua, M. Automated phase-measuring profilometry of 3-D diffuse objects. Appl. Opt. 1984, 23, 3105-3108.

[10] Karasik A.; Smilansky U.; 3D scanning technology as a standard archaeological toolfor pottery analysis: practice and theory, Elsevier, Journal of Archaeological Science 35 (2008) 1148e1168

[11] Juan A. Barceló, Maurizio Forte and Donald H. Sanders , Virtual Reality in Archaeology, ArcheoPress, Oxford (British Archaeological Reports, International Series #843