ANALYSIS OF 3D SCANNING TECHNOLOGIES AND COMPARISON OF EXISTING SCANNING TECHNIQUES

Aydın GÜLLÜ[1], Ali ÇAĞLAR[2], M. Ozan AKI[3]
[1] Trakya University Vocational School of Ipsala
[2] Trakya University Institute of Science
[3] Trakya University Vocational School of Ipsala

Abstract

3D scanning technologies are used to transfer an existing object to the computer environment. Medicine, historical artifacts, produced engineering parts can be quickly modeled and identified. For these models, it is often done with 3D scanning technologies, photogrammetry, and laser scanners. It is used in many fields such as engineering, archeology, medicine, mining and architecture with photogrammetry and laser scanner methods. In this study, information on 3D scanning technologies and working methods will be presented.

Keywords: 3D modeling; Photogrammetry, Laser Scanner, Scanning Technology.

INTRODUCTION

It is necessary to make models of the earth and objects in order to solve the problems that arise in many areas. In order to create these models, the measurements of the objects should be made. It is possible to reach new information about the measured objects by analyzing the created models. In this case, it is important that the measurements and models made are compatible with reality. Since reality is three-dimensional, modeling in a 3-dimensional environment enables problems to be solved faster and more accurately [1].

Three-dimensional modeling is the expression of geometric data of an object in vector format in computer environment. By modeling the earth or any object in 3D, high accuracy evaluations can be made on these objects in computer environment.

With the recent developments in computers and information systems, 3D models have entered almost all areas of life [2].

It is possible to solve the problems by making 3D models with reverse engineering applications.

EXPOSITION

REVERSE ENGINEERING

The initial model of the product can be obtained with computer support by performing the process of going backwards by moving from the object itself and running the process backwards. These processes are called reverse engineering [3]. Reverse engineering can be defined as a measurement, analysis and testing process to duplicate an object or to enable it to be rebuilt functionally. In practice, in the production of parts without design information, in the analysis and repair or re-production of damaged parts, in developing a different product based on an existing part, producing a prototype, etc. used for purposes [4].

The reverse engineering process starts with the measurement of an object and then continues with the creation of a three-dimensional CAD model and ends with the production of a prototype or product. The standard production methods applied today include the processes that start with the CAD design of the product in computer environment and move to the production stage with appropriate CAM methods. In reverse engineering, the stages in the manufacturing process are analyzed backwards from the part [2,5].

The most commonly used 3D scanning technologies in reverse engineering applications are photogrammetry and terrestrial laser scanners. Photogrammetry is divided into three according to the evaluation methods. While analog photogrammetry was used in the pre-computer era, computer technologies and analytical methods were used. With digital recording and processing of images, digital photogrammetry has been widely used in recent years.

PHOTOGRAMETRY

The word photogrammetry was derived from the combination of the words "photos" meaning light in Ancient Greek, "gramma" meaning line and "metron" meaning measurement. Photogrammetry is the recording, measurement and interpretation of the photographs of objects and their environment and the electromagnetic energy they emit. As a result of these processes, reliable information about these objects and their surroundings is obtained [6,7].

Although photogrammetry was initially used to obtain the topographic structure of the earth, with the development of digital techniques, digital terrestrial photogrammetry is used in many areas such as industry, medicine, criminology, traffic accidents, mining and deformation measurements, engineering measurements, architectural measurements, and archaeological measurements [6,8].

Photogrammetry is divided into three according to the evaluation methods. While analog photogrammetry was used in the pre-computer era, computer technologies and analytical methods were used. With digital recording and processing of images, digital photogrammetry has been widely used in recent years [9-11].

Terrestrial Photogrammetry

The first applications of photogrammetry were in the field of terrestrial photogrammetry. Terrestrial photogrammetry is a method that enables the creation of two-dimensional drawing and three-dimensional models by special evaluators of photographs taken with the help of single or double cameras from close or long distances. Photographs taken from the ground are generally used in non-topographic application areas of photogrammetry [9,12].

Although terrestrial photogrammetry enables 3D drawings from near and far distances, it is especially used in close-up painting work. 3D models can be created thanks to photos obtained from cameras with different focal lengths and special software. With this method, 3D location information of the objects whose models are created is obtained. Terrestrial photogrammetry basically uses a network of photographs of an object taken from different angles. In terrestrial photogrammetry, the field of view is within the possibilities of the photo shooting point [2,13,14].

Long Distance Terrestrial Photogrammetry: It is the drawing of pictures taken from at least two stop points with phototeodolite or a single camera, after necessary orientations, mostly used in topographic studies.

Close Range Terrestrial Photogrammetry: It is a measurement technique used to obtain three-dimensional spatial information about an object. After the photographs taken with a single or stereometric (two) cameras and the target point coordinates on it have undergone various processes, two-dimensional drawing with the real dimensions of the object is a method that enables the creation of a three-dimensional model.

Local photographs taken from fixed stations on the ground surface are used in close-up photogrammetry. Acquisition of three-dimensional data depends on taking sequential and overlapping images from different stations. For this, it is necessary to adjust the camera layout and distances well, to calibrate the number and position of the control points on the object.

Close-up photogrammetry is restricted to the field of view of the current station point. Object space is generally close to the camera. However, according to the purpose of the study, shooting distances vary from a few cm to 300 meters, and the sizes of photographed objects vary from materials as small as human teeth to larger buildings or ships. "Close-up

Photogrammetry", which includes applications that involve especially short-range picture shooting, generally covers non-topographic applications [8,9].

Air Photogrammetry

Air photogrammetry is used in the atmosphere, etc. It is a photogrammetry technique that uses photographs obtained with the aid of aircraft (fig 1). Used for topographic purposes [12].

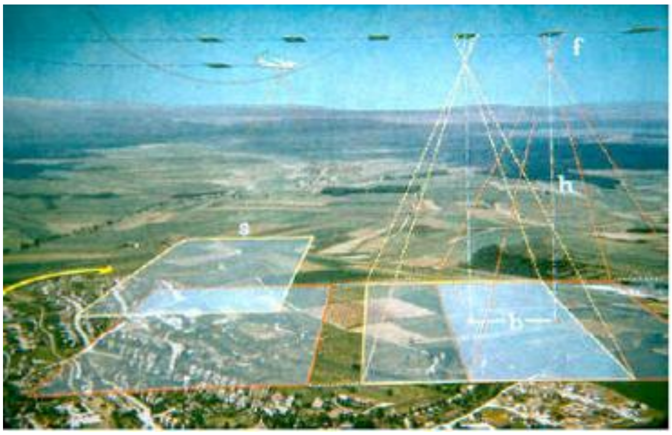

***Fig 1**. Aerial photogrammetry is done using pictures taken from specially equipped aircraft.*

Obtaining and evaluating the pictures with photogrammetry, obtaining the coordinates of three-dimensional objects from the measurements in the pictures are carried out quickly and easily. A complete view of the object being studied in detail can be obtained [6].

Volume calculations of inaccessible, risky to access or objects that require speed can also be effectively calculated. Photogrammetry shortens the time required to collect data in the field. Photographs can be used as legal evidence, as they accurately determine the moment of shooting. In addition to solid and fixed objects, fluid-volatile objects and moving and deformable objects can be recorded and measured. Mixed shapes and movements can be measured easily [8].

In addition to all these benefits, it is difficult to apply photogrammetry in unfavorable outdoor conditions (insufficient lighting, dust, etc.) [15].

LASER SCANNING TECHNOLOGIES

Laser is a word derived from the initials of the words in the sentence light amplification by stimulated emission of radiation. While normal light consists of waves with different phases and wavelengths, laser light consists of waves of high amplitude, in the same phase, parallel to each other, monochrome, with almost the same wavelength. The optical wavelength region lies between approximately one trillion hertz and three thousand trillion hertz. This region includes infrared rays, visible rays and ultraviolet rays of the electromagnetic spectrum [15]. It’s shown in fig 2.

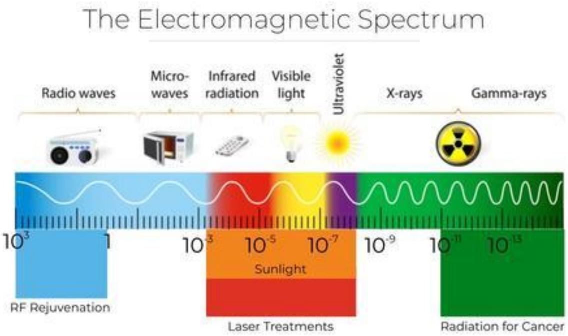

***Fig 2**. Light Spectrum*

Laser scanning technology enables 3D point clouds to be obtained through the reflections of light filters sent to objects. Laser scanners collect 3D geometric and visual information about the object to be collected, thanks to the point clouds obtained from the rays emitted from the device. A laser scanner can measure hundreds of thousands of points with millimeter precision within its own coordinate system. It finds (x, y, z) coordinates by considering the distance from the point itself and the angle to the planes [16]. Three-dimensional models of objects are created by recording, joining, refining, filling point gaps, and filtering point clouds [1]. In other words, laser scanning method is a technology that provides direct, precise and automatic 3D coordinates of objects [17].

Laser scanning technologies are used in engineering projects, reverse engineering applications, registration of cultural heritage, map production, geological applications and deformation measurements. For example, with laser scanning, a full digital model of an existing factory can be obtained, new equipment can be programmed with a visual 3D installation and work can be done without stopping production. In addition, if the cultural heritage is damaged with accurate, real, visual 3D models, restorations can be provided and all people can visit historical heritage virtual (virtual tourism) via the internet [1,18].(fig 3)

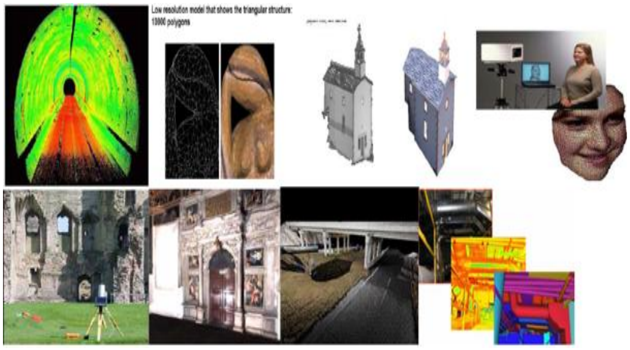

***Fig 3**. Some Samples of 3D Laser Scanning*

Working Principle of Laser Scanners

Terrestrial laser scanners have a mechanism that can rotate horizontally and vertically. The modulated laser beam exits the electronic unit of the instrument and hits the rapidly rotating optical part. Acting like a mirror, the beam on the surface of this optical unit is reflected and emerges from the instrument at a specific angle. Immediately after obtaining this angle, the laser scanner rotates at a very small angle around the vertical axis to obtain the next angle. This process continues periodically until the scanning process is finished. A large set of points is obtained during scans, and each point in this set of points is expressed in polar coordinates. Today, laser scanners record the radiometric densities of each point as well as the geometric locations. In addition, photographs are also recorded by laser scanners with high-resolution camera systems, and colored point clouds can be obtained thanks to these photographs [15].

Triangulation Based Laser Scanners

The coordinates of the scanned point are determined by optical triangulation method in scanners operating with the triangulation method. According to this method, the reflector sends the laser beam to the object surface and the CCD camera collects the reflected laser beam. The coordinates of the points on the object surface are obtained from the triangles formed. Single-camera and dual-camera solutions are applied to determine the position in scanners operating with the triangulation method [17]. Triangulating system scanners are more useful for precise scanning of small sized objects [18]. The figure 4 and figure 5 shows the working principle of the triangulation method and the scanning method.

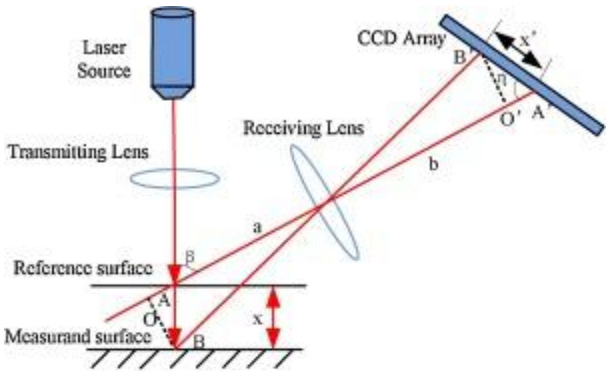

***Fig.4**. Working principle of scanners using triangulation method*

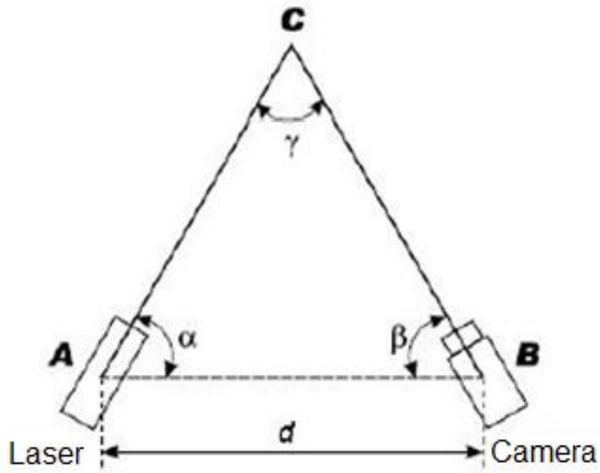

***Fig.5**. Triangulation method*

If we express Figure 5 in detail, if the distance (d) between the laser and the camera and the two angles (α) and (β) of the triangle are known, it is possible to calculate the coordinate of the point (c). The magnitude of the (γ) angle affects the resolution at depth. If (γ) gets bigger, depth resolution increases, if it gets smaller, it decreases [2].

Processing of the phase comparison method Scanners

The laser beam transmitted in scanners operating with the phase comparison method is modulated by harmonic waves. In this method, there is a fixed laser beam emanating from the scanner. The device measures the distance thanks to the phase difference between incoming and outgoing rays [16,17].

Scanners Using Laser Beam Flight Time

In scanners operating with laser beam flight time, the length between the scanner and the scanned point is calculated by measuring the time difference between the transmission and reception of the laser beam. This type of scanners have a photo diode used to collect the laser beam reflected from the surface of the object and a very sensitive clock mechanism that starts working with the emission of the laser beam and stops with the capture of the reflected beam. Thanks to these mechanisms, the time difference is determined. Typical standard deviations of length measurements are a few millimeters. 3D accuracy is also affected by the angular pointing accuracy of the beam [2,17].

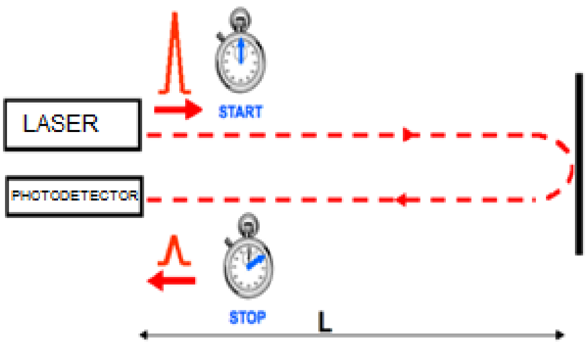

***Fig.6**. Working principle of Laser Beam Flight Time method*

Laser scanners, which operate according to the laser beam time-of-flight method and the phase comparison method, are mostly used in the scanning of long-range and large objects due to their distance measurement up to a few hundred meters and their sensitivity from a few millimeters to centimeters depending on the total distance. The working principle is shown in figure 6. On the other hand, scanners working with the phase comparison method can receive more point data in a shorter time than scanners operating with the principle of flight time and are approximately ten times faster. Scanners working with the principle of flight time can measure at greater distances.

Scanners working with the triangulation method, which are close range scanners, are used in scanning small sculptures and small objects in the documentation of cultural assets [16-18].

Laser scanners create high-precision 3D models of scanned objects and contain a high level of object-related detail. They are fast in data collection [18]. Lerones et al. concluded in their study that the laser scanning method reduced the time required for fieldwork 75% and the time required for drawing operations by 25% [19,22].

The information obtained from laser systems is compatible with the reality and three-dimensional geometric and visual information can be obtained at low cost. With these scanners, measurements can be made in confused, inaccessible, dangerous objects and areas. Scanning operations are independent of ambient lighting, scanning can be performed even at night. Measurements can be made in all weather conditions and objects can be measured remotely without the need for contact. In addition, laser scanners can capture everything in one go. Thus, if data is required again, the person performing the scan does not have to return to the field [1,20].

Measurement-based errors have been eliminated thanks to laser scanning technologies. In addition, laser dimensions can be easily integrated with other existing measurements. It is possible to display the data obtained as a result of the measurement in different formats (20,21).

In addition to all these, millions of points are obtained in the scanning process performed with the laser scanning device and the large size of these points on the computer slows down the processing of data. Therefore, computers with high working capacity should be used in processing data (17).

CONCLUSION

Although digital photography methods are effective in 3D modeling, they have some shortcomings. First, image manipulation and orientation are required before analyzing the model. For this reason, efficient information retrieval time from data is longer than laser scanner technology. In addition, photogrammetry is not suitable for use in unfavorable outdoor conditions (insufficient lighting, dust, adverse weather conditions). However, Duran et al. showed that the terrestrial photogrammetric method gave more accurate results than laser scanning in terms of point coordinates in their study. In addition, they concluded that laser scanning gives more accurate results in terms of the dimensions of the object and that the 3D model is obtained more detailed and smoothly by laser scanning.

REFERENCE

[1] K. Gümüş ve H. Erkaya, «Mühendislik Uygulamalarında Kullanılan Yersel Lazer Tarayıcı Sistemler,» %1 içinde TMMOB Harita ve Kadastro Mühendisleri Odası 11. Türkiye Harita Bilimsel ve Teknik Kurultayı, Ankara, 2007.

[2] O. Akyol, Düşük Maliyetli Lazer Tarayıcı Sistemi Tasarımı (tez), İstanbul, 2011.

[3] İ. Şahin, T. Şahin, H. Gökçe ve O. Eren, «Hasarlı Dişlilerin Tersine Mühendislik Yaklaşımıyla Yeniden Oluşturulması,» Düzce Üniversitesi Bilim ve Teknoloji Dergisi, no. 5, pp. 485-495, 2017.

[4] A. Ç. Önçağ, Ç. Tekcan ve H. Özden, «Mekanik Parçaların Tersine Mühendislik ile Modellenmesinin Değerlendirilmesi ve Bir Uygulama,» Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, cilt 24, no. 1, pp. 43-49, 2018.

[5] S. A. Güleç, Yersel Fotogrametri Yöntemi ile Rölöve Alım Tekniğinin Taç Kapılarda Uygulanışı Konya Örnekleri (tez), Konya, 2007.

[6] A. S. Toprak, Fotogrametrik Tekniklerin İnsansız Hava Araçları ile Mühendislik Projelerinde Kullanılabilirliğinin Araştırılması (tez), Konya, 2014.

[7] A. Ulvi, Antik Tiyatroların Fotogrametrşk Rölöve Planlarının Çıkarılması Üzerine Deneysel Bir Çalışma (tez), Konya, 2008.

[8] H. M. Yılmaz ve M. Yakar, «Digital Yersel Fotogrametrinin Hacim Hesabında Kullanılması,» %1 içinde TMMOB Harita ve Kadastro Mühendisleri Odası 11. Türkiye Harita Bilimsel ve Teknik Kurultayı, Ankara, 2007.

[9] R. A. Kuçak, F. Kılıç ve A. Kısa, «Tarihi Eserlerin Dokümantasyonunda Çeşitli Veri Toplama Yöntemlerinin İncelenmesi,» %1 içinde Uzaktan Algılama-CBS Sempozyumu (UZAL-CBS 2014), İstanbul, 2014.

[10] B. Kula ve E. Ergen, «Lazer Tarayıcı Teknolojisinin Yapım Yönetiminde Kullanım Alanları,» %1 içinde Uluslararası Katılımlı 7. İnşaat Yönetimi Kongresi, Samsun, 2017.

[11] R. Çömert, U. Avdan, M. Tün ve M. Ersoy, «Mimari Belgelemede Yersel Lazer Tarama Yönteminin Uygulanması (Seyitgazi Askerlik Şubesi Örneği),» Harita Teknolojileri Dergisi, cilt 4, no. 1, pp. 1-18, 2012.

[12] U. Avdan, E. Pekkan ve R. Çömert, «Mağara Ölçümlerinde Lazer Tarayıcıların Kullanılması,» Harita Teknolojileri Elektronik Dergisi, cilt 5, no. 2, pp. 16-28, 2013.

[13] P. M. Lerones, J. L. Fernandez, A. M. Gil, J. G. G. Bermejo ve E. Z. Casanova, «A Practical Approach to Making Accurate 3D Layouts of Interesting Cultural Heritage Sites Through Digital Models,» Journal of Cultural Heritage, cilt 11, no. 1, pp. 1-9, 2010.

[14] E. S. Bozkurt, «Tersine Mühendislik Süreci ve Uygulamaları,» Mühendis ve Makina, cilt 50, no. 597, pp. 35-42, 2009.

[15] Z. Duran ve U. Aydar, «Digital Modeling of World's First Known Length Reference Unit: The Nippur Cubit Rod,» Journal of Cultural Heritage, cilt 13, no. 3, pp. 352-356, Temmuz 2012.

[16] E. Kocaman, «Fotogrametrinin Gelişimi ve 21. Yüzyıl Başlarında Fotogrametri,» Selçuk-Teknik Online Dergisi, cilt 1, no. 3, 2001.

[17] E. Ö. Avşar, Tarihi Köprülerin Digital Fotogrametri Tekniği Yardımıyla Modellenmesi (tez), İstanbul, 2006.

[18] İ. Şanlıoğlu, M. Zeybek ve G. Karauğuz, «Photogrammetric Survey and 3D Modeling of Ivriz Rock Relief in Hittite Era,» Meditrranean Archaeology and Archaeometry, cilt 13, no. 2, pp. 147-157, Aralık 2013.

[19] P. Arias, J. Armesto, J. Vallejo ve L. Henrique, «Close Range Digital Photogrammetry and Software Application Development for Planar Patterns Computation,» Dyna, cilt 160, no. 160, Aralık 2009.

[20] A. Yaman, H. M. Yılmaz ve M. A. Yıldırım, «Obje Yüzey Eğimlerinin Yersel Lazer Tarayıcıların Konum Doğruluğuna Etkileri,» Selçuk Üniversitesi Mühendislik, Bilim ve Teknoloji Dergisi, cilt 5, no. 1, pp. 61-

71, 2017.
[21] A. M. Tanyer ve M. K. Pekeriçli, «İnşaat Sektörü İçin Bilgi Teknolojilerindeki Son Gelişmeler,» Türkiye Mühendislik Haberleri, no. 5, pp. 21-26, Mayıs 2008.
[22] Z. Duran, M. E. Atik ve M. F. Çelik, «Yersel Fotogrametrik Yöntem ile Yersel Lazer Taramanın Karşılaştırılması ve Doğruluk analizi,» Harita Dergisi, no. 158, pp. 20-25, Temmuz 2017.