Design and Development of a Rotary 3D Scanner for Human Body Scanning

Khalil KHALILI*, Mojtaba ZERAATKAR
University of Birjand, Birjand, Iran

DOI: 10.15221/17.312 http://dx.doi.org/10.15221/17.312

Abstract

In recent years, reverse engineering industry has experienced remarkable overhaul owing to the advancements in electronic and optic industries. 3D scan technology finds new applications ranging from industrial to common everyday subjects. One of its applications is in the field of 3D scanning of human body. Human scanning is of complicated items for modeling due to non-rigidity and large time interval required for entire body measurement. Human scanning has different applications in the fields of sculpturing, medicine, sports, clothing and security. There are limited number of commercial scanners in the field of human body scanning and are generally categorized into two groups depending on the utilization of laser technology or image for extracting the geometric parameters. A variety of companies offer laser systems, although they are often costly. With regard to human scanning, it must be noted that some scanners may be hazardous or dangerous for human due to their special lighting (such as laser). Plus, individuals mentally prefer not to be exposed to laser radiation. Hence, image-based scanners are more acceptable for human scanning. This paper presents the design and manufacture of a rotary 3D scanner for human scanning which employs the structure from motion method to extract 3D data from the object. The system employs typical inexpensive camera and lighting source, as a result of which the system is very low cost. The design process to create a 3D scanning system that is presented in this paper may be categorized into three general sections. First section includes the design and creation of physical structure of the system, second section includes the electronic components of system, and the third section is the system software. The scanner uses 2D images to extract the 3D model. For image capturing and their quick transmission to the server, relevant camera and boards were utilized. The boards together with the cameras should be mounted in certain positions relative to the object, and they should have 360° of rotary freedom to be capable of capturing images from the object. The design and production process has been carried out in the University of Birjand.

Keywords: reverse engineering, 3D scanning, image-based scanners, human scanning

1. Introduction

In recent years, reverse engineering industry has experienced remarkable overhaul owing to the advancements in electronic and optic industries. Measurement methods for extracting 3D sizes of parts are generally divided into two groups, namely, active and passive. Fig. 1 shows this classification. In active methods, the measurement system is in direct contact with the object and special lighting is required. In passive method, the measurement system does not have any contact with the part. Passive methods are those which are capable of finding the depth and dimensions of object without the use of radiation on the part and no special lighting is required for them and ambient light is usually used for extracting the object's dimensions. Active methods which generally use laser or structured light, are referred to as laser-based systems. A variety of companies offer such systems, although they are often costly. Image-based systems, because of several reasons such as the absence of any special lighting source as well as the utilization of typical camera, have usually low costs. The presence of such advantages results in the attractiveness and the diversity of such systems' applications in reverse engineering.
The work conducted in this paper is the production of a 2D-image-based rotary 3D scanner which employs the structure from motion method to extract 3D data from the object. The 3D scanner introduced in this paper is based on a work by Richard Garsthagen [2] with the difference that our scanner is rotary and 2D images are captured by rotating around the object in order to extract the 3D model. In this method, at first, different images are captured from the object and the 3D point cloud is extracted by properly linking the pixels of images. Technics such as the detection of local features [3] and their verification to link different images are used. The design of the introduced scanner in this paper has been considered for thorough scanning of human body; however, it may be employed for other objects as well. The applications of the presented 3D scanner can be found in sculpturing, medicine, sports, clothing and security.

* kkhalili@birjand.ac.ir; +98- 56- 32202008

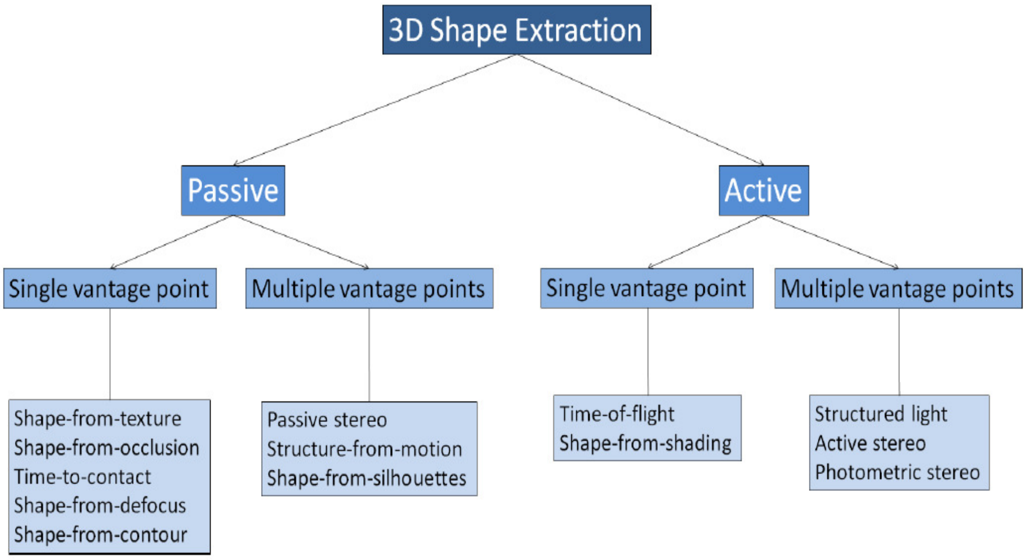

Fig. 1. Classification of methods for the extraction of information on 3D shape

2. Background

3D scanning technology has numerous applications. It is usually operated in various scales. From this aspect, the works accomplished in the field of 3D scanning may be classified into three groups. This technology can be used for scanning larger-than-human objects such as a building, objects with approximate size of a human, and objects smaller than human such as tools and industrial parts. For each different scale, 3D scanning technology has different applications which is discussed in continuation.

The scanning of historic places with archaeological purposes [4, 5] can be cited as an example of the objects larger than human. Gu and Xie [6] explained the feasibility of 3D scanning for the evaluation and extraction of mines. This technology is also applied in tunnel inspection [7]. It is also used in reconstruction of a scene such as a street or accident [8, 9] and urban planning [10].

Human scanning as well as equal-to-human-size objects scanning are among the other applications of 3D scanning technology. The concentration of the work presented in this paper is also on human scanning. Human scanning, due to the presence of relatively more complicated features than some objects as well as the displacements during scanning, is considered one of most difficult scans. Medical applications are among the applications of human scanning. For instance, the evaluation of the shape of scoliosis patients' back [11, 12], consideration of human skeleton changes during daily life [13], and consideration of the effect of sports on body [14] are among the applications of 3D scanning in medicine. The extraction of the features of body organs and the production of them are among the 3D scanning applications in biomedical engineering [15]. The employment of 3D scanning in the field of clothing design is another absorbing application of this technology, which is widely feasible in tailoring and making product recommendations [16, 17]. With regard to human scanning, it must be noted that some scanners may be hazardous or dangerous for human due to their special lighting (such as laser). Plus, individuals mentally prefer not to be exposed to laser radiation. Hence, image-based scanners are more acceptable for human scanning.

The application of 3D scanning for the objects smaller than human is very extensive and widespread. The scanning of various industrial parts as well as the inspection and quality control of the parts may be cited as its applications. Plants are among difficult objects for scanning because of non-rigidity and having components with different sizes [18]. Zeraatkar et al., using high precision 3D scanning system, modeled a saffron flower [19]. The scanning of different organs of human such as hand, leg, etc. as well as the detection of human facial expressions [20] are other applications of this technology for smaller-than-human parts.

3. System Design

The design process to create a 3D scanning system that is presented in this paper may be categorized into three general sections. First section includes the design and creation of physical structure of the system, second section includes the electronic components of system, and third section is the system software, which are described below.

3.1. Physical structure

The presented 3D scanner uses 2D images to generate the 3D model. To this end, at first, several images must be captured from different angles around the given object. For image capturing and their quick transmission to the server, relevant camera and boards were utilized. The boards together with the cameras should be mounted in certain positions relative to the object, and they should have 360° of rotary freedom to be capable of capturing images from the object. To this end, a structure in compliance with what is shown in Fig. 2 was designed. To produce the structure, wood and steel have been used. As it is shown in Fig. 2a, the rotary table is constituted of two concentric circles, i.e. an inner circle with a diameter of 172 cm and an outer circle with an internal diameter of 180 cm and an external diameter of 200 cm. The inner circle is fixed and it is actually the place of the supposed object. The outer circle provides the assumed rotation about the object through the rollers assembled between itself and the inner circle (Fig. 2a) and those assembled under it (Fig. 2b). The set of inner and outer circles are placed on a circle with a diameter of 200 cm (Fig. 2c) in order to reduce the vibrations caused by the floor's roughness. The set of rotary table was produced as two separate parts to facilitate the transportation.
12 cameras with relevant boards have been used in the scanner. For holding these modules, 3 steel bars with the diameter of 3.8 cm and length of 210 cm were used as shown in Fig. 2b. These bars are positioned approximately 90 cm off the center of inner circle by fasteners to be located on outer circle.

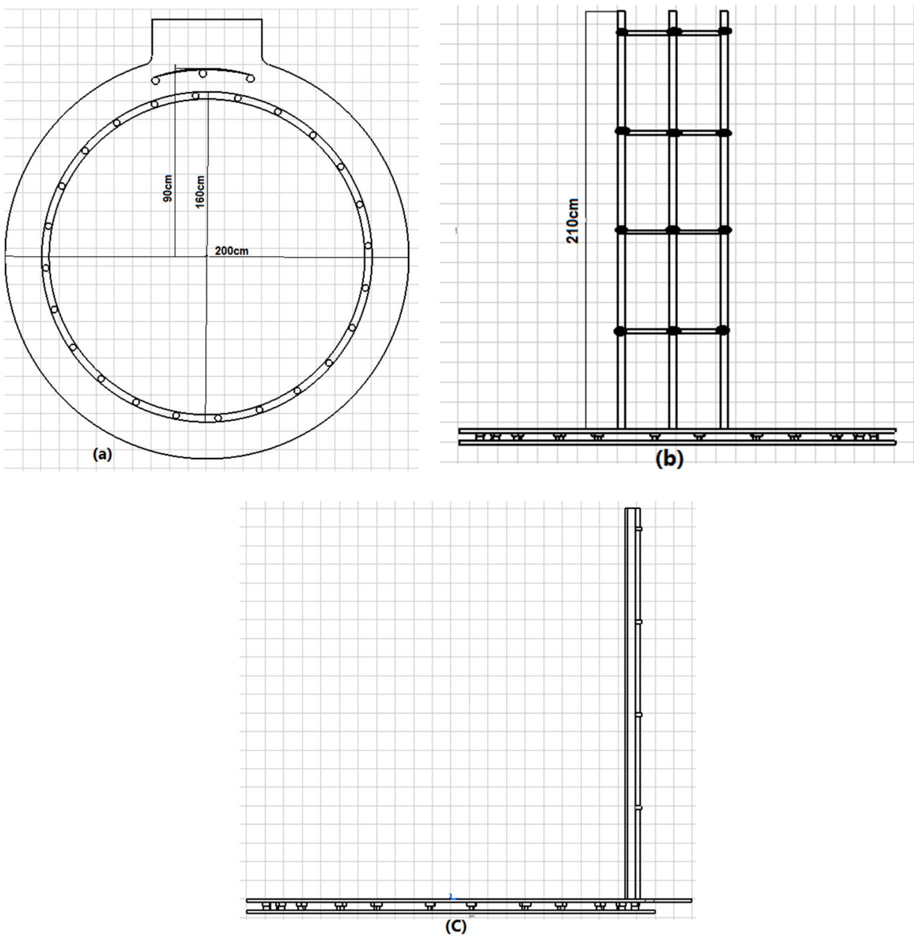

Fig. 2. (a) Top view— inner and outer circles with rolls between them; (b) Front view— steel bars with location of cameras and bottom rollers; (c) Right view— Bottom circle below the rotary table

To provide an appropriate overlap between the images, the angle between the steel bars is adjusted as 15 degrees. To prevent the vibration of cameras during the rotation of table, the bars are constrained by other bars (Fig. 2b).
The cameras together with their relevant boards are placed on the steel bars in 4 different levels as shown in Fig. 2b. There are 3 cameras in each level. The height of the levels from the rotary table's surface is 50 cm for first level, 100 cm for second level, 150 cm for third level, and eventually 200 cm for forth level. To hold the boards and cameras on the bars, fasteners made of compact Teflon were designed. Fig. 3 shows the physical structure of the 3D rotary scanner.

3.2. Electronic Components

The electronic components of 3D scanning system incorporate the following items:

- Main server which is a computer
- 12 boards
- 12 cameras
- 12 external storage 8-GB
- Adjustable power supplies
- 16-port Ethernet switch
- Ethernet cable
- Lighting system

The cameras are directly connected to the relevant boards and the 8-GB micro SD storage is inserted into the special socket on the board. The micro SDs are used for installing the intended operating system on the board. They can also be used as a temporary memory for storing the captured images before transmitting to the main server. A pair of cables including a power supply cable and an Ethernet cable is connected to each board. Most of the electronic components are connected to the Ethernet switch using the Ethernet cables.
The lighting system is one of significant parts of the presented scanner. It may be boldly said that, in addition to the camera's resolution in image-based scanners, it is the lighting system that has the highest impact on final model quality. The lighting adjustment should be such that there is no dark zone; on the other hand, it should not be such that it creates shadow on the object and background. The more suitable and uniform the lighting is and the better texture the scanned objects have, the higher the precision of created model will be. In the current work, different lightings have been tested and eventually, as it is shown in Fig. 4, strip LED lights with Soft Box were utilized to focus the light on the target. The designed 4 projectors which perform the lighting from 4 different points (2 in front and 2 in back with 45° angle relative to object) as well as the strip LED lights that perform the lighting from top, constitute the lighting system.

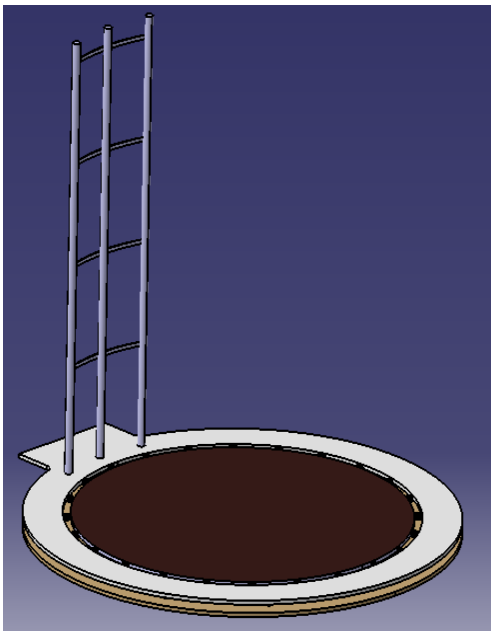

Fig. 3. Physical structure of the 3D rotary scanner

Fig. 4. Lighting in 3D scanning system

3.3. Software

3D scanner works by capturing images in four different levels around the object. This task is accomplished by sending a message from the main server to the boards. Upon the reception of the message, the relevant boards capture the images from different views in a fraction of a second and upload them to the main server. Then, the scanner table rotates and the process is repeated. The process continues until the different images around the object are thoroughly captured. The time required for a complete rotation about the object depends on the number of positions that the scanner stops to capture the images. The interval is about 30 seconds for capturing 96 images from 8 positions (45° angle). The entire operation including image capturing from certain positions, transmission of images to the main server, and saving as a specific file, is done automatically by software upon the operator's command. The captured images are afterwards processed within several stages to create a 3D model. The software-processed different stages are described in the next section.

3. Results

The creation stages of the physical structure of a scanner, electronic components, and the software used by scanner were explained in previous section. A 3D rotary scanner was produced in the University of Birjand by assembling the different parts of the system (Fig. 5). In this section, the manner of the scanner's operation is briefly discussed.

Scanning process begins by positioning a human or an intended object on the fixed part of the table (Fig. 5). The introduced scanning system does not require any calibration. With the beginning of lighting system, the images are captured with the operator's command to the software. The images are obtained from different angles and heights around the human or object and they are transmitted to the main server to extract the 3D point cloud. The mentionable note is that the position of cameras as well as the rotation angle must be set such that there is overlap between images in both longitudinal and latitudinal directions. To generate a CAD model through 2D images, first the 3D point cloud is extracted by verifying the feature points [3] across the captured images. Fig. 6a depicts the tie point cloud. After the creation of tie point cloud, dense point cloud is created as shown in Fig. 6b. Then, the dense point cloud is meshed (Fig. 6d). Tie point cloud may also be used for meshing, however, it shows fewer details of the object. Fig. 6c suggests the wireframe model of the intended object. In every stage of 3D model creation, it is possible to export an output with arbitrary format from the software to be read by other commercial reverse engineering software packages. For instance, it is possible to export an output with STL or OBJ format from the created mesh for printing the model by 3D printers. Also, texture and color may be added to the 3D model by using the captured images (Fig. 6e).

Fig. 5. 3D rotary scanning system

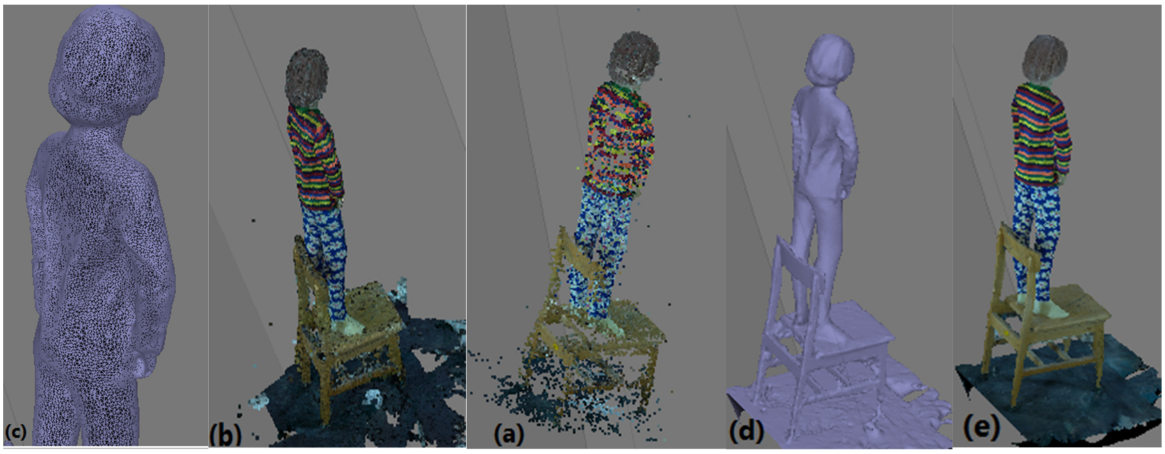

Fig. 6. (a) Tie point cloud; (b) Dense point cloud; (c) Wireframe model; (d) Showing the mesh; (e) 3D model with texture

References

[1] T. Moons, “3D Reconstruction from Multiple Images Part 1: Principles”, *Foundations and Trends® in Computer Graphics and Vision*, vol. 4, no. 4, 2008, pp. 287-404, http://dx.doi.org/10.1561/0600000007.
[2] R. Garsthagen. "The Pi 3D Scanner Project", http://www.pi3dscan.com/, accessed 2016.
[3] D. G. Lowe, "Distinctive Image Features from Scale-Invariant Keypoints”, *International Journal of Computer Vision*, vol. 60, no. 2, 2004, pp. 91-110, http://dx.doi.org/10.1023/B:VISI.0000029664.99615.94.
[4] L. Nesi, “The use of 3D laser scanning technology for buildings archaeology: The Case of Måketorpsboden in Kulturen Museum, Lund”, Lund University, Lund, Sweden, 2013.

[5] A. G. Burens, P.; Guillemin, S.; Carozza, L.; Leveque, F.; Mathé, V., "Methodological developments in 3D scanning and modelling of archaeological French heritage site: The bronze age painted cave of "LES FRAUX", Dordogne (France)," in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Strasbourg, France, 2013, pp. 131-135, https://doi.org/10.5194/isprsarchives-XL-5-W2-131-2013.
[6] F. X. Gu, H., "Status and development trend of 3D laser scanning technology in the mining field", in RSETE, 2013.
[7] J. Laurent, R. Fox-Ivey, F. S. Dominguez, and J. A. R. Garcia, "Use of 3D scanning technology for automated inspection of tunnels", *Proceedings of the World Tunnel Congress 2014 – Use of 3D Scanning Technology for Automated Inspection of Tunnels*, Foz do Iguaçu, Brazil.
[8] V. PAGOUNIS, M. TSAKIRI, S. PALASKAS, B. BIZA, and E. ZALOUMI, "3D Laser Scanning for Road Safety and Accident Reconstruction", Munich, Germany, 2006.
[9] S. Nas, and S. Jucan, "Aspects regarding 3D laser scanning surveys for road design," *Agric. Agric. Pract. Sci. J.*, vol. 85, 2013, pp. 140-144.
[10] J.-S. Shih, and T.-T. Lin, "Fusion of image and laser-scanning data in a large-scale 3D virtual environment", *Proc. SPIE 8881, Sensing Technologies for Biomaterial, Food, and Agriculture*, 2013, pp. 88810B-88810B-1, http://dx.doi.org/10.1117/12.2030996.
[11] F. Berryman, P. Pynsent, J. Fairbank, and S. Disney, "A new system for measuring three-dimensional back shape in scoliosis", *European Spine Journal* ,vol. 17, no. 5, 2008, pp. 663-672. http://dx.doi.org/10.1007/s00586-007-0581-x.
[12] M. Ares, S. Royo, J. Vidal, L. Campderrós, D. Panyella, F. Pérez, S. Vera, and M. A. G. Ballester, "3D scanning system for in-vivo imaging of human body", in In Fringe 2013, New York, NY, USA, 2014, pp. 899-902, https://doi.org/10.1007/978-3-642-36359-7_168.
[13] C. N. Stephan, and P. Guyomarc'h, "Quantification of Perspective-Induced Shape Change of Clavicles at Radiography and 3D Scanning to Assist Human Identification", *Journal of Forensic Sciences*, vol. 59, no. 2, 2014, pp. 447-453, https://doi.org/10.1111/1556-4029.12325.
[14] P. Treleaven, and J .Wells, "3D body scanning and healthcare applications", *Computer*, vol. 40, 2007, pp. 28-34, https://doi.org/10.1109/MC.2007.225.
[15] O. Ciobanu, and G. Ciobanu, "The use of 3D scanning and rapid prototyping in medical engineering", *Fiabil. Durab*, vol. 1, 2013, pp. 241-247.
[16] R. P. Crease, "Invasion of the Full-Body Scanners", *Wall Street Journal*, 7 January, 2010.
[17] N. D'Apuzzo, "3D body scanning technology for fashion and apparel industry," in Proc. SPIE San Jose (CA), USA, 2007.
[18] M. Zeraatkar, K. Khalili, and A. Foorginejad, "Studying and Generation of Saffron Flower's 3D Solid Model", *Procedia Technology*, vol. 19, 2015, pp. 62-69, https://doi.org/ 10.1016/j.protcy.2015.02.010.
[19] M. Zeraatkar, K. Khalili, and A. Foorginejad, "High-Precision Laser Scanning System for Three-Dimensional Modeling of Saffron Flower", *Journal of Food Process Engineering*, vol. 39, no. 6, 2016, pp. 553-563, https://doi.org/ 10.1111/jfpe.12248.
[20] T. Stuyck, D. Vandermeulen, D. Smeets, and P. Claes. "HR-Kinect-High-Resolution Dynamic 3D Scanning for Facial Expression Analysis", December 2016; http://www.student.kuleuven.be/~s0200995/paper.pdf