Construction of low-cost 3D scanner using triangulation and Screened Poisson Surface Reconstruction techniques

K Saptaji1,*, M Faizul2 and A Fakhri3

1Department of Mechanical Engineering, Faculty of Engineering and Technology, Sampoerna University, Jakarta, Indonesia
2Top Glove Sdn Bhd, Lot 4969, Jln Teratai, 6th Miles, Off Jln Meru, 41050 Klang, Selangor D.E., Malaysia
3Faculty of Manufacturing and Mechatronic Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur, Malaysia

*kushendarsyah@sampoernauniversity.ac.id

Abstract. The application of 3D scanner technology among industrial practitioner in Indonesia and Malaysia is still at the beginning stage. Compared to others, this technology has already been adapted mostly by growing country such as China, Korea, US, Germany and Italy. This technology can be seen implemented in manufacturing, aerospace, medical and dentistry industries. The concept of 3D scanner technology is mainly to improve the reverse engineering process. Due to the high cost of 3D scanner machine available in the market, therefore a reasonable cost-effective 3D scanner is needed to be developed especially for education purposes. The objective of this project is to develop low-cost 3D scanning setup to create a mesh of a small-scale object with the help of open-sources software for 3D scanning and 3D mesh processing. Triangulation technique was used for the scanning process to capture the object surface. Screened Poisson Surface Reconstruction techniques was applied to improve the uncomplete and uneven surface mesh. In order to test the setup, 3D scanning was conducted on 4 different objects with different colours and surface finish. The scanning results show that the proposed method produced a good 3D mesh with less noise and less uncomplete surface.

1. Introduction

A 3D scanner is a machine, or a gadget used to collect data and to recreate a surface of the 3D object or model. The 3D scanner has been applied in many industries, such as in manufacturing, medical industry [1], dentistry [2], architectural and even for crime investigation [3]. There are various applications of 3D scanning in medical industry such as to capture the 3D image of patient, to design high precision medical devices and tooling, to develop prosthesis and orthotics and to design tissue engineering [1]. The 3D scanning technology is also helped dentistry in designing dental models, customized bracket and archwires and also in removing appliances and occlusal splints [2]. The 3D facial scanning proved to have better result in analyzing the human face compared to 2D photography. The result can be useful to be applied in orthodontic and orthognathic surgical diagnosis and treatment planning [4]. The application of 3D scanner as a new technology may also be helpful in the contemporary audio visual to produce hybrid new media production [5].

A flexible 3D scanning process using robot-mounted 3D scanner was developed [6]. This method can provide complete automation of registration of point clouds and use for customized surface...
characteristics of the component and accuracy requirements [6]. In order to recreate the 3D model, photogrammetric 3D scanning technique can also be applied. In this technique, the 3D model develops from photographs. Reljić et al. [7] studied various software for generating 3D models using photogrammetric 3D scanning technique. They argued that Photoscan produced the best result in term of model resolution (point number), model file size (MB), total 3D model reconstruction time (seconds), texture file size (MB) and visual qualitative analysis performed by an expert in the field [7].

Nowadays, the 3D scanning is not only able to scan in the fix position where the sample need to bring to the 3D scanner equipment location. Portable 3D scanner with various brands and methods are available. Kersten et al. [8] compared hand-held 3D scanning systems such as Agisoft Photoscan, RealityCapture, 3DFLOW Zephyr, and Meshroom in term of their capabilities on the applications and size of the various objects. Amonrvit and Sanokhan [9] also compared various hand-held 3D scanning for face recognition in term of processing time and dimensions accuracy. It was observed that 3D scanner is affected by the scanning length and pattern of scanning and the accuracy of an optical scan is dependent on the technology used by each scanner.

There are various 3D scanning techniques, one of them is laser triangulation technique. The triangulation 3D laser scanner uses triangle formation of the laser dot, the camera and the laser emitter. The length and distance of one side of the triangle; the distance between the camera and the laser emitter is known, same with the angle of the laser emitter at the corner [2]. This method is suitable for a scanning a complex object within a small distance, such as scanning a complex gear design. This technique is known to be cheapest technique since it needs only a digital camera instead of special hardware. The objective of this project is to develop and build a low-cost 3D scanning setup using the proposed technique and open-sources software for 3D mesh scanning and processing in order to produce a 3D mesh model for a small-scale object. A reasonable low-cost of 3D scanner is necessary to be built. A low-cost 3D scanner can be applied for educational purposes.

2. Methodology

2.1. Technique

A non-contact active triangular technique was chosen among the other techniques. The triangulation technique was designed for a short-range scanning and the scanner was made for small scale object. In addition, it has a high accuracy (tens of micrometres) compared to other techniques. Triangulation technique implements the laser stripe for scanning. The laser stripe was chosen as the best method and the best performer since it is fulfilled the requirements: fast and precise. The Screened Poisson Surface Reconstruction technique was used to reconstruct the surface of the mesh, reduce the uncomplete faces on the mesh and remove the noise result for the mesh so that a smoother result can be created.

2.2. Software

The software used in this project is David Laserscanner [10] and MeshLab [11]. David Laserscanner is an open-source software suitable for a low-cost 3D laser scanning. It can scan an object in three-dimensional using a camera, e.g. webcam, a laser that projects a line, and two pattern boards for a laser tracking. David Laserscanner grabs the figure of the object from a single viewpoint. In order to make a full 3D mesh, the object needs move and rotate multiple time, scans the new surface and creates a new mesh until all of object surfaces are scanned. The output of the software is meshed 3D point cloud in .obj file. MeshLab is an open-source software specialized for editing and processing 3D triangular meshes.

2.3. Procedure

A hand-held red laser line (RM 12) was used because it is low-cost and suitable for the software. A low-cost Lenovo webcam (RM 120) was also used for the setup. The software required a special patterned background which was printed on A4 paper and was glued to a board and position according to the software setup in Figure 1. Once the object placed in the setup, the David Laserscanner software was
opened, and the setup type and camera were selected. Arduino (RM 55) and DC motor (RM 5) were also used. Therefore, the total cost of the setup is about RM 192. Then, the camera was calibrated with the V3 pattern board and the laser was chosen as red prior the scanning process.

![Figure 1. Hardware setup for the 3D scanning [1].](image)

The scanning process started by placing the laser line at horizontal and around 45° angle. The laser was moved up and down in vertical motion while keeping the laser line at horizontal. The object needs to move and rotate several times and the scanning process was repeated until all the surfaces captured. Once the scanning finished, the file was saved in .obj file extension. The file opened using MeshLab for editing, aligning and resurfacing of the mesh process. The mesh was measured using Measuring tool to examine any measurement error and the file is saved in .stl format.

3. Results and discussion

Four objects with different colours namely red, blue, yellow, and grey are selected and scanned. In order to quantify the results, three dimensions are measured for each of the object: length, width, and height. These three measurements are compared to the scanned results. The steps conducted during the scanning process are scanning, editing and aligning. Subsequently after editing and aligning processes, the mesh is seen to be incomplete. The scanned results have holes (missing surfaces) and uneven surface due to the limitation of free version of David Laserscanner software. The software is not able to produce high-resolution and smooth scanning results. Therefore, Screened Poisson Surface Reconstruction was used to solve the problem. Screened Poisson Surface Reconstruction is a technique where it creates a surface called “watertight” surface from surrounding point samples. This technique is good in removing noisy data in mesh and misalign mesh.

3.1. Red object

The red object selected is a red colour toy truck. Figure 2 (a) and (b) show the real object in several angles and 3D mesh of red colour toy truck after Screened Poisson Surface Reconstruction respectively. It can be seen by using Screened Poisson Surface Reconstruction tool in MeshLab, it is able to fill the hole and align all the misalign surface.

![Figure 2. (a) Red colour object (toy truck), (b) 3D mesh object after screened poisson surface reconstruction.](image)
From the observation during the scanning process, the David Laserscanner software having difficulty in capturing the surface of the object because of the colour of the object and colour of the laser line is the same which is red. However, the details of the object can still be captured, and it gives good result.

3.2. Blue object
The second object is a blue colour toy van. Figure 3 (a) and (b) show the real object in several angle and the 3D mesh of blue colour toy van after Screened Poisson Surface Reconstruction respectively. The observation during the scanning process shows David Laserscanner software also having a difficulty in scanning the detail of the object. This can be occurred because of the blue colour from the object reduce the laser line intensity and sometimes David Laserscanner unable to detect the laser line.

![Figure 3.](image-url) (a) Blue colour object (toy van), 3D mesh object after screened poisson surface reconstruction.

3.3. Yellow object
The third object is a yellow colour toy lorry. Figure 4 (a) and (b) show the real object in several angle and 3D mesh of yellow colour toy lorry after Screened Poisson Surface Reconstruction respectively.

![Figure 4.](image-url) (a) Yellow colour toy lorry, (b) 3D mesh object after screened poisson surface reconstruction.

The surface result of the scanning object is relatively better compared to object with red colour and the detail result is better than blue coloured object. However, yellow coloured object produces more noise data compared to red and blue coloured objects. It can be seen for the 3D scanning results of blue and yellow objects from Screened Poisson Surface Reconstruction technique have good results. The large hole on the top side of the mesh can be filled and solved the problem from David Laserscanner results due to the single viewpoint. In addition, Screened Poisson Surface Reconstruction can reconstruct the surface to cover the uncomplete faces of the mesh. It also reduces the noise data on yellow object.
3.4. Grey object
The last object used in this experiment is a grey coloured DC motor. The surface of DC motor is matte surface, which is less shiny than the other objects. The only part with shiny finish is the shaft of the motor which is chrome finish. Figure 5 (a) and (b) show the real object in several angle and the result from Screened Poisson Surface Reconstruction technique respectively. It can be seen that the scanned result cover one of the misalign side of the object. It also able to build a surface on 90° angle side where there is a gap between the surface.

![Figure 5. (a) Grey coloured object (DC motor), (b) 3D mesh object after screened poisson surface reconstruction.](image)

The scanned result is better compared to other objects with low noise data. However, it does not capture the shaft part of the DC motor because of the limitations of David Laserscanner software which cannot detect a chrome finish object. The low shiny finish on the object can make David Laserscanner easier to grab the surface of the object.

3.5. Mesh measurements error and transform scale
Mesh measurement error was conducted in order to quantify the difference between the true-object and the scanning result by measuring the dimensions of the true-objects and compared it with the scan results. The error can be caused by random error or systematic error from moving the object frequently or error in camera position after calibration causing the scan to have different measurements. The error might also be from coming from the differences in colour or surface finishing of an object. The initial mesh results produce large error, therefore Transform Scale feature available in MeshLab was applied. This tool can rescale the object close to the original dimension. However, the dimensions cannot be exact same as the original depends on the error of the data. The Transform Scale process was conducted prior to aligning process. Subsequently, the scan result was measured using the measurement tool in MeshLab. The error in measurement was calculated using the equation as in Equation 1. Table 1 shows the result of the Transform Scale process.

$$\text{Error} \, (\%) = \left| \frac{\text{Mesh} - \text{Object}}{\text{Object}} \right| \times 100\%$$

![Table 1. Error calculation between the mesh and object after transform scale.](image)
It can be seen in Table 1, Transform Scale process can reduce the error on the 3D Mesh significantly (lower than 10%). The grey colour scanned object has the smallest error after Transform Scale. The grey colour 3D Mesh has the closest dimensions to the original object compared to other colours. Possible reason for the error might be from the limitations of David Laserscanner software which is the free version only allowed the mesh to be saved in low-resolution mesh. Therefore, it might cause an error during capturing the mesh measurement in MeshLab. It is considered to purchase the full version of David Laserscanner software for future research. In short, this result shows that Transform Scale can be a useful process of editing in 3D Scanning process with its ability to reduce the error of measurement for the 3D Mesh.

In term of the colour effect, the use of red laser and the shiny surface finish of the objects might be the cause of the error. However further investigation is needed in order to understand the effect of the object colour and surface finish.

4. Conclusion
The low-cost and simple 3D scanner with the total cost of about RM 192 has successfully developed and built. The 3D scanner was constructed using red laser, webcam, Arduino and open-source scanning software such as David Laserscanner and MeshLab; and also the application of a triangulation technique. In addition, the application of Screened Poisson Surface Reconstruction and Transform Scale techniques were greatly improved the scanned result by reducing the total dimensions errors. The proposed setup is able to achieve total dimensional error of less than 10%. However, the result may vary depending on the colour and surface finish of the object. Grey colour with matte surface finish has the best scanning result with low noise data, great surface scanning and low dimensions error compared to red, blue, and yellow coloured objects with shiny finish surface. In order to further improve the scanning result, a green coloured laser line will be applied. In addition, a high-resolution camera for easy camera-to-software calibration and scanning process will also be applied to produce more precise 3D mesh.

References
[1] Haleem A and Javaid M 2019 3D scanning applications in medical field: A literature-based review. Clin Epidemiol Glob Heal 7 199–210
[2] Javaid M, Haleem A and Kumar L 2019 Current status and applications of 3D scanning in dentistry. Clin Epidemiol Glob Heal 7 228–33
[3] Tredinnick R, Smith S and Ponto K 2019 A cost-benefit analysis of 3D scanning technology for crime scene investigation. Forensic Sci Int Reports 1 100025
[4] Zogheib T, Jacobs R, Bornstein M, Agbaje J, Anumendem D, Klazen Y and Politis C 2018 Comparison of 3D Scanning Versus 2D Photography for the Identification of Facial Soft-Tissue Landmarks Open Dent J. 12 61–71
[5] Harditya A 2019 Hybridity In New Media: A Pre-Production Guideline Indones J Comput Eng Des (IJoCED) 1
[6] Rao R M and Radhakrishna D S U 2018 Development of a Robot-mounted 3D Scanner and Multi-view Registration Techniques for Industrial Applications Procedia Comput Sci 133 256–67.
[7] Reljić I, Dunder I and Seljan S 2019 Photogrammetric 3D Scanning of Physical Objects: Tools and Workflow TEM J. 8 383–8
[8] Kersten T, Lindstaedt M and Starosta D 2018 Comparative geometrical accuracy investigations of hand-held 3d scanning systems – an update ISPRS - Int Arch Photogramm Remote Sens Spat Inf Sci. XLII–2 487–94
[9] Amornvit P and Sanohkan S 2019 The Accuracy of Digital Face Scans Obtained from 3D Scanners: An In Vitro Study International Journal of Environmental Research and Public Health 16
[10] David Laserscanner [Online]. Available from: http://freeartsoftware.com/survey3d2d-downloads/download-info.php?sid=1003
[11] MeshLab [Online]. Available from: http://www.meshlab.net/