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3D Modeling Using Laser Scanning for Reverse Engineering Applications: Verification Test

Dr. Zulkepli Majid
Vote: 79353, FKSG

Khairulazhar Zainuddin[1], Halim Setan[1], Zulkepli Majid[1] & Azran Hazemi Jusoh[2]

[1]3D Measurement Lab, Photogrammetry and Laser Scanning Group, Universiti Teknologi Malaysia 81310 Skudai, Johor, Malaysia. Email: khairulazhar@live.com.my, halim@fksg.utm.my
[2]FARO Singapore Pte Ltd, Malaysia Branch, Puchong Malaysia. Email: Azran.Jusoh@faro.com

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Abstract –*Creating 3D model and CAD model of existing part or object is one of the main tasks in reverse engineering process. The data for generating the model can be obtained using contact (CMM and touch probe) and non-contact (laser scanner, optical and structured light) measurement. Recently, laser scanners have being used for many applications. This technology offers fast and accurate measurement for creating 3D model. This paper describes the comparison between Vivid 910 and Faro Photon 80 laser scanner for creating 3D model and CAD model of MMV boat hull and MyVi car. Vivid 910 is a triangulation based laser scanner and suitable for capturing small objects in close range. Faro Photon 80 employed phase measurement principle in capturing data and capable to acquire large objects in short time. The aim of this study is to analyze the capability and ability of Vivid 910 laser scanner for capturing middle and large objects. The results obtained in this study indicate the suitability, capability and limitation of using Vivid 910 laser scanner.*

Keywords: laser scanning, Vivid 910, Faro Photon 80, 3D modeling.

I. Introduction

Nowadays, three dimensional (3D) models can be rapidly and effectively created using laser scanning techniques. This technology is capable to measure million of points with milimeter level of precision. Some of the disciplines now are benefiting from the use of laser scanner e.g. structural engineering, architectural modeling, building reconstruction, accident investigation [1], cultural heritage recording, design and manufacture of automobiles [2] and Craniofacial [3][4]. In engineering the laser scanner is used for collecting infrastructure information such as buildings, bridges, tunnels, underground facilities and for 3D virtual city modeling [5][6][7]. The most applications of laser scanning in engineering are 3D modeling of existing structures and equipment [8].

Recently, reverse engineering (RE) employs laser scanning for creating 3D model of physical objects. Reverse Engineering refers to creating a CAD model from existing physical object, which can be utilised as a design tool for producing a copy of an object, extracting the design concept of existing model, or re-engineering an existing part [9]. The RE process includes the point data acquisition, data segmentation and creating new useful and useable model. In general, the object can be measured using contact (caliper, tape and CMM) and non-contact (structured light digitizers, computed tomography and laser scanners) measurement.

Laser scanners offer high precision and accuracy in data acquisition for RE applications. It can be categorised into three classes; time-of-flight, phase measurement and triangulation. Time-of-flight laser scanner calculates the pulse travel time between transmission and reception signal. This laser scanner allows unambiguous measurement of distances up to several hundred of meters. The advantage of long ranges implies reasonable accuracy. Phase measurement laser scanner represents the other common technique for medium range and limited to one hundred meters. This scanner calculates the distance of object using the phase difference between transmitted and receiving harmonic wave. Accuracy of the measured distances within some millimeters is possible [10]. Triangulations based laser scanners mostly use in industrial applications especially reverse engineering. Typically this system is suitable to measure small objects in close range, where measurement distances range from 0.6m to 2m. Some triangulations systems required an object to be placed on rotating table that rotate the object in front of static scanner [11]. Accuracies down to some micrometers can be achieved with triangulation laser scanner [12].

This paper describes the comparison between triangulation and phase measurement laser scanner principle for capturing data and generating 3D model and CAD model. The aim of this study is to analyze the capability and ability of Vivid 910 laser scanner for capturing middle and large objects. Two objects were used in this study which is MMV hull model (middle) and MyVi car (large). Vivid 910 is a triangulation based laser scanner and suitable for capture small objects in close range. Phase measurement based laser scanner in this study employed Faro Photon 80 which is capable to acquired large objects in short time.

II. Vivid 910

Vivid 910 (Fig.1) is a non-contact 3D digitizer using a laser beam to measure object. This system has the capability to record the whole measurement in a snap (about 0.3 sec (fast mode), 2.5 sec (fine mode), and 0.5 sec (colour mode)). It can measure up to 307 000 point clouds in a single scan [13]. The distance range for capturing data for this scanner is between 0.6m to 2.5m. This triangulation based laser scanner employs the light-stripe method that emits a horizontal stripe laser to the object and scans it by a galvanic mirror. The advantages of this device lie on its speed, precision, and simplicity (i.e. point and shoot simplicity for consistently excellent results). The accuracy (Z, typically) of Vivid 910 laser scanner is within 0.008 mm using fine mode. Other advantage using Vivid 910 is that it does not require the calibration process prior to the measurement session [14]. Vivid 910 is equipped with three removable lenses with different focal distances i.e. Tele (25mm focal length), Middle (14mm focal length) and Wide (8mm focal length). Vivid 910 comes with Polygon Editing Tool (P.E.T) software for real time scanning. The measurement result gives the sets of point cloud data used for generating 3D model in RapidForm2004 (Refer section 5).

Fig. 1: Vivid 910 wtih three removable lens.

III. Faro Photon 80

Faro Photon 80 (Fig.2) is a high resolution and precision 3D scanner, ideal for laser scanning metrology applications such as reverse engineering, inspection, modeling, as-built documentation and asset management. This system works by sending an infrared beam into the centre of a rotating mirror by deflecting the laser on a vertical rotation around the environment being scanned. The beam is then reflected back into the scanner and the phase shift of the infrared is measured giving the distance of the laser from the object. Faro Photon 80 is designed for quick and easy data capture which can measure up to 120 000 points per second. The distances range of this system is between 0.6 m to 76 m with 360° horizontal and 320° vertical surrounding field of view capability. Faro Photon 80 gives ±2mm accuracy at 25m measurement distance [15].

Fig.2: Faro Photon 80

IV. Procedure

This section describes the methodology test procedure to evaluate the hardware and software in this study. The procedure comprises of (Fig.3) data acquisition (3D point cloud), polygon surface reconstruction (3D model and CAD model) and distance measurement (linear).

Data acquisition, system setup and data processing were designed in the planning stage. In data acquisition stage, Vivid 910 and Faro Photon 80 were used to capture whole surface of MMV hull model. Point cloud data acquired using Vivid 910 and Faro Photon 80 were processed to generate 3D models using RapidForm2004 and Geomagic Studio 10 respectively. The 3D models are then undergoing the inspection process in

RapidForm2004 (surface deviation and distances measurement) (Fig.4). Measured linear distances from close range photogrammetry are used as a reference to evaluate the accuracy of distance measurement for both scanners.

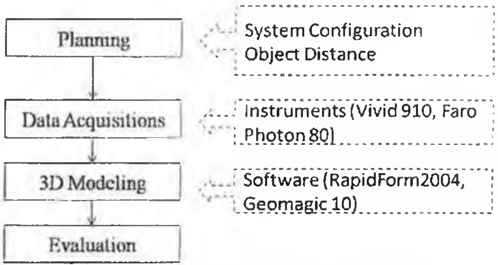


Fig. 3: The methodology of the study

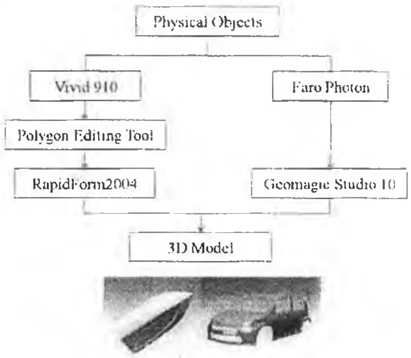


Fig. 4: The procedure of the study

V. MMV Hull Model Data Capturing

Single Vivid 910 with Wide lens was used in capturing MMV hull surface. The object was setup 1.8m apart from the fix scanner with three difference positions to capture whole part of MMV hull surface (Fig. 5). For data capturing using Faro Photon 80, the procedure consists of moving scanner setup at 3m from fix object. The hull surface was captured from two difference scanner positions to get whole part of hull surface. For easy point cloud alignment, three special spheres were placed near to study object (Fig. 6).

Fig. 5: Three different object positions on data captured using Vivid 910.

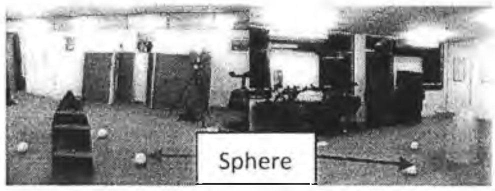


Fig. 6: MMV hull data captured using Faro Photon 80 with sphere placed near to object.

VI. Perodua MyVi Car Data Capturing

Dual Vivid 910 with Wide lens was used in capturing Perodua MyVi car body surface for fast data captured. The scanning procedure consists of moving scanner around fix object. The scanner was setup 2m apart from the object (Fig. 7). To capture the whole part of car body surface, the Vivid 910 was mounted on three difference tripod heights in each scanner positions (Fig. 8).

Fig. 7: Vivid 910 placed 2m apart of object with 15 stations

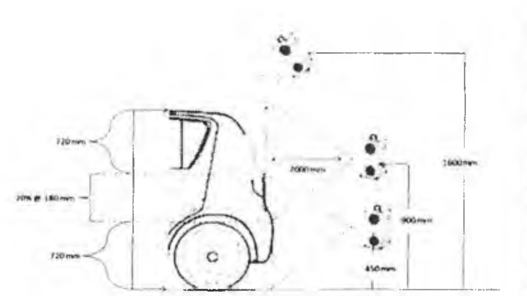


Fig. 7: Three different level of Vivid 910.

Four positions were selected to capture whole body surface using Faro Photon 80 (Fig. 9). The scanner was setup at 7m from the object. Four spheres were located on top roof surface and two was on hood for easy point cloud alignment in Geomagic Studio 10 (Fig. 10).

Fig. 9: Faro Photon 80 setup at four different stations with 7m from object.

Fig. 10: Sphere placed on top of roof for easy point cloud alignment.

VII. 3D Modeling

After data acquisition, point cloud from both laser scanners undergoing 3D model reconstruction in processing software. Data from Vivid 910 (stored in *.cdm format) was processed in RapidForm2004 software. RapidForm2004 is the most powerful featured software for processing 3D scan data. This software converts data from any 3D scanning device into high quality polygon mesh, accurate freeform NURBS surfaces or geometrically perfect solid models [16]. Data from Faro Photon 80 was exported into Geomagic Studio 10 for generating 3D model. Geomagic Studio provides a comprehensive toolset for converting 3D scanned point data to find CAD-ready models used in reverse engineering and rapid prototyping [17].

Generating 3D model from point cloud data (Fig. 11) consists of two phases; point phase and polygon phase. Point phase is use to generate surface model from point cloud data. This task includs point reduction, noise elimination, triangulate into polygon mesh model, multiview registration of polygon mesh and merge all polygon models to get single 3D model. In polygon phase, 3D model was optimized to get better 3D model to use in reverse engineering applications including cleaning the model surface, holes filling, refinement and decimation, defeaturing and smoothing the model before can be exported into RE format or used to extract the CAD model (refer to [18] for specific procedure on data processing).

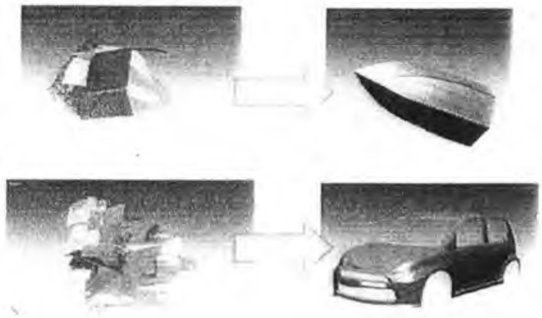


Fig. 11: From point cloud to 3D model.

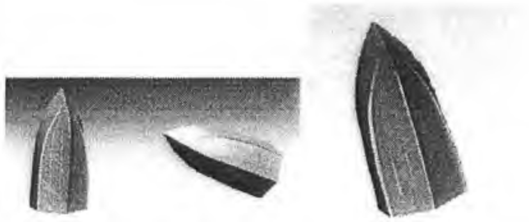
Extraction of CAD model required creation of NURBS surface onto 3D model. The NURBS (Non-Uniform Rational B-splines) surface is defined by a network of curve lines (Fig. 12). Basic CAD entities such as circles, lines and rectangles can be easily created by manual fitting methods based on 3D model. NURBS surface patch can be created using the curve fitting line (Fig. 13).

Fig. 12: Curves fitting on 3D models for NURBS surface preparation.

Fig. 13: NURBS surface generated from curve fitting boundary line.

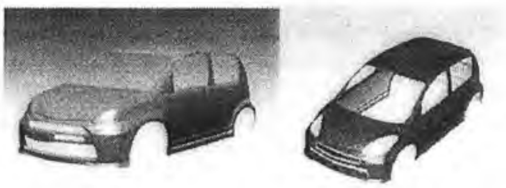
VIII. Results

Fig. 14 show the 3D models of MMV hull and Fig. 15 show the 3D models of MyVi car generated from Vivid 910 and Faro Photon 80 scanner respectively. Table 1 shows the comparison of data capturing and processing from both laser scanners of both objects.



(a) (b)

Fig. 14: MMV hull 3D models; generated using Vivid 910 point cloud and (b) generated using Faro Photon 80.



(a) (b)

Fig. 15: MyVi car 3D models; (a) generated using Vivid 910 point cloud and (b) created from Faro Photon 80 data.

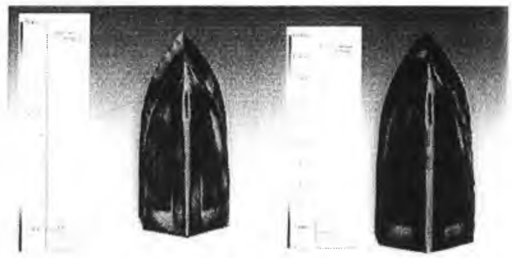
Table 1: Comparison on data capture and processing between Vivid 910 and Faro Photon 80.

Objects	MMV Hull		MyVi Car	
	Vivid 910	Faro Photon 80	Vivid 910	Faro Photon 80
Number of scanning	3	2	108	4
Scanning Time (minutes)	5	9	7	60
Number of Processing data	3	2	70	4
Processing Time	45 minutes	60 minutes	3 months	120 minutes

Table 1 shows the number of data and time acquired to complete the scanning task, number of point cloud data used and duration to generate 3D model using both laser scanners. For MMV hull model case study, both laser scanners give average results on data capturing and data processing to get final 3D models. This indicates that the Vivid 910 suitable for capturing middle objects since it gives same quality as Faro Photon 80 3D model.

Vivid 910 uses large number of datasets compared to Faro Photon 80 for MyVi car case study. Seven hours are required for completing data collection task while the Faro Photon just took only an hour to complete the job. Each point cloud data from Vivid 910 consists of average 200 000 points. However, not all the point cloud data acquired from Vivid 910 are used for 3D modeling. The processing task using Vivid 910 datasets required three months approximately to generate final 3D model due to large number of point cloud to be registered and optimized the 3D model. From the results indicates that Vivid 910 capable to capture large object (in this case larger than 1.5m) but are not recommended since the processing time are too tough to get perfect 3D model.

For investigate the surface accuracy of MMV hull 3D models from both laser scanners, surface deviation method are used in this study. 3D model generated from close range photogrammetry are used as a reference in this analysis. The results give 1.624mm accuracy for Vivid 910 and 1.847mm for Faro Photon 80 (Fig.16).



(a) (b)

Fig. 16: Surface deviation compared to close range photogrammetry 3D model; (a) Vivid 910 and (b) Faro Photon 80.

Since there is no existing reference 3D model of MyVi Car, the surface investigation just focus on Vivid 910 only and 3D model from Faro Photon 80 used as a reference (Fig. 17). The results give 4mm surface deviation between both laser scanners.

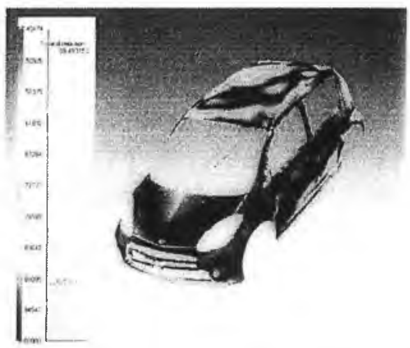


Fig. 17: Surface deviation between Vivid 910 and Faro Photon 80.

For linear accuracy, several distances have been selected and measured on 3D model. Measurement from close range photogrammetry is used as a reference for MMV hull case study and geodetic method using TM5100 electronic theodolite is used as a reference for MyVi car case. Table 2 shows the statistical analysis on linear accuracy between both laser scanners. The results indicate that Vivid 910 can gives accuracy in mm level for middle and large object to use for industrial measurement especially RE applications.

Table 2: Numerical analysis on 3D models between both laser scanners.

Objects	MMV Hull		MyVi Car	
	Vivid 910	Faro Photon 80	Vivid 910	Faro Photon 80
Min Different (mm)	0.024	-0.253	0.054	0.000
Max Different (mm)	2.419	1.401	2.799	2.436
Mean (mm)	-0.532	-0.509	1.182	0.204
Standard Deviation (mm)	1.869	1.177	2.224	2.000

3D models generated in processing software can be stored in RE format for use in RE software for modification on existing model or creating new model. Usually, direct export from 3D model engaged for rapid-prototyping application and the model is stored in STL format. For downstream RE applications, 3D model need to saved in IGES or STEP format. In this case, the CAD model need to be generated first before can be exported into RE software through STL and STEP format. Fig. 18 show the CAD models generated from 3D model in RapidForm2004 software.

Fig. 18: CAD model of MMV hull and MyVi car.

IX. Conclusion

This paper describe the comparison between Vivid 910 and Faro Photon 80 laser scanner for capturing data and generating 3D model and CAD model of MMV hull and MyVi Car. From the results indicates the Vivid 910 is suitable and capable to capture and model middle objects but for objects larger than 1.5m need long time for data capture and 3D model processing. Faro Photon 80 prooved the ability to captured large object since the phase measurement is made for large scenario. Moreover the accuracy for middle and large object using Vivid 910 is acceptable (mm level).

X. Acknowledgment

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