Close Range Measurement and 3D Modeling

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Key word : 3 D modeling, Laser scanning, Precise measurement, Photogrammetry

SUMMARY

Some practical applications require surveyors to perform dimensional measurement and generate three dimensional (3D) computer models of the measured objects. The measurement tasks could be carried out using close range measuring instrument such as total stations, cameras, or scanners. The accuracies of measurement vary from micron to cm levels. Currently, majority of the measurement systems employ digital technology, and provide the data in digital form, which could be used for 3D modeling. This research involves the collaboration between the Faculty of Geoinformation Science & Engineering, UTM and the Faculty of Mechanical Engineering, UTM. In this research, several measurement systems (photogrammetric, total station, Coordinate Measurement Machine, and laser scanning) were tested for measurement and modeling of several objects. The results indicate the practicality of photogrammetric system, in terms of speed, reliability, flexibility, and accuracy.

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1. INTRODUCTION

Industrial applications require surveyors to perform dimensional measurement and generate three dimensional (3D) computer models of the measured objects. The available industrial measurement systems (Figure 1) comprise of contact and non-contact methods. The contact methods vary from conventional/simple direct tape measurement to the sophisticated Coordinate Measuring Machine (CMM). The non-contact (close range, mobile) methods consist of laser scanning/tracking system (e.g. VIVID910 laser scanner), geodetic theodolite/total station system (e.g. AXYZ system) or vision metrology/close range photogrammetric system (e.g. V-STARS system). The accuracies of these measurement systems vary from cm to micron levels. Currently, majority/all of the above measurement systems employ digital technology, and provide the data in digital form, which could be used directly for 3D modeling.

The commonly used industrial measurement systems in mechanical engineering are the traditional contact measurement and CMM. The traditional contact measurement is slow and subject to errors. CMM system, although highly accurate, is a rigid (non-mobile) system (requires stable platform), and the object sizes are limited to the size of CMM measuring table.

This research involves the Faculty of Geoinformation Science & Engineering, UTM and the Faculty of Mechanical Engineering, UTM. The main objective of this research is to explore the practicality of non-contact precise measurement systems (especially close-range photogrammetry via V-STARS), as an alternative to the contact measurement systems. Consequently, several measurement systems (photogrammetric, theodolite intersection, CMM, and laser scanning) were tested, followed by 3D computer modeling of the test objects using RHINOCEROS 3.0 software.

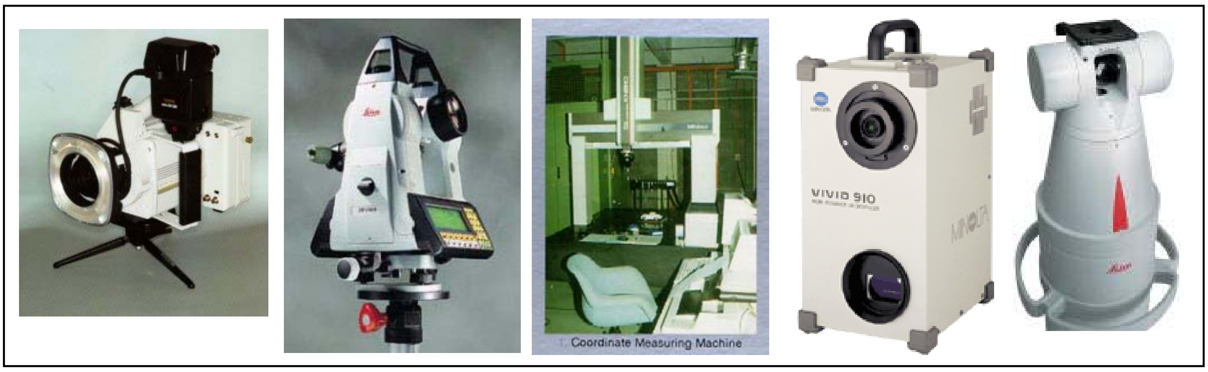


Figure 1: V-STARS, AXYZ, CMM, laser scanner and laser tracker systems

This paper comprises of 5 main sections, and begins with the introduction in section 1. Sections 2 and 3 highlight the measurement and 3D modeling procedures respectively. The results and analysis are given in section 4. Finally, conclusions and future works are discussed in section 5.

2. MEASUREMENT TECHNIQUES

As discussed in section 1, the following close range industrial measurement systems were used: non-contact (photogrammetric using V-STARS, theodolite intersection via AXYZ, laser scanning via VIVID910) and contact (CMM).

Normally, V-STARS requires high contras retro-reflective targets to represent points on the object. Multiple images of points are then taken (using single camera) around the object. Similarly, in AXYZ, points on the object are measured via intersection from theodolites (minimum 2). Typically, points are identified using physical targets (such as features on the object or retro-reflective targets) or laser pointing. VIVID910 uses a laser beam to generate a digital 3D copy of an object. CMM does not require targets as the contact measurement is based on the selected interval, for example every 5 mm. Figure 2 shows the measurement configuration for V-STARS, VIVID910, AXYZ, and CMM.

V-STARS employs special intelligent camera (INCA), special targets (high contras retro-reflective coded targets, autobar, scalebar) and special software for the automation of the entire measurement process (GSI, 2002; Ganci & Brown, 2001; Ganci & Clement, 2000; GSI, 2000; Fraser, 1999; Brown, 1998). The typically accuracy of V-STARS is better than 10 ppm or 1:100,000 (i.e. about 0.050mm (or 50 micron) on a 5.0m object).

AXYZ uses high precision electronic theodolites TM5100A with 0.5” measurement accuracy, and typical accuracy of 1:100,000. However, the measurement process still requires skill operator for set-up and pointing. CMM is totally automated with the measurement accuracy of 0.02mm.

Laser scanning with VIVID910 offers the following advantages: high speed (scanning time of 0.3 sec (fast mode) or 2.5 sec (fine mode)), enormous data (up to 77,000 or 300,000 points for fast and fine modes respectively), high accuracy (scanning accuracy of 0.22mm, 0.16mm, and 0.10mm in x, y and z respectively), and simplicity (i.e. point and shoot simplicity). VIVID910 has 3 types of exchangeable mounted lens for handling different object sizes and measurement distances. Table 1 illustrates the relationship between the lens type, field of view and the resolution.

The steps for data capture and data processing (via V-STARS) is summarized in Figure 3 (Halim & Mohd Sharuddin, 2003). Initially, V-STARS, AXYZ and CMM were used for data capture and processing. The results of the processing are exported to suitable format for 3D modeling purpose. In addition, VIVID910 was also used in the comparison test, as the scanned data are ready for 3D modeling.

Lens type	Field of view (@ 0.6 m)	Field of view (@ 2.5 m)	Max resolution (depth)
Tele	111 x 84 x 40 mm	460 x 350 x 130 mm	0.039 mm (0.0016")
Middle	196 x 153 x 70 mm	830 x 622 x 220 mm	0.068 mm (0.0026")
Wide	355 x 266 x 92 mm	1200 x 903 x 400 mm	0.090 mm (0.0035")

Table 1: Exchangeable lens for VIVID910

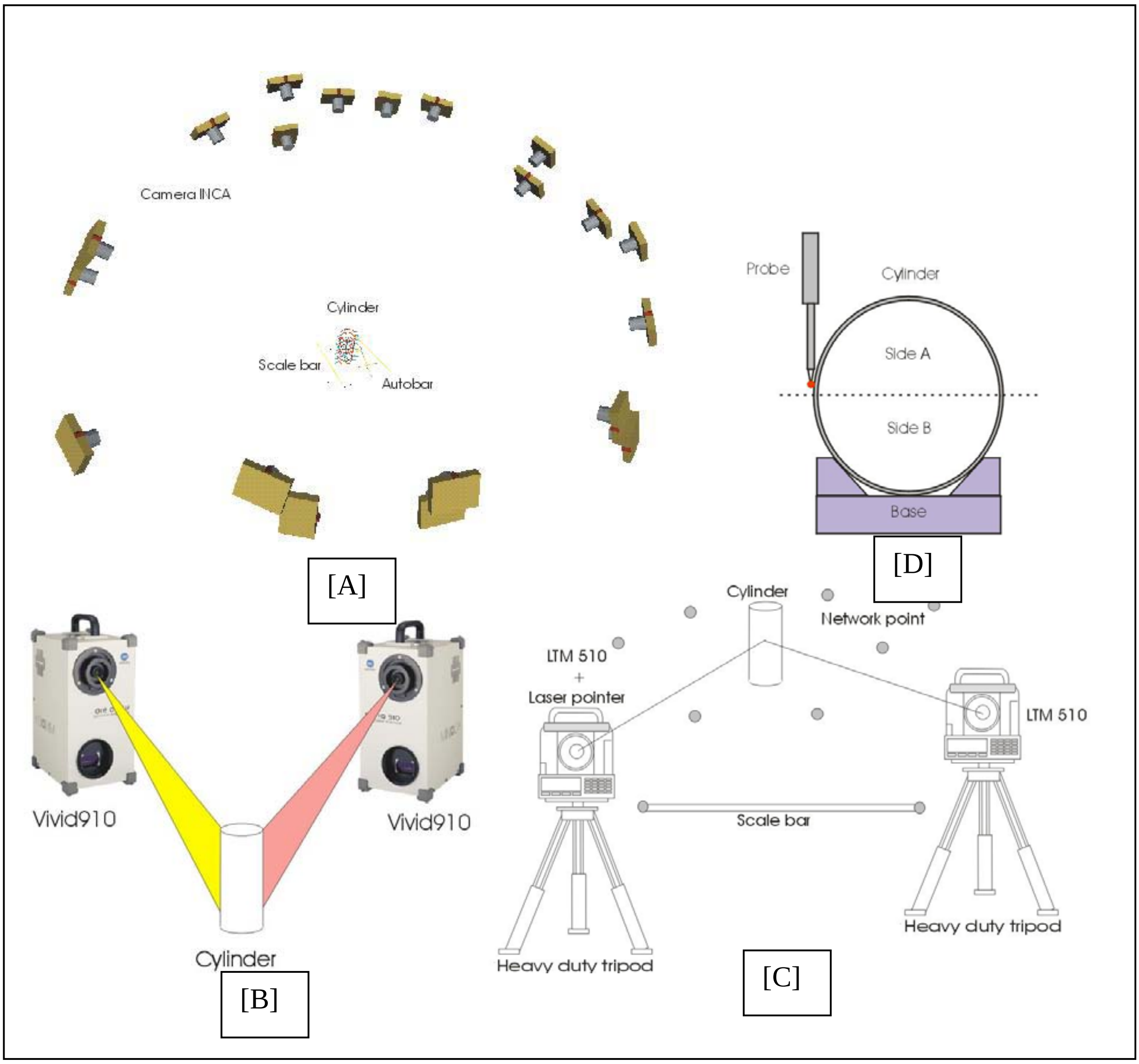


Figure 2: Measurement configuration: [A]V-STARS, [B]VIVID910, [C]AXYZ, [D]CMM

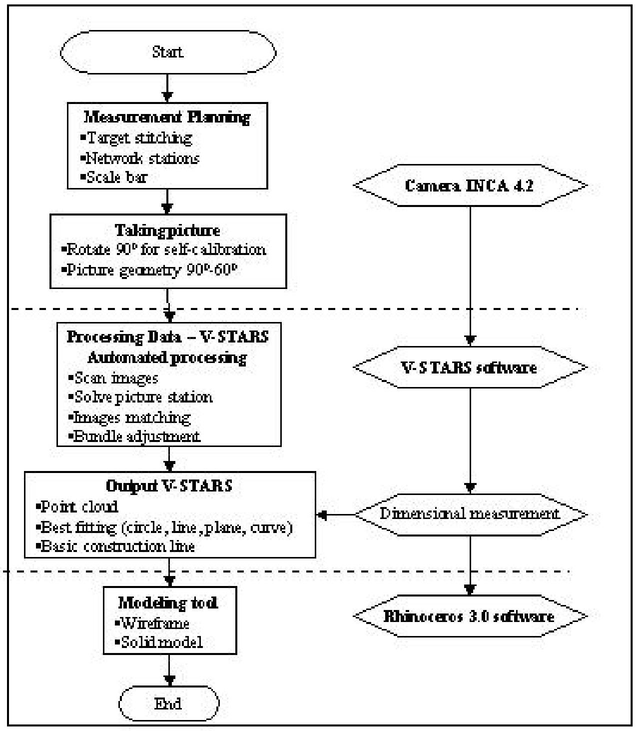


Figure 3: The V-STARS/S measurement procedure

3. 3D MODELING PROCEDURE

RHINOCEROS 3.0 is a commercial 3-D NURBS (non-uniform rational B-spline) modeling program for Windows. Among its capabilities are: generation of wire frame, generation of solid 3D model, and dimensional measurement.

In this research, the developed procedure for 3D modeling using RHINOCEROS 3.0 comprises of (Figure 4): Import IGES data (point cloud) from V-STARS, AXYZ and CMM; form basic construction line (using line and polyline functions); create wire frame; create solid 3D model from wire frame; and measure for dimensional measurement (Halim & Mohd Sharuddin, 2003).

4. RESULTS AND ANALYSIS

The tests consist of 4 main parts:
- Comparison of accuracy between V-STARS, AXYZ, CMM, and VIVID910
- Comparison of accuracy between V-STARS, AXYZ, and AUSTRALIS
- Performance of V-STARS
- 3D modeling of selected objects (cylinder, vessel model, fan and propeller)

In the tests, several system/software were used (i.e. V-STARS, AXYZ, AUSTRALIS, VIVID910, PET (Polygon Editing Tool), RHINOCEROS 3.0, RAPIDFORM2004).

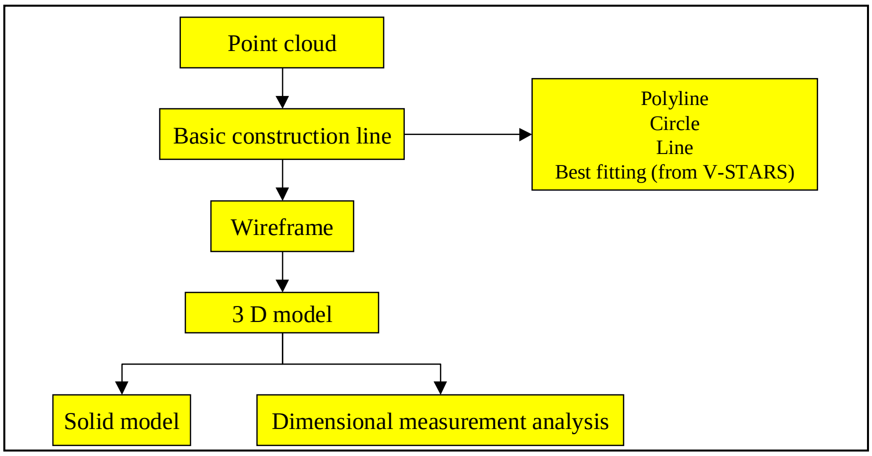


Figure 4: The 3D modeling procedure

4.1 Comparison of accuracy: V-STARS, AXYZ, CMM, VIVID910

In the first test, a cylinder (i.e. PVC pipe) with known radius (45 mm) was measured using 4 systems, i.e. V-STARS (off-line mode using single INCA), AXYZ (real time mode using two TM5100A electronic theodolite), CMM and VIVID910. The cylinder was divided into 7 sections from A to G, i.e. 7 sets of radius (Figure 5). All the systems use different number of targets (Table 2) due to different measurement techniques (Figure 2). For each section, V-STARS uses 12-13 targets (randomly selected), AXYZ uses 7 targets (randomly selected), and CMM uses more than 60 targets (automatically measured at 5mm interval).

During measurement using V-STARS and AXYZ, the cylinder remained stationary, and the camera and theodolites were moved around the cylinder. However, measurement via CMM requires two parts/sides (A and B), because CMM measurement platform is rigid. After side A is measured, the cylinder was turned to allow side B to be measured (Figure 2).

During laser scanning with VIVID910, the cylinder was rotated after each scan, to provide complete 3D point clouds of the cylinder. PET (Polygon Editing Tool) software is used for data processing and 3D modeling (collect, register and merge scanned data, process 3D model, and measurement).

The collected data were processed in 2 ways for comparison purposes:

1-Direct comparison to determine radius of cylinder for each section using best fitting curve (data from V-STARS, AXYZ and CMM) using V-STARS solid module software

2-Direct comparison to determine radius of cylinder using best fitting cylinder (data from V-STARS, CMM and VIVID910) using RAPIDFORM2004 software

Figure 5: Cylinder measurement

Number of observed targets				
Section	V-STARS	AXYZ	CMM (interval 5mm)	
			Part A	Part B
A	12	7	33	31
B	12	7	32	31
C	12	7	33	32
D	12	7	32	32
E	12	7	34	32
F	13	7	34	30
G	12	7	32	30

Table 2: Number of targets for measurement

1- V-STARS, AXYZ, CMM

Table 3 and Figure 6 show the estimated radius of the cylinder, with the difference (from known radius 45mm) between -0.28mm to 0.22mm. The accuracies for each system were: –0.06mm to -0.09mm for V-STARS (range of 0.03mm), -0.28mm to 0.22mm for AXYZ (range of 0.50mm), and –0.18mm to 0.20mm for CMM (range of 0.038mm).

Section	Radius of the cylinder (known value 45 mm)					
	V-STARS/S	AXYZ	CMM (mean)	Difference (known 45mm)		
				V-STARS/S	AXYZ	CMM
				(target thickness=0.5mm)		
A	44.592	44.449	45.184	-0.092	0.051	-0.184
B	44.563	44.428	45.121	-0.063	0.072	-0.121
C	44.571	44.575	45.038	-0.071	-0.075	-0.038
D	44.569	44.633	44.941	-0.069	-0.133	0.059
E	44.565	44.776	44.923	-0.065	-0.276	0.077
F	44.556	44.585	44.906	-0.056	-0.085	0.094
G	44.556	44.278	44.804	-0.056	0.222	0.196

Table 3: Radius of the cylinder: comparison

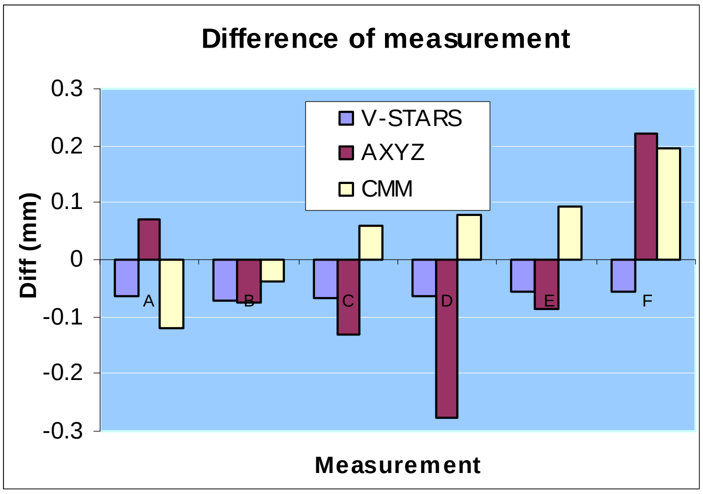


Figure 6: Analysis of accuracy

2- V-STARS, VIVID910, CMM

Table 4 shows the differences of measurement radius using best fitting cylinder (from known radius 45mm). The accuracy for each system are: 0.043mm for V-STARS, 0.016mm for CMM, and 0.836mm for VIVID910.

Measurement	Radius of cylinder (mm)	Difference (mm)
V-STARS	44.957	0.043
CMM	45.016	0.016
VIVID910	44.164	0.836

Table 4: Best-fitting cylinder: comparison

The differences between all 4 systems are within sub-mm, indicating that all systems are highly precise. V-STARS has the capability to measure the whole object (although off-line mode), and the most consistent amongst the 4 systems (Figure 6). Moreover, V-STARS, AXYZ and VIVID910 are more practical than CMM due to their mobility.

4.2 Comparison of Accuracy: V-STARS, AXYZ, AUSTRALIS

Another test was also performed to study the accuracy of V-STARS, AXYZ and AUSTRALIS (photogrammetric software). The tested object (Figure 7) was a flat target sheet (280mm x 196mm) comprises of 70 retro targets (with centre points, and 6mm diameter). The main task in this test was to compare distances between the target points for accuracy evaluation. Although V-STARS and AUSTRALIS work with non-centered retro targets, AXYZ requires centered targets for precise pointing.

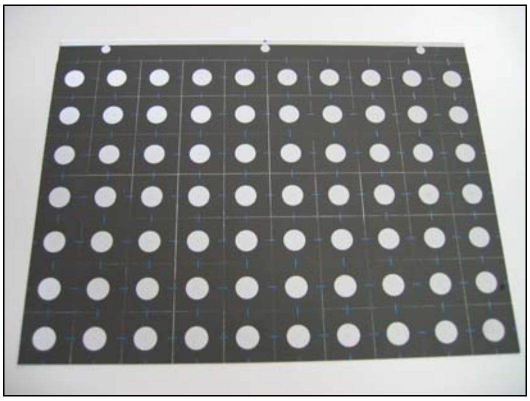
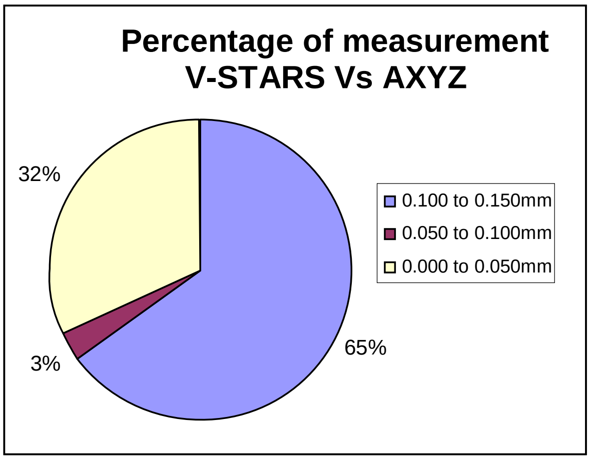


Figure 7: 70 retro targets with centers

The comparisons between V-STARS and AXYZ indicate that 65% of the results are within 0.000mm to ±0.050mm, 32% within ±0.050 to ±0.100mm, and 3% within ±0.100mm to ±0.150mm. These results verify the high accuracies of both V-STARS and AXYZ, to sub-mm level. The comparisons from V-STARS and AUSTRALIS show consistent results with 93% are within 0.000mm to 0.050mm, and 7% within 0.050mm to 0.100mm (Figure 8).



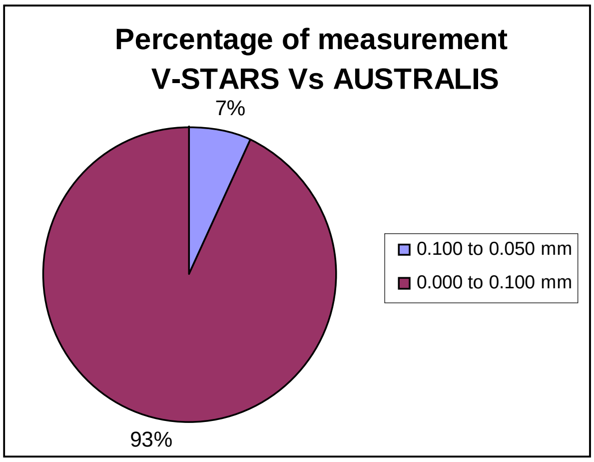


Figure 8: Comparison of results: V-STARS, AXYZ and AUSTRALIS

4.3 Performance of V-STARS

During this study, V-STARS was used to measure up to 27 projects/data sets, and the relevant results (geometry, RMS for observation) were extracted for performance/stability study of the system. As shown in Figure 9, V-STARS is a very stable system, as the geometry is always between 1-2, and the RMS between 0.138µm to 0.336µm (typically less than 0.40µm).

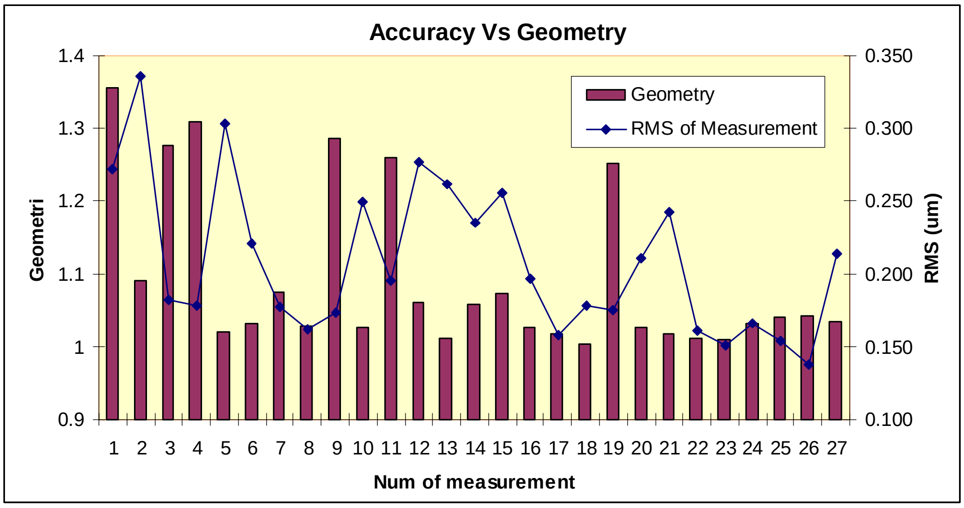


Figure 9: Performance of V-STARS

4.4 3D Modeling

RHINOCEROS 3.0 uses data from V-STARS for 3D modeling, measurement and visualization. The results from V-STARS are saved as graphic data files in *.IGS (or *.IGES) format (contains point cloud, and basic design from best fitting process). Rhinoceros has the capability to import these *.IGS files.

Figure 10 shows the process of 3D modeling in RHINOCEROS. Figure 11 summarizes the measurement configuration, results from V-STARS (point clouds), and 3D modeling via RHINOCEROS (wire frame and solid model). Results of 3D modeling of other objects are shown in Figure 12.

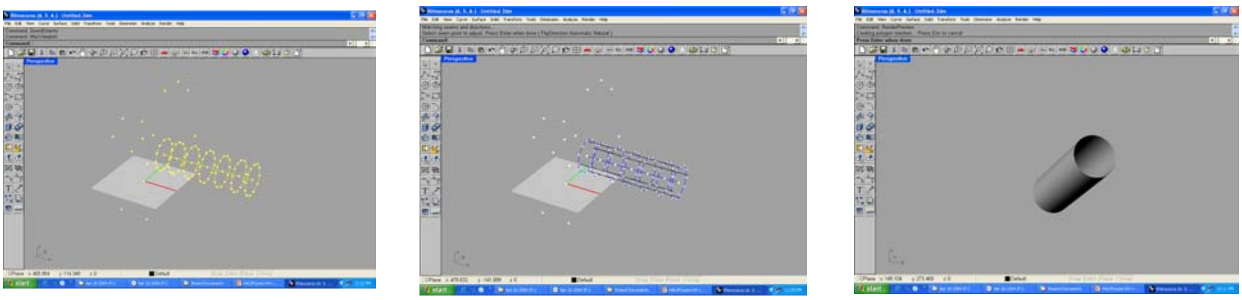


Figure 10: 3D modeling with RHINOCEROS 3.0

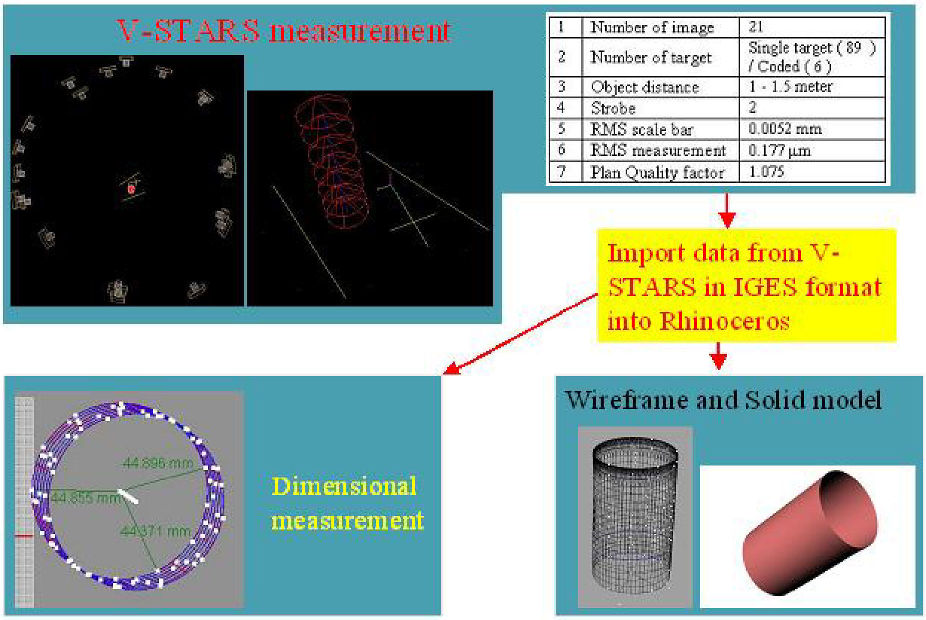


Figure 11: Measurement and 3D modeling of a cylinder

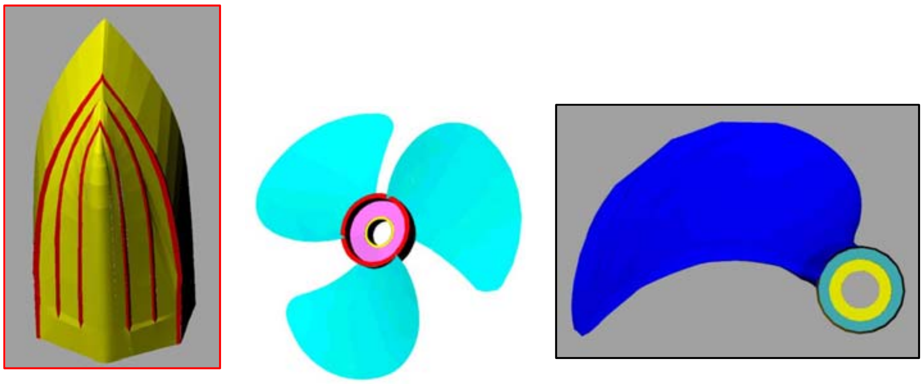


Figure 12: 3D models of a vessel, fan and propeller

5. CONCLUSIONS

Various systems are available for close range measurement and 3D modeling of objects. Examples of the close range measurement instruments are total stations, cameras, CMM, and scanners. This research concentrates on precise dimensional measurement and 3D modeling for industrial applications. The developed procedure consists of a fully automated measurement and analysis using V-STARS (a precise close range non-contact and mobile digital photogrammetric technique), together with 3D modeling using RHINOCEROS 3.0 software. By adopting simple measurement procedure, the accuracy of sub-mm is easily achievable.

V-STARS measurement system is suitable for high precision industrial measurement applications due to the following factors: special camera (INCA), special target (retro-reflective) and special software (V-STARS) for the automation of the entire measurement processing. The typically accuracy of V-STARS is better than 10ppm. The results from V-STARS were also verified with CMM, AXYZ and VIVID910.

Output from V-STARS in IGES format is useful for 3D modeling and dimensional measurement purposes. In this study, 3D modeling of several objects was carried out successfully using RHINOCEROS 3.0 software. The results from this research indicate the practicality of V-STARS photogrammetric system, in terms of speed, reliability, flexibility, and accuracy.

The on-going research focuses on measurement using VIVID910 laser scanner and 3D modeling via RAPIDFORM2004 software, for both industrial and medical (cranio facial) applications.

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BIOGRAPHICAL NOTES

Dr. Halim Setan is a professor at the Faculty of Geoinformation Science and Engineering, Universiti Teknologi Malaysia (UTM). He holds a B.Sc. (Hons.) in Surveying and Mapping Sciences from North East London Polytechnic (1984), a M.Sc. in Geodetic Science from Ohio State University, USA (1988) and a Ph.D from City University, London (1995). His current research interest is in deformation monitoring, precise measurement, industrial metrology and 3D modeling.

Mohd Sharuddin Ibrahim holds a BSc degree in land surveying, from the Universiti Teknologi Malaysia (UTM) in 1997. Currently, he is a MSc research student, under the supervision of Dr. Halim Setan, at the Faculty of Geoinformation Science and Engineering, UTM. His research focuses on precise measurement and 3D modeling.

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