

3D Modelling of Star Ferry Pier by Laser Scanning Technology

Dominic SIU and Lesly LAM, Hong Kong

Key words: 3D modelling, laser scanning, historical structures.

SUMMARY

Civil Engineering and Development Department (CEDD) of HKSAR Government captured detailed features and setting of the old Star Ferry Pier, which had served Hong Kong for decades, including the clock tower by advanced laser scanning technology before its demolition. The data and images collected enable the government of HKSAR to consider how to incorporate some special features of these buildings in the design of the new central harbour front. Huge amount of points or “point clouds” were collected and stored in digital form.

The laser scanning system is capable of generating 3D images through “point clouds” and measuring distances & angles between points, producing cross-sectional plans, making computer fly-through animation and deriving structural drawing. Different materials and surfaces have different colours and reflective intensities. The laser scanning system can retrieve colours and textures of surveyed objects from the point clouds and colour photographs taken by the system.

This paper will first introduce the background of this scanning project and go on to describe data capturing, data reduction and achievable accuracy of the point clouds, and lastly illustrate various types of products obtained from the scanned data (e.g. 3D models, cross-sectional plans, flythrough animation, etc) for the purpose of re-construction or re-location of these buildings.

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1. INTRODUCTION

In 2002, Civil Engineering and Development Department (CEDD) of Hong Kong Special Administrative Region (HKSAR) started to use the 3D laser scanning technology for slope measurement and monitoring survey. With the rapid development of technology and the successful employment of the more advanced 3D laser scanner in 2004, CEDD is now expanding her expertise to the digital recording of historical structures. The laser scanning of the old Star Ferry was one of the most recent tasks that the Survey Division of CEDD had completed capturing the 3D models for the purpose of heritage protection.

1.1 Background

Serving Hong Kong for almost fifty years, the old Star Ferry Pier was a historical landmark and a very popular tourist attraction. Many tourists had the experience of taking the Star Ferry and enjoy watching beautiful scenery of Victoria Harbour, one of the busiest ports in the world, with blue sky, green and salty smell sea water, modern buildings and the Victoria Peak as the backdrop. You could also feel comfortable breeze brushing on your face and hear the sound of waves splashing onto the body of vessel. To many tourists who had visited Hong Kong and taking the ferry before, it certainly brought back very good memory to them.



Fig 1. The Old Star Ferry Pier (left) and Clock Tower (right)

For protection of "collective memory" and heritage preservation, laser scanner is the ideal surveying tool to capture all the details of the old Star Ferry Pier and the Clock Tower. The application of advance technology of laser scanning enabled the Government to incorporate some special features of the Pier and its Clock Tower into the design of the new Central Harbourfront or rebuild the Clock Tower in open space on the new Harbourfront.

Last summer, CEDD started the laser scanning survey operation of the old Star Ferry Pier including the interior of the Clock Tower. Every single detail of the Ferry Pier had been recorded and stored in digital form. The digital data can be retrieved in the form of 3D images and help preserving peoples "collective memory".

1.2 Location

The old Star Ferry Pier was situated in the Central District facing the Victoria Harbour. It was very convenient for commuters to get to many prestige and prominent building as well as government offices after crossing the harbour. To the north of the Pier were the Hong Kong Bank Building (one of the most technological advance in design and expensive building in the world), International Finance Centre (IFC, the tallest building in Hong Kong), and Mandarin Hotel (top ten hotels in the world); they were all within walking distance of 5 to 10 minutes from the Pier.

Further down to the east of the Pier were Wanchai, Causeway Bay and North Point. The Western District and Kennedy town were on its West.

The old Star Ferry Pier covered a total floor area of approximately 10000 sqm. It consisted of two levels with 4 ferry berth and the clock tower of about 20m high in the central position. The bells inside the clock toward were struck every 15 minutes in a pre-set pattern.

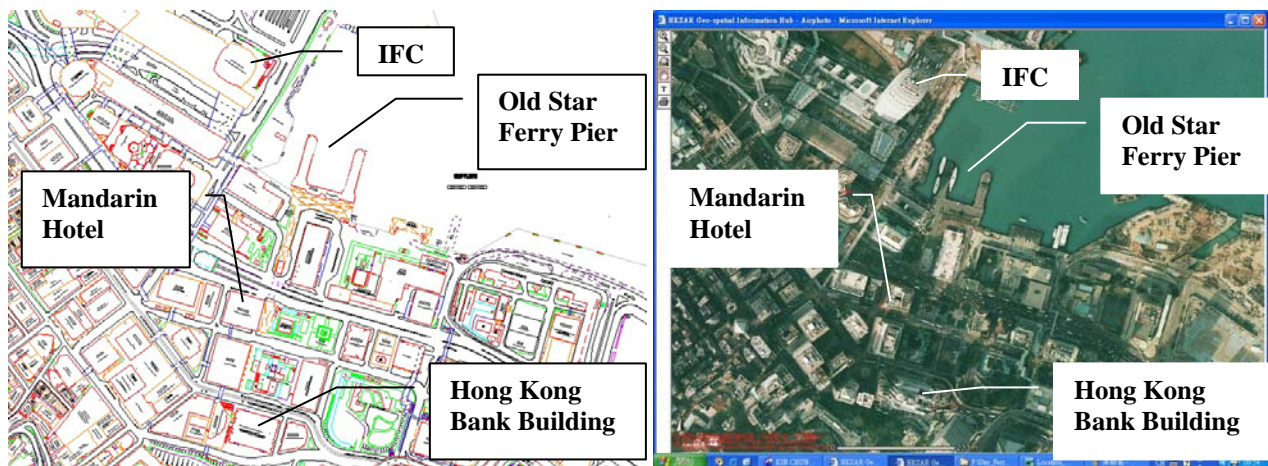


Fig 2. Location Map (left) and Aerial Photo (right) of the Old Star Ferry Pier

This article will describe this 3D laser scanning technology and illustrate in detail its application to the 3D modelling of old Star Ferry Pier.

2. BASIC PRINCIPLES OF 3D LASER SCANNING

3D laser scanning is a brand new survey and mapping technology that uses high-speed laser to scan the surfaces of objects and capture a huge amount of 3D coordinates. These captured 3D coordinates can be integrated to form “Point Clouds” and high-resolution 3D models in various software. There are 2 fundamental steps for a 3D laser scanner to measure the 3D coordinates:

1. **Distance:** A 3D laser scanner is used to emit pulse laser to objects. By measuring the time difference as the laser reflected back to the 3D laser scanner, distance can then be derived.
2. **Angle:** The angle of emission is controlled by two rotating mirrors inside. The 3D laser scanner would record how much the two mirrors rotated.

The 3D laser scanner would make use of the distance and the angle to derive 3D coordinates. Then, even with no physical contact with the objects, dense and accurate 3D coordinates can still be acquired. The basic concept of data capturing is thus evolved from the “point” and “line” to “surface” and “model” perspective.

3. 3D LASER SCANNING SYSTEM LEICA HDS3000

The 3D laser scanning system HDS3000 used in this scanning project is manufactured by Leica Geosystems. Some of the important technical specifications are summarized in Table 1.



Fig 3. The 3D laser scanning system Leica HDS3000 at the Old Star Ferry Pier

	Leica HDS3000
Metrology method	pulsed time of flight
Field of view	360° horizon., 270° vertical
Optimal scan distance	1m – 100m
Scanning speed	up to 1800 points/sec
Accuracy in distance (50m)	6mm (single measurement)
Angular resolution	60 micro-radians
Divergence / Spot size in 50m	□ 6mm
Calibrated video camera	RGB 64 megapixels, spatially rectified

Table 1: Technical specifications of the laser scanner Leica HDS3000

The software as summarized in Table 2 is also a substantial component of 3D laser scanning system. By virtue of the software, a notebook can control the scanner during the data acquisition phase, the registration, geo-referencing of point clouds from different stations and deliverables production in CAD systems.

Software	Leica HDS3000
Scanning	Cyclone™ SCAN
Post Processing	<ul style="list-style-type: none"> ♦ Cyclone™ REGISTER for registration, target-matching, rendering and geo-referencing ♦ Cyclone™ MODEL for point clouds manipulation and modelling ♦ Cyclone™ SERVER for collaborative work group access to databases and data management ♦ Leica Cloudworx™ for manipulating point clouds in CAD systems

Table 2: Software for the laser scanning system Leica HDS3000

4. DATA ACQUISITION, REGISTRATION AND GEO-REFERENCING

The old Star Ferry Pier was a busy interchange for land and sea transport. The conduct of laser scanning for it was surely a new challenge to CEDD. To minimize nuisance to the public, the work required us to avoid disturbing pedestrians, vehicles, newsstands, shops etc. All detailed features have to be recorded and stored as 3D images with the 3D laser scanning technology. The work covered not only the interior and exterior of the pier and clock tower, but also the peripheral walkway.

As such, the laser scanning work needed thorough planning. Site inspection was necessary to decide the locations of survey control points. To transform the coordinates of scanned objects into that of the local coordinate system – HK 1980 grid system, traversing and levelling for the establishment of the survey control points were of utmost importance. The working steps

thus included data acquisition, registration and geo-referencing of captured point clouds into the local coordinate system.

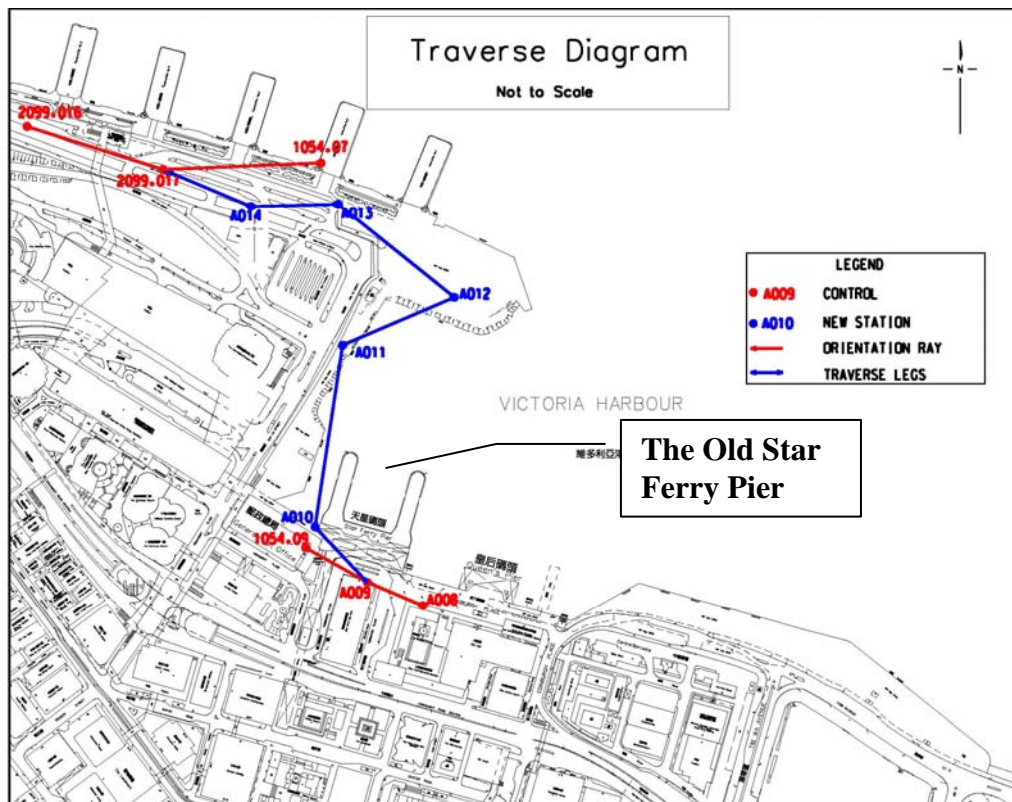


Fig 4. Traversing at the Old Star Ferry Pier

There were 3 main steps in registration namely (1) pairwise registration – for adjacent scans; (2) global registration – for all scans; and (3) world registration – for transformation to the local coordinate system. To geo-reference the scanning stations in pairwise registration, either (1) Tie-point / Tie-point constraint; or (2) Point Cloud / Point Cloud constraint (with a minimum of 3 points or 40% overlapped scanning coverage) was used. To maintain the accuracy, the incident angle of each laser beam was kept smaller than 60°.

Scanning Statistics	Leica HDS3000
# of tie points / spherical reference targets	153 tie points + 10 reference targets
# of scanning stations	200
# of scans	200
# of points [Million]	150
Volume of data [MB]	5000
Grid width in 50m / Scan [cm]	2
Scanning time / station [min]	60
Scanning time in total [days]	48

Total scanned floor area [sqm]	13500
Total scanned surface area [sqm]	39000

Table 3: Scanning statistics for the laser scanner Leica HDS3000

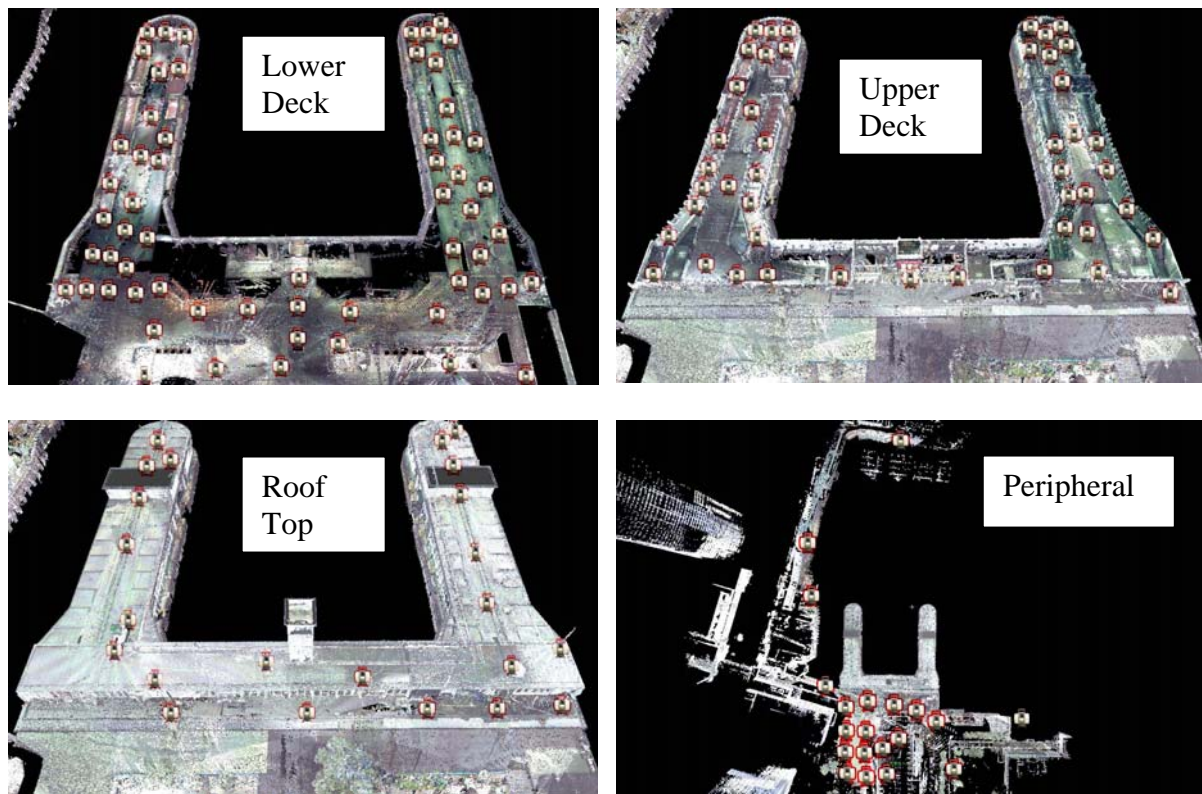


Fig 5. Geo-referenced point clouds and Scanning Stations at Old Star Ferry Pier

5. THE GEOMETRIC QUALITY OF THE MEASUREMENTS

The technical data of the scanner is listed in Table 1. Though the manufacturers give detailed technical information on its system, it is not easy to directly assess the quality of the measurements itself. There is no direct information about the accuracy of the captured 3D-coordinates and the measured elements (Frohlich, 2005).

Actually, the assessment of the quality of the measurements cannot be found out from single measurements (Frohlich, 2005). As such, we resorted to focus on the assessment of the derived elements (columns, cylinders, etc.).

5.1 Verification of the measured Centres and Diameters

In order to estimate the achievable accuracy, the centre coordinates of scanned columns at different floors in the old Star Ferry Pier were so derived in a least-squares adjustment approach as shown Fig 7. Then, comparisons were made with the centres of those same columns scanned at different floors. The centre coordinates were derived at 4 different levels

at about 4m, 6m, 7m and 10m. Moreover, analysis on the derived diameters of the scanned columns at different floors was also made. The locations of columns and the results of the deviations are shown in Fig. 6 / Fig. 7 and Table 4 respectively.

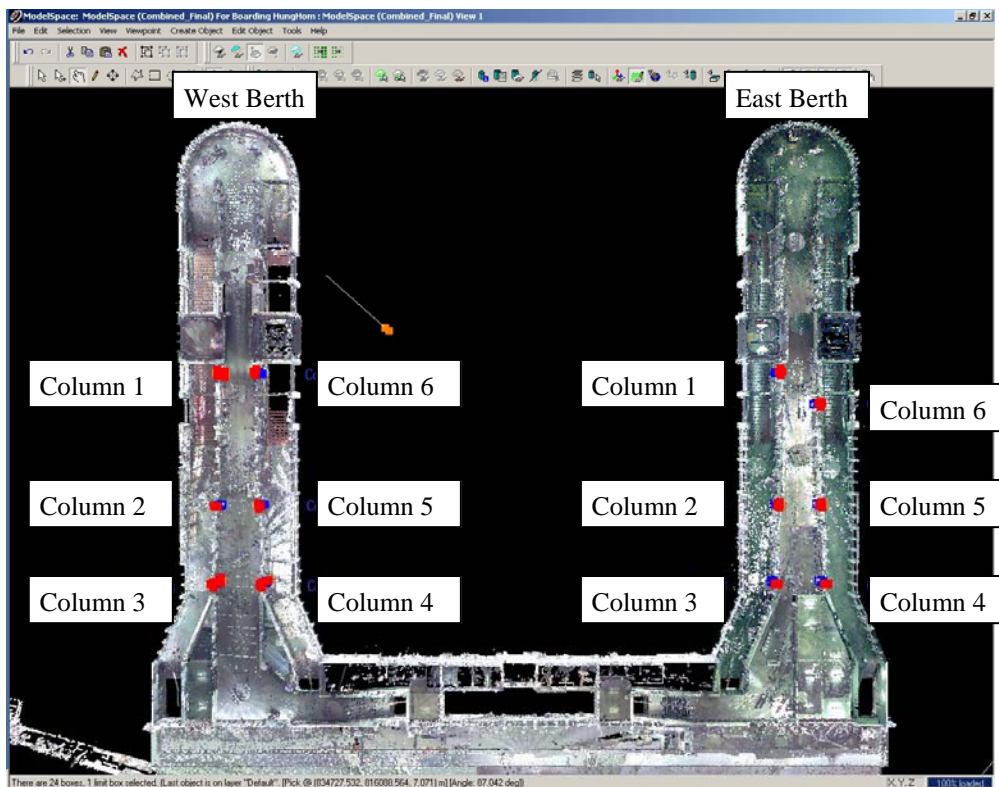


Fig 6. Location of Columns inside Old Star Ferry Pier

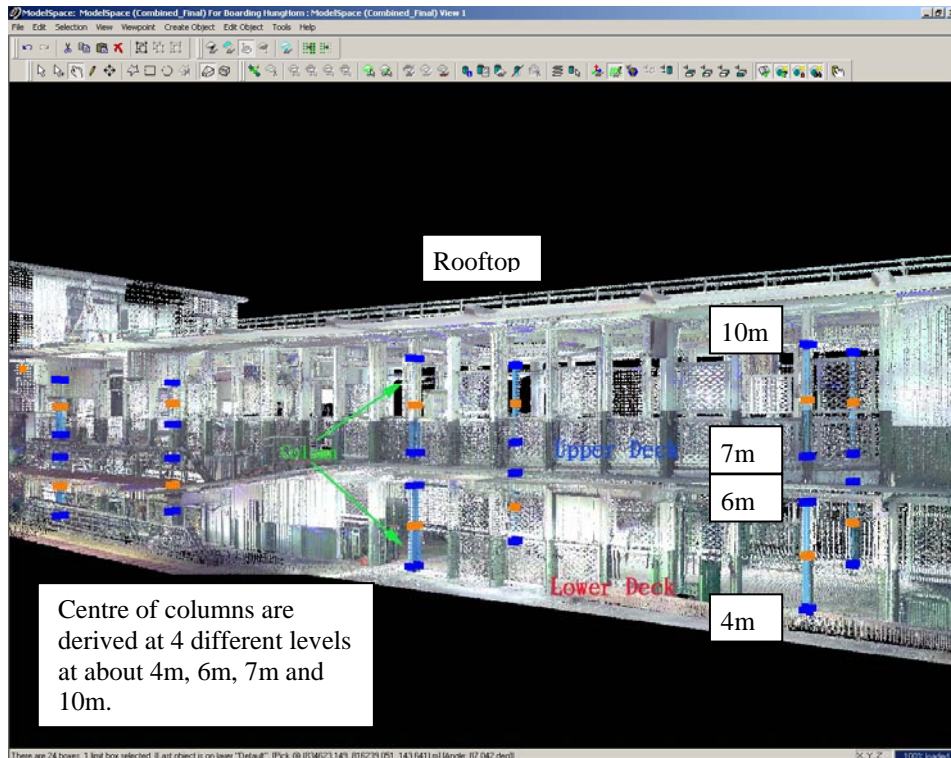


Fig 7. Centres (blue in colour) on the columns to be compared

Name: <18553>
 Object Info:
 Origin = (834632.621, 816108.011, 8.338) m
 Axis = (0.2534, 0.9674, -0.0042)
 Width Axis = (0.9674, -0.2534, 0.0012)
 Height = 0.147 m
 Depth = 2.784 m
 Width = 0.347 m
 Color = [75, 150, 255]
 Insulation Thickness = 0.000 m

Derived from cloud with 149602541 points
 Fit Quality:
 Error Mean = 0.000 m
 Error Std Deviation = 0.004 m
 Absolute Error Mean = 0.003 m
 Maximum Absolute Error = 0.031 m
***** The small error shows that the derived centre is highly accurate.**

Circular Column	Coordinates		
	Northings	Eastings	Level(mPD)
E1	816108.088	834632.639	9.729
E1	816108.076	834632.639	6.946
E1	816108.076	834632.646	6.269
E1	816108.072	834632.636	3.889

Fig 8. East Berth Column 1 - Sample Calculation Procedure in Cyclone™ MODEL

Circular Column	Standard Deviations (m)		
	Northings	Eastings	Overall
West Berth 1	0.000	0.013	0.013
West Berth 2	0.013	0.013	0.018
West Berth 3	0.000	0.000	0.000
West Berth 4	0.018	0.013	0.022
West berth 5	0.000	0.013	0.013
West Berth 6	0.013	0.026	0.029
East Berth 1	0.013	0.018	0.022
East Berth 2	0.013	0.000	0.013
East Berth 3	0.013	0.000	0.013
East Berth 4	0.000	0.013	0.013
East Berth 5	0.013	0.000	0.013
East Berth 6	0.018	0.013	0.022

Table 4. Standard Deviation of Centre Coordinates

The surfaces of columns at different floors were scanned by the independent setups of laser scanner. Their surface coordinates were found after the registration process as mentioned in section 3. From Table 4, the largest standard deviation of the derived centres from scanned surface coordinates at different levels is 0.029m only. At 95% confidence interval, the largest standard error can be regarded as about $0.029\text{m} \times 1.96\sigma \approx 0.057\text{m}$ only.

5.2 Verification of the Diameters

Comparisons were also made on the diameters of those same columns scanned at different floors. The results of the deviation are shown in Table 5.

Circular Column	Derived Diameters (m)		Discrepancies (m)
	Upper Deck	Lower Deck	
W1	0.350	0.302	0.048
W2	0.334	0.350	-0.016
W3	0.339	0.359	-0.020
W4	0.322	0.328	-0.006
W5	0.327	0.345	-0.018
W6	0.351	0.374	-0.023
E1	0.347	0.359	-0.012
E2	0.345	0.346	-0.001
E3	0.343	0.346	-0.003
E4	0.346	0.347	-0.001
E5	0.344	0.337	0.007
E6	0.349	0.343	0.006
Standard Deviation			0.019

Table 5. Deviations of Diameters

From Table 5, the discrepancies of the derived diameters at different floors are from -0.023m to 0.048m . Such discrepancies may be due to the various quality of workmanship and the inconsistent thicknesses of painting. However, the standard deviation is still 0.019m only. At 95% confidence interval, the largest standard error can be regarded as about $0.019\text{m} \times 1.96\sigma$ \square 0.037m only.

The above assessment shows that the laser scanning results are reasonably accurate and precise at centimeter level in term of the internal accuracy.

6. VARIOUS PRODUCTS BY 3D LASER SCANNING

After the above work, various value-added products, such as 3D models, cross-sections and structural plans, contour, flythrough animation etc., can be prepared.

6.1 Image Analysis

As the intensity of reflected laser depends on the nature of materials being scanned, point clouds with similar intensity value can be grouped for further analysis. As shown in figure 9, different colours represent different intensities of reflected laser beams. Different nature of materials can then be identified.

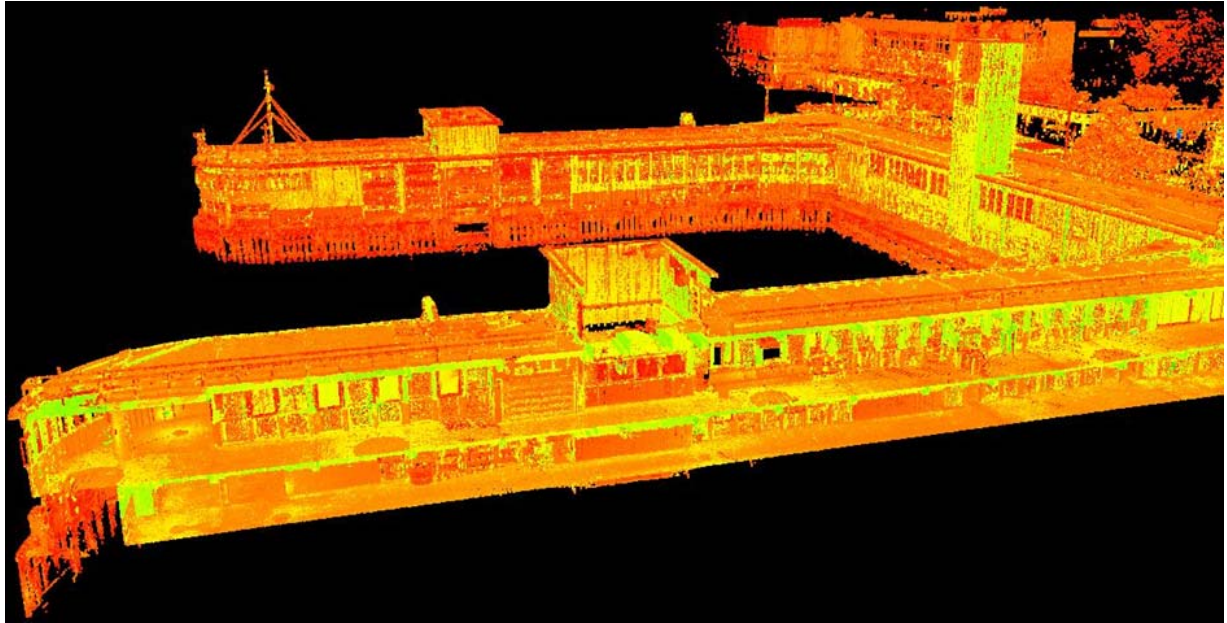


Fig 9. Point Clouds of old Star Ferry Pier (Cross-Section)

6.2 3D Model Simulation

A 3D laser scanner takes colour photographs in the vicinity during scanning work. 3D models of an object can be displayed with colours and texture by adhering the colour photographs on the point clouds. As shown in figure 10, the texture of the structure are clearly displayed for further analysis. Moreover, structural framework can be formed from the 3D models.

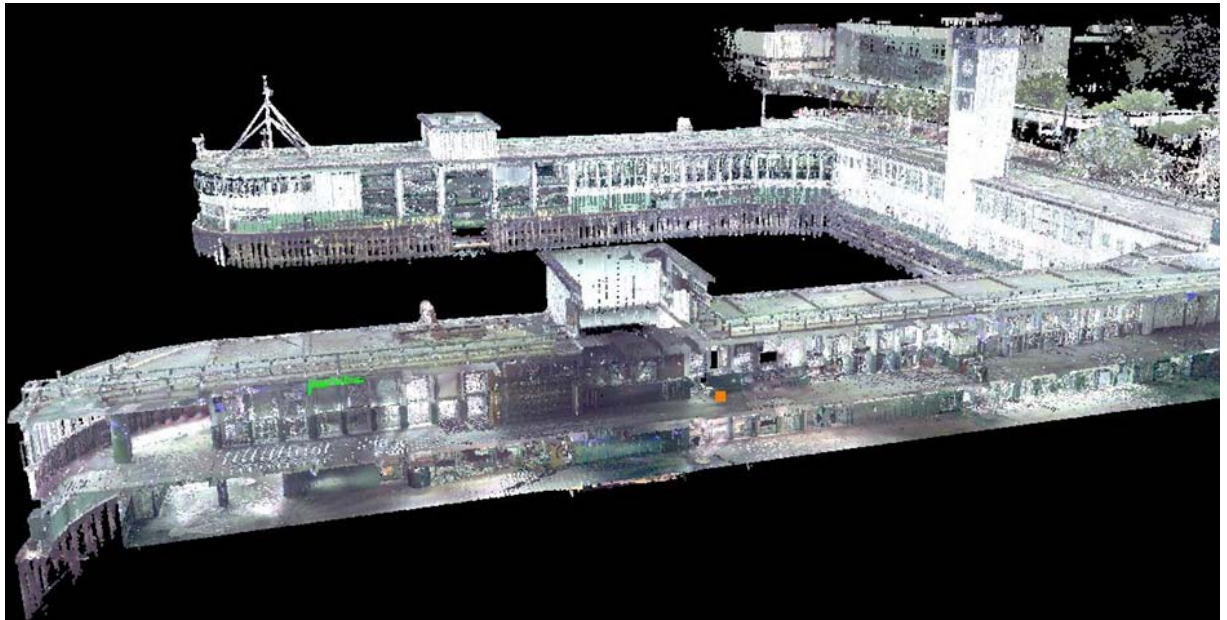


Fig 10. Point Clouds of Old Star Ferry Pier with colours and texture (Cross-Section)



Fig 11. Old Star Ferry Pier and Clock Tower (Cross-section)



Fig 12. Level of detail of the Landing Bridge

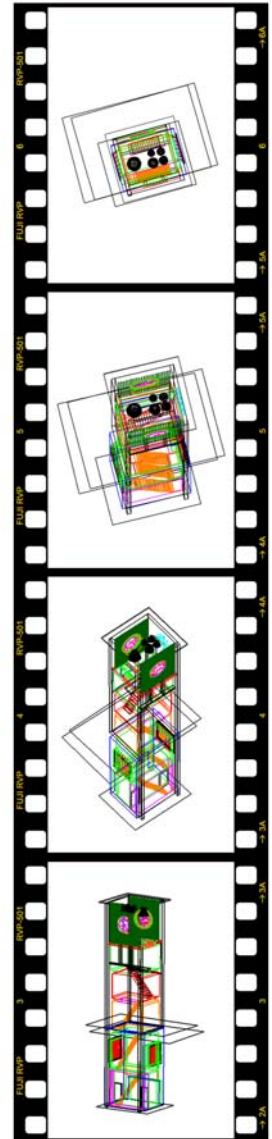


Fig 13. Structural Framework of Clock Tower

6.3 Multi-angle Visualisation

As shown in Fig. 14 and 15, the 3D model can be presented in different angles and flythrough animation is made possible in various software, e.g. Cyclone™ MODEL, Autodesk 3D Max, Autodesk Viz, etc.

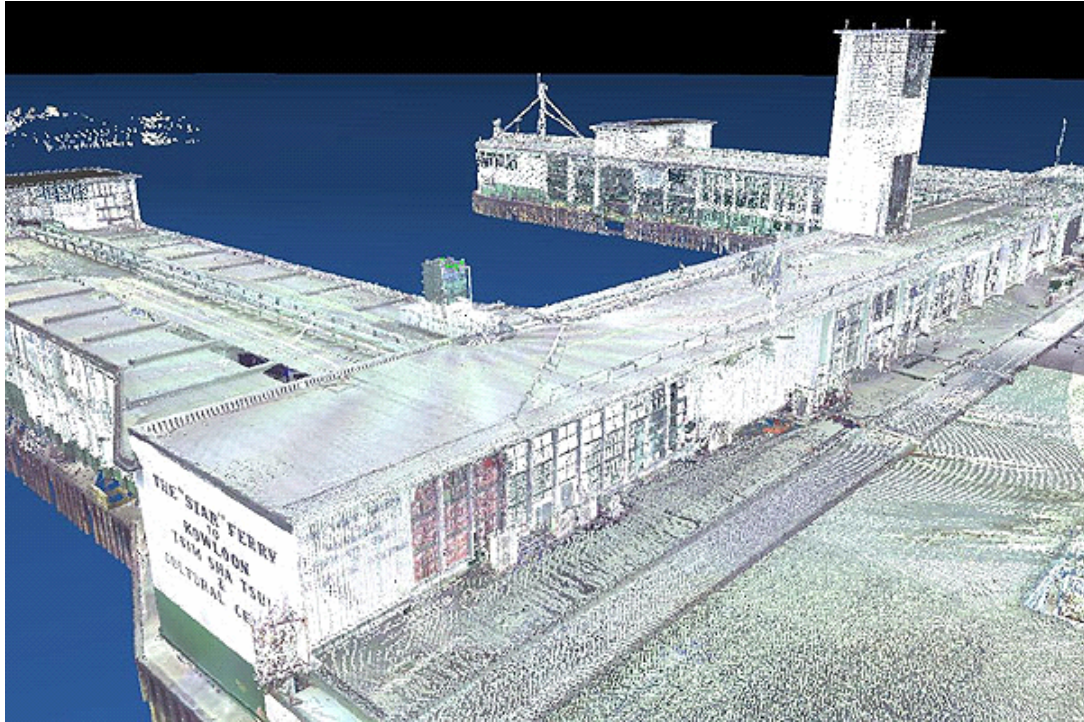


Fig 14. A Snapshot in Flythrough Animation at Clock Tower

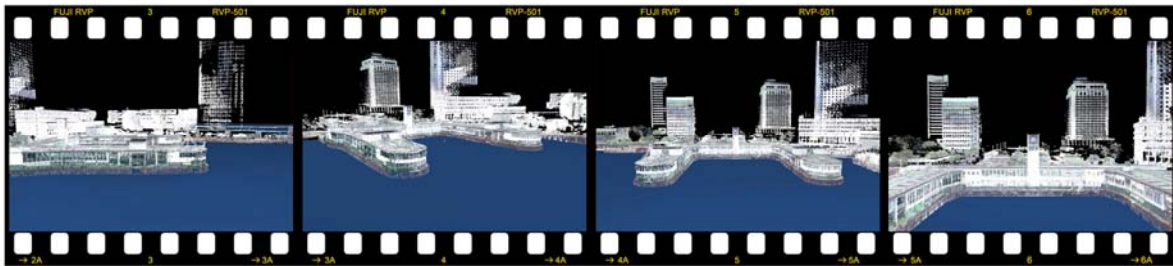


Fig 15. Some Snapshots in Flythrough Animation at old Star Ferry Pier

7. APPLICATIONS OF 3D LASER SCANNING ON OTHER SIMILAR PROJECTS

Beyond the demolition of the old Star Ferry Pier, CEDD also assisted the relocation of the old Blake Pier Cover and fireboat “Alexander Grantham” to the other venues.

7.1 Relocation of Old Blake Pier Cover

The century old cover of the Old Blake Pier, previously situated in Central, was relocated in the Morse Park during the reconstruction of the old Central Pier. The Government will relocate it next to the Murray House at Stanley. Since the original structural plans were lost, 3D laser scanning was found necessary to create its 3D model, cross-sections and structural

plans prior to its demolition and relocation. The 3D model was used to create flythrough animations for public consultation before the commencement of the project.



Fig 16. The Old Blake Pier Cover will soon be relocated from the Morse Park (left photo) to Stanley (right photo)

7.2 Fireboat “Alexander Grantham”

Built in 1953, the fireboat “Alexander Grantham” was a historical figure of fire services in HK for half a century. Its facilities had changed a lot since launching, and such changes were not shown on the original design drawings.

Its structure and facilities, particularly the pipes in the engine room, were recorded in detail and precisely with the use of the 3D laser scanning technology. For the determination of their center positions in particular, it could hardly be achieved by the conventional approach. The efficiency and effectiveness of work were both greatly enhanced with the use of point clouds and 3D models.



Fig 17. Fireboat “Alexander Grantham” (left photo) and its Point Clouds (right photo)

8. DISCUSSIONS

1. Apart from carrying out sophisticated surveying works, 3D laser scanning technology is suitable for recording historical structures or heritage with historical significance.
2. With its relatively high internal accuracy measurements as shown in section 5, laser scanner can effectively records down the dimensions of various features, e.g. sculptures, elevated pipes, the soffit of a viaduct, overhanging and cylindrical features, the ceiling of a building, the faces of large objects, columns and tower structures, etc. If using conventional surveying approach, such extensive and accurate measurements cannot be achieved easily.
3. Using the huge amount of collected data, various products including cross-sections, structural drawings, 3D visualization models and flythrough animations are thus made possible.

9. CONCLUSION

The acquired laser scanning data enables the Government to consider how to incorporate these special features into the design of the new Central harbourfront. CEDD produced a series of structural plans as fundamental information for the Planning Department to carry out the “Central Reclamation Urban Design Study”. Moreover, several flythrough animations were also prepared for engineers’ and other professionals’ reference. The 3D laser scanning technology indeed offers high accuracy with measurements for wide range of applications and products.

Indeed, the deployment of this technology helps CEDD deliver more value-added products and hence better services. Since the public is getting more concerned about preservation of historical features, it is foreseeable that more preservation elements would be introduced to the future civil engineering projects. With comprehensive laser scanning data, urban planning can be more flexible and more diversified to meet the community needs. For each historical feature, be it preserved or demolished, the feature and the vicinity have to be recorded for consideration of what approach to take. Engineers can even make use of 3D models to explain the project details to the public and for reference by bureaux, which allows various large-scale civil engineering projects to be implemented with ease.

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REFERENCES

- Barber, D., Mills, J., Bryan, P. 2004, Towards a Standard Specification for Terrestrial Laser Scanning of Cultural Heritage, School of Civil Engineering and Geosciences, University of Newcastle upon Tyne.
- Boehler, W., Marbs, A., 2004, Investigating Laser Scanner Accuracy, i3mainz, Institute for Spatial Information and Surveying Technology, FH Mainz, University of Applied Sciences, Mainz, Germany.
- Cheng, X., Jin W. 2006, Study on Reverse Engineering of Historical Architecture Based on 3D Laser Scanner, Journal of Physics: Conference Series 48 (2006) 843–849.
- Frohlich, C., Mettenleiter, M. 2005, Terrestrial Laser Scanning – New Perspectives in 3D Surveying, Zoller + Frohlich (Z+F) GmbH, Simoniusstr, Germany.
- Kersten, T H., Sternberg, H., Stiemer, E. 2005, First Experiences with Terrestrial Laser Scanning for Indoor Cultural Heritage Applications using Two Different Scanning Systems, Proceedings of the ISPRS working group V/5 “Panoramic Photogrammetry Workshop”, IAPRS, Vol. XXXVI, Part 5/W8.
- Lam, L. 2007, Application of 3D Laser Scanning Technology, CEDD Newsletter, 2007.
- Leica HDS3000 Product Specifications, Cyra Technologies, Inc., Leica Geosystems.
- Lerma, J L., Biosca J M. 2005, Segmentation and Filtering of Laser Scanner Data for Cultural Heritage, CIPA 2005 XX International Symposium, Torino, Italy.
- Lindenbergh, R., Pfeifer, N., Rabbani, T. 2005, Accuracy Analysis of the Leica HDS3000 and Feasibility of Tunnel Deformation Monitoring, ISPRS WG III/3, III/4, V/3 Workshop “Laser Scanning 2005”.
- Yokoyama, H., Chikatsu, H. 2005, 3D Modelling for Historical Structure using Terrestrial Laser Scanning Data, Department of Civil Engineering, Tokyo Denki University.
- Zhang, Y Z., Hu, G Y. 2006, Capture of Urban Detailed Spatial 3D Data by Laser Scanning System, Department of Civil Engineering, Tsinghua University.

BIOGRAPHICAL NOTES

Dominic Siu

Professional Qualifications:

Member of Royal Institution of Chartered Surveyors (MRICS)

Member of Hong Kong Institute of Surveyors (FHKIS)

Academic Qualifications:

BSc(Hons) Degree in Surveying and Mapping, University of East London, UK
(formerly known as North-east London Polytechnic)

Current Position:

Chief Land Surveyor, Civil Engineering and Development Department, Hong Kong SAR
Government

Activities in home and International relations:

Chairman, Land Surveying Division, Hong Kong Institute of Surveyors, 2004-2006

Member, Surveyors Registration Board, 2006-2007

Honorary Secretary, FIG Working Week 2007 Organising Committee

Lesly Lam

Professional Qualifications:

Member of Royal Institution of Chartered Surveyors (MRICS)

Member of Institution of Civil Engineering Surveyors (MInstCES)

Member of Hong Kong Institute of Surveyors (MHKIS)

FIG/IHO Cat. A Hydrographic Surveyor

Academic Qualifications:

Graduate Management Research in Business and Management, University of South Australia

MSc Degree in Hydrographic Surveying, University College London (UCL), UK

BSc(Hons) Degree in Surveying and Geo-Informatics, Hong Kong Polytechnic University
(HKPU), HK

Advanced Certificate in Human Resource Management in the Public Sector, The Hong Kong
Institute of Human Resource Management (HKIHRM)

Current Position:

Land Surveyor, Civil Engineering and Development Department, Hong Kong SAR
Government

Activities in home and International relations:

Chairman, Young Surveyors Group, Hong Kong Institute of Surveyors, 2004-2005

Member, External Affairs Committee, Hong Kong Institute of Surveyors, 2005-2006

Member, Board of Professional Development, Hong Kong Institute of Surveyors, 2003-2005

Council Member, Land Surveying Division, Hong Kong Institute of Surveyors, 1999-2007

Public Relation Manager, FIG Working Week 2007 Organising Committee

CONTACTS

Dominic Siu

Civil Engineering and Development Department, Hong Kong SAR Government
19/F, One Mongkok Road Commercial Centre
1 Mong Kok Road, Kowloon
Hong Kong
Tel. + 852 2309 5000
Fax + 852 2714 0174
Email: wcsiu@cedd.gov.hk
Web site: www.cedd.gov.hk

Lesly Lam

Civil Engineering and Development Department, Hong Kong SAR Government
18/F, One Mongkok Road Commercial Centre
1 Mong Kok Road, Kowloon
Hong Kong
Tel. + 852 2309 5011
Fax + 852 2391 5714
Email: lslam@cedd.gov.hk
Web site: www.cedd.gov.hk