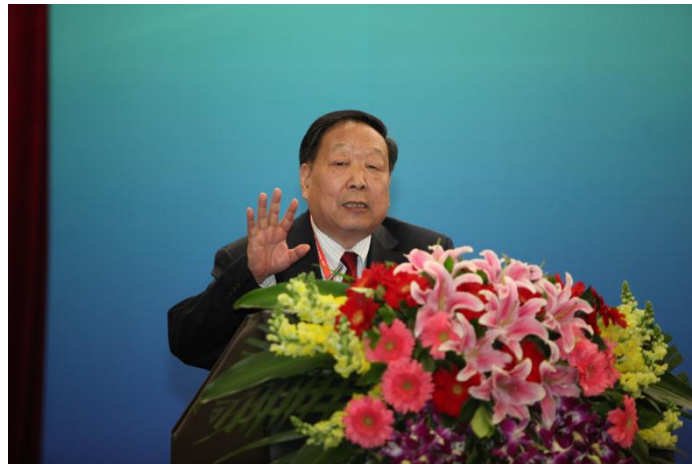


Digital Documenting for Dunhuang Mogao Grottoes

LI Deren

Wuhan University, China



Abstract

Dunhuang Mogao Grottoes located in the ancient Silk Road of China, preserves 735 caves, over 45 thousand square meters painted murals, 2415 bodies of painted sculptures and 5 ancient Dou-gong buildings. In 1987, Mogao Grottoes was designated as world cultural heritage. But in recent years, due to the damage from human activities and the natural environment, the mogao Grottoes are facing the crisis of accelerated extinction. In order to preserve the mogao Grottoes permanently in the digital way, from 2007 to 2012, Wuhan University launched a series of mapping programs over Mogao Grottoes area: using airborne laser scanning to get the terrain and landform around the Mogao Grottoes, using terrestrial laser scanning to obtain the data of culture heritage and façade of cliff, using the fixed baseline stereo camera to acquire the data of ancient building and using the precise control surveys to integrate all these data into a uniform world coordinates. According to the particularity of the cultural heritage data and problems encountered during the data processing, some key algorithms were developed, such as fast triangulation of terrestrial laser scanning data based on spherical projection and high fidelity texture reconstruction. Finally the digital documents of the relics in Mogao Grottoes and the surrounding virtual geographic environment are established for the study, archaeology, art and protection of the Mogao Grottoes cultural heritage.

**4th International Conference on
RS in Archaeology(ICRSA4)**

**Digital Documenting for Dunhuang
Mogao Grottoes**

Deren Li

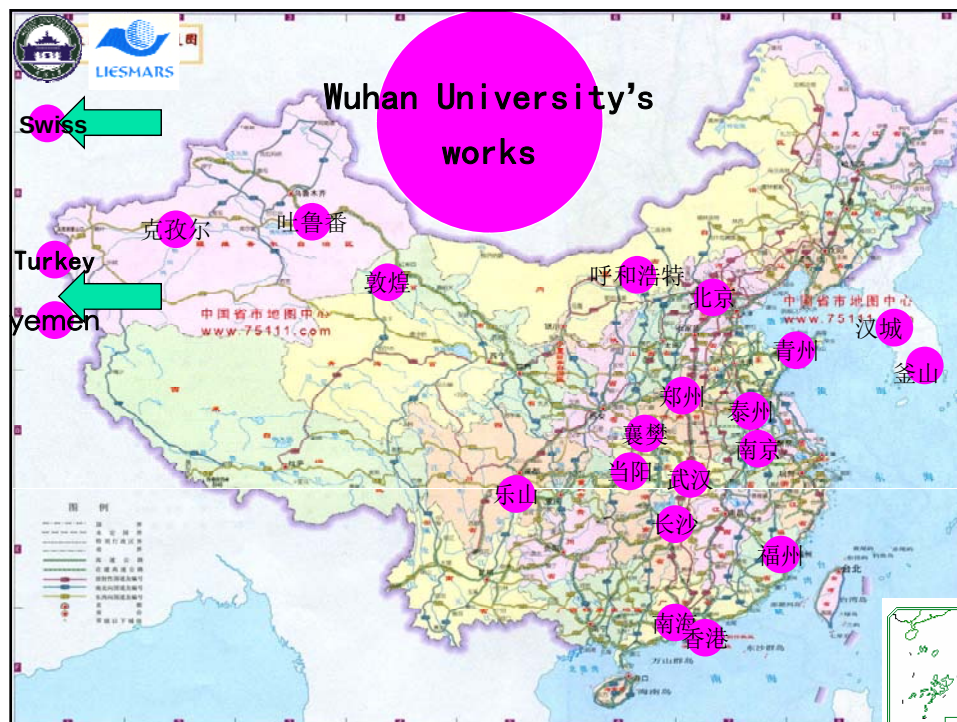
**State Key Lab of Information
Engineering in Surveying, Mapping and
Remote Sensing, Wuhan University**



Oct. 24, 2012 Beijing, China

43 World Culture Heritage in China





Contents

- 1. Introduction of Mogao Caves
- 2. Data Acquiring and 3D Modeling for Dunhuang Mogao Caves
- 3. Integration and Visualization
- 4. Conclusions

■ 1. Introduction of Mogao Caves



1.1 Silk Road and Mogao Caves

■ The Silk Road

- the most important thoroughfare in ancient Eurasia linking up China, India, Persia, Babylon, Egypt, Greece, and Rome
- showcased the major seven stages of the history of ancient human civilization.

■ The Mogao Caves

- a miracle remained after cultural collision between east and west
- an artistic treasury of Northwest China
- a shining pearl on the Silk Road

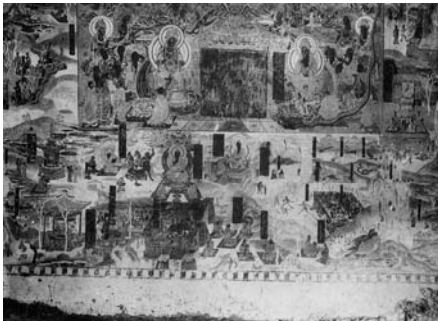


➤ Dunhuang Mogao Grottoes



1.2 Actuality of Mogao Caves

- In recent decades, a large number of cultural heritage is facing the crisis of accelerated extinction. For example, a fresco on the south wall of cave no.217, Mogao Grottoes:



Shot by Paul Pelliot (Franch) in 1908



Shot by Dunhuang Academy in 2005



1.2 Actuality of Mogao Caves

- There are fearful diseases for all the grottoes in different extents and the speed of painted statues damage and fresco degradation is wondrously horrendous
 - damaged from the nature factors
 - Earthquake
 - collapses of cliffs
 - ablation from fierce sand blown by wind
 - damaged by human being
 - contrived destroy
 - over-load tours
- In order to more effectively protect the Mogao Caves, a world cultural heritage, we need to bring forward the aims and the process to build *Digital Mogao Caves*.



1.3 Our Aims and Methods

- Aims--Digital Mogao Caves
 - Reconstruct the scene and grottos of Mogao Caves by the latest computer and surveying technologies
 - Offer detail and digital archives
 - Support the digitalized archaeology
- Main method--Digital Cultural Heritage
 - Obtain the 3D data of every grottoes and 200km² around them for archiving the digital documentation
 - Create high-precision textured 3D models
 - Develop a Virtual Architectural Environments (VAEs) using VR and 3D GIS technologies

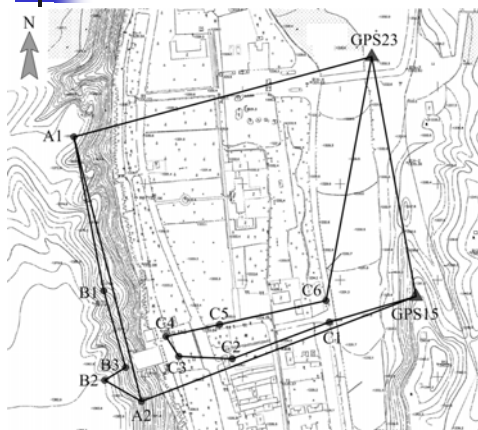


2. Data Acquiring and 3D Modeling for Mogao Caves

- 2.1 Control Surveying
- 2.2 Multi-viewpoint Stereo Photogrammetry
- 2.3 Air borne and Land based Laser Scanning



2.1 Control Surveying



- Offer all the absolute coordinates with high precision
- Build up a conversion relationship from the relative coordinates acquired in ways below to their geodesic ones
- measurement accuracy is better than $\pm 15\text{mm}$

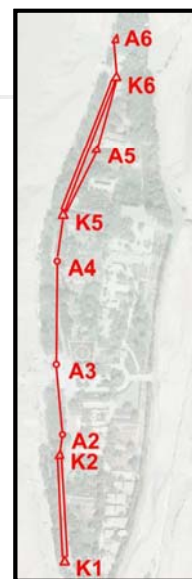
2.1 Control survey

- Control survey is used for
 - registering ALS and TLS point clouds, because the world coordinate of control points in TLS can be measured
 - constraining the registration between TLS point clouds, to avoid the accumulated error
 - establishing the relative position between the caves.

2.1 Control survey

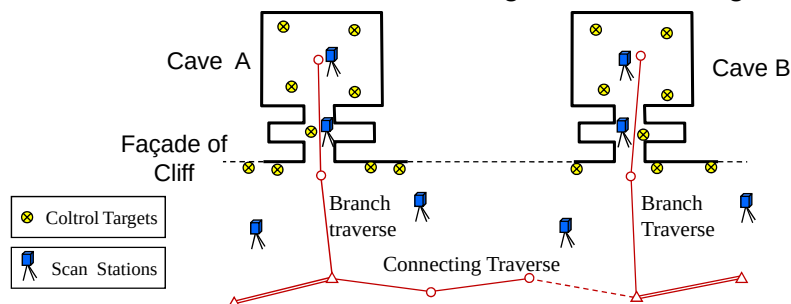
• Traverse survey

- **Nine control points** run through the Southern area of Mogao Grottoes.
- One connecting traverse and two triangular closed traverse.
- Closure error of angle: **22 sec** (The Tolerance is 42 sec)
- Error in point measurement: **11mm**



2.1 Control survey

- Control target survey for laser scanning
 - extending the branch traverse into the caves
 - measuring the control targets by total station
 - scanning caves and façade of cliff along with the control targets by terrestrial laser scanner
 - at last, registering the laser scanning point clouds to unified coordinate using the control targets.



2.2 Multi-viewpoint CCD System





2.2 Multi-viewpoint Stereo Photogrammetry



(a)

(b)

- Based on the theory of aero-photography measurement and computer vision
- An effective method of acquiring scene information
- The significant advantages in concentrating the objects' 3D shape and texture



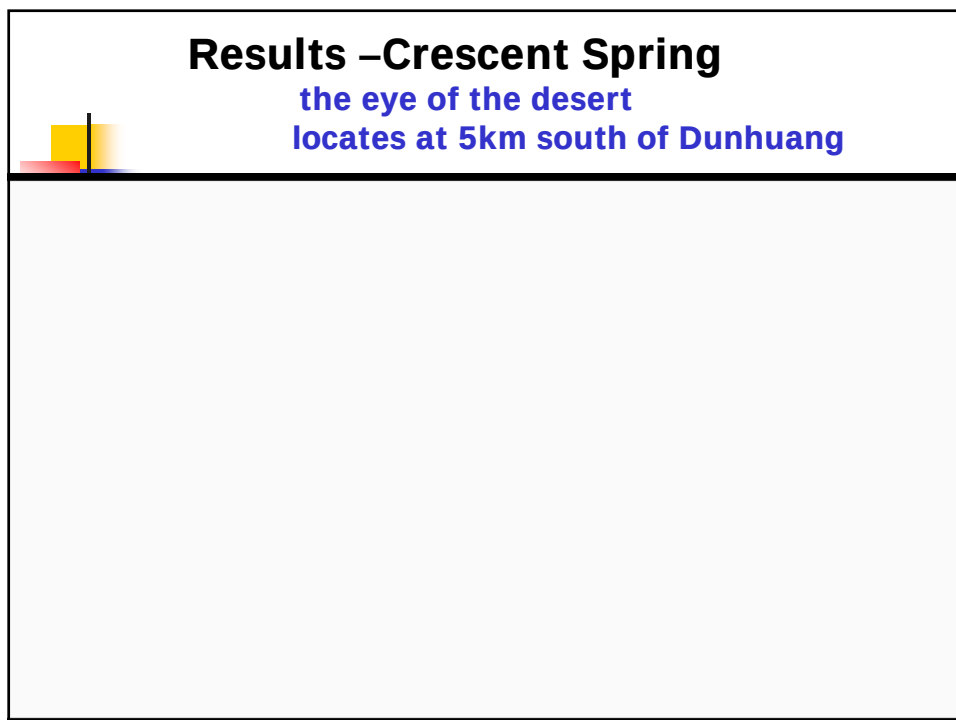
Results – 9-storied Mogao Caves



■ a photo of real scene



■ a snap of 3D virtual scene



2.3 Airborne and Terrstial Laser Scanning

- 2.3.1 Introduction
- 2.3.2 Airborne laser scanning
- 2.3.3 Terrestrial laser scanning
- 2.3.4 Integration

2.3.1 Introduction

- Entirely documentation in digit
 - Inner cave
 - Facade of cliff
 - Environment



Inner cave – terrestrial LiDAR



Facade – terrestrialLiDAR

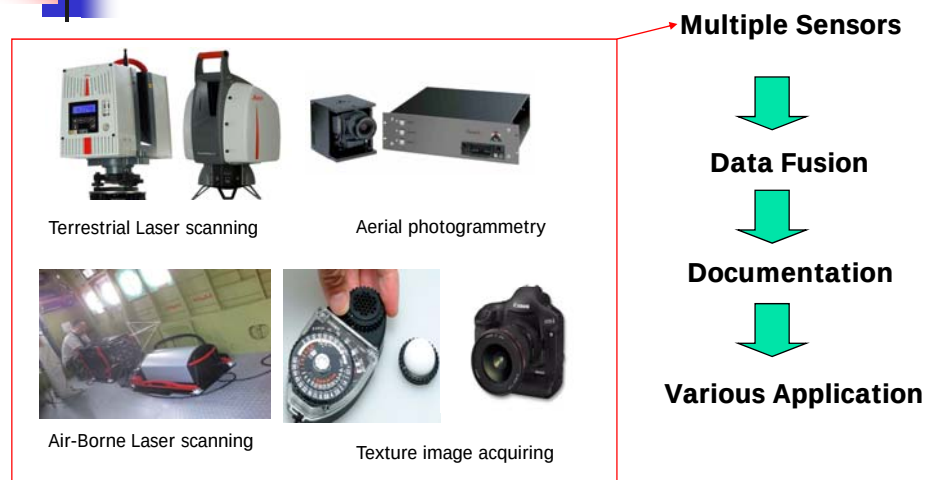


Environment - Airborne LiDAR

➤ 2.3.1 Introduction - Significance

- **Modeling the environment around the cultural heritage for conservational analysis, such as wind direction, dune moving, etc.**
- **Precise position for the cultural heritage on world coordinate system.**

➤ Introduction – Multiple sensors



2.3.2 Airborne Laser Scanning

- Flight Plans
- Data Acquiring
- Data Processing

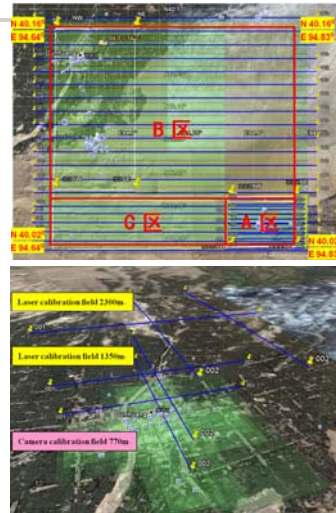
Flight Plans

- **Instrument**
 - Leica ALS-60
 - Frequency: 100 Pts/S
 - Field of Vision: 75Deg
- **Working Zone**
 - About 280 square kilometers
 - Altitude 1000m~1600m
- **Absolute flying height : 2750-2850m**



2.3.2 Airborne laser scanning

- Instrument
 - Leica ALS-60
- Multi-resolution scanning
 - 300 km²
 - Zone A – Mogao Grottoes
 - Average point space: 0.44m
 - Image resolution: 0.12m
 - Others – Dunhuang City
 - Average point space: 0.71m
 - Image resolution: 0.31m



Ground calibration field

➤ Airborne laser scanning – Data





Flight Plans

- **Multi-resolution scanning**
 - **Zone A – Mogao Grottoes**
 - Average point space: 0.44m
 - Image resolution: 0.12m
 - **Others – Desert**
 - Average point space: 0.71m
 - Image resolution: 0.31m

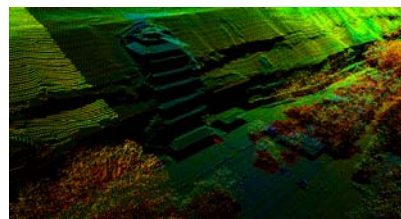
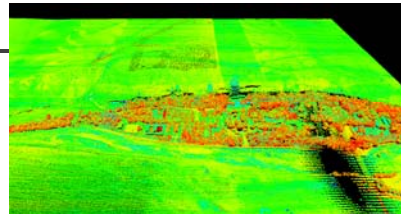
Ground calibration field



Data Acquiring

- **718 Digital Aerial Images**
 - Resolution: 30-50cm
 - Focal length: 35mm
 - Frame size: 39 million pixels, about 80GB
- **ALS Point Cloud Data**
 - 30 strips
 - About 20GB (in LAS Format)

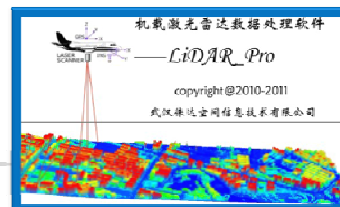
Data Acquiring



Airborne Point Cloud
(colored by echo intensity)

Aerial Images
(Dunhuang city center
and Mogao Grottoes)

Data Processing



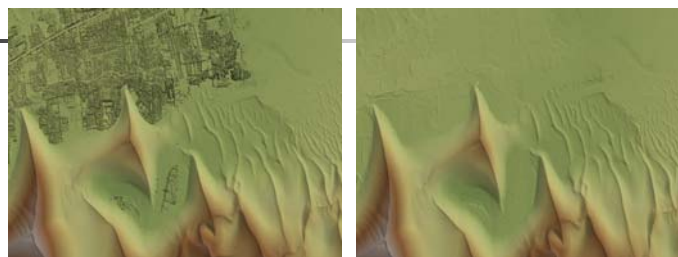
- **Tool: LiDAR_Pro**
 - From Lidar Data to DEM, DOM, DLG, Contour
 - Self-developed software at Wuhan University.
 - Supported by National High-Tech Research & Development Program of China (863 Project)
 - Efficiency and precision equal to TerraSolid.

Data Processing

■ Fruits List:

- 700 DOMs(80GB in tiff)
- DEM (Resolution: 1m, 2m, 5m)
- Contour Line (1:1000,1:5000,1:10000)
- DLG

Data Processing



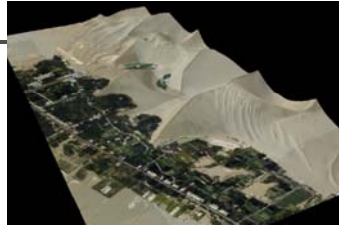
DSM

DEM

- Accuracy Statistics(by Surveying and Mapping Bureau of Gansu Province)

RMSE	LAE	MAE	Mean Error
0.15m	0.01m	0.27cm	0.12cm

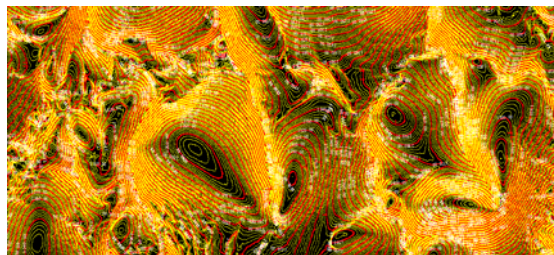
Data Processing



DOQ+DEM



DOQ+DLG



Contour Line

2.3.3 Terrestrial Laser Scanning



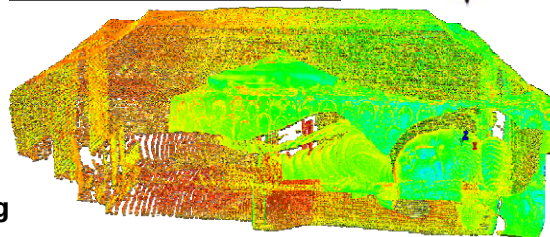
- Instruments
- Data Acquiring
- 3D Modeling
- Results



LIESMARS

2.3.3 Laser Scanning

- Laser scanning technology has been widely used in the model reconstruction for ancient buildings
- A spherical projection based on triangulation algorithm is developed to process the data
- Main step
 - Triangulation
 - Smoothing
 - Hole filling
 - Decimating
 - Model merging



Point cloud of Cave No. 158

Instruments



HDS6000



HDS6000 & Z+F Imager5006i -

Phase-based
terrestrial laser
scanner

FOV: 360° x310°
Max Dist.: 79m
Accuracy(single pt): <6mm
Resolution: <1.6mm
Frequency: 500,000 pts/s



HandyScan -
3D scanner for
reverse engineering

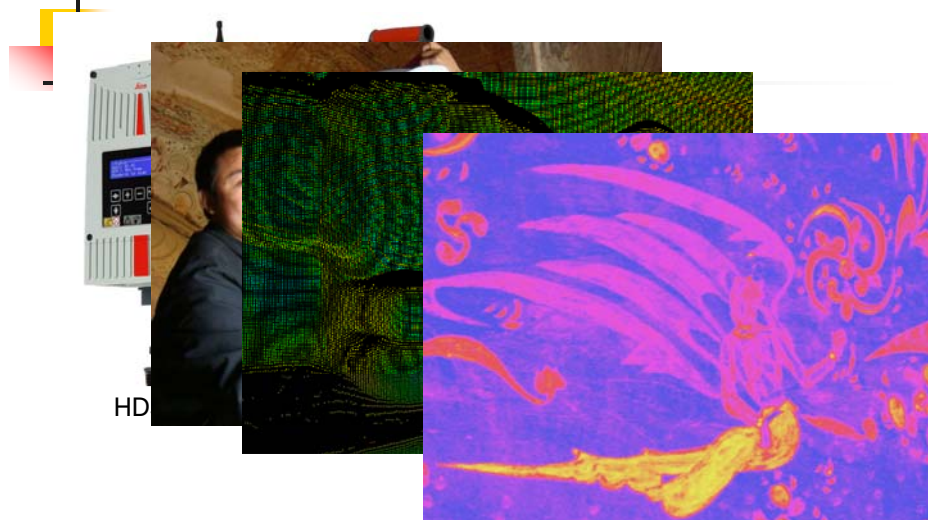
Principle: triangulation
Accuracy: <0.4mm
Resolution : 0.1mm
Frequency: 25,000 pts/s
Self-Positioning



EOS-1D Mark III -
Digital Camera for
texture collecting

Resolution: 5616 x 3744 pixel
Sensors type: CMOS
Sensor size: 36 x 24 mm
Pixel size: 6.4 um
Full-Frame camera

2.3.2 Geometric data acquiring



Pattern of the painting can be represented by the point cloud intensity.

Data Acquiring

- **Cave No.158**
 - **Buddha's nirvana**
 - **15.6m long**
 - **18 stations**
 - **Point cloud:**
 - 1.5 billion pts**
 - **62 images**



Data Acquiring

■ Cave No.196

- Tang dynasty
- 2.8m in height
- 1.6m in width
- 14 stations TLS
- Point cloud:
3 billion pts
- 120 images



Data Acquiring

■ Cave No. 285

- About 40 m²
- 5 Buddha statues
- Mural area: 200m²~
- 8 stations TLS
- 2billion pts
- More than 600 images



Data Acquiring

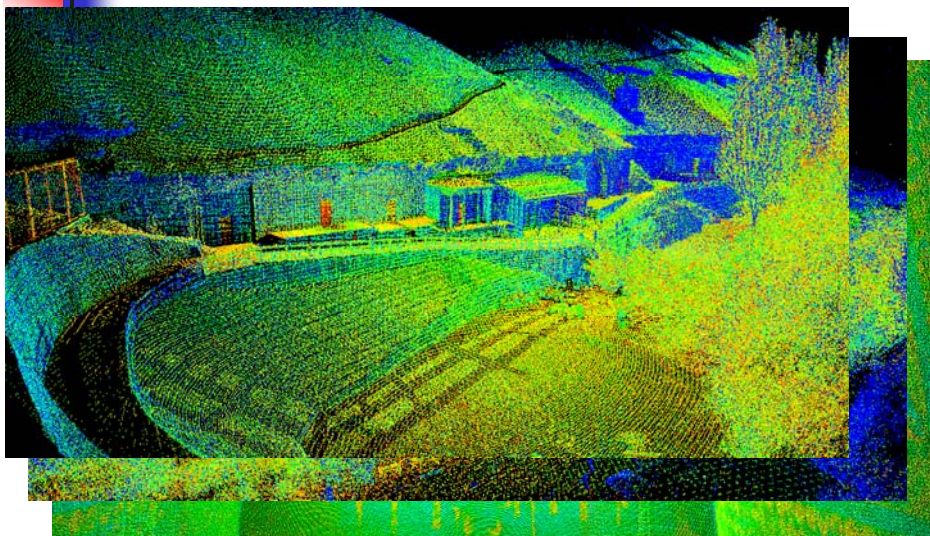
- Facade
- Length 1800m~
- Ground station
 - 77 stations
- Lift station
 - Lift 20m in height
 - 38 stations
- Total Data Siza
 - Point Clouds 150G
 - More than 500 Images



Façade of cliff



➤ Terrestrial laser scanning - Data



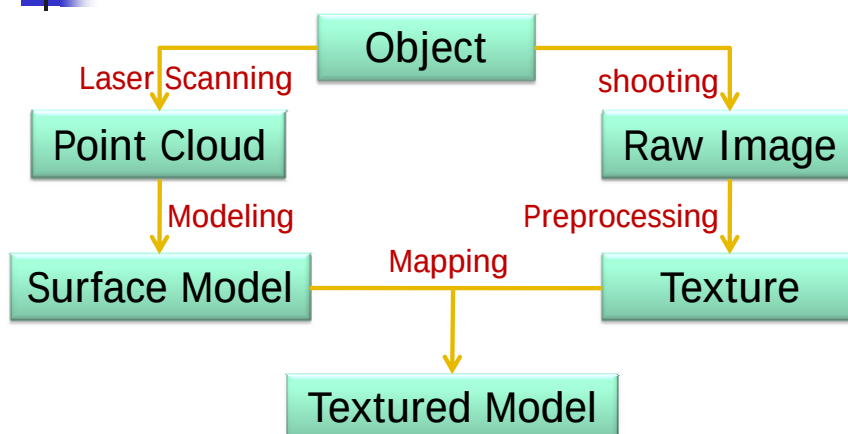


3D Modeling

- Working flow
- Geometric data gathering
- Point cloud data processing
- Texture preprocessing
- Texture mapping
- Results



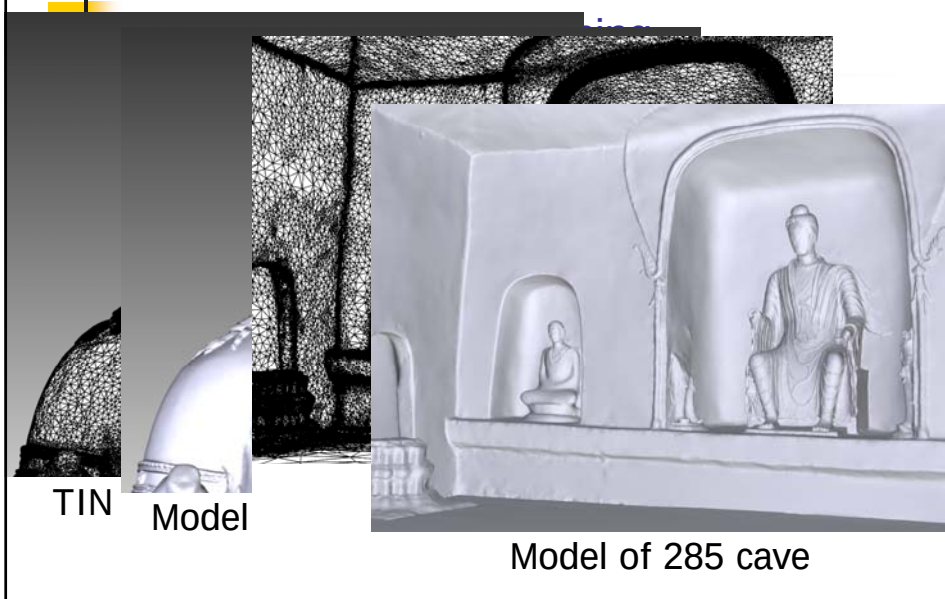
Working flow





Point cloud data processing

- | | |
|--|--|
| <ul style="list-style-type: none"> ■ Steps: ■ Registration ■ Generate TIN ■ Reduce noise ■ Edit mesh ■ Simplify ■ | <ul style="list-style-type: none"> ■ Tools: ■ Geomagic Studio ■ Polyworks ■ Self-developed tool ■ |
|--|--|



TIN

Model

Model of 285 cave



Texture preprocessing

- **Camera: Canon EOS-1Ds Mark III**
- **Photos are stored in *Camera Raw* format. Preprocessing can adjust the color temperature, tone, exposure, saturation, etc. to approximately uniform the color between photos.**



Texture mapping(2D to 3D)

- **Platform:**
ModelPaint ---- a self-developed tool, special for texture mapping on irregular, complex object.
- **Main steps:**
 - Geometric alignment between texture and model
 - Texture blending
 -



LIESMARS



Texture mapping – alignment

- Control Points Assignment
- Robust Least Square resolve Camera Parameters
- Project Whole Image to Model
- Semi-Automatic Adjust of small inaccuracy mapping



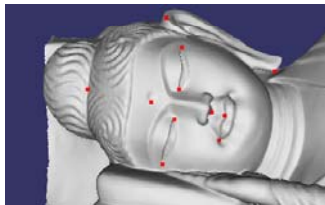
LIESMARS



Texture mapping – alignment



Control points on texture



Corresponding points on model



Model with Texture

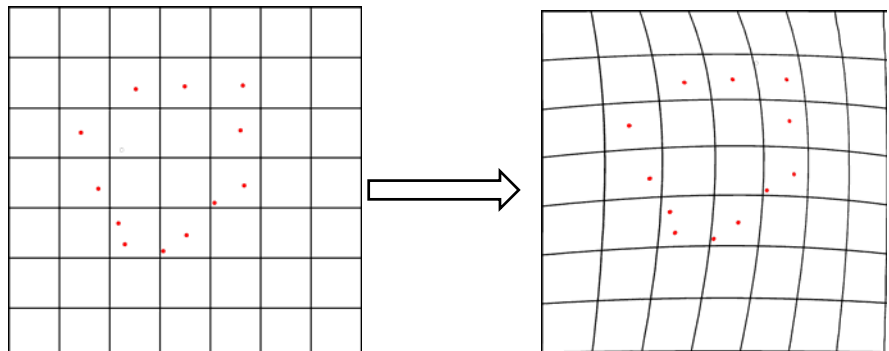


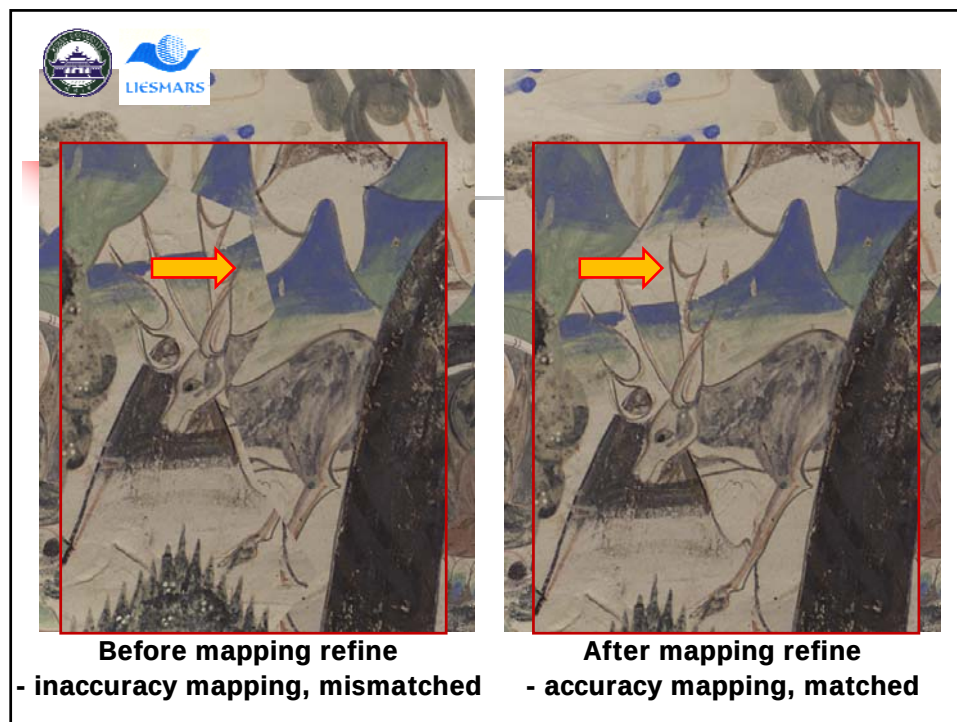
Mesh patch based texture Mapping



Mapping Refine

- After mapping using camera parameter
- There still has wrong mapping need to refine
- ➔ weighted distortion image according control points





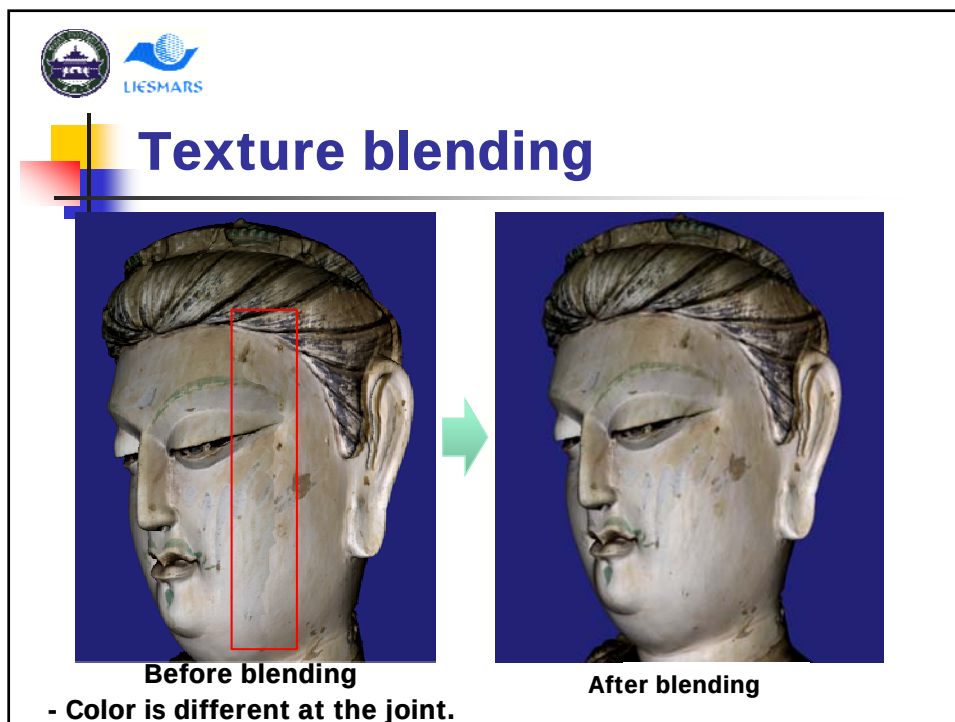
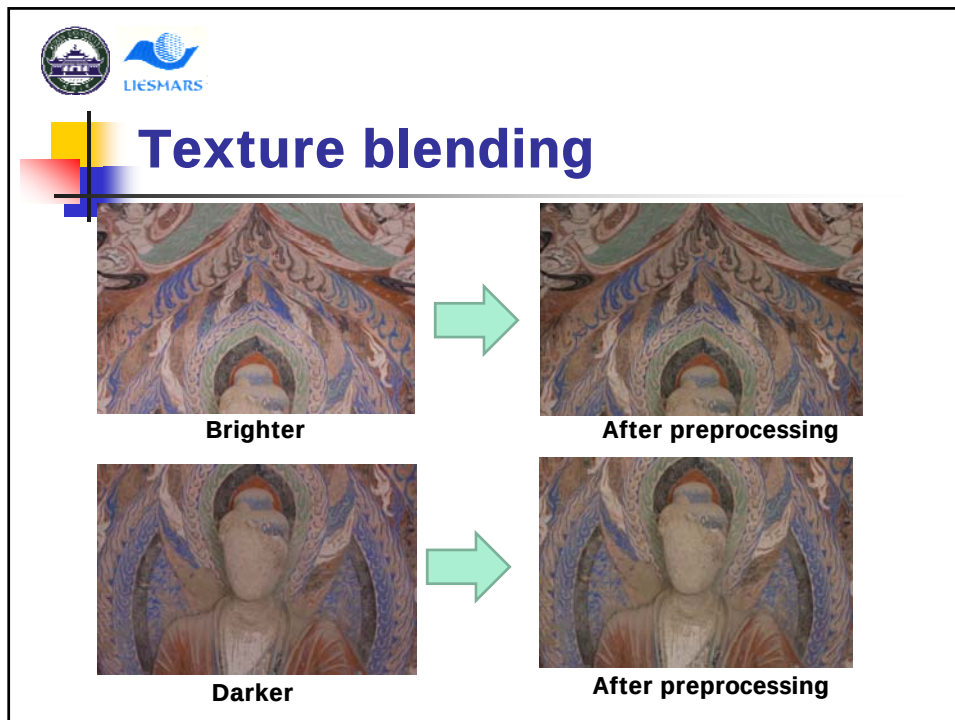
Texture blending

Precondition:

1. Textures Overlap
2. Textures Precisely Mapping

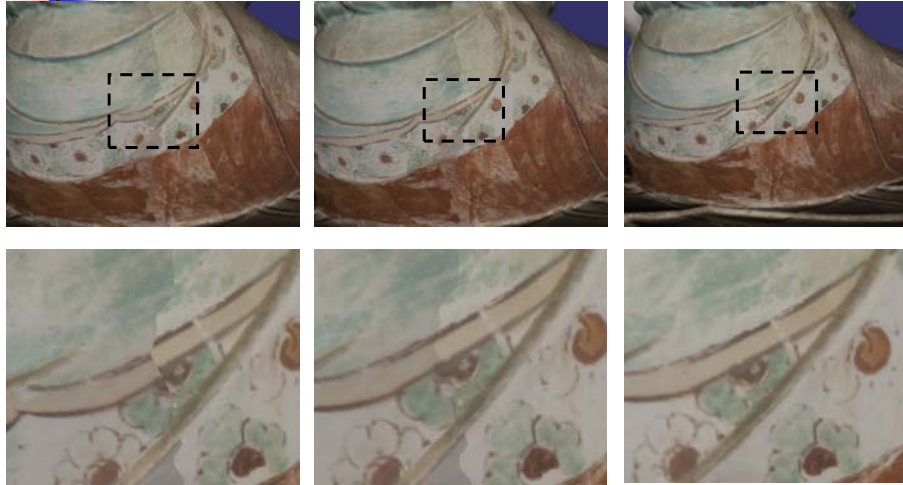
Processing:

1. Region of Interest Finding
2. Decomposition of Image into Frequency Space
3. Blend in Frequency Space



➤ Texture reconstruction

– Refining and blending



Before processing

texture mapping **refined**Refine texture **blended**

➤ Results – cave 158



Photo



Textured 3D model

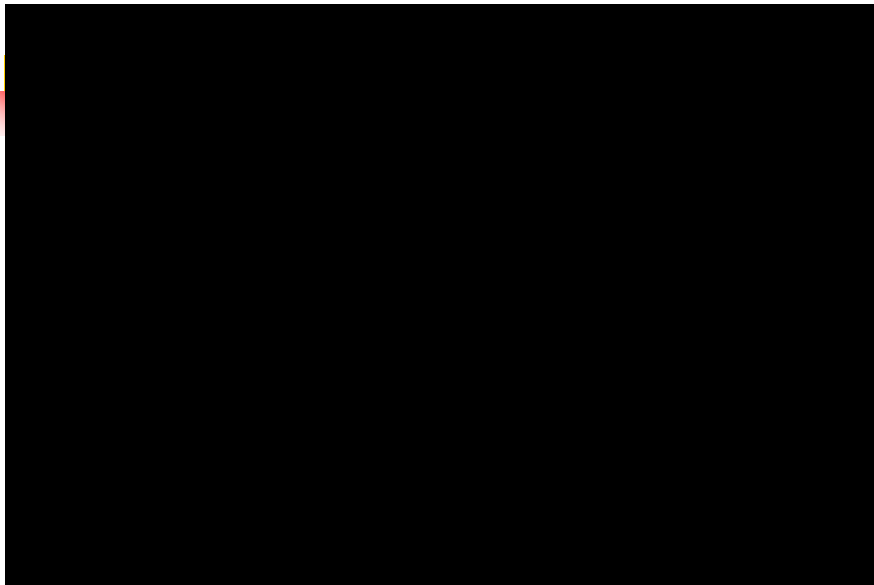


Textured 3D model

- A statue of nirvana
- Tang Dynasty
- 15.1m in Length



Results – 3D model of Cave No. 158





Results – 196 Cave

- Buddha: Tang Dynasty
 - Height 2.8 meter
 - Width 1.6 meter
- Data:
 - Point Clouds: 3 billion
 - Original image: more than 200 pics
- Result:
 - Triangles : 1.2 million
 - Used images: 51 pictures

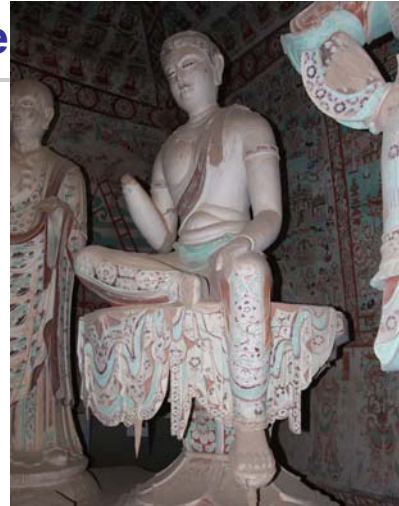


Photo of 196 Buddha



Results – 196 Cave





Results – 196 Cave





Results – Cave 285

- West Wei Dynasty
 - The best one of Mogao Grottoes
 - About 50 m²
- Data
 - Point clouds: 4 billion points
 - Original image about 500 pictures
- Result
 - 1.23 million triangles
 - 208 images used
 - 6.8 GB data for 3D model
 - High resolution image can be printed as same size as real cave



Results – 285 Cave

Results - Cave No.322



Geometry model



Textured Model



Photo

Results - Cave No.322



A photo of the statues in west niche, cave no.322.

3D Textured model of the statues.

Geometry model is from handyscan and TLS.

82 digital images is mapped as the texture.



3. Integration and Visualization

- Difficult problem
 - Different scale
 - Different aspect
 - Different resolution
 - Different ...



Airborne data

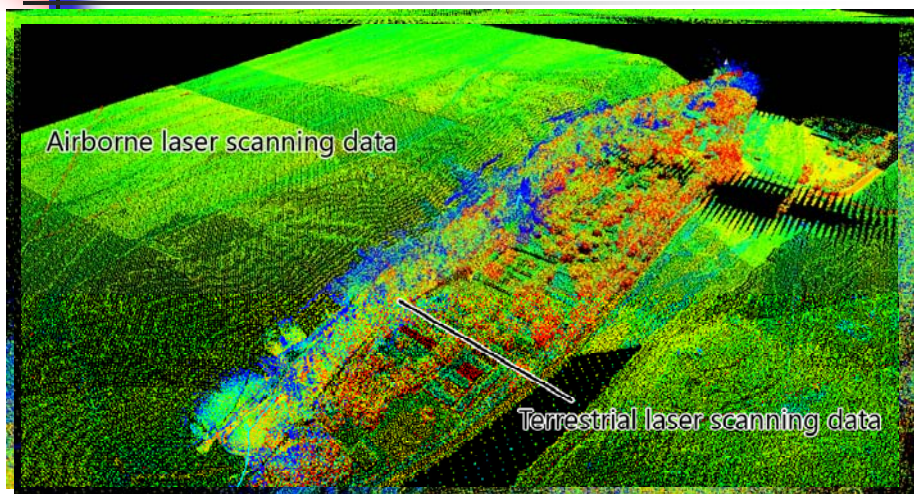


Facade – terrestrial data



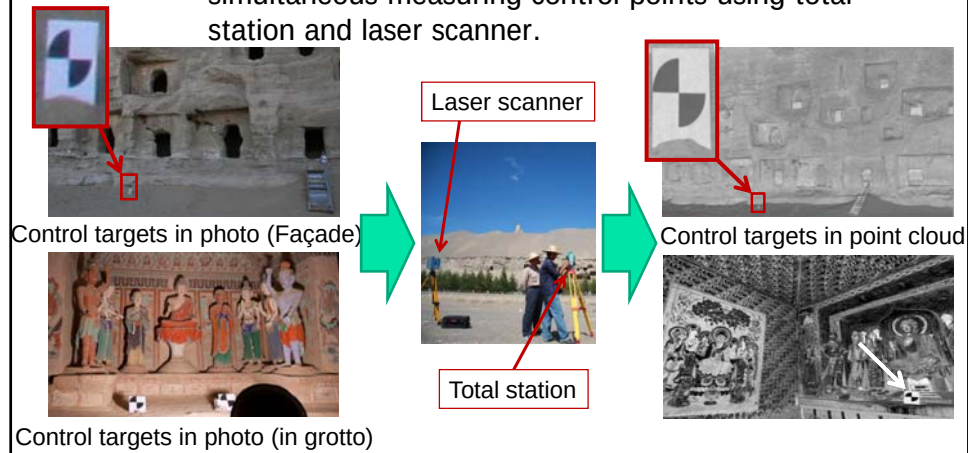
Inner grotto – terrestrial data

- Integration - Primitive registrator results
- Point cloud data: 20G, LAS format

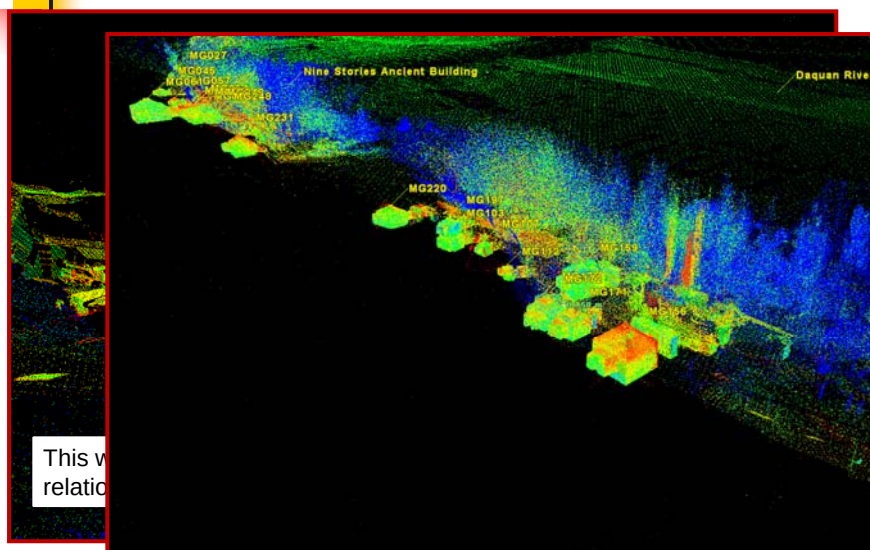


3. Integration and Visualization

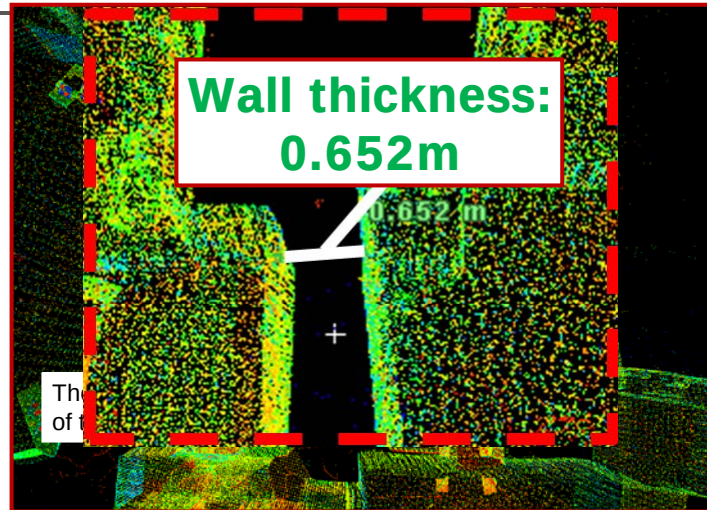
- ALS point cloud and TLS point cloud are integrated by the uniform world coordinates of control points.
- Point cloud of façade and inner caves are registered by simultaneous measuring control points using total station and laser scanner.



3. Integration and Visualization



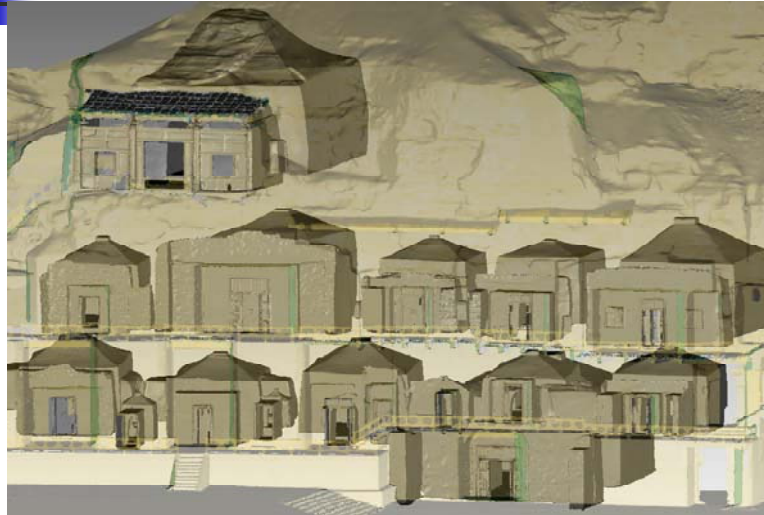
3. Integration and Visualization



3D scene of Mogao Grottoes and surrounding area



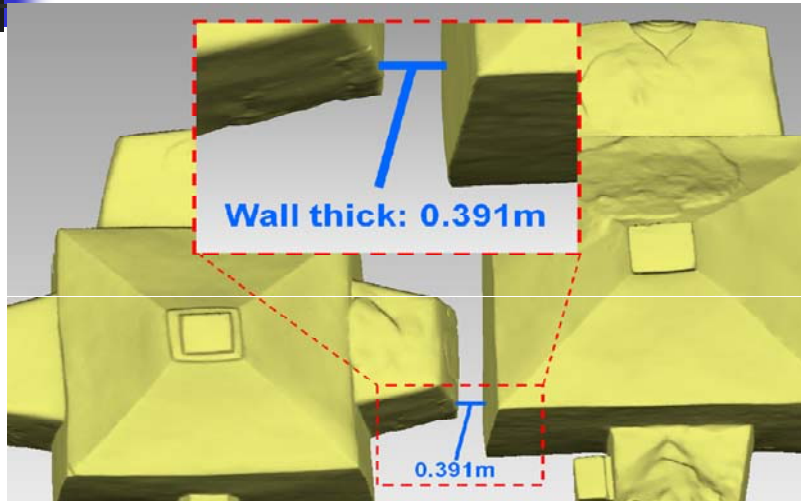
caves and translucent façade



The textured model of cave no. 285

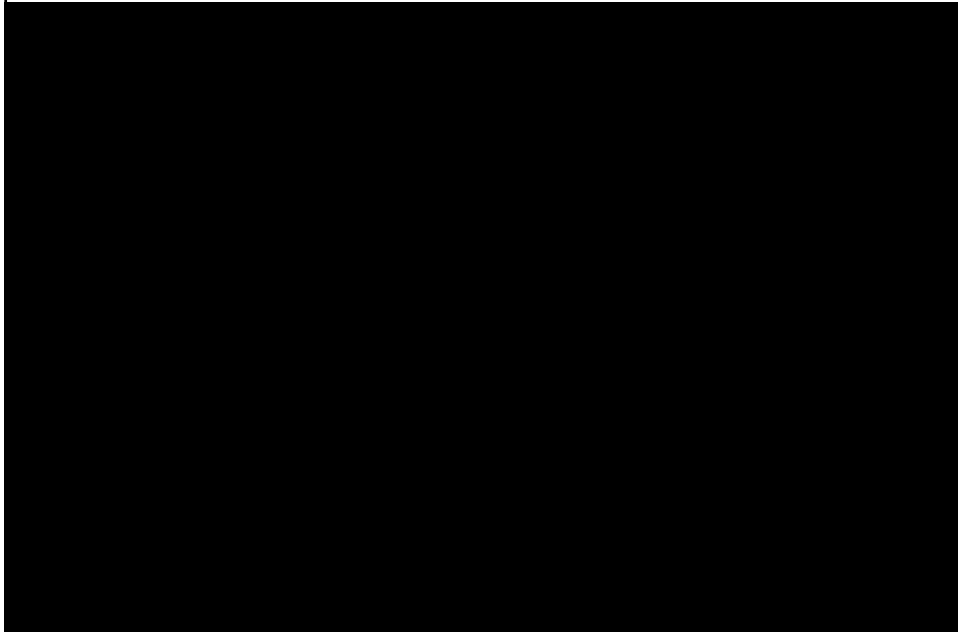


The thinnest cave wall is determined only 0.391m thick



Integration of Airborne and Terrestrial LiDAR for Mogao Cave

Augmented Mogao Grottos



4. Conclusions

- With the well development of Laser Scanning, Digital Photogrammetry, Virtual Reality and 3D GIS, it is possible to build up a digital cultural heritage.
- Based on the multidimensional information about the cultural heritage in levels of detail, database management system will offer convenient information inquiring and searching.
- An on-line tourism can be set up to replace the real one for better and all-sided view in order to reduce the overloaded tourism.
- Totally, Digital Cultural Heritage is the most effective way in researching, protecting and utilizing of the cultural heritage.



■ We will do:

■ Virtual Reality

- More completed data acquiring
- More accurate modeling
- More convenient and mature workflow



■ We will do:

■ Augmented Reality

- Color restoration and inversion based on elements of pigments analysis
- Virtual restoration for mural and statue
- Buddhist history presentation



■ We will do:

■ Interactive Reality

- More effective and vivid visualization
- Individuation interactive visualization
- Self-adapting multi-modal visualization



Interactive
visualization



Individuation visualization

Thank you for your attention!

