## FIG Working Week 2007, Hong Kong

## Use of 3D Laser Scanner for Rock Fractures Mapping


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Evolution of Indirect Capturing Method of X, Y and Z Coordinates:

1. Theodolite
2. EDM
3. Total Station
4. Laser Scanner
5. Terrestrial Photos taken from laser scanner integrated with camera

No color pixel

1 M color pixel per image taken

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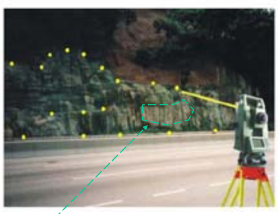
## Why Laser Scanning?

**Conventional Methods:**

- Accurate, but limited to selected locations.

**Laser Scanning:**

- Acquire several millions of 3D points over an entire structure.
- Provide a complete representation of the structure.



Mapping of rock fracture plane

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Software available for Integration of Scanning and Photogrammetric Process:

1. Cyclone
2. Arc GIS
3. Reverse Engineering (Reconstructor)
4. Rock Fracture Mapping (HKU)
5. AutoCAD 3D Studio Max

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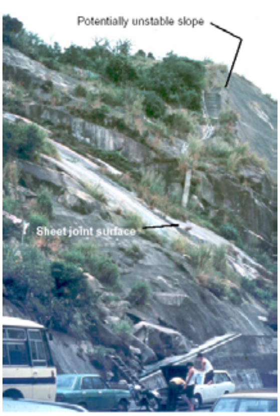


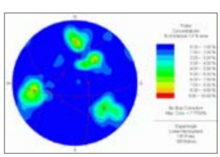

**Non-contact Mapping of Rock Joint Without Scaffolding**

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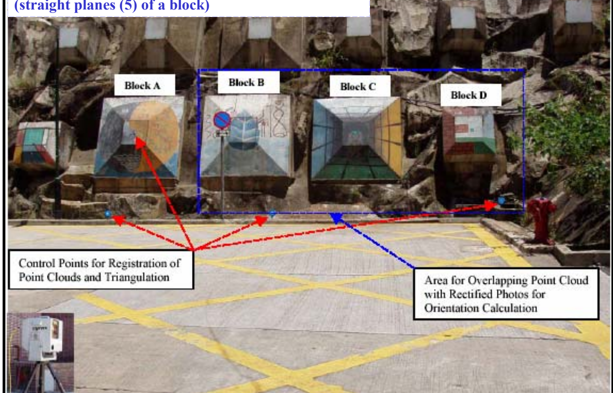
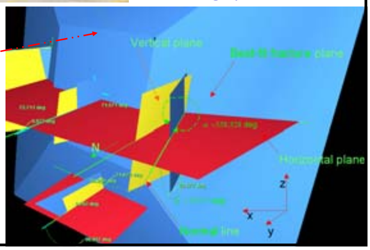
**First to test the methodology and accuracy of orientation of objects that have a planar structure (straight planes (5) of a block)**

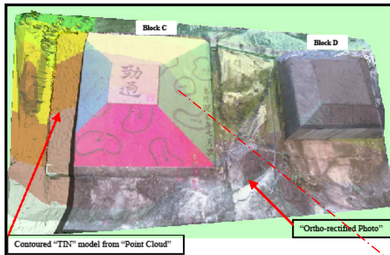


## Applications to Measuring Fracture Planes Orientation and Dimensions

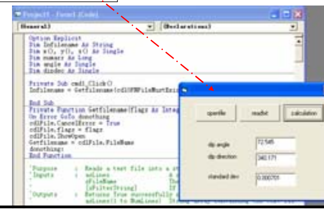

Modeling of Point Cloud using Cyclone Software

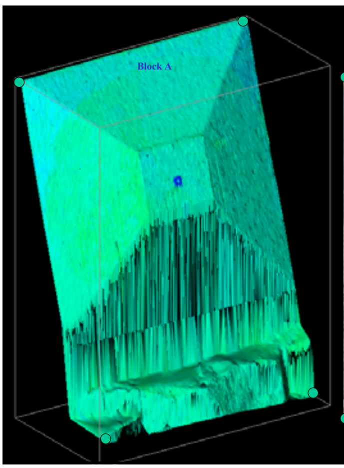
Close-up View of a Block



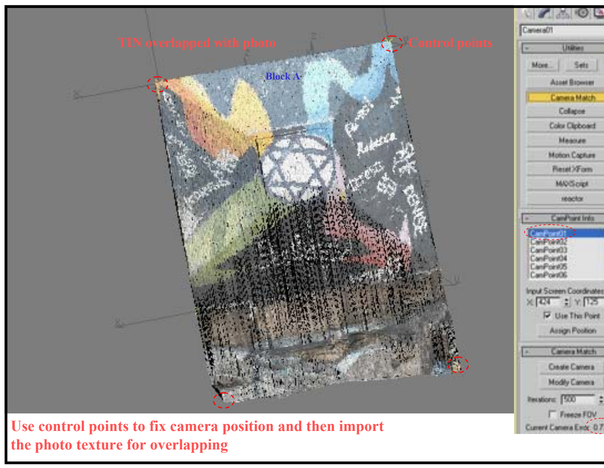

Modeling of Point Cloud using GIS Software



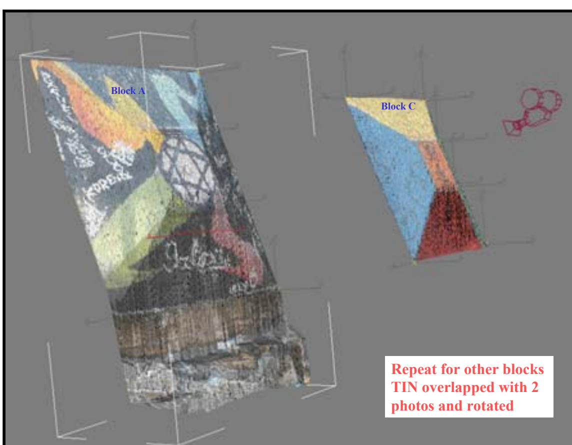



Modeling of Point Cloud in 3D Studio Max for Multiple Objects

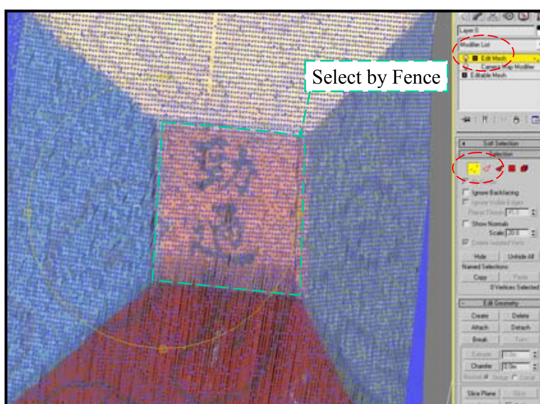

Identify common control points in Photo and in the TIN



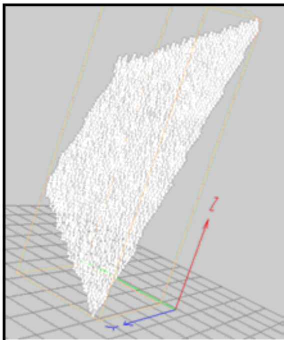

Use control points to fix camera position and then import the photo texture for overlapping



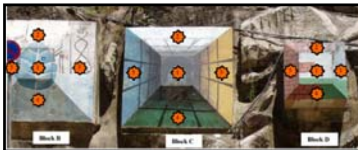

Repeat for other blocks TIN overlapped with 2 photos and rotated




Extract points correctly from points based on the photo texture in the front layer



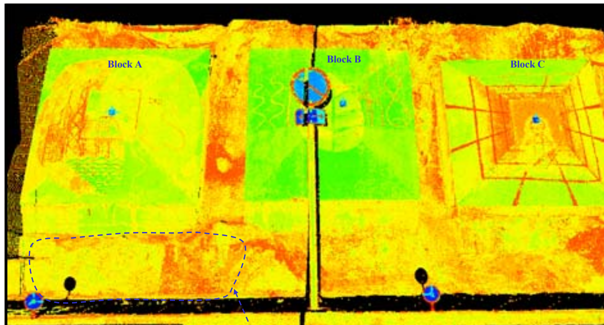
Points exported for calculations

Comparisons of measured and calculated Dip Angle and Dip Direction

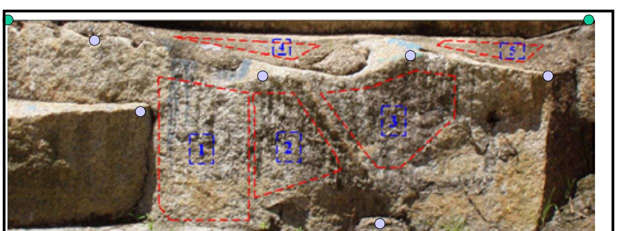
| Anchor Block (a) | Face (b) | Multivariate Regression Analysis based on Point Cloud (c) | | Hand Held Compass (d) | | Difference (e)=(d)-(c) (e)=[(d)-(c)]/(d)*100% | |
|---|---|---|---|---|---|---|---|
| | | Dip Angle | Dip Direction | Dip Angle | Dip Direction | Dip Angle | Dip Direction |
| B | 1 | 73.0° | 358.8° | 74° | 359° | 1.0°<br>1.4% | 0.2°<br>0.1% |
| | 2 | 53.7° | 0.0° | 52° | 359° | -1.7°<br>-3.3% | -1.0°<br>0.3% |
| | 3 | 73.4° | 340.4° | 74° | 339° | 0.6°<br>0.8% | -1.4°<br>-0.4% |
| | 4 | 89.2° | 359.0° | 89° | 359° | -0.2°<br>-0.2% | 0.0°<br>0.0% |
| | 5 | 72.7° | 18.7° | 74° | 19° | 1.3°<br>1.8% | 0.3°<br>1.6% |
| C | 1 | 69.8° | 0.0° | 71° | 0° | 1.2°<br>1.7% | 0.0°<br>0.0% |
| | 2 | 51.8° | 359.7° | 51° | 0° | -0.8°<br>-1.6% | 0.3°<br>0.1% |
| | 3 | 71.3° | 339.8° | 72° | 339° | 0.7°<br>1.0% | -0.8°<br>-0.2% |

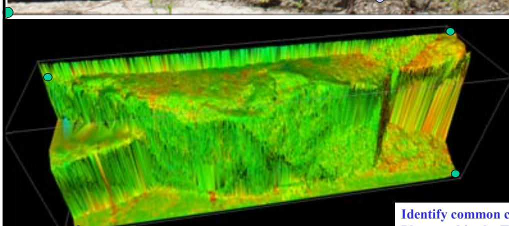

**Second is to test the methodology and accuracy of a rock jointed block**




**Rock Planes in this Study**

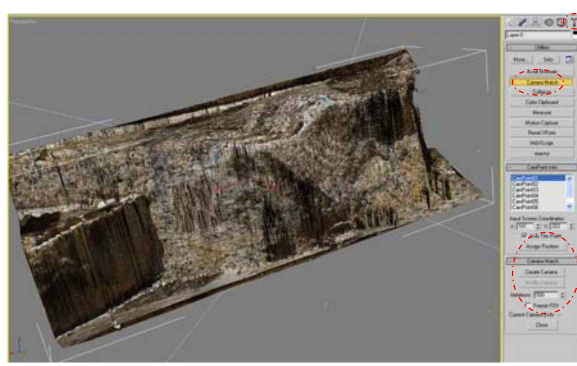
Point Cloud after registration



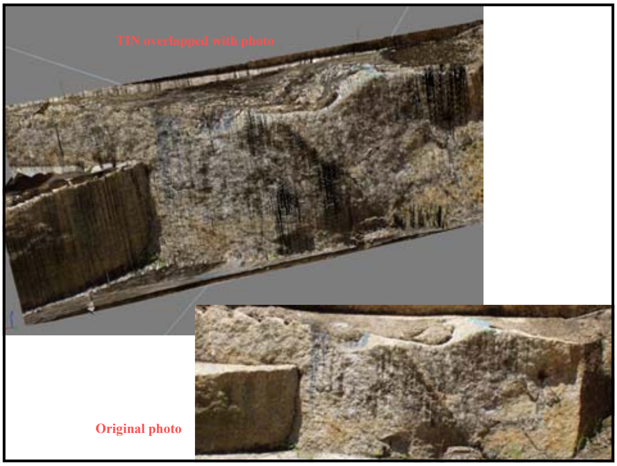



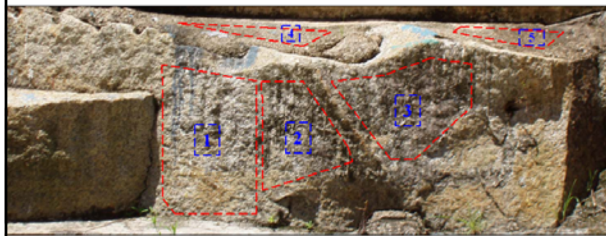
**Control Points**

**Identify common control points in Photo and in the TIN**

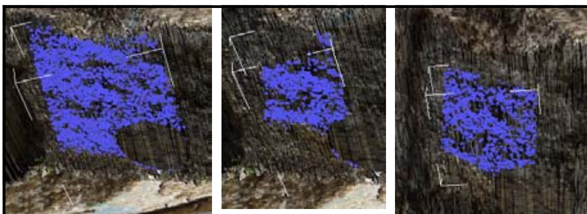


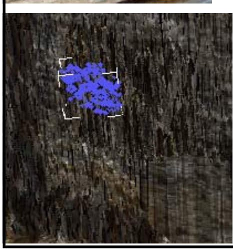
Use "Camera Match", assign the CamPoint position and adjust the Camera Coordinates until the Error is less than 1.



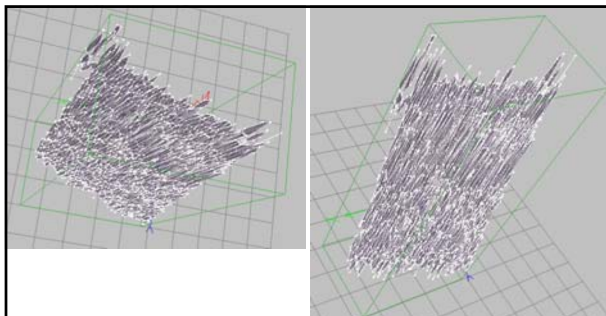




5 Joint Planes
within a block

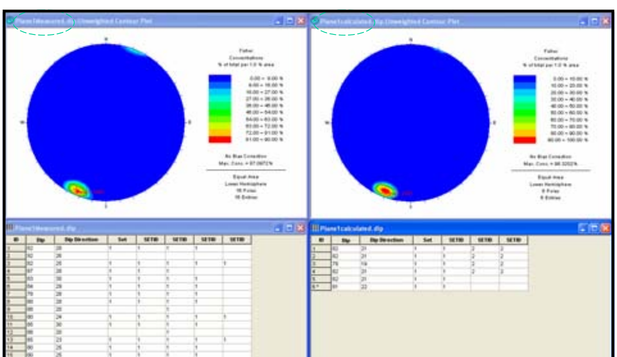




Extract points from
Joint Plane 1



Plane 1 extracted for Calculations (Dip Direction and Dip Angle)



Comparisons of Measured and Calculated Dip Angle and Dip Direction

Magnetic Declination = 2.17 degree West

## Comparisons of 5 Joint Plane Orientations (compass versus calculated)

| | From compass | | From Linear Regression | | Difference (Compass-Linear Regression) | |
|---|---|---|---|---|---|---|
| Plane | Dip Direction | Dip Angle | Dip Direction | Dip Angle | Dip Direction | Dip Angle |
| | Degree | Degree | Degree | Degree | Degree | Degree |
| 1 | 24 | 82 | 21 | 81 | 3 | 1 |
| 2 | 9 | 85 | 7 | 83 | 2 | 2 |
| 3 | 344 | 75 | 340 | 71 | 4 | 4 |
| 4 | 356 | 6 | 355 | 7 | 1 | -1 |
| 5 | 349 | 15 | 345 | 14 | 4 | 1 |

About 3 degree
differences due to
scale effect

## Computation of Dip Angle and Dip Direction

Equation of a best-fit plane

$$z = b_0 + b_1 x + b_2 y$$

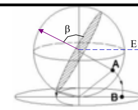
Method of Least Square

$$\min \varepsilon^2 = \sum \left[z_i - \left(b_0 + b_1 x_i + b_2 y_i\right)\right]^2$$

Solve the matrix using Gaussian Elimination

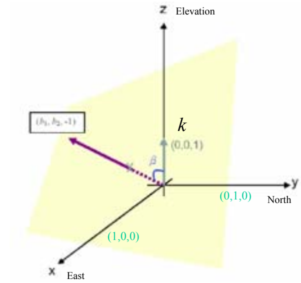
$$\begin{bmatrix} n & \sum_{i=1}^{n} x_i & \sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_i & \sum_{i=1}^{n} x_i^2 & \sum_{i=1}^{n} x_i y_i \\ \sum_{i=1}^{n} y_i & \sum_{i=1}^{n} x_i y_i & \sum_{i=1}^{n} y_i^2 \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} z_i \\ \sum_{i=1}^{n} x_i z_i \\ \sum_{i=1}^{n} y_i z_i \end{bmatrix}$$

## Determination of Dip Angle β based on Unit Vector

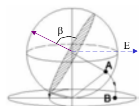



$$k \cdot n = |k||n| \cos \beta$$

$$\beta = \cos^{-1}\left|\frac{1}{\sqrt{b_1^2 + b_2^2 + 1}}\right|$$

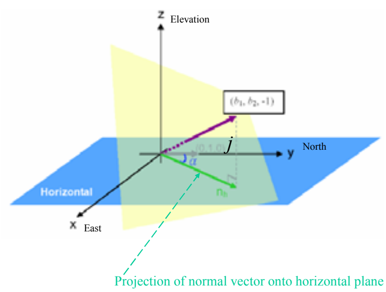



## Determination of Dip Direction α based on Unit Vector

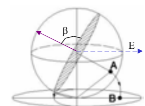



$$j \cdot n_h = |j||n_h| \cos \alpha$$

$$\alpha = \cos^{-1}\left|\frac{b_2}{\sqrt{b_1^2 + b_2^2}}\right|$$




## Determination of Dip Direction α relative to North

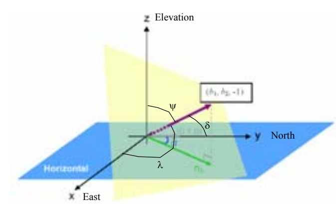


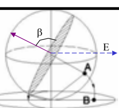

- Normal vector could rest on any of the 4 quadrants
- Determine the direction cosine of the normal vector

$$\cos \lambda = \frac{b_1}{\pm\sqrt{b_1^2 + b_2^2 + 1^2}}$$

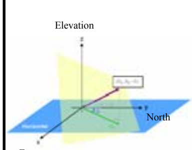
$$\cos \delta = \frac{b_2}{\pm\sqrt{b_1^2 + b_2^2 + 1^2}}$$

$$\cos \psi = \frac{-1}{\pm\sqrt{b_1^2 + b_2^2 + 1^2}}$$




## Determination of Dip Direction α relative to North




| Conditions | Normal Vector | Quadrant | Dip Direction |
|---|---|---|---|
| $\cos\lambda \ge 0, \cos\delta \ge 0 \; and \; \cos\psi \ge 0$ | Upward | North East | α |
| $\cos\lambda \ge 0, \cos\delta < 0 \; and \; \cos\psi \ge 0$ | Upward | South East | 180°- α |
| $\cos\lambda < 0, \cos\delta < 0 \; and \; \cos\psi \ge 0$ | Upward | South West | 180°+ α |
| $\cos\lambda < 0, \cos\delta \ge 0 \; and \; \cos\psi \ge 0$ | Upward | North West | 360°- α |
| $\cos\lambda \ge 0, \cos\delta \ge 0 \; and \; \cos\psi < 0$ | Downward | North East | α |
| $\cos\lambda \ge 0, \cos\delta < 0 \; and \; \cos\psi < 0$ | Downward | South East | 180°- α |
| $\cos\lambda < 0, \cos\delta < 0 \; and \; \cos\psi < 0$ | Downward | South West | 180°+ α |
| $\cos\lambda < 0, \cos\delta \ge 0 \; and \; \cos\psi < 0$ | Downward | North West | 360°- α |

Feng (2004)

## Correlation Coefficient, $R^2$, to determine how close a best-fit plane to the selected points

$$R^2 = \frac{\left[\sum\left(z_i - \bar{z}\right)\left(\hat{z}_i - \bar{\hat{z}}\right)\right]^2}{\sum\left(z_i - \bar{z}\right)^2 \sum\left(\hat{z}_i - \bar{\hat{z}}\right)^2}$$

$$\hat{z}_i = b_0 + b_1\left(x_i - \bar{x}\right) + b_2\left(y_i - \bar{y}\right)$$

Summary:

1. Overcome the limitation of photo texture offered in 3D laser scanning program.
2. The use of 3D graphical software can merge more than 1 photo accurately onto a mesh, thus overcomes the limitation of GIS program.
3. Results show a good comparison between measurements from compass and calculation based on linear regression of a plane.  Expect 3-5 degree difference due to scaling effect.
4. Mapping of rock joint plane orientation can be accurately calculated without accessing the rock face.
5. Improving efficiency, cost and safety to mapping practice.
6. Methodology commonly applicable to other engineering applications, e.g., as-built drawing, 3D CAD modeling, archeology, restoration of history buildings etc.