FIG Working Week Athens, 22 – 27 May 2004

Terrestrial Laser Scanning – Investigations and Applications for High Precision Scanning

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- **Short introduction to laser scanning**
- **Investigation of laser scanners**
  - Trunnion axis error
  - Distance measurement system
- **Application of terrestrial laser scanners**
  - Chapel of „Neubrueck“ (cultural heritage)
  - „Muehlebach“ – Tunnel (high precision scanning)
- **Conclusion**

Short introduction to laser scanning (1)

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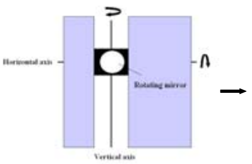
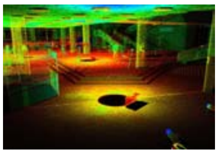
Concept of Zoller+Froehlich laser scanner (Imager 5003)

- Laser beam is deflected by a fast rotating mirror
- 360° scan is possible (full view scan)
- "Panorama Scanner" (opposite: "Camera Scanner")

→ Result is a 3D point cloud





Laser scanner "Imager 5003" (2)

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Phase distance measurement system

- First laser scanner with the principle of the phase measurement system
- Carrier wave (λ = 780 nm)
- Signals are simultaneously bi-modulated with a sinusoidal signal on a coarse and a fine frequency:
  - 2 coarse frequencies to determine ambiguities
    Up to 25.2 m (λ ~ 54 m) : Measurement mode „close“
    Up to 53.5 m (λ ~ 108 m): Measurement mode „far“
  - 1 fine frequency (λ ~ 6.7 m) for accurate measurements

Laser scanner "Imager 5003" (3)

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Scan modes: "scanning" + static

Four different "scanning" modes

(specifications in the table relate to a full view scan)

Scan mode	File size* [MB]	Number of Pixels [mill.]	Scan time [s]
Super high	1011	202	404
High	253	50	202
Middle	63	13	101
Preview	4	1	25

* file size is based on the binary uncompressed ZFS-format

Trunnion axis error (1)

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Instrumental error

→ Laser scanner used as a geodetic instrument like a total station

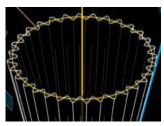
Experimental setup

- Leica Nivel 20 was fixed on the scanner
- Scanner was rotated around the vertical axis
- Measuring the inclination in two orthogonal directions at each position
- Deriving the trunnion axis error (t) from the inclinometer values (x,y)

$s_i = \sqrt{x_i^2 + y_i^2}$ **s – current vertical axis error**

$v = \frac{1}{n}\sum_{i=1}^{n} s_i$ **v – mean vertical axis error**

$t_i = v - s_i$ **t – trunnion axis error at position i**



Trunnion axis error (2)

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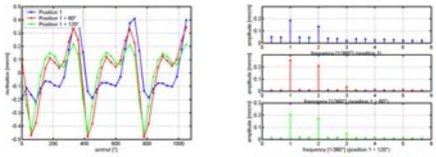
Modeling the trunnion axis error as a harmonic oscillation

→ **Fourier Transformation** shows the parameters
- Amplitude, phase angle, frequency and trend (the trend corresponds to the vertical axis error)
- Frequency with highest amplitude represents trunnion axis error

Three data series were measured with a shifted start angle of 60°



Trunnion axis error (3)

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Results:

- Vertical axis error approximately constant
- Amplitude not constant
- Phase angles do not correlate with shift angle (60°) and are not constant
- Influence in a distance of 60 m approx. 1 cm

Assumption: Influence of the “unbalanced system” causes deformation of the tribrach

5kg

For verifying this assumption the investigation was repeated.

→ **The scanner was mounted on a solidly built table (granite table).**

Trunnion axis error (4)

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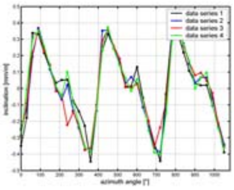
Results of new investigations:

- Vertical axis errors are constant
- Amplitudes are constant
- Phase angles are constant
- Influence in a distance of 60 m: also approximately 1 cm

→ Trunnion axis error only reproducible (until now):

if this “unbalanced” scanner is mounted on a **stable “surrounding”**



Distance accuracy (1)

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Experimental setup

- Accuracy of the phase measurement system was analysed on the 52 m interferometric test line at the IGP lab according to the distance range of the scanner
- Tests were carried out both in static mode and in scanning mode
  - On a white target with a black scale (static mode)
  - On calibrated spheres with well known diameters (scanning mode)

Distance accuracy (2)

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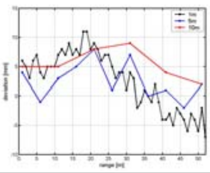
Results of the tests (static mode):

- Deviations lie within 10 mm over the whole length
- Conceivable systematic effects of the distance measurement system:
  - Addition constant
  - Scale factor, but not uniformly (positive and negative)
  - “Look up table” maybe erroneous



Distance accuracy (3)

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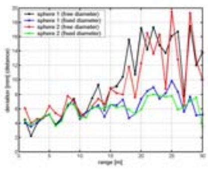
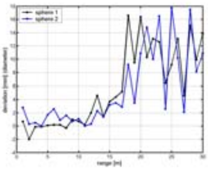
Results of the tests (scanning mode “super high”):

- Spheres (diameters: 12cm and 15cm) are well observable up to max. 15m
  - Deviations in distances within 10mm
  - Deviations in diameters within 2mm
- Distances to spheres with “fixed” diameter better than with “free” diameter
- Addition konstant of approx. 4mm





Chapel “Neubrueck” (1)

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Cultural heritage

- **Location**
  “Vispertal“, Valais – Switzerland,
- **Problems**
  - Difficult area around the chapel (road, railway, river)
  - ➡ Limited choice of view points



Chapel “Neubrueck” (2)

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Scanning principle and results

- 5 view points: 4 sides and the interior
- Minimum number of 3 control points in each scan
- Separate scans of chapel and spheres from each view point
- Resolution of the scans: middle (chapel) & super high (spheres)
- Registering the scans by using control points
- Creating a 3D-Model including texture mapping


“Muehlebach” – Tunnel (1)

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High precision scanning

- **Location**
  “Mattertal“, Valais – Switzerland
- **Problems**
  Linear object: small angles between tunnel surface and laser beam
  ➡ view points close to each other (max. 10m)

“Muehlebach” – Tunnel (2)

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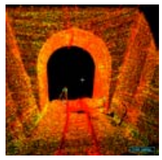
Scanning principle and results

- For each view point 360° scan of the tunnel (resolution “middle”) and fine scan of the spheres (resolution “super high”)
- Registration of scans by using control points





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- Laser scanning is a promising technology
- For high precision applications the accuracy and the behaviour of the instrument have to be investigated (such as instrumental and methodological errors, distance accuracy,…)
- Planning the view points and control points is important for a successful project
- Scanning takes not as much time as the traditional technologies (except photogrammetry)
- Results are high detailed scans with huge point clouds and a lot of information
- “Post processing” work (creating a 3D-Model) can be quite intensive (ratio between scanning and modeling extends up to 1:10)

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Thank you
for your attention

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Zoller+Froehlich

Scan-File (binary format) <*.zfs>

↓

Zoller+Froehlich → HDS, Leica-Geosystems

ASCII-File <*.pts>

↓

HDS, Leica-Geosystems

Software Cyclone

Date series	Frequenzy 1		Frequenzy 1		Vertical axis error
	Amplitude [mm/m]	Phase angle [°]	Amplitude [mm/m]	Phase angle [°]	[mm/m]
1	0.21	119	0.15	126	1.24
1 + 60°	0.26	177	0.21	131	1.27
1 + 120°	0.20	199	0.17	139	1.26
2	0.26	317	0.18	291	0.47
2a	0.28	321	0.17	292	0.42
2b	0.27	324	0.14	289	0.42
2c	0.27	319	0.17	293	0.43