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Spatial Approximation of Terrestrial Laser Scanner Profiles by Considering Observations with Stochastic Information

XXV FIG Congress, Kuala Lumpur, Malaysia, 18th June 2014

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- Uncertainty modelling using a Monte Carlo approach
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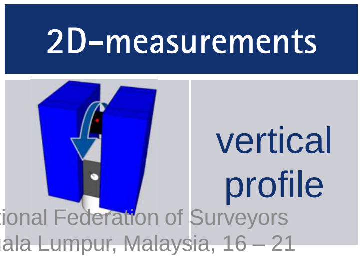
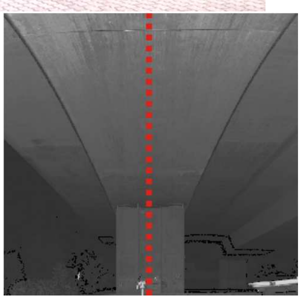
Relevance and objectives

- Structural health monitoring is a key issue, age and traffic are increasing
- Monitoring of bridges to evaluate life cycles
- Kinematic laserscanning (k-TLS) detect geometry changes over time
- Profile-wise acquisition of the bridge deflection
- No interference in the traffic



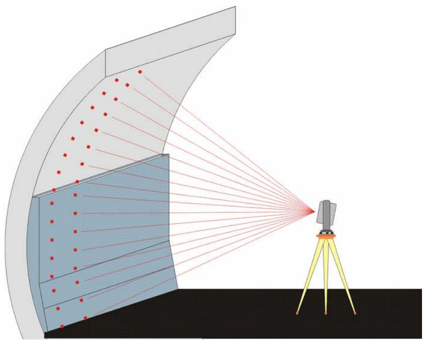


Aim:

i) Modelling of measurement uncertainties

ii) Study influence on deformation estimation

Characterization of TLS



Observation properties

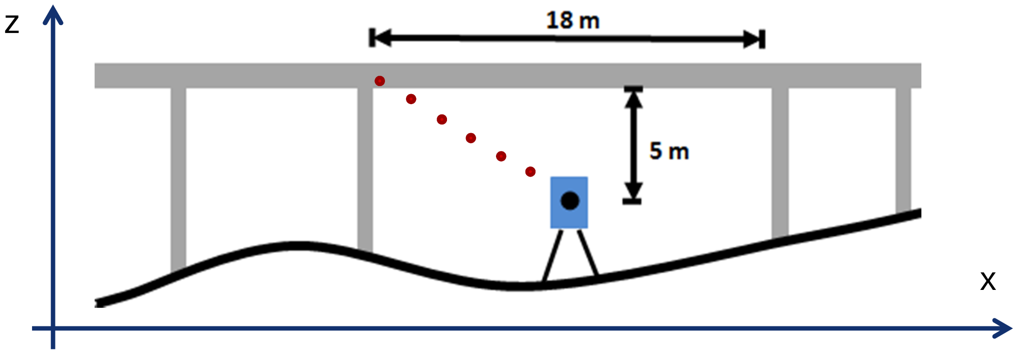
- Polar measurements (φ, λ, s → X ,Y, Z)
- Very fast measurements
- High spatial resolution

- Rapid
- High data rates

Z+F Imager 5006
- 500 kHz data rate
- 360°x 270° FOV
- 79 m cover. range
- 1-3 mm precision

- On (mostly) arbitrary surfaces
- Immanently related to surfaces but not single points (!)

Adjustment model



Modelling in a Gauß-Markov- model (Schmitt et al. 2013)

- Approximation of profile data at discrete positions
- Estimation of the profile by using B-splines in a least squares adjustment
- **Functional model:**
  - Observations: z-coordinates
  - Error-free nodes: x-coordinates
  - Unknown: control points P

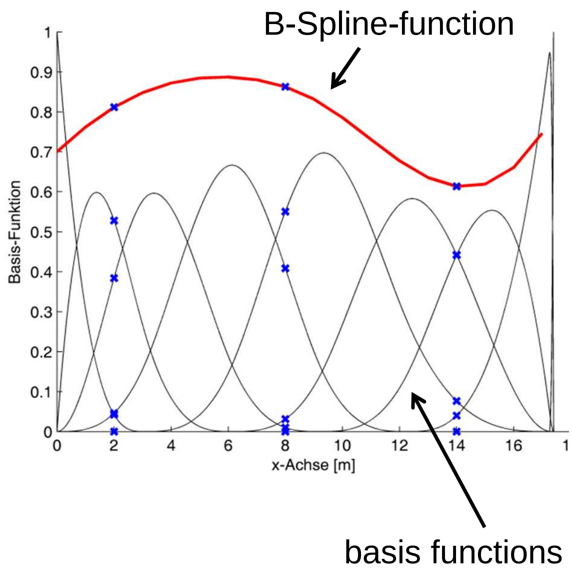
$$f(x_k) = C(x_k) = \sum_{i=0}^{n} N_{i,p}(x_k) \cdot P_i$$

- **Stochastic model:** observations have unequal weights; no correlation: Classical and Monte Carlo uncertainty modelling

Adjustment model

Basis Splines (B-Splines)

- Consist of polynomial-segments (basis functions)
- For every basis function belongs one control point (scale factor)
- B-spline-function is the sum of the individual basis functions



$$C(uk_h) = \sum_{i=1}^{n+1} N_{i,p}(uk_h) P_i$$
$$U\{0_{1,\dots,p+1}, a_{p+2}, \dots, a_{m-p-2}, 1_{m-p-1,\dots,m}\}$$

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Uncertainty modelling

Mathematical backgrounds for uncertainty

- Approximation theory
- Stochastics: classical GUM
- Bayes theory: Monte Carlo
- Dempster-Shafer theory
- Interval mathematics
- Fuzzy theory

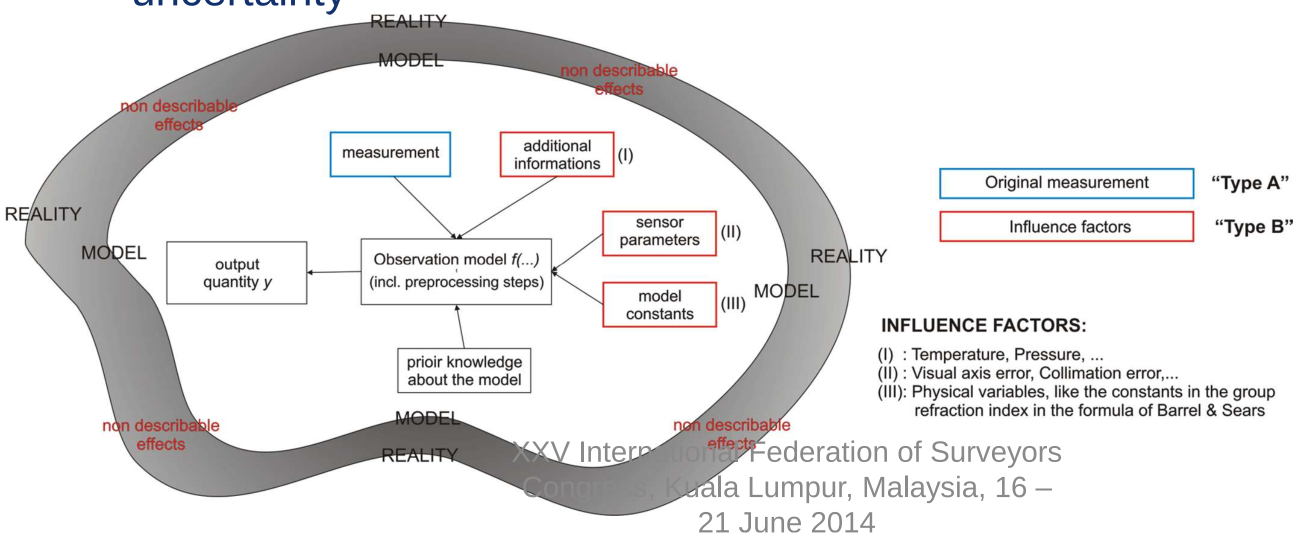
Tasks
- Estimation
- Filtering
- Prediction
- Testing

Modeling, treatment, propagation of uncertainty

Tools?

Uncertainty modelling

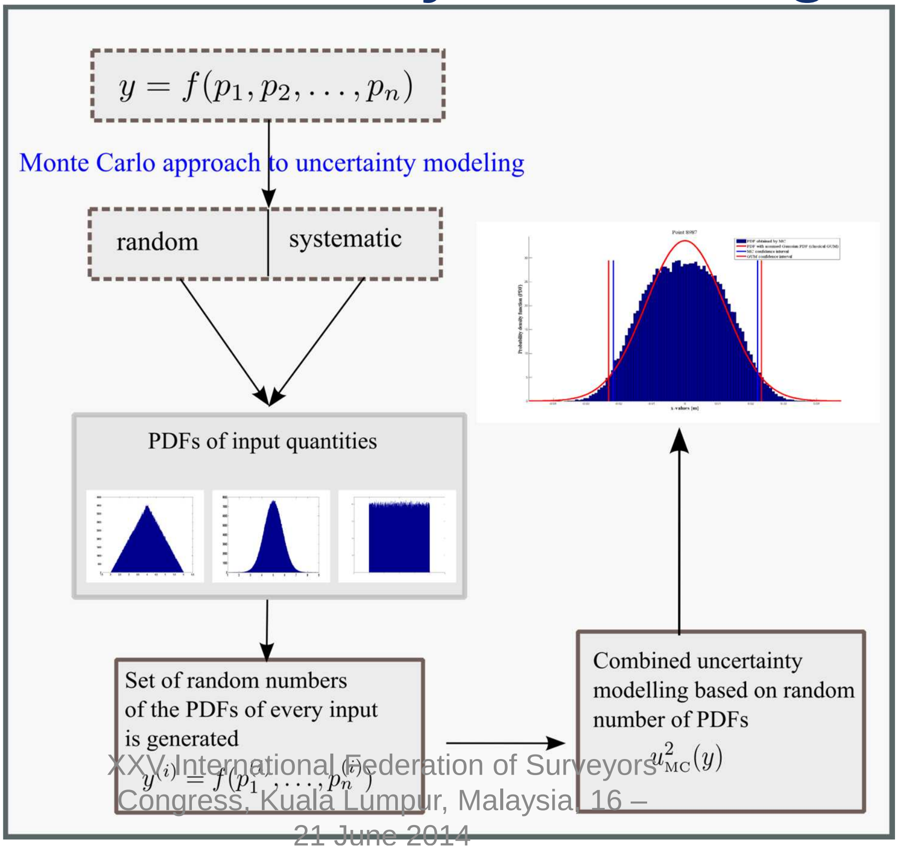
- Uncertainties come from the data or the measurements, statistical evaluation of the model and from the model
- The "Guide to the Expression of Uncertainty in Measurements (GUM)" is a standard reference in uncertainty



Uncertainty modelling

Monte-Carlo

1. Modeling of uncertainty for input quantities
2. Choice of pdf
3. Evaluating uncertainty for output quantities



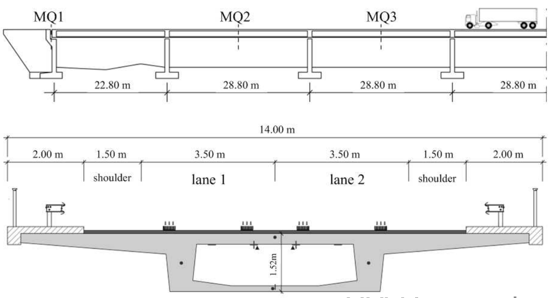
Object and setup

Bridge near Hanover in northern Germany

Interdisciplinary project based on “Application of life cycle concepts to civil engineering structures”

Experiment: deformations due to defined traffic loads

- Static loads in four positions, dynamic loads
- Monitoring in all spatial modes: 3D / 2D / 1D
- Fixed scanner position



Scanner in use: Z+F Imager 5006

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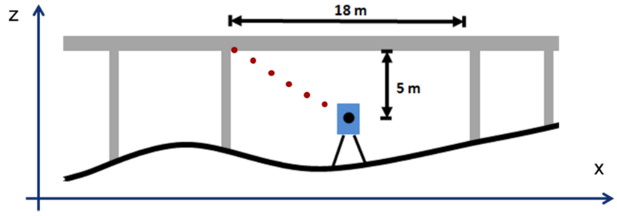
Object and setup

MC-simulation of 2D k-TLS profile observations

Unloaded state:

3000 profiles
14000 pts/profile



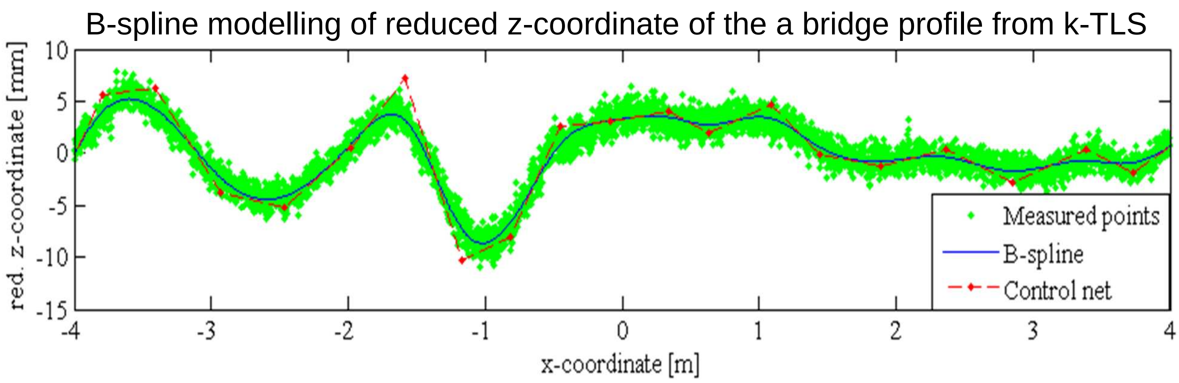
Approach: Reproduction of the situation by:

- identical geometrical configuration
- identical repetition rate
- randomly varying observation values (MC-simulation)
  - Distance: constant metric component (Z1)
  - Distance: distance proportional component (Z2)
  - Zenith angle: constant angular component (Z3)
  - Vertical resolution for the zenith angle (the step width of the motor) (Z4)

100.000 samples per random quantity

Results

The parameters of the B-spline for the approximation are chosen as three for the degree and 21 for the number of control points.



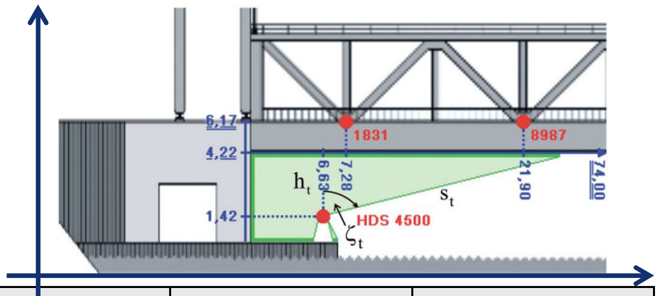
$$C(uk_h) = \sum_{i=1}^{n+1} N_{i,p}(uk_h)P_i$$

$$U\{0_{1,\dots,p+1}, a_{p+2}, \dots, a_{m-p-2}, 1_{m-p-1,\dots,m}\}$$

Results

MC-simulation input-output parameter (Alkhatib & Kutterer, 2013)

$z = s_t \cos\zeta$ and $x = s_t \sin\zeta$



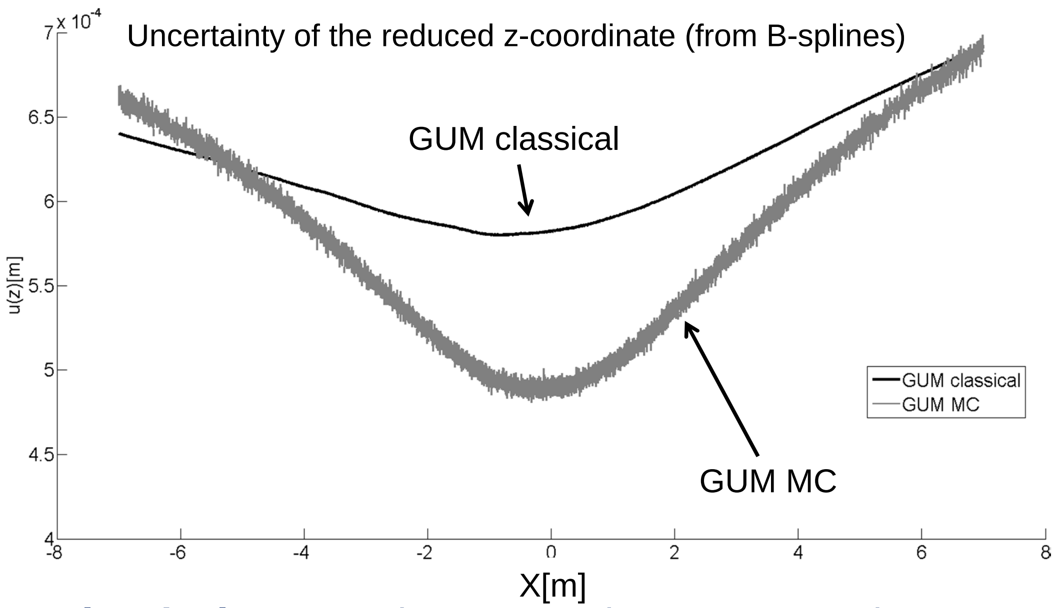
Input quantity	Error component	Power density function	PDF Type	Num. value (std. dev.)
Distance: constant	random	$N(m_{Z_1}, {\sigma_{Z_1}}^2)$	Normal	0.3 mm
Distance: proportional	systematic	$N(m_{Z_1}, {\sigma_{Z_1}}^2)$	Normal	30 ppm
Zenith angle	random	$N(m_{Z_3}, {\sigma_{Z_3}}^2)$	Normal	5 mgon
Vertical increment	random	$U(Z_{7l}, Z_{7u})$	Rectangular	10 mgon

$N(\mu, \sigma)$:= Normal distribution with expected value and std. dev.

$U(\mathrm{U}, \mathrm{L})$:= Uniform distribution with upper and lower range

Results

GUM classical & GUM MC

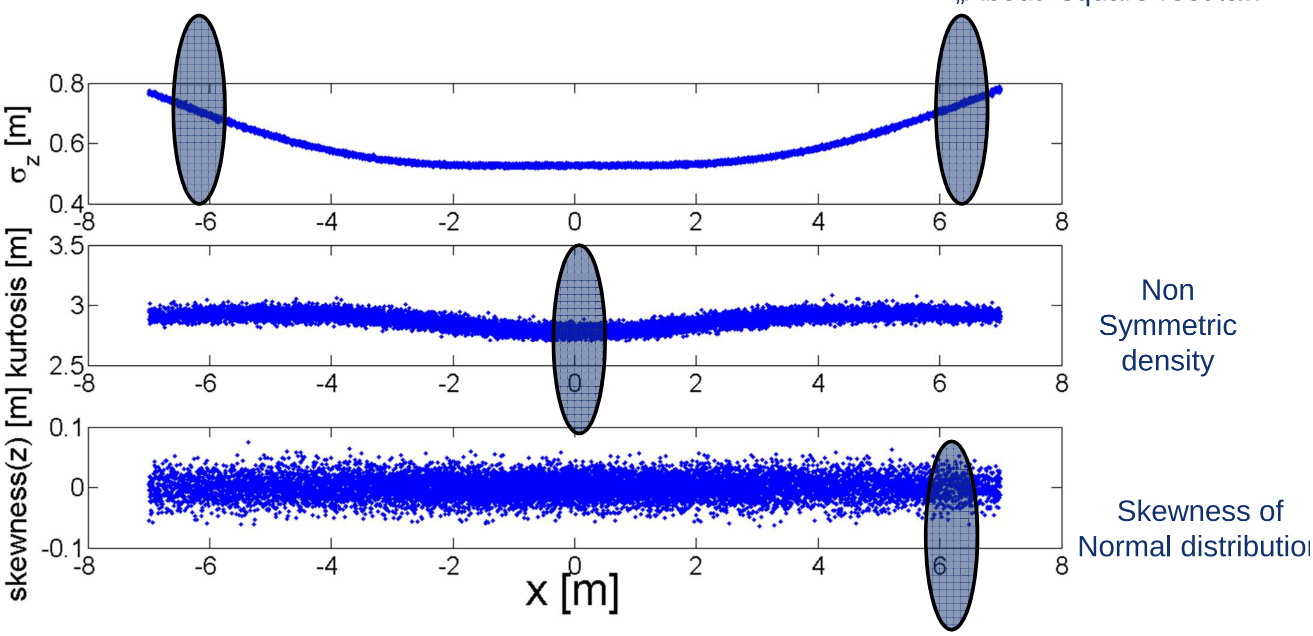


GUM Classical: Variance covariance propagation

GUM MC approach: 100.000 samples were drawn for each random quantity according to the table above

Results

Monte Carlo simulation

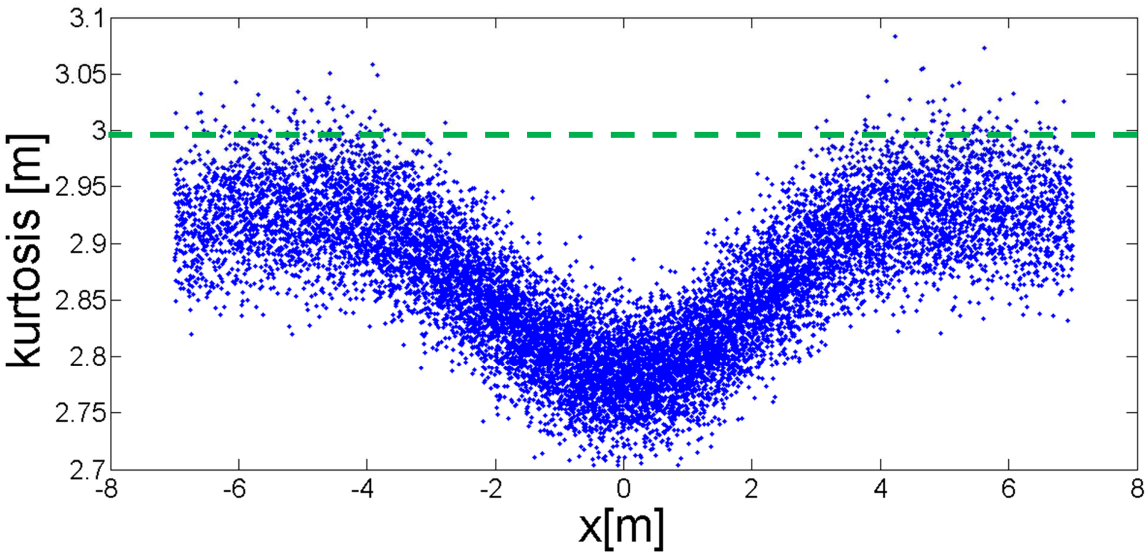


Comprehensive reproduction of the real-data results !

GIH

Results

Monte Carlo simulation



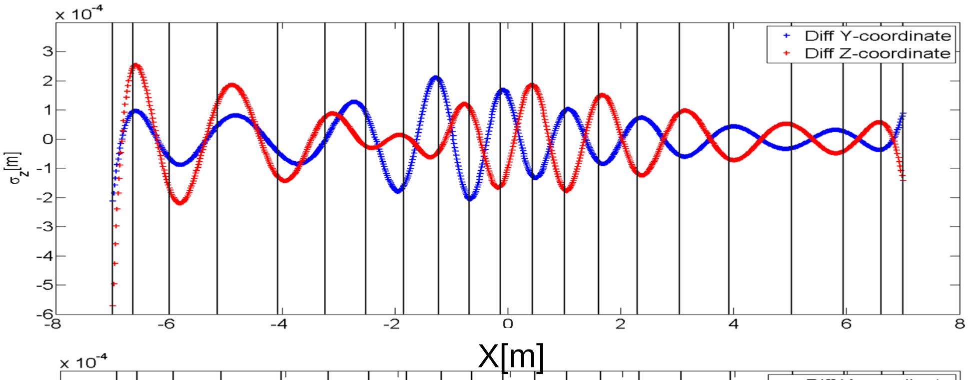
Evidence for non-normal random influences from:

i) the uniform distribution and the other from

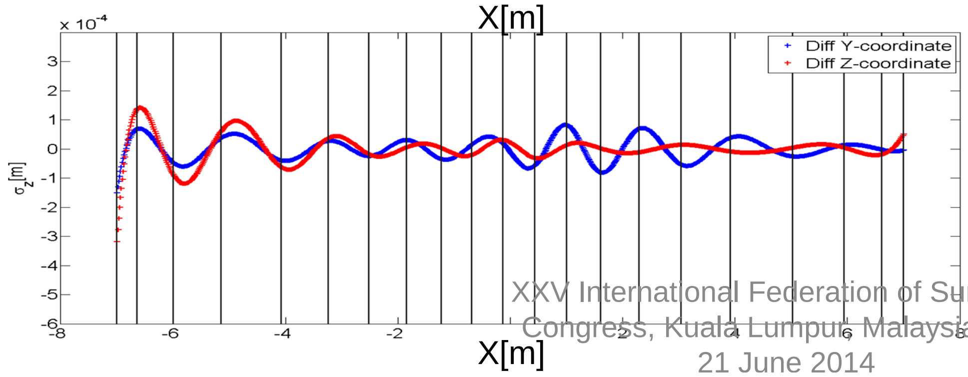
ii) the (non-linear) cosine and sine function

Results

Difference between estimated Y- and Z-coordinate for the approximated curves (B-Spline) with and without VCMs information



using classical GUM



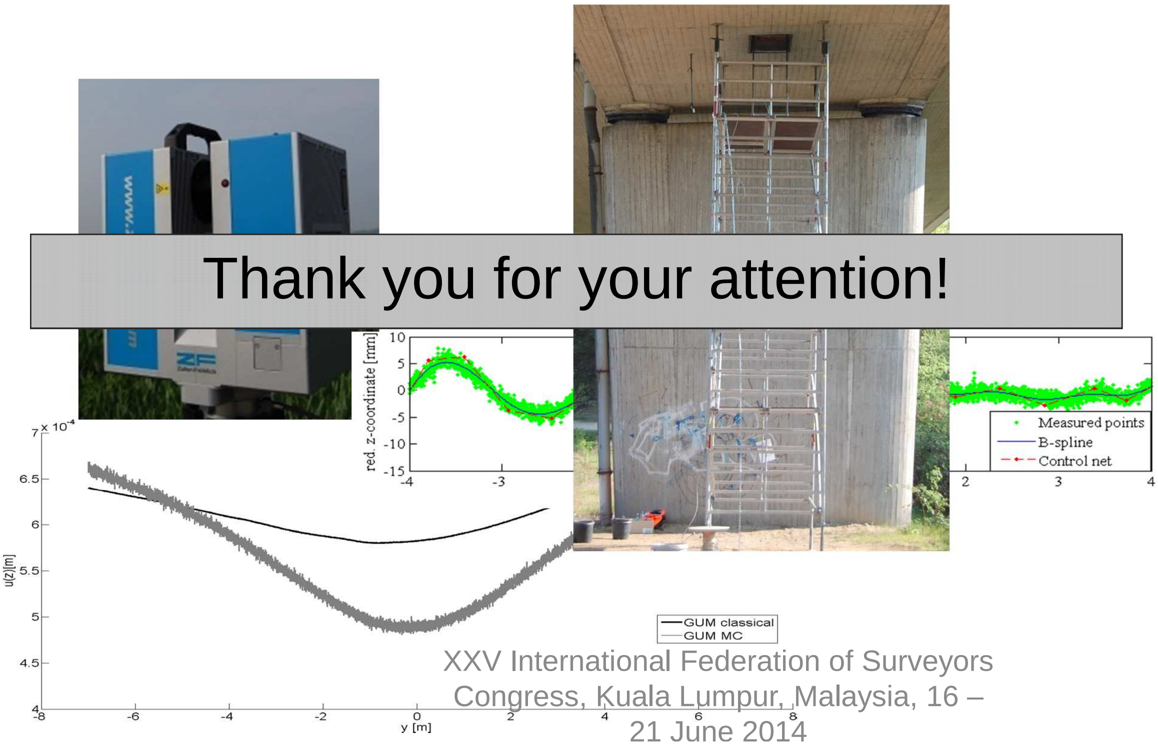
using MC GUM

Conclusions

- Measurement instrument with sufficient measuring rate and accuracy ➔ k-TLS
- Significant quality improvement by data approximation with B-spline curves.
- Simulation of observation processes is important for both pre-analysis and post-analysis.
  - Monte-Carlo techniques are effective and easy-to-implement.
  - An extended error model is required for a meaningful simulation.
- Real-data series give evidence for non-normal random influences.

→ A meaningful uncertainty modelling requires for k-TLS data a Monte Carlo approach (MC GUM)!

→ The estimated results are influenced by the uncertainty model.



Thank you for your attention!

Adjustment model

- The basis function is dependent on the used order p of the function.
- The multiplication of the design matrix $\mathbf{A}$ and the unknown control points $\mathbf{u}$ is equal to the curve C of the free form curve

$$C(\mathbf{x}) = \mathbf{A} \cdot \mathbf{u} \text{ mit } \mathbf{u} = \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_n \end{bmatrix}, \quad \mathbf{A} = \begin{bmatrix} N_{1,p}(x_1) & \cdots & N_{n,p}(x_1) \\ \vdots & \vdots & \vdots \\ N_{1,p}(x_m) & \cdots & N_{n,p}(x_m) \end{bmatrix}$$

- Sparse design matrix for B-Splines