Deformation Analysis of Tripods under Static and Dynamic Loads

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1. Motivation

- Short term precise monitoring tasks (no pillars / consoles available) => flexible use of tripods
- Temporal stability of tripods is essential precondition for accurate results
  Minimization of random and systematic errors by tripod head movements
- Tripod stability = height stability (Δz) and horizontal stability (Δx, Δy)
- 'Stability' must be referred to the length of the measurement process

- External loads (e.g. sun, wind, soil instability and vibrations)
- System tripod ⇔ tacheometer also affected by tacheometer itself
  - robot tacheometers: typical mass 5 - 8 kg and rot. speed up to 128 gon/s
  - static and dynamic loads by mass, accelerations resp. decelerations

  => elastic or plastic tripod deformations

1. Motivation

- Increasing number of tripod types available on the market
- Introduction of new materials in tripod manufacturing (e.g. fibreglass: Nanjing Survey / Crain Inc.)
- Cooperation between TU Vienna and Leica Geosystems for investigation of standard tripods (diploma thesis)
- Investigations realised at Leica labs / Heerbrugg

- Focus on
  - interaction tacheometer load ⇔ tripod (no external disturbances): lab
  - at first: inner height stability and quasi-static drift reactions
  - later: also dynamic effects (like horizontal torsional rigidity)

1. Motivation

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- Investigation of 7 different standard tripod types:
  - companies Leica, Nanjing Survey and Crain Inc.
  - material: wood, aluminum, fibreglass
  - light and heavy tripods (different admissible load)

GST120-9 H · CTP101 H/L · GST05 L · GST05L L · CTP103 L · Trimax H · S40 H

Wood	Aluminum	Fibreglass

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2. Theoretical simulations

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- First step: theoretical simulations for expected deformation range
- Simple Finite Element model (FEM) of tripod
  - each tripod leg is system of three homogenous and isotropic beams
  - rigid connection (neglection of clamps)
  - legs connected in single knot (tripod head)
  - supported by non-elastic ground
- Restricted to static vertical loads (=> height stability)
- For simulation: geometrical parameters derived from Leica GST120-9 (H)
- Young's modulus from dry hardwood
- 'Loaded' with typical test mass m = 30 kg ($F \approx 300$ N)

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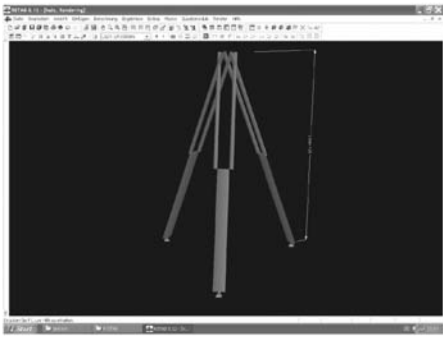
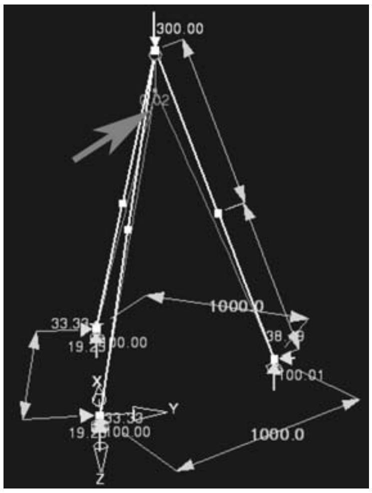
2. Theoretical simulations

- Static reaction of tripod head: Δz = 0.02 mm
- Model verified by following measurements ($\Delta z_{meas} \approx$ 0.02 – 0.03 mm)
- FE-model enables calculation of failure (≈ 240 kg)





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3. Static tripod deformations

- Investigation of <u>height stability</u> under static loading
- Required accuracy for monitoring system derived from FEM results
- Monitoring system:
  - combination of precise levelling instrument (Leica DNA03) and short levelling rod (Leica GWLC60)
  - inner accuracy for repetition measurements (small cutout): $s_{\Delta h}$ < 0.01 mm
  - automated registration of measurements
  - measuring frequency restricted to f = 0.25 Hz (compensator influence)
- Experimental setup under controlled environmental (lab-) conditions
- Tripod legs fully extended, spaced (1 m), clamps tightened with torque spanner
- Controlled loading with Leica test masses (m = 30 kg for H and 10 kg for L)

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3. Static tripod deformations

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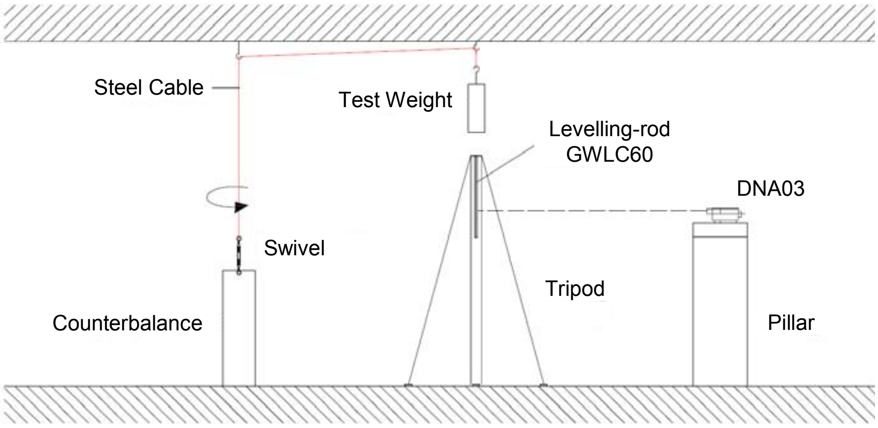
Experimental setup



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3. Static tripod deformations

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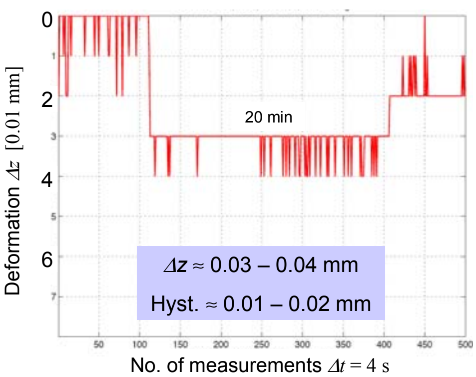
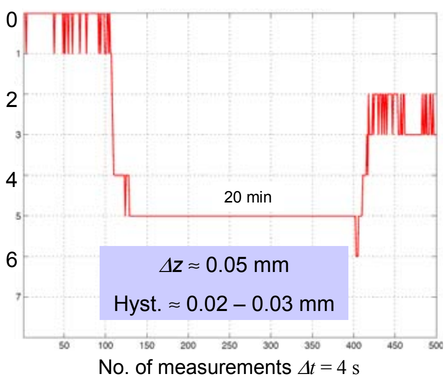
Leica GST120-9: static load m = 30 kg
H / Wood



Crain Trimax: static load m = 30 kg
H / Fibreglass



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3. Static tripod deformations

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Results for vertical static loads

Height stability (H = heavy / L = light tripod)

Tripod	Company	Material	Test load [kg]	Vert. def. Δz [0.01 mm]	Boundary ISO12858 [0.05 mm]	Hysteresis [0.01 mm]
GST120-9 (H)	Leica	Wood (beech)	30	3	OK	1.5
S40 (H)	Nanjing Survey	Fibreglass	30	4	OK	-2
Trimax (H)	Crain Inc.	Fibreglass	30	5	OK	3
CTP101 (H/L)	Leica	Wood	30	3	OK	1
GST05 (L)	Leica	Wood (pine)	10	1.5	OK	0
GST05L (L)	Leica	Aluminum	10	3	OK	1
CTP103 (L)	Leica	Aluminum	10	2	OK	0.5

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4. Quasi-static tripod deformations

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- Investigation of quasi-static drift behaviour => slow long-term effect
- Horizontal torsion of tripod more critical than vertical movement
  - time-dependent error in tacheometer orientation
  - systematic error in measured horizontal directions
- One main reason (indoor): continous stress decomposition in tripod
- Requires another kind of monitoring system:
  - Leica autocollimator and autocollimation mirror (accuracy $\sigma_\Theta < 2^{cc}$)
  - automated registration of measurements (integrated PSD)
  - measuring frequency f = 16 Hz
- Experimental setup under controlled environmental (lab-) conditions
- Static tripod loading with tacheometer Leica TCA2003 ($m \approx 8$ kg)

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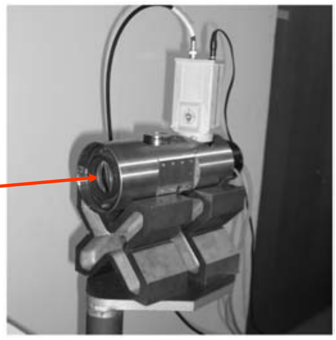
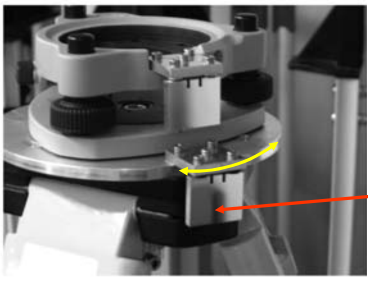
4. Quasi-static tripod deformations

Experimental setup

Autocollimator



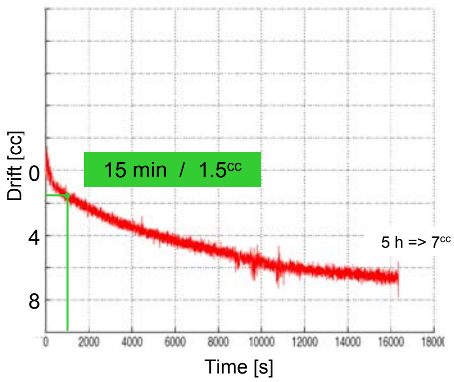
Tripod with
autocollimation mirror



4. Quasi-static tripod deformations

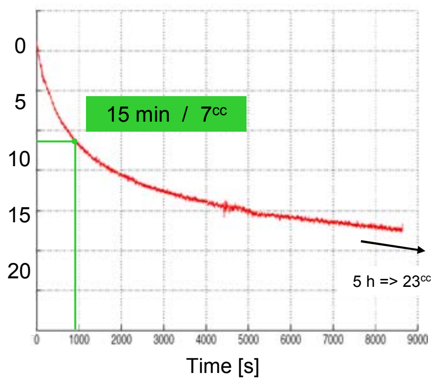
Leica GST120-9: loaded with Leica TCA2003

H / Wood



Nanjing Survey S40: loaded with Leica TCA2003 (cutout)

H / Fibreglass



4. Quasi-static tripod deformations

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Results for quasi-static deformations

(TCA2003 σ_r = 1.5^{cc})

Horizontal drift investigation

Tripod	Company	Material	Total drift [cc]	Drift after 15min [cc]	Boundary [8^{cc}]
GST120-9 (H)	Leica	Wood (beech)	6.5	1.5	OK
S40 (H)	Nanjing Survey	Fibreglass	22.5	7	NO
Trimax (H)	Crain Inc.	Fibreglass	9	8	NO
CTP101 (H/L)	Leica	Wood	4	1.5	OK
GST05 (L)	Leica	Wood (pine)	3	0.5	OK
GST05L (L)	Leica	Aluminum	23	15	NO
CTP103 (L)	Leica	Aluminum	9.5	2	NO

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5. Dynamic tripod deformations

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- Tacheometer rotation (esp. accelerations and decelerations) also induces torsional moments to tripod => up to M_T = 60 Ncm
- New task: investigation of horizontal torsional rigidity (resistance of tripod against torsional moments)
- Short-term effects with high frequencies (more than 50 Hz)
- Autocollimator (16 Hz) not suitable for investigation

- Development of a monitoring system at TU Vienna
- Just an outlook to first results
- Monitoring system consists of combination highspeed PSD and miniature laser
  - measuring frequency up to 30 kHz
  - relative position accuracy laser spot on PSD $s_{\Delta Y} = s_{\Delta X}$ = 5 µm

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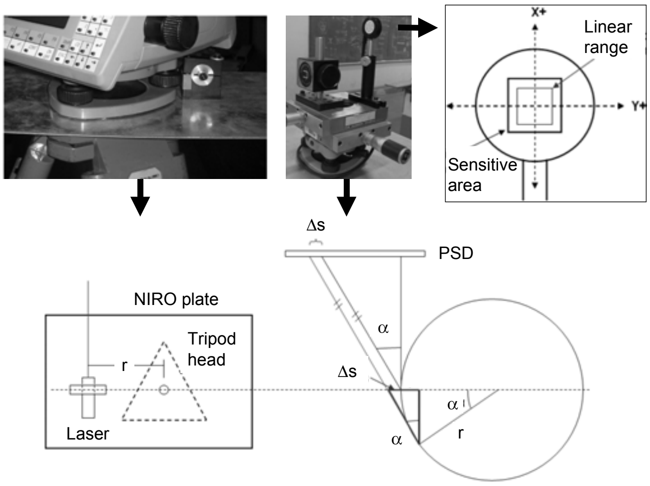
5. Dynamic tripod deformations

Experimental setup

- Laser on NIRO plate
  - fixed on tripod
  - performs tripod rotation
  - weight ≈ 200 g
- PSD fixed on pillar
- Distance 8 m
- Compensated background radiation



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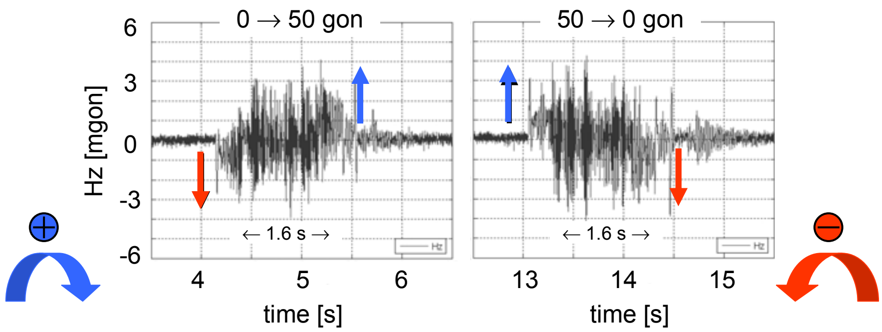
5. Dynamic tripod deformations

- Tripod Leica GST120-9 (H)
- Loading: rotating Leica TCA1800
- PSD meas. frequency f = 1 kHz

- Movement clockwise 0 → 50 gon
- Movement counterclockwise 50 → 0 gon
- Acceleration - constant vel. - deceleration



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6. Conclusions and outlook

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- Inner height stability is no real problem for short-term monitoring tasks
- Small amplitudes and hysteresis effects / wood best & fibreglass worst behaviour

- Quasi-static drift is much more critical
- Aluminum and fibreglass: drift influence cannot be neglected (in relation to specified tacheometer accuracy) / wood shows acceptable amplitudes
- Recommendation: tripod relaxation of min. 1-2 hours after tacheometer mounting

- Dynamic torsional moments may induce tripod torsions up to 3 mgon (and more)
- Only short phases, mainly in acc. and dec. phases / face changes …
- May have significant influence esp. on kinematic measurements

- New PSD-laser-system: further investigation of dynamic tripod deformations (e.g. influence of unbalanced tacheometer masses) => diploma thesis

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Thank you very much for your attention !

Special thanks to Leica Geosystems for equipment, lab facilities and local advice

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