Motion Detection of Munich's Olympic Tower with a Multi-Sensor System Operating at Different Sampling Rates

Dipl.-Ing. Thomas Schäfer
Technische Universität München
Chair of Geodesy

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The Olympic Tower in Munich

- Construction: 1965 - 1968
- Total height: 291.28 m
- Weight: 52 500 tons
- Viewing platforms & Revolving Restaurant
- Broadcasting & Communication facilities
- 1 million visitors per year



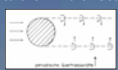
Motion of Tower Constructions

- Motion due to external forces:

  Sun: one-sided warming of the ferro-concrete surface leads to daily elliptical ground tracks as the sun is moving → semi-major axis ~30 cm

  Wind load: Eigenfrequency induced by the wind f ~ 0.15 – 1.5 Hz, Amplitude < 1 mm

  periodical „dead water" (turbulences) on cylindrical profiles cause forces perpendicular to the wind direction → elliptical oscillations



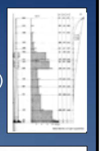
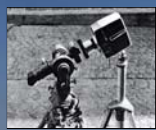
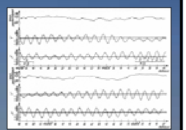

short-time motion during intervals of 20 seconds (each icon)

- Long-term deformations:
  permanent loading, civil works, land consolidation, change in ground water levels, wearout

Olympic Tower Montoring

- 1968: FE-Models & pressure sensors:
  f_n = 0.184 Hz (T=5.44 sec/cycle)
- 1972: Theodolite T2 + Film-Camera:
  observation of a target (16 pics/sec)

  → verification of theoretical estimated eigenfrequency

- 1998: Student Excercises:
  Tracking of the antenna over the course of a hot summer day by intersection

Changeover to DVB-T

- Danger Zone: High radiation of TV-Antenna
  → no access to the top
  → only remote monitoring methods possible
- New Antenna for „Digital Video Broadcasting – Terrestrial" (DVB-T) in 2005
- Unique chance for geodetic measurements during test stage (antenna turned off)
- Installation of a GPS-Antenna & 360°-Prism on the very top of the tower



The Multi-Sensor System

291 m

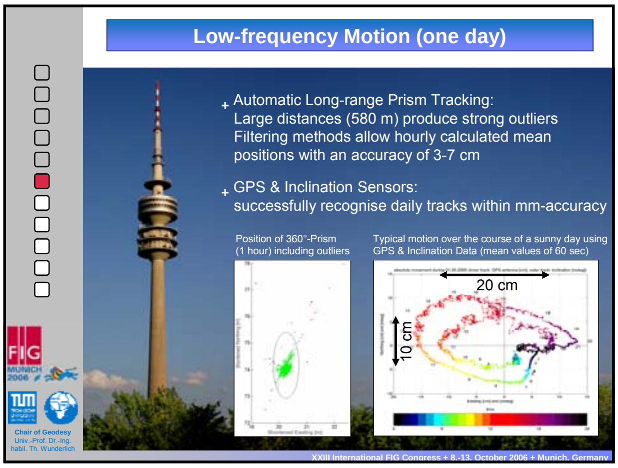
203 m

- High-frequency GPS Receiver:
  Leica GPS AX1202 @20 Hz for 34 days
  → 1.7 Mio baselines per day

- Dual Axis Inclination Sensor:
  Leica Nivel20 @ 5 Hz for 36 days

- Inertial Measurement Unit (IMU/INS):
  iMAR iNAV-RQH @ 100 Hz for 2 hrs
  → servo accelerometers
  → (ring laser gyroscopes)

- Automatic Long-range Prism Tracking:
  2 × Leica TCRA1101+ @ 2.5 Hz for 36 hrs
  → CCD-based Automatic Target Recognition
  → GeoBasic Application for measuring routine


Low-frequency Motion (one day)
Automatic Long-range Prism Tracking:
Large distances (580 m) produce strong outliers
Filtering methods allow hourly calculated mean positions with an accuracy of 3-7 cm
GPS & Inclination Sensors:
successfully recognise daily tracks within mm-accuracy
Position of 360°-Prism (1 hour) including outliers
Typical motion over the course of a sunny day using GPS & Inclination Data (mean values of 60 sec)
20 cm
10 cm
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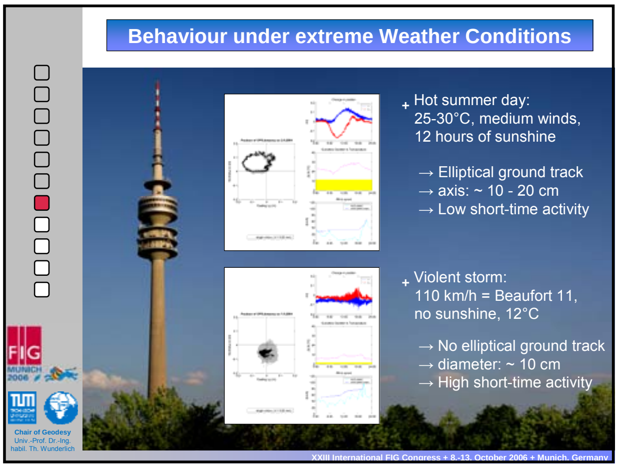
Behaviour under extreme Weather Conditions
Hot summer day:
25-30°C, medium winds,
12 hours of sunshine
→ Elliptical ground track
→ axis: ~ 10 - 20 cm
→ Low short-time activity
Violent storm:
110 km/h = Beaufort 11,
no sunshine, 12°C
→ No elliptical ground track
→ diameter: ~ 10 cm
→ High short-time activity
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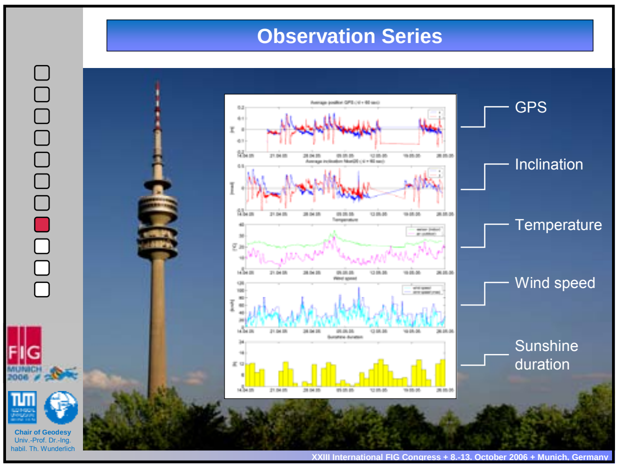
Observation Series
GPS
Inclination
Temperature
Wind speed
Sunshine duration
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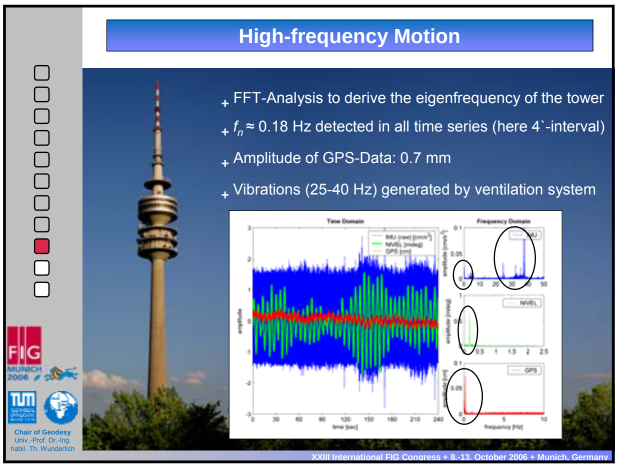
High-frequency Motion
FFT-Analysis to derive the eigenfrequency of the tower
f_n ≈ 0.18 Hz detected in all time series (here 4`-interval)
Amplitude of GPS-Data: 0.7 mm
Vibrations (25-40 Hz) generated by ventilation system
Time Domain
Frequency Domain
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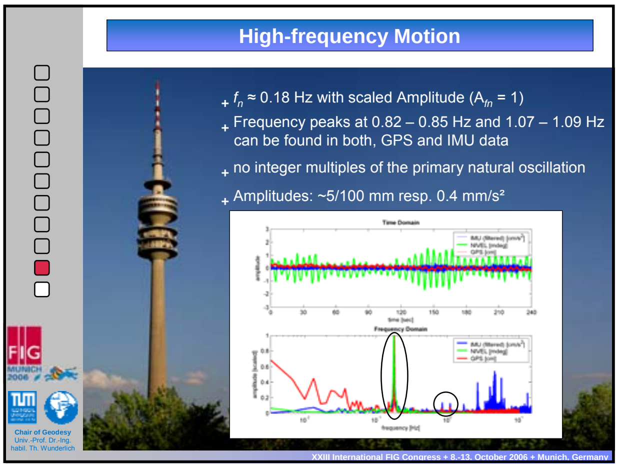
High-frequency Motion
f_n ≈ 0.18 Hz with scaled Amplitude (A_{fn} = 1)
Frequency peaks at 0.82 – 0.85 Hz and 1.07 – 1.09 Hz can be found in both, GPS and IMU data
no integer multiples of the primary natural oscillation
Amplitudes: ~5/100 mm resp. 0.4 mm/s²
Time Domain
Frequency Domain
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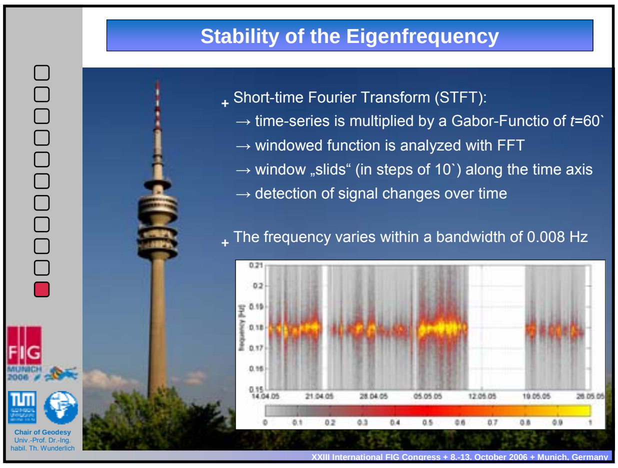
Stability of the Eigenfrequency
Short-time Fourier Transform (STFT):
→ time-series is multiplied by a Gabor-Functio of t=60`
→ windowed function is analyzed with FFT
→ window „slids“ (in steps of 10`) along the time axis
→ detection of signal changes over time
The frequency varies within a bandwidth of 0.008 Hz
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Questions?

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Univ.-Prof. Dr.-Ing. habil. Th. Wunderlich