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

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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 \( f \approx 0.15 - 1.5 \text{ Hz} \), Amplitude < 1 mm
- Peridical „dead water“ (turbulences) on cylindrical profiles cause forces perpendicular to the wind direction → elliptical oscillations
- Long-term deformations:
  - permanent loading, civil works, land consolidation, change in ground water levels, wearout

Olympic Tower Monitoring
- 1968: FE-Models & pressure sensors: \( f = 0.184 \text{ Hz} \) (\( T = 5.44 \text{ sec/cycle} \))
- 1972: Theodore T2 + Film-Camera: observation of a target (16 pics/sec) → verification of theoretical estimated eigenfrequency
- 1998: Student Exercises: Tracking of the antenna over the course of a hot summer day by interpolation

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 lower

The Multi-Sensor System
- 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 → rate of 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 2-7 cm.
- GPS & Inclination Sensors: successfully recognise daily tracks within mm-accuracy.

Position of 360°-Prism (mean over a sunny day without GPS & Inclination data)

Typical motion over the course of a sunny day using GPS & Inclination Data (mean values of 60 sec)

Position of 360°-Prism

20 cm

10 cm

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

Observation Series

- GPS
- Inclination
- Temperature
- Wind speed
- Sunshine duration

High-frequency Motion

- FFT-Analysis to derive the eigenfrequency of the tower
  \( f_n \approx 0.18 \text{ Hz} \) detected in all time series (here 4`-interval)
  Amplitude of GPS-Data: 0.7 mm
- Vibrations (25-40 Hz) generated by ventilation system
- Frequency peaks at 0.82 – 0.85 Hz and 1.07 – 1.09 Hz can be found in both, GPS and IMU data
  Amplitudes: ~5/100 mm resp. 0.4 mm/s²
- No integer multiples of the primary natural oscillation
- Short-time Fourier Transform (STFT):
  → time-series is multiplied by a Gabor-Function of \( \pi 60° \)
  → windowed function is analyzed with FFT
  → window „slides“ (in steps of 10`) along the time axis
  → detection of signal changes over time
- The frequency varies within a bandwidth of 0.008 Hz
Questions?

We would be pleased to welcome you at our booth "Geodätisches Prüflabor!"

INTERGEO Hall C1 Booth 1751