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

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Key words: GPS, INS, Long-Range Target Recognition, Eigenfrequency, Fast Fourier Transform (FFT), Short-Time Fourier Transform (STFT)

SUMMARY

This paper introduces a multi-sensor system which was implemented to test the achievement potential of several sensors in order to observe absolute deformations as well as high-frequency motions of buildings. For the model experiment Munich's Olympic Tower with a height of 291 m was chosen as test object. Depending on wind conditions and insolation the magnitude of the motion can thereby achieve several decimetres.

During the changeover to DVB-T (Digital Video Broadcast - Terrestrial) it was possible to implement a multi-sensor system consisting of a Leica GPS1200 receiver which was placed on the very top of the tower and two total stations (Leica TCRA 1101+) tracking a 360° prism mounted below the GPS antenna. In addition a biaxial inclination sensor (Nivel20) and an Inertial Measurement Unit (IMU) by iMAR were placed at a level of 203 m.

All in all the sensors collected data during a period of 36 days including two storms with a maximum wind speeds over 30 meters per second. Running at different sampling rates (TPS at 2.5 Hz, Nivel20 at 5 Hz, GPS at 20 Hz and IMU at 100 Hz) the data is used to derive the absolute movement over the course of the days as well as to determine the natural frequencies of the building.

A short introduction in technology of all sensors is described and operational experiences with high-frequency GPS data acquisition/processing and with long-range target recognition and tracking are given. Signal processing includes frequency analysis using fast Fourier transform (FFT) and windowed short-time Fourier transform (STFT) to detect small changes in the natural frequency.

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1. INTRODUCTION

Munich's Olympic Tower (Fig. 1) has a height of 291.28 m with a weight of 52 500 tons. At 182-190 m there is a viewing platform and a revolving restaurant. Since being opened in 1968, this huge tower has attracted more than 37 million visitors and, of course, has withstood every single storm. Nevertheless, the tower is subject to external forces like wind and sun and therefore is never standing motionless. In fact, the antenna' top e.g. is moving around its mean standing axis within more than ten centimetres.

The Chair of Geodesy at the Technische Universität München (TUM) has a long tradition in observing the short-term behaviour of the tower: already in 1972 the former Geodetic Institute was using a theodolite in combination with a film-camera taking 16 pictures per second (Fig. 2a). After observing a target at 248 m during a period of 200 seconds Wittmann and Hillebrand (Wittmann & Hillebrand, 1973) succeeded in deriving the natural frequency of the building. Since 1998 student exercises take place in the Olympic Park to measure the track of

Fig. 1: One of the town's landmarks: the Olympic Tower in Munich

the antenna over the course of a hot summer day by intersection. However, due to the high transmitting power of the tower's television antenna, access to this danger zone is permitted. Therefore geodetic measurements were limited to remote monitoring methods.

The tower reached its actual height on April 5, 2005 (growing 1.75 m) while a Russian specialist helicopter under Swiss flag has been used to lift off the old antenna's top and put up a new antenna piece by piece (Fig. 2b). From now on the new antenna provides six million TV viewers in Munich and the south of Bavaria with digital TV broadcasting (DVB-T). During this changeover, we had the unique chance to mount a GPS antenna on the very top of the tower (Fig. 2c). To complete the experiment, several other sensors were implemented into the monitoring system.

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Fig. 2: Geodetic progress in Olympic Tower Monitoring: (a) Theodolite Wild T2 combined with a Nizo S8 film-camera in 1972, (b) change of the TV-antenna with a helicopter and (c) installation of a GPS-antenna and a 360° prism in 2005.

2. MOTION OF TOWER CONSTRUCTIONS

The Stuttgart (world's first) Television Tower, a concrete and steel construction was opened in 1956. Since then it has become the technical prototype for nearly all television towers throughout the whole world. Already during the stage of construction first deformation measurements were done (Eilfort, 1957). Interestingly, even at that time the surveyors turned their attention more to the reliability of its position in order to use the tower as control point in the national triangulation system and not to the stability of the building itself. Thereby a motion over the course of the day was recognized. However, the spectrum of tower motion includes a high-frequency part as well – the natural frequency.

2.1 Sun

During a sunny day the ground track of the tower resembles an ellipse (Fig. 7 & 8a) correlated with the position of the sun. Due to one-sided warming the enlightened surface is subject to thermal expansion. That means e. g. that a tower with a height of h =200 m at temperature gradient between sunny and shady side of Δt =10° with an expansion coefficient of ferro-concrete α =11.5 $\cdot 10^{-6}$ K^{-1} the sunny side might be 23 mm longer than the shady side, resulting in an inclination of the tower with a non-linear bending line. The speed of the antenna's top can rise up to 3 centimetres per hour. All in all this motion sequence can amount semi-major axes of almost 30 centimetres depending on the height and the latitude of the tower. Usually this trajectory is not repeated day after day, since sunshine duration and temperature change. Especially on hot summer days, it is possible that the deformation is not fading away during the cooling period at night.

2.2 Wind load

The second well known phenomenon is the resonance frequency of the building induced by the wind (Möhlenbrink, 1984). Typically, the primary oscillation for such high towers is

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$0.15 < f < 1.5$ Hz. As the amplitude of the daily trajectory covers decimetres, high-frequency oscillations only cover a few millimetres or even less. Thus, according to the Nyquist-theorem, methods for monitoring wind induced deformations on towers need to record reliable and accurate data at a frequency of at least 3 Hz.

For the Olympic Tower in Munich, a theoretical value of 5.82 seconds per cycle was estimated. Pressure sensors set in the concrete of the Olympic Tower delivered a measured cycle duration of T = 5.44 sec corresponding to a natural frequency of $f = 0.184$ Hz (Schneider, 1975). This value was verified by the photogrammetric measurements by Wittmann and Hillebrand.
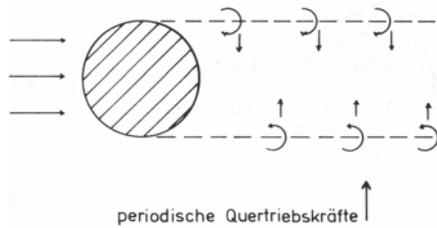

Fig. 3: Turbulences caused by the wind (Möhlenbrink, 1984)

In addition, especially on cylindrical profiles so-called periodical "dead water" occurs (Fig. 3). These turbulences cause forces perpendicular to the wind direction leading to strong elliptical oscillations as well. The data shown below (Fig. 4) was derived from an inclination sensor during a period of almost seven minutes. Each picture successively shows 100 data values (20 seconds) and their least squares ellipses with a permanently changing angle of the major axis. You can see the ratio of major (perpendicular to the wind direction) to minor (lengthwise to wind direction) axis which is about 5:1. With increasing wind speed, these turbulences collapse and the lengthwise amplitude dominates the wind load effects.
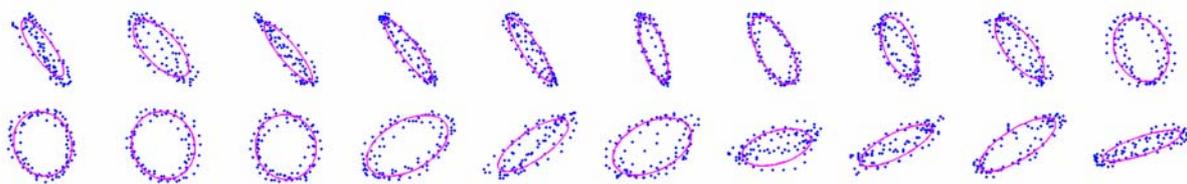

Fig. 4: Ratio of major and minor axis of the short-time motion due to wind turbulences

2.3 Long-term deformations

Besides periodical appearing oscillations also permanent loading and civil works may affect the building as well. Possible are land consolidation, changes in ground water levels and wearout. In order to maintain the building, geometric parameters have to be surveyed from time to time. Long-term deformation measurements are not object of this article.

3. THE MULTI-SENSOR SYSTEM

In (Schmidt & Möser, 2004) a multi-sensor system for motion detection is introduced and was implemented at the Television Tower in Dresden. The system combining GPS, TPS (total station) and an inclination sensor enables a continuous observation of the tower's movement. In respect of the aim to detect and map the trajectory during one day, only data

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logging in intervals of 15 seconds (GPS), 1 minute (inclination sensor) and 5 minutes (TPS) were realized. As discussed in chapter 2.2, these measuring rates are not sufficient for capturing the eigenfrequency of approximately 0.18 Hz. The multi-sensor system introduced in the following (see its components in Tab. 1) meets this requirement with a minimum measuring rate of 2-3 Hz.

Tab. 1: Overview of the deployed sensors

Sensor	Method	measuring rate	installation height	observation time
TPS (TCRA1101+)	automatic long-range prism tracking	2.5 Hz	291 m	36 hours
GPS (GPS1200)	high-frequency kinematic GPS	20 Hz	291 m	34 days
Tilt sensor (Nivel20)	biaxial tilt angles with liquid horizon	5 Hz	203 m	36 days
IMU/INS (iNAV-RQH)	servo accelerometers, (ring laser gyroscopes)	100 Hz	203 m	2 hours

In addition, meteorological data (average and maximum wind speeds, air temperature and daily sunshine duration) for all 36 days is available. During this period a violent storm with a maximum wind speed of 110 km/h (11 Beaufort) was occurring in Munich – a truly extraordinary burden for the tower and the sensors. Unfortunately, no information on wind direction and temperature gradients of the concrete are existent.

For an integrated evaluation of the observation series, time synchronisation is necessary. Since each sensor was located on different positions running on different platforms, effort was reduced to a minimum by setting the internal clocks to the correct coordinated universal time (UTC) at the beginning of the campaigns. So time synchronisation was done within an accuracy of about 1 sec.

As far as possible, measurements were done in a combined coordinate system. Anyway, each sensor delivers data in different dimensions (angles, coordinates, accelerations and angle rates) which can not easily be converted. To compare the time series, it is therefore reasonable to take a look at the frequencies hidden in the data. For this purpose FFT-analyses were done (see section 4.2).

3.1 Automatic long-range Prism Tracking

For the automatic prism tracking a 360° prism mounted below the GPS-antenna with a known offset (Fig. 2c) was observed from two stations. For this method two total stations (Leica TCRA1101+) were applied on pillars in the Olympic Park with known (GPS) coordinates.

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These instruments provide automatic target recognition (ATR). With ATR you only need to point roughly with the optical sight and trigger a measurement. The infrared beam transmitted from the telescope is reflected back by the prism and analyzed instantly. Then the instrument moves the telescope, fine points to the centre of the prism and measures. The lock mode is part of ATR and enables the total station to track a moving reflector. According to the specifications target recognition is possible up to a range of 500 m. The distances between the pillars and the target measured 480 and 580 m – close to and over the operating limits.

Fig. 5: Telescope (magnification 30 x) locked onto the reflector in a distance of 580 m

Day and night data was collected during 36 hours. The measurement based on an on-board application that automatically registers the position of the prism for 55 minutes 2-3 times a second. The last five minutes of each hour were used for remote target measuring in order to detect effects like drifting of the graduated circle or twisting of the pillars.

Already during the experiment, problems occurred in remaining locked onto the reflector. Strong sun reflections caused confusions so that these reflexions were observed instead. Hence, the standard deviations σ of each hourly calculated mean position are within several decimetres. Due to the long ranges the spot of the infrared signal mapped on the CCD-chip is very small and even small disturbances result in large errors, whereas the electronic distance measurement is more or less unaffected. Figure 6 shows the positions from the first standing point registered during one hour. Outliers (red) can mainly be found perpendicular to the observation vector. After using an elimination method σ can be reduced to 3-7 cm (green). Afterwards the track over the course of a day can be derived, but still the data is very noisy and not usable for high-frequency motion analysis.
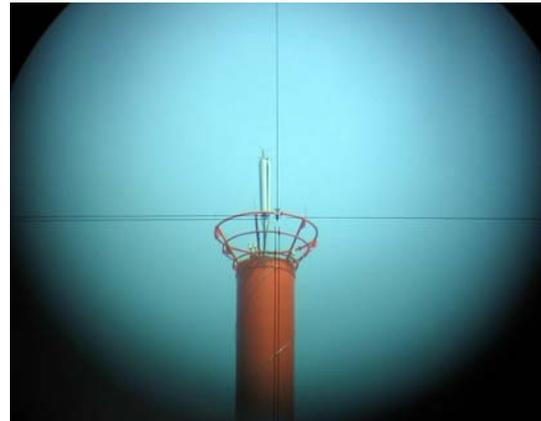

Fig. 6: Position of the prism (1 hour) including outliers

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Further developments in tacheometry (e. g. Trimble's S6) specify their ATR algorithm for distances for up to 700 m. Consequently, it would be interesting to repeat the experiment in respect of different techniques.

3.2 High-frequency GPS Receiver

For monitoring the TV antenna's movement a GPS1200 Surveying System (Leica Geosystems) was used. Since the receiver antenna (AX1202) was fixed on the top of the tower no elevation mask was necessary up there – but a lightning protection was absolutely essential. For security reasons, this area was not accessible for maintenance work. Therefore a connecting cable with a length of 100 m was established to the receiver (GX 1230) which was situated on a platform close to the other sensors. Last but not least an amplifier was interposed to obtain a good transmission quality. A reference station (with identical configuration) was set up on the roof of the TUM. Any virtual reference stations (e.g. SAPOS or ASCOS) were not in use, since they do not support a measuring rate of more than 1 Hz.

The systems provide dual frequency phase measurement (L1 + L2) with 12 channels each. Data was collected at its maximum capturing rate of up to 20 Hz over a period of 34 days. To handle the large amount of data (0.7 MB raw data per minute) Leica's GPS Spider Software for single stations and reference station networks was used. Running on a notebook this software communicates via OWI interface with the receiver and manages data protection every 10 minutes.

For baseline calculation in post-processing mode Leica Geo Office (LGO) was used. Each day was divided into three evaluation periods, because LGO is not able to handle projects with 2 GB of data. Since GPS Spider was developed for reference stations it only allows to measure in static mode – but processing had to be done in kinematic mode, since the aim of our investigation was to calculate 20 independent coordinates per second (1.7 million baselines each day). Therefore, rover data had to be adapted manually by changing the RINEX files. For each evaluation period the first 5 minutes remained static to solve ambiguities, afterwards data has been declared as kinematic measurements.

As already mentioned, data was saved from the receiver's internal memory (capacity 32 MB) to the notebook's hard disk every 10 minutes. From time to time, more satellites were visible than expected. This circumstance implicated a data overflow just before backup started resulting small data gaps. To fix these gaps, time information had to be adjusted as well, leading to a long winded data snooping. In fact, this is the reason that at press date not every GPS day was completely processed.

3.3 Dual axis Inclination Sensor

As inclination sensor Leica's Nivel20 was chosen. The sensor measures tilt angles in both directions using a liquid horizon with an accuracy of $\sigma = \pm 0.005$ mrad + 0.5 % within an effective range of ± 1.5 mrad (= ± 1.5 mm/m). The instrument was deployed on a telecommunication platform at a height of 203 m inside the building. Its orientation was

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determined by a compass, so the tilt components can be calculated in the used reference system and can generally be compared to the other sensors. For remote control and data storage a Notebook was deployed next to the sensor. Apart from a failure in the storage process, inclination was measured during the whole campaign for 36 days at a measuring rate of about 5 Hz. The oscillation with a frequency of 0.18 Hz (Fig. 10) is clearly visible throughout the whole campaign at any time. Thanks to the high accuracy of the sensor measuring noise is negligible.

3.4 Inertial Measurement Unit

Inertial Navigation Systems (INS) are mainly used for navigation purposes (dead reckoning) and are combined with GPS because of high drifting rates. Latest developments in engineering surveying also use the sensor as stand-alone device for kinematic monitoring of bridges (Neuhierl & Foppe, 2004) and for kinematic carrying forward of bearings in tunneling shafts (Neuhierl, 2005).

The IMU iNAV-RQH is a custom product by iMAR Ltd. (St. Ingbert, Germany) for the Institute for Astronomical and Physical Geodesy (IAPG) and the Chair of Geodesy at TU München. It includes three servo accelerometers and three ring laser gyros and is operated via RS232 or Ethernet. Alignment measurements in static mode (in this case the small amplitudes of the tower motion are negligible) and several transformations allow to locate the IMU in the project coordinate system.

The measuring rate of each sensor was 100 Hz (in fact the sensor will be upgraded to 2000 Hz soon). Due to the large amount of data and the high drifting rates this experiment was running for only about two hours – so it is not appropriate for detecting daily motions with this configuration. During the measurement the IMU was placed directly on the floor (concrete) on the same platform the inclination sensor was located (203 m). That means that also vibrations caused by a running ventilation system and ongoing construction work were probably registered as well (see section 4.2.1).

4. RESULTS

4.1 Low-frequency Motion

Figure 7 gives a good impression of a typical motion over the course of a sunny day (temperature: 20-25 °C, sunshine duration: 12 hours, wind speed: ≈ 20 km/h). The two sensors (GPS and inclination) confirm each other even though the dimensions do not agree. In this example every 60 seconds a mean value for the position/inclination is calculated to hide the high-frequency motion part. On such a sunny day the elliptical motion begins almost at sunrise and causes deviations about 10 cm (Fig. 8a) until the sun is setting. On a cloudy day this motion is not happening. But strong winds (60 – 110 km/h) also cause oscillations with amplitudes of about 10 cm (Fig. 8a). Figure 9 shows the complete long-time observation with GPS (not completely processed at press date) and inclination sensor in terms of meteorological aspects.

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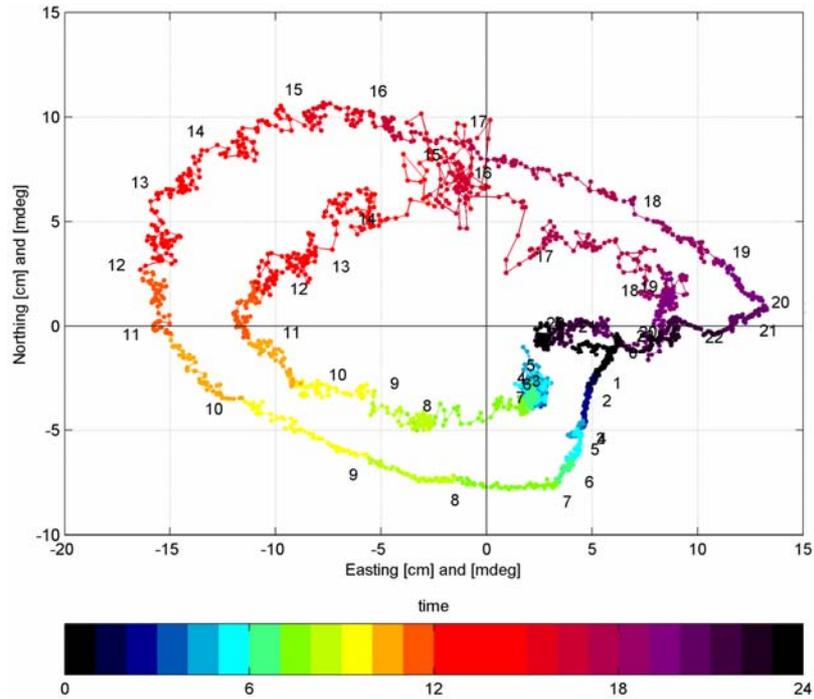Munich, Germany, October 8-13, 2006

Fig. 7: Absolute movement of the tower on May 1, 2005. Each data point
indicates the mean position/inclination during 60 seconds.
- Inner track: position of the GPS-antenna in cm
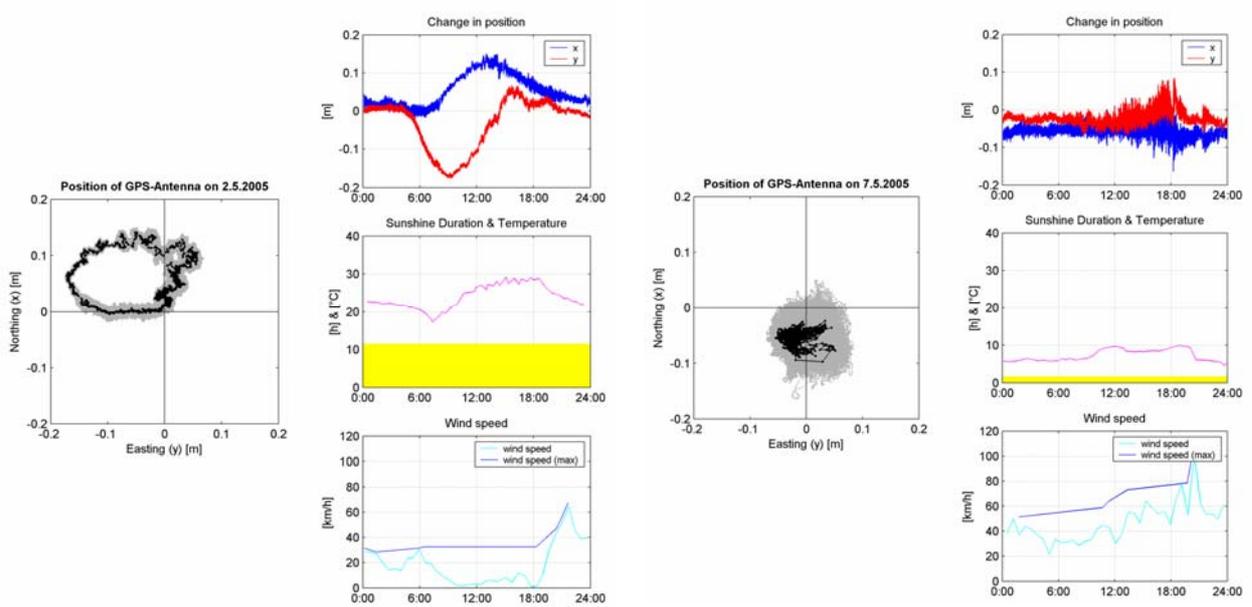- Outer track: inclination of the tower in mdeg

Fig. 8: Motion of the GPS antenna on a sunny (left) and a stormy day (right). The black marker
indicates the mean position during 60 seconds, while the gray data includes every
position calculated at 20 Hz

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Fig. 9: Long-time series of GPS- and NIVEL-data in terms of meteorological aspects

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4.2 High-frequency Motion

In Figure 10 a short section (4 minutes) of GPS-, IMU- and inclination-data is shown in the time domain. Especially the inclination angles illustrate the natural frequency and the permanently changing amplitudes very well. But also the GPS-position of the antenna obviously describes the same frequency, whereas accelerations seem to be very noisy.

4.2.1 FFT-Analysis

For extracting high-frequency motion, a FFT-analysis delivers frequencies and corresponding amplitudes (Fig. 10, frequency domain). IMU-data (only horizontal accelerations) indicates several strong frequencies (25-40 Hz) with high amplitudes. These vibrations should not be assigned to the behaviour of the building but were possibly generated by a running ventilation system and ongoing construction work (Fig. 11 shows a filtered signal). Below 10 Hz several other peaks can be detected. The strongest peak in this frequency band is about 0.18 Hz. This frequency can also be found in inclination data as well as in the GPS data with amplitude of 0.8 mm. Beyond, GPS data contains two very small (a < 0.1 mm) frequencies at about 1 Hz.
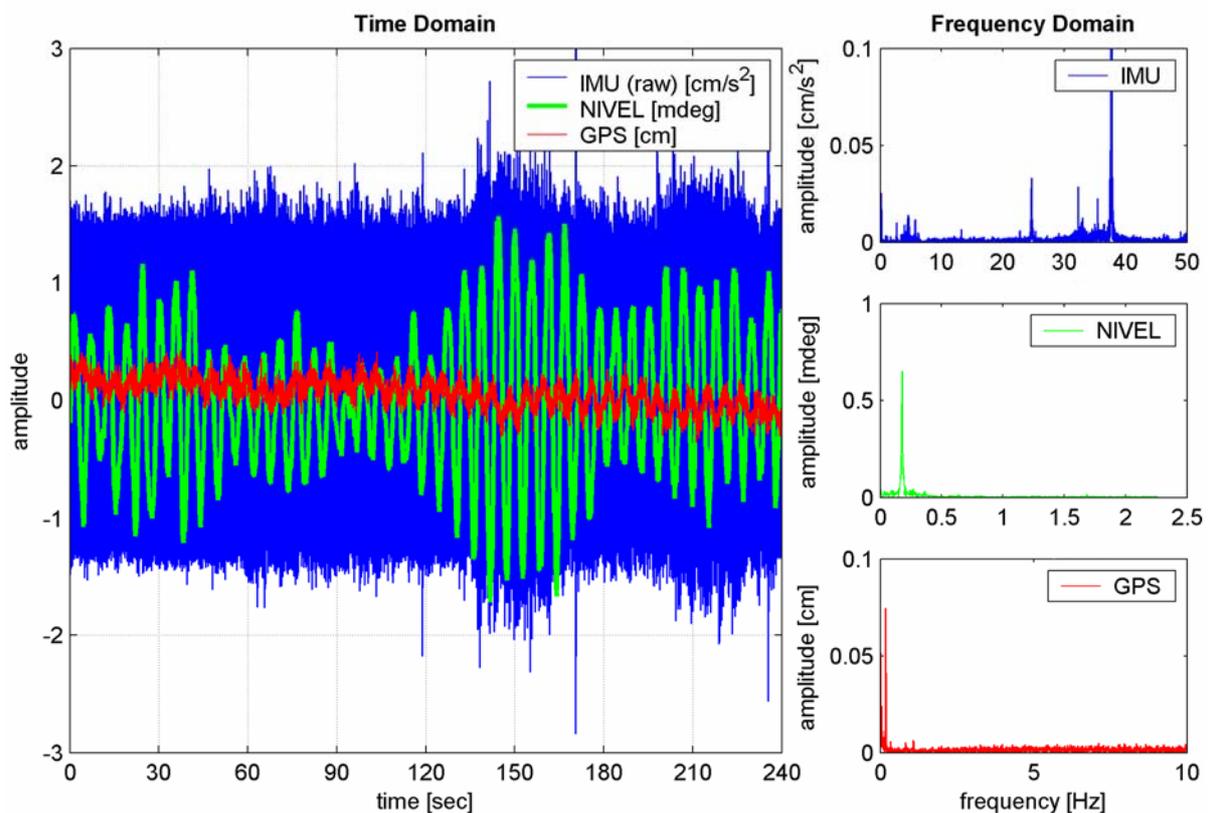

Fig. 10: Example for FFT analysis of a short section of high-frequency data (left: time domain, right: frequency domain). Daily solutions of FFT analysis give almost identical results with different amplitudes depending on wind conditions.

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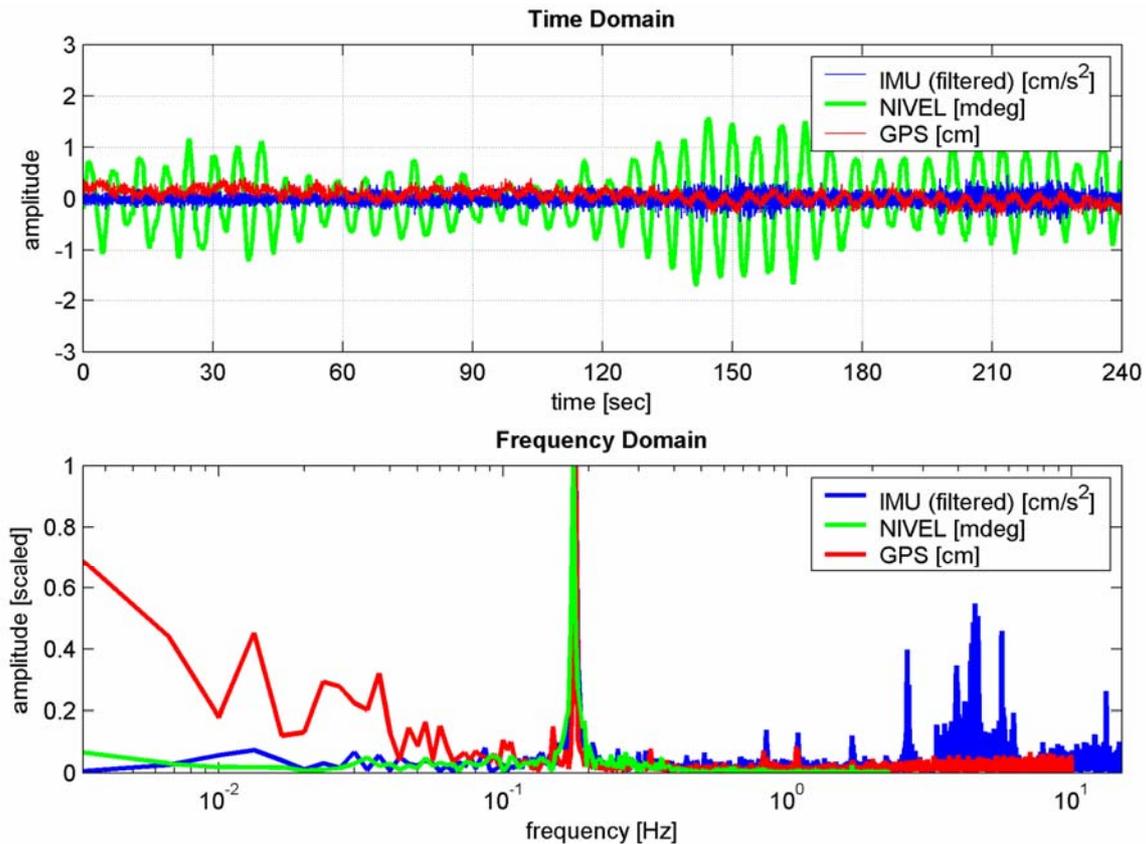Munich, Germany, October 8-13, 2006

Fig. 11: A closer look at the time and frequency domain of the same observation series. Eigenfrequency can be detected by all three sensors precisely. Amplitude is scaled ($A_{fn=0.18} = 1$)

A closer look at the frequency spectrum (Fig. 11) shows, that the natural frequency can be derived precisely by all three sensors. Other frequencies which are not integer multiples of the natural frequency can be found in both, GPS and IMU data (at 0.82-0.85 Hz and 1.07-1.09 Hz) with very small amplitudes (about 5/100 mm resp. 0.4 mm/s²). Due to the congruence of the peaks, randomness can be excluded. From 2.7 to 6.5 Hz several other frequencies seem to be involved. At this point of time, these frequencies can not be explained.

4.2.2 STFT-Analysis

Short-time Fourier transform is used to determine the sinusoidal frequency and phase content of local sections of a signal as it changes over time, whereas the fast Fourier transform gives no information on time resolution (Schmidt, 2001). Simply described, in the continuous-time case, the function to be transformed was multiplied by a Gabor window function for only a short period of time (in this example 60 minutes). The Fourier transform (a one-dimensional function) of the resulting signal is taken as the window is slid (in steps of 10 minutes) along the time axis, resulting in a two-dimensional representation of the signal (Fig. 12).

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Purpose of this analysis is to test the stability of the eigenfrequency. Amplitude and clearness of the peaks mainly depend on wind conditions. Nevertheless, the strongest amplitude of each window can be regarded as the eigenfrequency. This frequency varies within a bandwidth of 0.008 Hz.
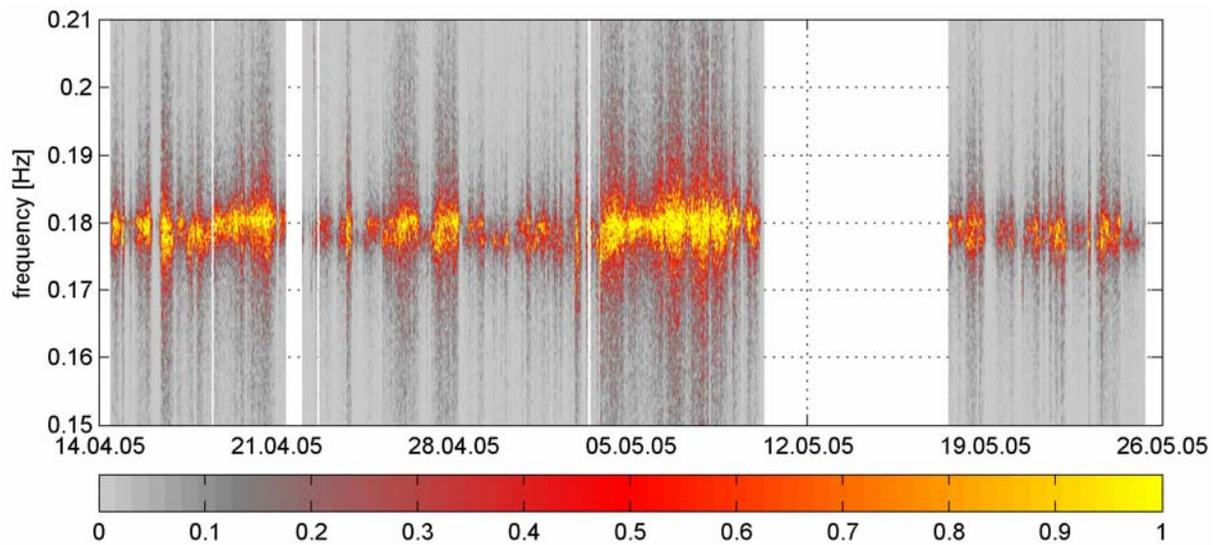

Fig. 12: STFT-spectrum of tower inclinations

5. CONCLUSION

The results show, that every sensor is suitable for deriving low-frequency motions of high tower buildings. However, long-range target tracking causes problems due very long distances resulting. After eliminating outliers calculated mean positions reached an accuracy of 3-7 cm. Thus this method is not appropriate to observe high-frequency motion.

The easiest procedure to monitor resonance frequencies is inclination measurement. But to convert tilting angles into expressive information (especially metric horizontal movements) knowledge about the bending-line of the building are necessary. Acceleration measurements with a high-sensitive IMU map every frequency occurring in contrast to ring laser gyroscopes measurements which turned out to be useless. To reduce noise either appropriate filtering methods can be done or sampling rate should be limited according to the interesting frequencies. To derive illustrative metric horizontal movements data has to be integrated twice – in this case, the initial value problem has to be solved first.

As reported, GPS is a proper way to gain information on natural frequencies. High accuracy allows detecting amplitudes smaller than one millimetre. FFT analyses have shown that even higher frequencies with smaller amplitudes can be recognized.

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REFERENCES

Eilfort, H., 1957, Bewegungsmessungen am Stuttgarter Fernsehturm. Zeitschrift für Vermessungswesen, No. 82, pp. 258-263, 1957

Neuhierl, T., Foppe, K., 2004, Anwendungen inertialer Messsysteme in der Ingenieurgeodäsie. In: Proc. of Kinematische Messmethoden – Vermessung in Bewegung. DVW Series, Volume 45, p. 165, Augsburg, 2004

Neuhierl, T., 2005, Eine neue Methode zur Richtungsübertragung durch Koppelung von Inertialmesstechnik und Autokollimation. Dissertation at the Faculty of Civil Engineering and Surveying, TU München, Munich, 2005

Möhlenbrink, W., 1984, Zur Entwicklung eines Meßverfahrens für die Bestimmung von Bauwerksverformungen aus Neigungs- und Beschleunigungsmessungen. Deutsche Geodätische Kommission, Verlag der der Bayerischen Akademie der Wissenschaften, Reihe C - Dissertationen, No. 307, Munich, 1984

Schmidt, J., Möser, M., 2004, Nachweis von Turmbewegungen mit einem Multisensor-system. In: Ingenieurvermessung 2004 - 14th International Conference on Engineering Surveying, Zurich, 2004

Schmidt, M., 2001. Grundprinzipien der Wavelet-Analyse und Anwendungen in der Geodäsie. Habilitation at the Faculty of Civil Engineering and Surveying, TU München, Shaker Verlag, Aachen, 2001

Schneider, F. X., 1975, Wind- und Betonspannungsmessungen am Olympiaturm München. Beiträge zur Anwendung der Aerolastik im Bauwesen, No. 1, Munich, 1975

Wittmann F., Hillebrand, H. 1973, Vergleichende Schwingungsmessungen am Münchener Fernsehturm. Der Bauingenieur, No. 48, p. 343, 1973

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