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Influence of electric power lines on the reception of GNSS-signals in automatic steering systems

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Global Navigation Satellite Systems (GNSS) are widely applied for positioning and navigation. They play a vital role in the realm of precision farming. As an integral part of automatic steering systems they relieve the driver and reduce costs by increasing efficiency and saving input material such as diesel, fertilizer and chemicals. For some applications the highest achievable accuracy of 2 cm must be maintained permanently.
Related to the renovation of the German power grid the influence of underground and above-ground power lines on the performance of GNSS receivers in agricultural applications has been investigated.

Keywords
GNSS, power lines, steering system, Precision Farming

The use of automatic steering systems in agriculture has substantially increased over the last decade. They steer tractors and implements without interference of the driver and maintain an accurate distance between subsequent tracks. Independent of visibility (night, fog), overlaps and gaps in cultivation, the application of fertilizers and chemicals are thus being minimized. All GNSS-based steering systems rely on correction data which in many cases is being transmitted by cellular networks.

The German power grid is currently under reconstruction in order to meet the requirements of a more sustainable power supply based on renewable energies. With new power lines being planned and implemented, there have been an increasing number of reports on steering systems being affected in their functionality when passing under or over power lines. Power lines could affect the GNSS signals as well as the correction data transmitted over mobile cellular networks. In order to verify whether the reports from farmers can be reproduced under defined conditions, the Bayernwerk AG has tasked the University of Applied Science Weihenstephan-Triesdorf to investigate the effect of power lines on the functionality of different steering systems.

State of the art

Bancroft (2012), Pollock and Wright (2011), and Silva and Olsen (2002) only found weak or no relation between the presence of power lines and the position quality of GNSS receivers. Silva and Olsen (2002) state that electromagnetic fields induced by power lines may interfere either with the satellite signal itself or with electronic components inside GNSS receivers. However, they were unable to locally relate power lines with decayed GNSS positioning. They also emphasize that they have observed an average of 1.2 outages per day over three month which occurred independently of evident external factors.

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De Bakker (2007) reports that electromagnetic fields may affect the ability of GNSS receivers to track satellites or negatively affect the signal-to-noise ratio (SNR). The noise power from an electromagnetic field can override the power of the desired signal so that the information conveyed cannot be extracted properly.

Bancroft and Morrison (2011) investigated the reliability of GNSS receivers under DC and AC power lines. The authors could not find any relation between the power lines and the reliability of GNSS positioning.

Material and methods

The operation of three tractors with different steering systems on a test circuit passing under and over power lines has been a key element of the investigations on the effect of power lines on GNSS signals. They were conducted on two different test sites. All systems received correction data using the same cellular network (T-Mobile). Additionally, a static test with two GNSS receivers within and outside the expected zone of influence was carried out to support the dynamic tests.

The first test site was located in Upper Franconia with two 110 kV overhead power lines and one 110 kV underground power line crossing the test circuit. The tractors have been continuously moved over the test course on two subsequent days during the morning, mid-day and afternoon (Table 1). The periods were chosen in order to cover different GNSS-satellite constellations. Vehicle speed was randomly varied between 5 and 20 kph. While travelling on the test circuit NMEA messages (http://www.nmea.de/nmea0183datensaetze.html) from the receivers were logged at an interval of 1 s (1 Hz). All steering systems could provide the NMEA GGA, GSA and VTG messages. The NMEA GST message was only available from two receivers, one receiver additionally provided access to the NMEA GSV message. Collecting the data allowed to monitor and analyze the most important impact factors on the availability and accuracy of GNSS systems such as correction status, satellite geometry (PDOP) and the signal-to-noise ratio.

Average air temperature during the trials on site 1 was 13 °C with no significant rainfall (1.2 mm/day). Relative humidity was 72 %. On site 2 the average daily temperature was 9 °C. Rainfall was below 0.1 mm/day. Mean humidity was 74 % during the first day and 57 % during the second day

Table 1: Trial periods on site 1 (Upper Franconia)

Date	Morning		Mid-day		Afternoon	
	Start	End	Start	End	Start	End
2016/04/04	09:15	10:15	12:15	13:15	14:50	15:50
2016/04/05	09:45	10:45	13:00	14:00	15:00	16:00

The NMEA logfiles were processed and imported into the GIS-software QGIS (www.qgis.org). The location of the power lines was also determined with the software QGIS based on digital orthophotos (https://www.ldbv.bayern.de/produkte/luftbild/orthophotos.html) and site maps. The polyline features served as a basis for creating the potential zones of influence of the power lines by buffering the line features with a distance of 10 m (Figure 1). Buffering resulted in five different zones of influence with some zones being affected by two power lines (Table 2).

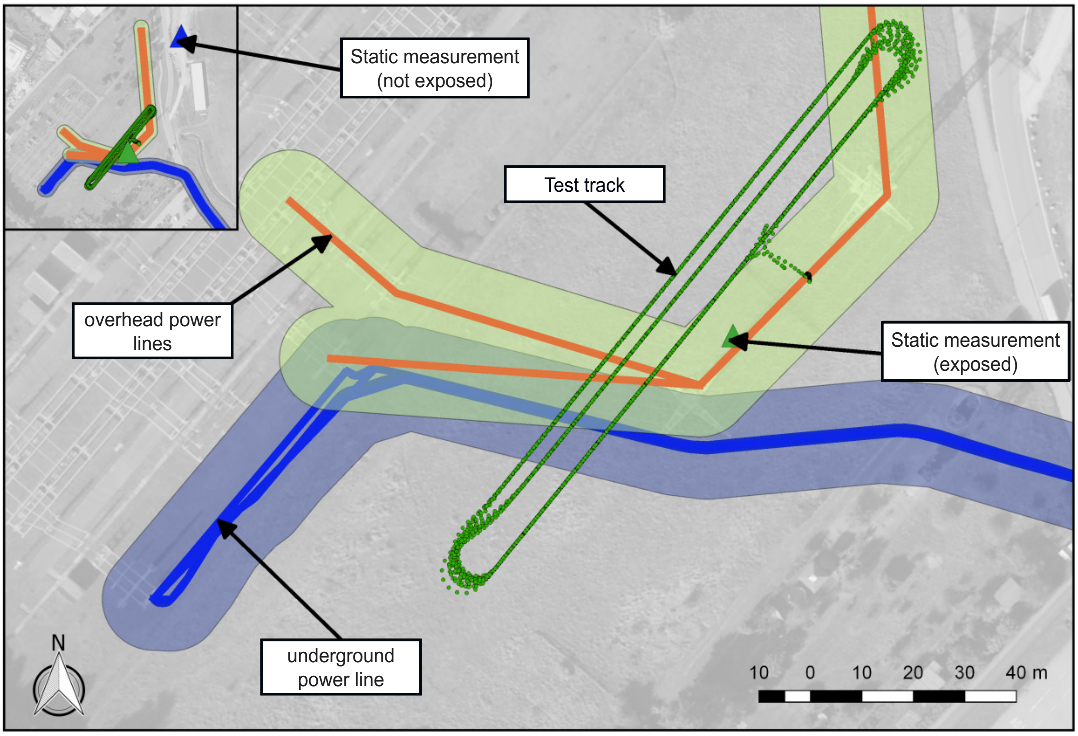

Figure 1: Location/Zones of influence of power lines and test circuit on site 1

Table 2: Zones of influence on site 1 (Upper Franconia))

Zone	110 kV Underground Line	110 kV Overhead Line_1 [1)]	110 kV Overhead Line_2
A (none)	0	0	0
B (over2)	0	0	1
C (over1)	0	1	0
D(over1_2)	0	1	1
E(under)	1	0	0
F(under_over2)	1	0	1

[1)] Overhead_1 was inactive during the trial period.

The data logged while travelling over the test course was divided by zones and analyzed for differences with respect to GNSS quality parameters.

The identical proceeding was applied for data acquisition on the second site in Central Franconia. The three tractors were operated on the test course on May, 3rd 2016 and May, 4th 2016 for one hour during morning, mid-day and afternoon. The test course passed under three overhead power lines with voltages of 110 kV, 220 kV and 380 kV. The respective zones of influence are summarized in Table 3.

Table 3: Zones of influence on site 2 (Central Franconia)

Zone	110 kV Overhead line_1	220 kV Overhead line_2	380 kV Overhead line_3
A (none)	0	0	0
B (Over3)	0	0	1
C (Over2)	0	1	0
D (Over2_3)	0	1	1
E (Over_1)	1	0	0

Additionally, data from two stationary GNSS receivers in and outside the influence zone of the power lines have been logged over 24 hours using a Trimble AgGPS 132 and a Trimble AgGPS 372 GNSS receiver. The aim was to collect additional data that allows to assess the influence of the power lines on the reliability of GNSS receivers.

Results

Data from the static tests was evaluated with respect to the standard deviation of pseudo range measurements (RMS) provided in the NMEA GST message. The RMS value rises when the signal is influenced by the environment. The RMS values of the receiver located under the overhead line 2 on site 1 frequently showed peaks which, however, were not related to the transmission power. The RMS was below 2 m during maximum transmission power of 30 MW while standard deviations of 10 to 20 m occurred when the transmission power was in the range of 10 MW. The transmission power measurements had been averaged over 15 minutes so that a comparison with a high resolution in the time domain was not possible.

The receiver located outside the influence zone of the power lines featured much higher RMS values of more than 60 m during the same period. This may be accounted to the difference in GNSS receiver models. However, it shows that the receiver model seems to have a higher influence of the RMS value than the power lines.

The NMEA data recorded during the dynamic tests did not reveal significant differences between the influence zones with respect to the signal-to-noise ratio (SNR) on either of the two test sites. This parameter could only be recorded from one of the three GNSS receiver systems. The differences between the SNR values recorded at the same time on different days was higher than the difference between the SNR values collected in and outside the influence zone of the power lines. It seems that the satellite constellation and the time of the day have a stronger influence on the signal-to-noise ratio than the presence of power lines.

The satellite geometry (PDOP) was not negatively affected by the power lines. This quality parameter rises when the satellite constellation degrades. Inside the influence zones, the PDOP was not significantly higher than outside. However, the value varied between the different systems and the subsequent periods of measurement.

The DGPS correction status is the most important measure for the operability of steering systems. To function properly the status must have a value of 4 (RTK). When reporting status 1, 2 or 5, the receivers have either lost connection to the reference system or other quality measures such as PDOP or RMS are out of range. Thus, the position cannot be determined with the highest available accuracy.

Steering systems operated with RTK-GNSS receivers are automatically deactivated when the correction status degrades.

In Table 4 the relative amount of RTK-corrected and not RTK-corrected positions are summarized for all influence zones. The results have been aggregated over all sites and periods of investigation.

Table 4: Relative amount of RTK- (status 4) and not RTK-corrected (status 1, 2, 5) positions of three steering systems in different influence zones (aggregation over all six repetitions on two sites)

Site	Zone	System A		System B		System C	
		RTK in %	Not RTK in %	RTK in %	Not RTK in %	RTK in %	Not RTK in %
1	A (none)	100.0	0.0	100.0	0.0	57.7	42.3
	B (over2)	99.5	0.5	99.9	0.1	55.0	45.0
	C (over1)	99.8	0.2	100.0	0.0	54.8	45.2
	D (over1_2)	99.2	0.8	100.0	0.0	56.5	43.5
	E (under)	99.8	0.2	100.0	0.0	56.0	44.0
	F (under_over2)	100.0	0.0	100.0	0.0	56.6	43.4
2	A (none)	98.7	1.3			97.0	3.0
	B (over3)	99.5	0.5			96.5	3.5
	C (over2)	100.0	0.0			98.2	1.8
	D (over2_3)	100.0	0.0			98.9	1.1
	E (over_1)	100.0	0.0			97.4	2.6

The measurements recorded from system B on site 2 were partially corrupted and could therefore not be analyzed. System C failed to receive or process correction data on site 1 for almost 50 % of the time. This phenomenon occurred inside and outside the influence zone of the power lines. On site 2 the mean availability of correction data was 97.6 %. The system failed to receive correction data within and outside the zone of influence of the power lines. In most cases (307 positions) the vehicle was located outside the zone of influence.

System A was operational 99.7 % of the time on site 1. An overall of 65 positions (approx. 1 minute out of 5 hours and 45 minutes) without correction were recorded, all of them in the influence zone of the power lines. On site 2, 189 positions where not RTK corrected and only 14 of them occurred in one of the influence zones. The majority of not RTK corrected positions occurred outside the influence zones of the power lines.

System B was available 99.9 % of the time on site 1. The correction data was not available for four positions which were in the influence zone of the underground line (Figure 2).

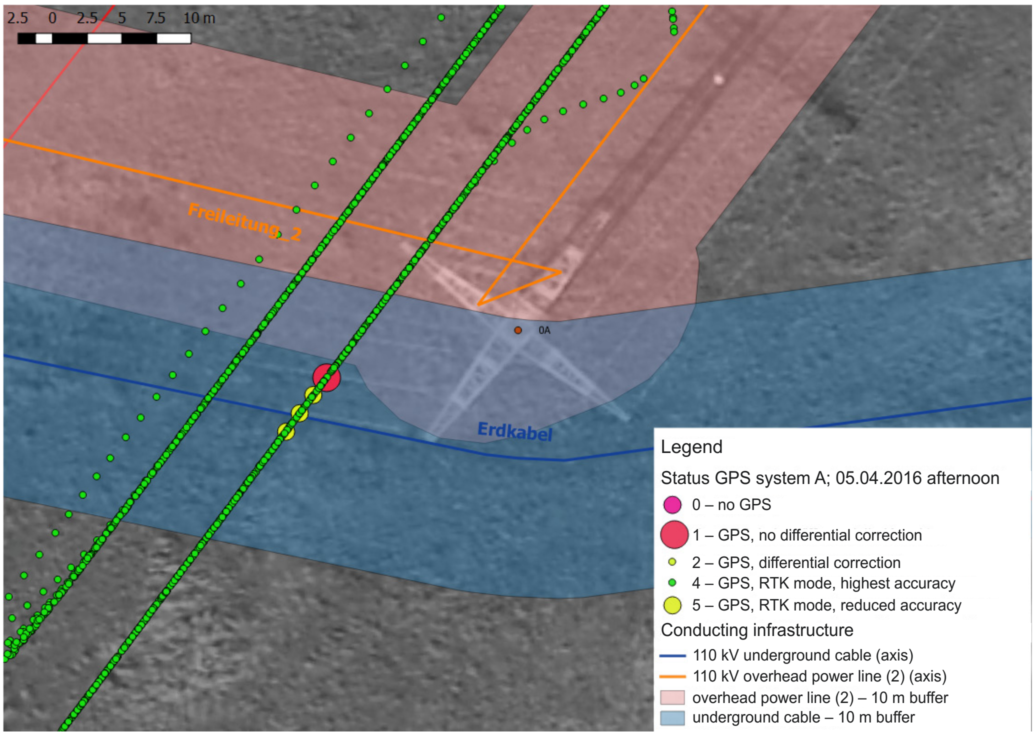

Figure 2: signal degradation in the influence zone of an underground power line

Discussion

The analysis of data collected with the three different steering systems on two sites did not reveal a relation between the presence of power lines and the operability of GNSS-based automatic steering systems. Neither underground nor overhead power lines had a significant effect on the quality of position data and the reception of correction data from a cellular network. An influence of quality parameters such as PDOP or pseudo range RMS can be neglected. Degraded position data was observed both within and outside the zones of influence of the power lines under investigation

The observations were supported by static tests under and far-off the power lines. The standard deviation of pseudo range measurements was even higher outside the zone of influence of the power lines. This effect may also be accounted to the difference between the receiver models.

One steering system performed poorly on site 1, while the other two systems were operated with almost no position outages. This emphasizes that faulty operation or configuration of steering systems has a larger influence on their operability than the presence of power lines.

The reliability of positioning varied substantially between the investigated steering systems. It can be concluded that the quality of hardware and signal processing have a larger influence on operability than power lines.

The lines were not under full power load. Maximum power load was outside the periods of measurement campaign on both sites. In addition, the power load was only available as an aggregate over 15 minutes so that the relation between power peaks and signal degradation could not be investigated. The limited scope of the investigation period restricts the significance of the conclusions. The influence of environmental factors such as ionospheric activity, temperature and humidity are not fully covered by a period of four days.

Conclusions

A measurement campaign in the influence zone of overhead and underground power lines was conducted in order to investigate the influence of the power lines on the operability of GNSS-based automatic steering systems.

Three tractors with steering systems were operated over two days on two different sites. The presence of power lines did not have a significant effect on the operability of the steering systems. The quality of installation and a correct configuration had a large influence on the reliability of the systems. One system failed to operate more than 50 % of the time on one site without any obvious influence of the power infrastructure.

Future measurements should be coordinated with the operator of the power lines more closely in order to match with times of maximum power load and to record power load with a higher resolution in the time domain. It is also suggested to extend the measurements over a longer period so that a wider variety of environmental influences can be covered.

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