Accurate High-Sensitivity GPS for Short Baselines

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Key words: Positioning, GPS, High-Sensitivity GPS, Low Cost GPS

SUMMARY

Improving efficiency for positioning tasks is an important responsibility for geodesists. In the context of this paper efficiency means to achieve of the same position quality with a decrease in costs. If it would be possible to use low-cost receivers, such as navigation type receivers for the geodetic accuracy levels, the costs could be considerably reduced. The only high-sensitivity GPS receiver available on the market, that may output phase data, is the u-blox LEA-4T. This paper presents the first results obtained using a u-blox LEA-4T and a notebook for data storage via USB-interface. The baselines ranging from 150 m to 7.7 km distance were determined using a receiver of geodetic accuracy level as reference station.

This paper will show that the u-blox LEA-4T may be used to determine coordinates in post-processing. The observation period has to be at least 20 minutes. In order to achieve higher reliability and accuracy 30 minutes have to be preferred. The accuracy levels obtained are 8 cm for a coordinate component. The baseline length between 150 m and 7.7 km has minor effects on quality parameters. In a multipath and shadowing free environment the accuracy level is better than 2 cm for 20 minutes observation time. This is a level that already meets the demands for geodetic applications.

ZUSAMMENFASSUNG

Eine wichtige Aufgabe für den Ingenieurgeodäten ist die Effizienzsteigerung bei der Positionsbestimmung. Das bedeutet, dass die selbe Positionsbestimmungsgenauigkeit mit geringerem Geldeinsatz erreicht werden soll. Wenn es möglich wäre, Low-Cost Empfänger wie z.B. Navigationsempfänger zur Positionsbestimmung auf geodätischem Genauigkeitslevel einzusetzen, könnte der finanzielle Einsatz deutlich reduziert werden. Der einzige am Markt verfügbare High-Sensitivity GPS-Empfänger, der Phaseninformationen ausgeben kann, ist der u-blox LEA-4T. Dieser Beitrag stellt die ersten Ergebnisse vor, die mit diesem Empfänger und einem Notebook zur Aufzeichnung via USB-Schnittstelle übermittelten Phasendaten gewonnen wurden. Die Basislinien zwischen 150 m und 7,7 km wurden mit einem geodätischen Empfänger als Referenzstation gemessen und ausgewertet.

Der Beitrag zeigt, dass der u-blox LEA-4T dafür geeignet ist, im Post-Processing Koordinaten zu bestimmen. Die Beobachtungsdauer muss mindestens 20 Minuten betragen. Um eine höhere Zuverlässigkeit und Genauigkeit zu erreichen, ist die Beobachtungsdauer auf 30 Minuten zu erhöhen. Die erreichte Genauigkeit beträgt 8 cm für eine Koordinatenkomponente. Die Basislinienlänge zwischen 150 m und 7,7 km hat nur geringen Einfluss. Für mehrwege- und abschattungsfreie Umgebungen können sogar unter 2 cm für 20 Minuten Beobachtungsdauer sichergestellt werden. Das ist ein Niveau, dass geodätischen Anforderungen genügt.

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1. INTRODUCTION

Improving efficiency for positioning tasks is an important responsibility for geodesists. In the context of this paper efficiency means to achieve of the same position quality with a decrease in costs. One possibility to improve efficiency is to bypass spending a high amount of money for geodetic GPS receivers. These receivers should be defined as delivering some cm in real time and mm to cm in post-processing by using phase data. If it would be possible to use low-cost receivers instead, such as navigation type receivers to reach the accuracy levels specified above, the costs could be considerably reduced. First investigations regarding Garmin navigation receivers were carried through by the University of Nottingham (e.g. HILL et al. 1999, HILL et al. 2001). The interface for raw phase and code data is neither documented nor officially supported by Garmin. In 2003 the author published the first results of his investigations using the same receiver type (SCHWIEGER 2003). The publications of the following years provided ongoing results. In SCHWIEGER & GLÄSER (2005) and SCHWIEGER & WANNINGER (2006) positioning in post-processing on the 2-cm level was presented for baselines up to 1.1 km and observation periods of 30 minutes. Additionally it could be shown that the accuracy for kinematic positioning was on the same level.
But the interface is still not supported by Garmin, so the author is looking forward to find other low-cost GPS receivers providing the code and phase information via a documented interface. The only low-cost variant available on the market is the u-blox module LEA-4T respectively the evaluation kit AEK-4T. It has to be mentioned that the follow-up module LEA-5T does not show these features. This paper presents the first results obtained using a u-blox LEA-4T and a notebook for the storing of data transmitted via the USB interface. The baselines were determined using a geodetic receiver as reference station.

2. HIGH-SENSITIVITY GPS

2.1 Overview

As described e.g. by WIESER & HARTINGER (2006) high-sensitivity GPS receivers provide positions even in case of low quality signals. High-sensitivity is defined as the possibility to track signals below -160dBW. The low signal strength may be caused by attenuation, multipath or non-light-of-sight signals. The advantage of the high-sensitivity receivers is the higher availability, the disadvantage is the lower quality of the available position. In general, the receivers use code measurements as well as phase measurements to calculate positions. The code measurements provide the navigation solution in real time. The phase measurements are necessary to smooth these code data. Thus, the navigation solution is more reliable and gains accuracy. According to SEEBER (2003) phase-smoothed DGPS solutions below 1 m may be obtained in comparison to 2 to 5 m with a pure code solution. The high-sensitivity receivers as well as all other low-cost GPS and GNSS receivers do not provide any phase solution that is essential to reach the mm to cm level required for most geodetic applications.

Thus, for the investigations described in this paper the possibility to store raw code and phase measurements is of great importance. The ability to track below -160 dBW is of minor importance.
In SCHWIEGER (2007) receivers of different manufactures are compared regarding availability, reliability and accuracy of the real time solution. Additionally, the possibilities to receive the code and phase measurements via a documented interface are analysed. The only receiver showing the technical specification and at the same time has the allowance to fulfill these specifications was the u-blox LEA-4T. This is still the case nowadays. The follow-up model of the u-blox company, the LEA-5T module does not offer these possibilities.

2.2 LEA-4T Receiver Characteristics

Figure 1 presents the evaluation kit AEK-4T including the antenna, the USB interface cable as well as the box for the LEA-4T module on the left side, additionally the module LEA-4T is presented on the right side. To give you an impression of the size imagine 5.5 x 5.5 x 2.4 cm for the box and 1.7 x 2.2 cm for the module itself.

Figure 1: u-blox evaluation kit AEK-4T and u-blox LEA-4T module

The evaluation kit includes the software u-center allowing to configure the transmitted data format and messages as well as to survey the data received via the configured interface. The software offers different possibilities to present numerically and graphically the satellite numbers, the elevation and the azimuth of the satellites as well as numeric quality indicators like standard deviations in 2D and 3D as well as geometric indicators like the PDOP (Position Dilution of Precision). The most important feature of the software is the possibility to configure the interface. Here the receiver is connected via USB connection and the software redirects the computer USB automatically to a serial port. In general this connection is realised automatically by the software. In this case or after successful manual port definition, the receiver tool bar in the upper left corner shows a green sign (compare fig. 2). The pull-down menu “View” offers the possibility to define the format (NMEA or ubx) that should be given out as well as the content of the format: the definitions of messages. U-center offers the choice between the well-known NMEA (National Marine Electronics Association) ASCII format and the well-documented binary ubx format. Since raw measurements are available via ubx only, this option has to be chosen. Thereafter the messages received on the computer have to be defined. Here the message RXM-RAW (Raw Measurement Data) was chosen to store the code and phase data in a file to be defined at the start of each measurement process.

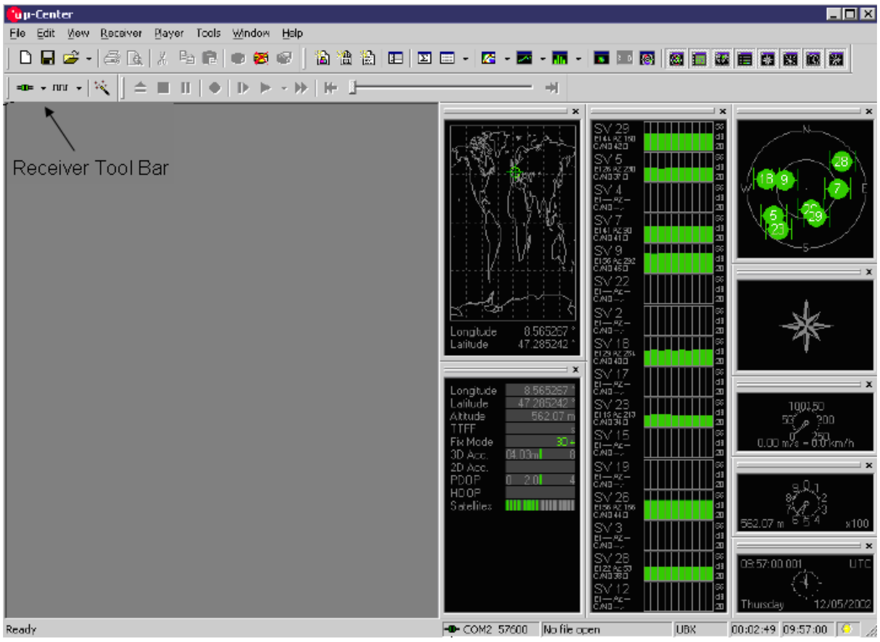

Figure 2: U-center software showing a connected receiver

3. DEVELOPMENTS AND PREPARATION

3.1 Hardware

In general no type of navigation receiver, neither the Garmin eTrex Vista investigated e.g. in SCHWIEGER (2003) nor the u-blox LEA-4T has a possibility to be fixed on and centralised above a well-defined point. A defined orientation to north is not possible as well. The second is important to eliminate antenna errors by orientation of u-blox receivers in the same way and applying determined antenna corrections (please compare section 3.3). In SCHWIEGER & GLÄSER (2005) a special antenna mount including a metal base plate was constructed for the Garmin eTrex Vista receiver to eliminate ground reflections. As shown the azimuth and elevation dependent corrections reach values up to 2.5 cm and enlarge the values of the Garmin eTrex Vista without base plate by a factor of approximately 2.5 (SCHWIEGER & WANNINGER, 2006). For this reason it was decided to construct a new adapter that avoids the reflection effects of the base plate. In contrast the ground reflections are not eliminated by the constructed adapter. Figure 3 presents this simple adapter that allows to fix the antenna with an accuracy of < 1 mm on the metal surface. The connection to the tribrach is realised by the Leica-system of forced centering device. For identical orientation and correct assignment of antenna corrections the antenna cable is always directed towards north.

Figure 3: Constructed adapter for the u-blox antenna

3.2 Software

Most commercial and scientific GPS evaluation software packages can deal with, besides proprietary formats, the receiver independent exchange format (RINEX). As described in section 2 the u-blox receiver delivers the code and phase data in a binary format: the ubx format. This has to be transformed into the RINEX format. For this task the software TEQC (UNAVCO 2008) may be used. It is available in the internet without the need of a license. As described in section 4.2 the follow-up processing of the code and phase data is realized by using the software Wa1 provided by the Technical University of Dresden as well as by Leica Geo Office.

In order to avoid contact with command-line driven commands the graphical man-machine interface “GPS tools” was developed (BUHAI 2008). It has the possibility to convert ubx format to RINEX format (see figure 4) as well as to perform the Wa1 processing. For Wa1 processing most of the evaluation options can be seen in figure 5. The observation time, the reference site, coordinates, antenna types, elevation cut-off angles as well as excluded satellites may be entered interactively. As an additional tool it is possible to divide a long observation period into multiple short observation periods and to automatically process all the short time periods using the same evaluation parameters like elevation cut-off angle or elimination of individual satellites. For example a two hours observation period may automatically be cut into blocks of 10 minutes and automatically be processed with an elevation cut-off angle of 15°. After processing all output and protocol files will be shown on the screen. Summarising „GPS tools“ may be used to generate RINEX files for processing the data externally using Leica Geo Office or to generate RINEX files and consequently process the data using Wa1. For more detailed information the author refers to BUHAI (2008).

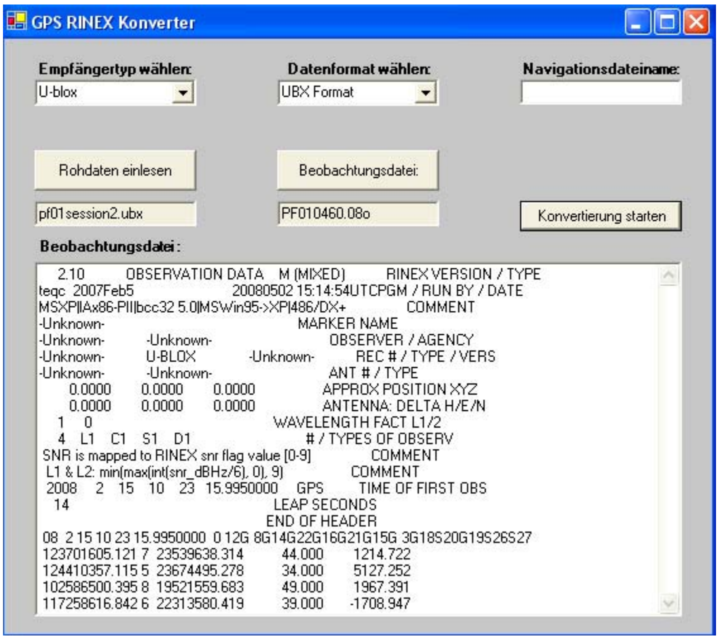

Figure 4: Screen of RINEX converter within „GPS tools“

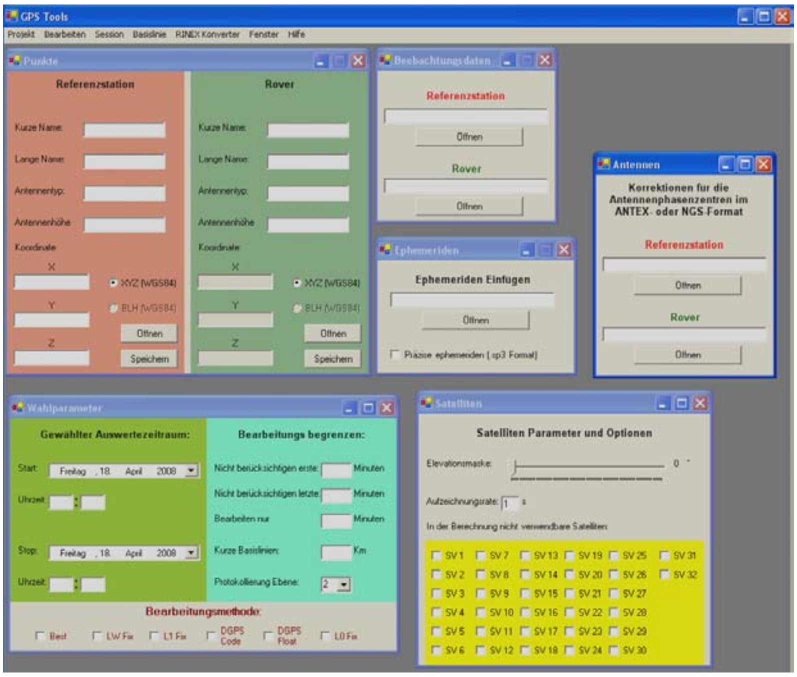

Figure 5: Processing options of „GPS tools“ based on Wa1

3.3 Antenna Calibration

As shown by SCHWIEGER & WANNINGER (2006) antenna calibration is an important task to obtain accurate positions using low-cost GPS receivers. The offsets as well as the elevation and azimuth dependent corrections are of importance. The determination of these quantities was realized by the Geodetic Institute of the Technical University of Dresden using their well known pillar network and equipment such as the automatic rotation instrument. The automatic rotation instrument allows the determination of azimuth dependent corrections. The evaluation was carried through by means of the antenna calibration module Wa1/Kalib of the WaSoft GPS processing software. The whole procedure delivers relative phase centre corrections that are converted into absolute phase centre corrections by using the absolute offsets and corrections of the reference antenna. For more details about the calibration procedure and the available hard- and software is referred to FREVERT et al. (2006).


Figure 6: Automatic rotation instrument (without u-blox antenna) and pillar network at the Technical University of Dresden (source: TU Dresden)

The measurements and the determination of the offset as well as the phase centre corrections are referred to the antenna reference point located in the middle on the antenna upper edge. The antenna cable was directed towards north as defined before. Figure 7 shows the obtained results. The offsets range from -0.1 mm and 5.9 mm for the horizontal components to -17.0 mm for the height component. The negative value for the height component is caused by the choice of the antenna reference point. The phase centre variations range from around -10 mm to +15 mm. The magnitude of the offset and variations clearly shows that the antenna calibration must not be omitted; especially if the u-blox receiver is used for mixed baseline solutions together with other receiver types like e.g. a Leica ATX 1230 antenna or for positioning within a network solution of a service provider like SAPOS or ASCOS. The results of the calibration are stored in an ATX file (Antenna Exchange Format) that may be included into Wa1 as well as into Leica Geo Office.

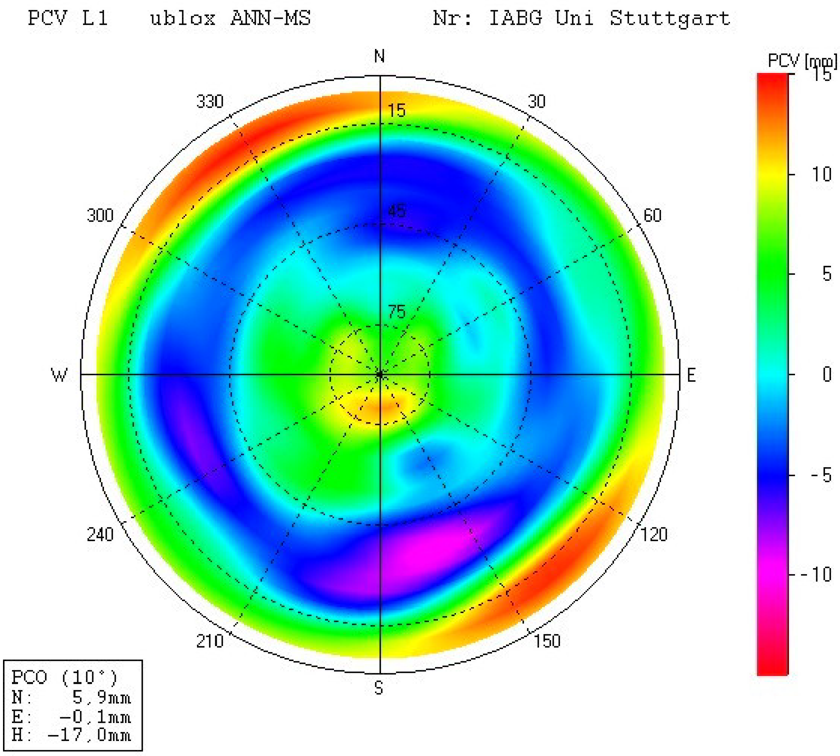

Figure 7: Offsets and phase centre variations for a u-blox LEA-4T antenna provided by the Geodetic Institute (Source: TU Dresden)

4. TEST SCENARIOS

4.1 Concept and field survey

The measurements effected should be used to investigate the accuracy and reliability of the tested receiver. For this task differential post-processing solutions are determined using Leica Geo Office and Wa1 Software. The measurements should be suitable to investigate the quality in dependence on

- baseline length,
- observation period and
- multipath effects.

For control purpose the measurements should be repeated another day in the same order.
The dependence on the baseline length should be investigated using different reference stations in combination with the same rover data of the u-blox receiver. Additionally two German Continuously Operating Reference Stations (CORS) networks were integrated for post-processing purpose. Observation data for so called VRS (virtual reference stations) were generated. Concerning the procedure and the general functionality of the CORS networks the author refers to WANNINGER (2006). The two CORS networks used were SAPOS (SAPOS 2008) and ASCOS (ASCOS 2008). The respective observations were generated for coordinates within the Stuttgart-Vaihingen pillar network (figure 9). These data should be used to demonstrate the possibilities using low-receivers within CORS networks. The

experiences are not documented within this paper, but some of the results are used later on in this section.
The dependence on the observation period can be analysed by observing a long time period and then subdivide this long period into short intervals. This is supported by the development of an respective software option within the software „GPS tools“ (compare 3.2). For different elevation masks the data is recorded with 0 degree elevation and during processing different elevation masks may be tested. Dependence on multipath and shadowing is checked in a simplified manner: points with and without multipath sources and shadowing effects were observed.
The measurements of the u-blox receiver were carried through in Stuttgart-Vaihingen, where the IAGB (Institute for Application of Geodesy to Engineering) has a pillar network at its disposal. The coordinates of these pillars are known at mm-level. Each of it is stable erected using reinforced concrete and has a forced centering device. Figure 3 shows a detail of the upper side and figure 8 presents the whole pillar including the u-blox receiver on top.

Figure 8: u-blox receiver within IAGB pillar network

Pillar P6 was chosen as a reference point and equipped with a Leica System 1200 receiver, thus baselines between 260 m and 410 m were measured with respect to the pillars P1, P4 and P3, that were measured using the u-blox receiver. Pillars P1 and P4 are partly shadowed by trees nearby. In the city centre of Stuttgart a second reference station was equipped with a Leica system 1200 receiver in order to include different baseline lengths for the investigations. Here the station was built up on a tripod. The respective baselines are around 7.7 km. Table 1 gives an overview of the measured baseline lengths and the observation times and periods. Figure 9 gives an overview of the pillars used in Stuttgart-Vaihingen and the measured baselines. On both observation days the measurement periods were fixed to 2 hours at identical times of day.

The measurements were carried through on January 31st and February 15th 2008 with a sampling rate of one second at identical observation times. For the reference station in Stuttgart city centre no given coordinates were available. For this reason the coordinates have to be determined in relation to the given coordinates of the reference station in Stuttgart Vaihingen exclusively using the Leica measurements. Surprisingly the eight hours of data provide different coordinates for the two observation dates. The coordinates differ about 4 cm per coordinate. This is far beyond the specified post-processing accuracy of the Leica GPS receivers and highlights the problem that even for high-accurate GPS receivers errors on the cam-level may occur. BUHAI (2008) used two different reference coordinate sets for the two days. In this paper another strategy is pursued. To decide which of the two coordinate sets is correct and reliable the CORS networks VRS data were taken into consideration for comparisons. For the first day the maximum 3D-deviation of the SAPOS and ASCOS solutions with respect to the baseline solution P6 - city centre is 5 mm; thus showing the high accuracy. In contrast the second day shows a maximum deviation of 11.2 cm. These results are quite inhomogeneous. These contradictions are not caused by the CORS data, since the author determined the coordinates of P6 using the CORS data and compared the results to the given coordinates as an additional control. The results show a high accuracy documented with maximum 3D-deviations of 9.3 mm. It has to be mentioned that a datum transformation has to be carried through before all the comparisons could be realised. Up to now the cause for this inhomogenity is not clear. The investigations are still ongoing. As a consequence for the 7.7 km baselines of the second day the data are not analysed within this paper.

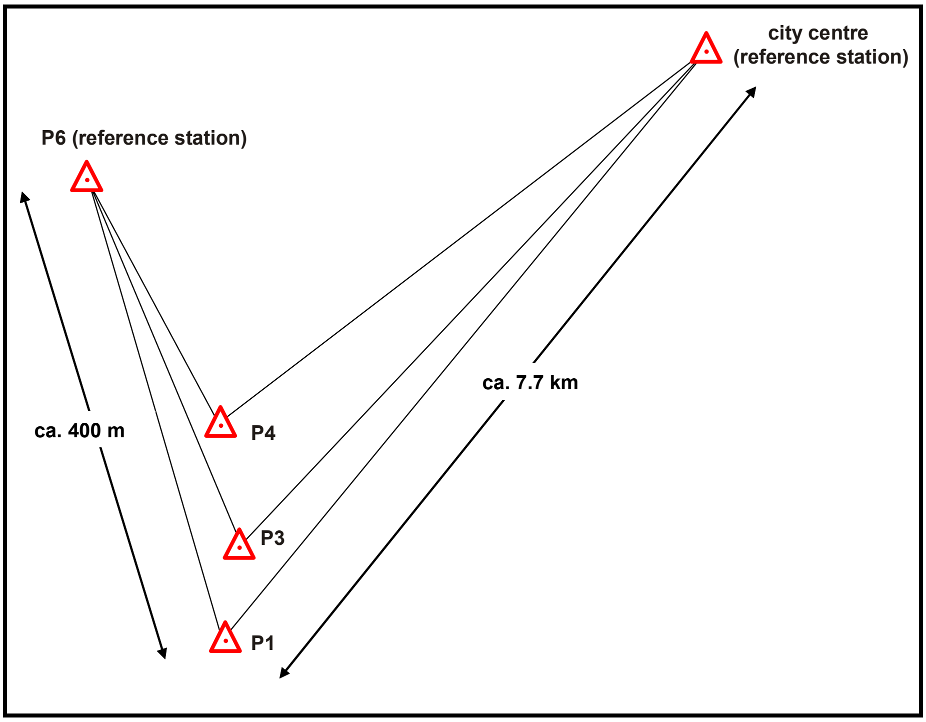

Figure 9: Pilar network Stuttgart-Vaihingen, Stuttgart city centre and measured baselines

Table 1: Realised Measurements

	baseline length in Vaihingen [km]	baseline length to city centre [km]	observation time on both days [hh:mm]
Pilar 1 (trees)	0.41	7.70	11:20 – 13:00
Pilar 3	0.37	7.69	13:40 – 15:40
Pilar 4 (trees)	0.26	7.69	09:00 – 11:00

4.2 Evaluation Procedure

As described in section 3.2 a new software „GPS tools“ was developed. It supports the processor by an interactive MMI and runs the RINEX converter TEQC as well as the software Wa1. In any case after RINEX conversion the evaluation was split up into the Wa1 processing and the Leica Geo Office processing lines. In both processing lines the antenna calibration parameters were introduced. Finally the comparison among different solutions with respect to reliability and accuracy based on the respective reference coordinates was carried through. Therefore the differences are transformed into local ellipsoidal coordinates (e.g. SEEBER 2003). Figure 10 gives an overview of the evaluation procedure.

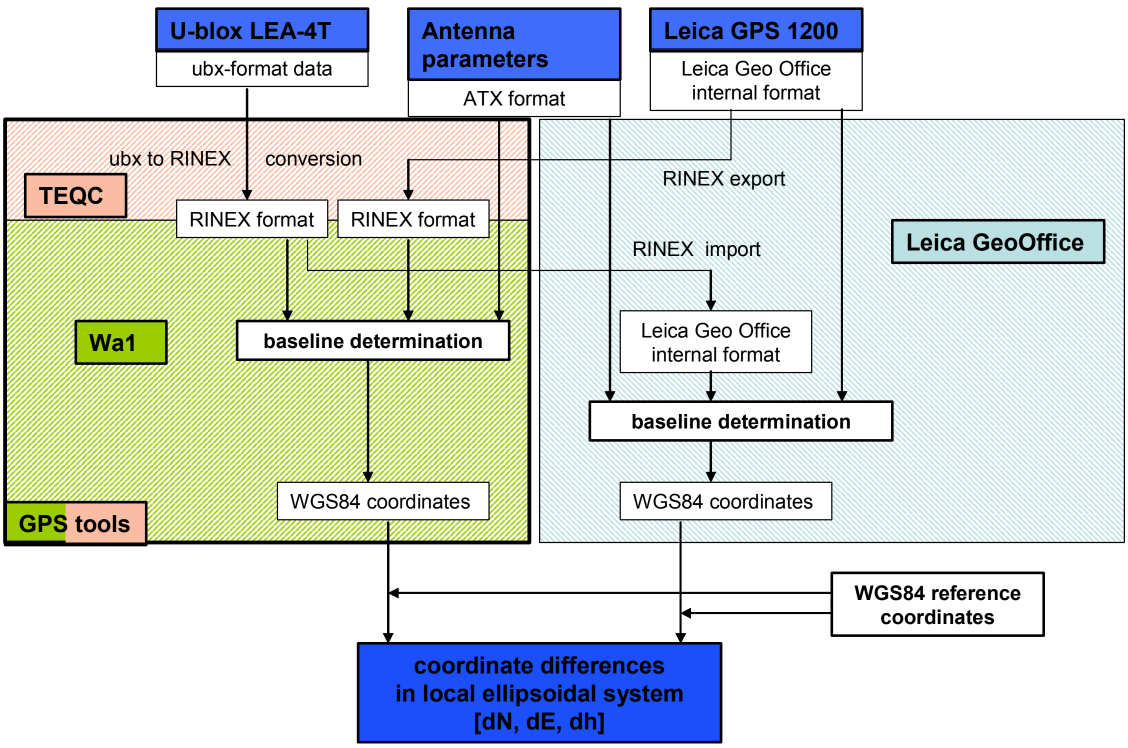

Figure 10: Evaluation procedure

5. RESULTS

5.1 General considerations

First of all the results for the three pillars with respect to the two reference stations are compared. As shown in table 2 the maximum deviation from the given coordinates is 3.6 cm in height, for horizontal coordinates the values are below 2 cm. No obvious difference between the solutions using the sub-km baselines (indicated with S = short in the table) and the 7.7 km baselines (indicated with L = long in the table) could be found. This means that no dependence on the baseline length can be proven. The same is valid for different measurement days; here S/1 and S/2. The deviations from the given coordinates are not worse for pillar P1, although the environment is shadowed by trees. It seems as if P4, that shadowed by trees too, has a disturbed environment. Within this research the reason could not be detected certainly. The measurement team reported that P4 was the point, where the car needed for power supply was parked nearest to the point. That could be the reason for multipath effects. In section 5.2 these effects are further investigated.
On the other hand table 2 shows that for short baselines the differences between Wa1 processing and Leica Geo Office processing reach a maximum of around 4 mm, for long baselines they reach 2.4 cm. Wa1 processing leads to a minor deviation from the given coordinates, especially for the height component. This means that the quality of Wa1 processing is superior to Leica processing for the u-blox data analysed up to now. This has to be validated in further investigations. In this paper the analysis of section 5.2 is realized using Wa1 processing only.

Table 2: Differences [mm] to given coordinates and between different software packages

differences [mm]		**given – Wa1**			**given - Leica**			**Wa1 – Leica** (absolute)		
Ref. st. / day	**pilar**	**dN**	**dE**	**dh**	**dN**	**dE**	**dh**	**dN**	**dE**	**dh**
S/1	1	-17.6	-1.7	-7.9	-17.3	-1.8	-12.1	0.3	0.1	4.2
	3	-8.7	-2.1	-12.7	-8.6	-2.4	-14.5	0.1	0.3	1.8
	4	-6.8	7.0	-24.8	-6.5	6.9	24.7	0.3	0.1	0.1
S/2	1	-18.9	-1.5	-9.9	-18.8	-1.4	-13.1	0.1	0.1	3.2
	3	-10.7	1.0	-20.2	-11.1	0.9	-24.3	0.4	0.1	4.1
	4	-5.1	7.4	-33.2	-4.6	7.1	-33.4	0.5	0.3	0.2
L/1	1	-18.6	-3.3	-2.0	-16.4	-2.1	-26.1	2.2	1.2	24.1
	3	-9.4	-4.0	-8.1	-7.4	-2.6	-28.5	2.0	1.4	20.4
	4	-7.5	2.9	-15.6	-5.6	3.3	-36.1	1.9	0.4	20.5

Table 3 provides the information that for identical processing software (here shown for Wa1 software) the repeatability of the results is at sub-cm level for the height component and below 0.5 cm for the horizontal coordinates. This is valid for different days as well as for different reference stations. The repeatability deviations are smaller than the deviation from the given coordinates indicating that systematic effects are still present. Up to now the investigations did not provide a clear answer with regard to this problem.

Table 3: Repeatability of Wa1 processing results, deviations between different reference stations and measurement days

differences [mm]	S/1 – S/2			S/1 – L/1		
pilar	dN	dE	Dh	dN	dE	dh
1	1.3	0.2	2.0	1.0	1.6	5.9
3	2.0	3.1	7.5	0.8	1.9	4.6
4	1.8	0.4	8.4	0.7	4.2	9.2

For further investigations the elevation cut-off angel was defined to 10°, since this seems to be the best compromise between a high number of observations using a low cut-off angle and a good quality using a high cut-off angle. In the second case, especially for short observation periods, the number of satellites is not sufficient to compute a solution or the geometry is not good enough (PDOP > 20) to obtain reliable results. For further details the author refer to (BUHAI 2008).

5.2 Dependence on observation period

As described in section 4.2 the 2 hours observation data were divided into data blocks of different short periods to determine the necessary observation periods for a required accuracy and reliability level. Therefore 60, 30, 20, 10 and 5 minutes data blocks were generated, processed and will be presented in the following. The subsequent figures show the standard deviations for each reference station. Each figure shows these standard deviations for the three components dN, dE and dh and the points P1, P3 and P4 in dependence on the observation period. For reasons of clarity the presentation is restricted to measurement day 1. Day 2 provides similar results for the short baselines.

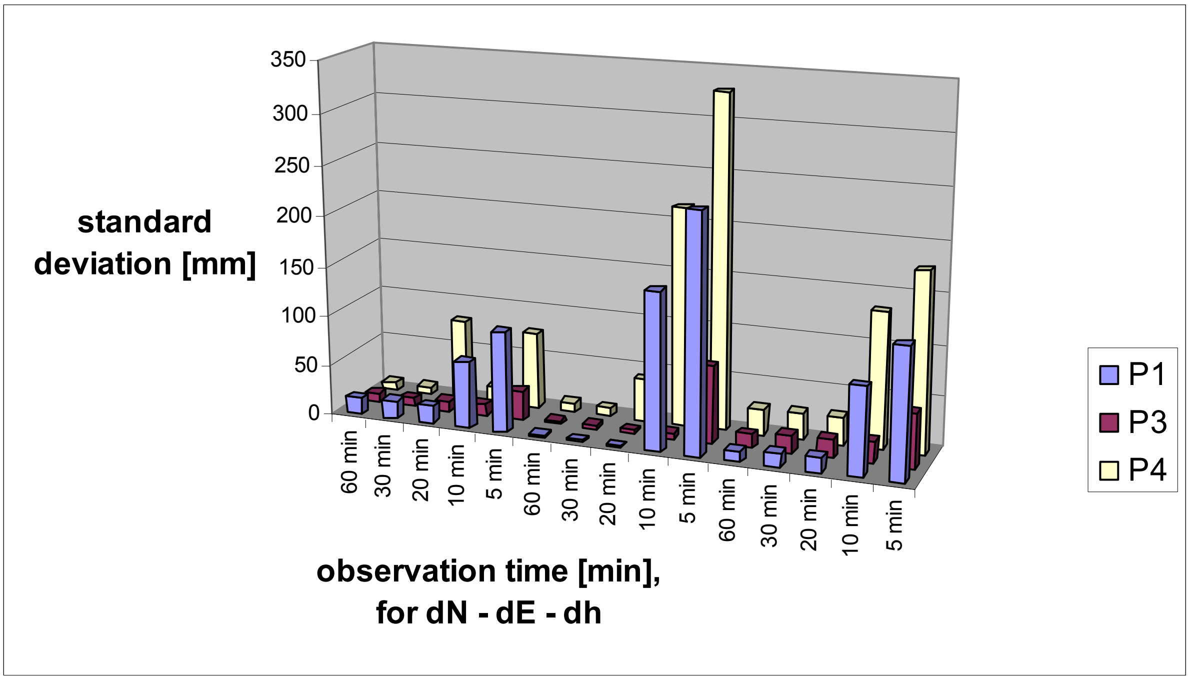

Figure 11: Accuracy in dependence on observation period for reference station P6

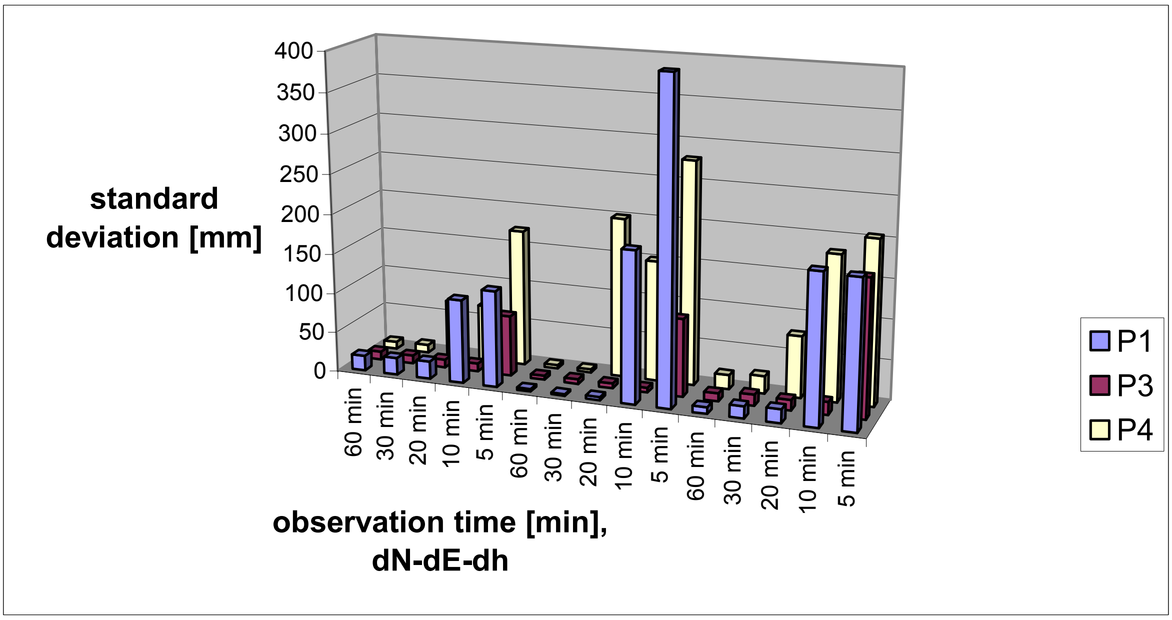

Figure 12: Accuracy in dependence on observation period for reference station city centre

Figures 11 and 12 clearly demonstrate that observation times of 10 or 5 minutes are not sufficient to obtain an accuracy keeping up wth the geodetic level. The standard deviations show values up to some dm. If the analysis is restricted to observation periods of minimum 20 minutes, one can say that for the short baselines the standard deviations are better than 8 cm. Regarding the 7.7 km baselines the coordinate standard deviations are also below 8 cm for all cases but one. In this case 20 cm is the value for dE of pillar P4. For 30 minutes baselines there is no standard deviation exceeding 2.7 cm. Outliers do not exist within the investigated data. The fact that 30 minutes periods can be used without problems is emphasised by table 4 showing the results with respect to availability and reliability. The availability is indicated by the percentage for no solutions; the reliability by the respective value for the float solutions. Thereby a float solution is defined as a solution for which the ambiguities could not be fixed to integer values. As a consequence the approximate non-integer solution has to be used as final (e.g. SEEBER 2003). For baseline lengths as described in this paper, this is a clear sign for erroneous data leading to a non-reliable solution. If one compares figures 11 and 12 to table 4, obviously a higher number of float solutions lead to worse standard deviations.

Table 4: Percentage of float solutions and no solutions in dependence on observation period

percentage [%]		**float solutions - reliability**					**No solutions - availability**				
period [min]		**60**	**30**	**20**	**10**	**5**	**60**	**30**	**20**	**10**	**5**
S1	**P1**	0	0	20	17	8	0	0	0	0	4
	P3	0	0	0	25	17	0	0	0	0	4
	P4	0	0	0	25	54	0	0	0	0	0
L1	**P1**	0	0	0	8	54	0	25	20	17	0
	P3	0	0	0	17	21	0	0	0	0	8
	P4	0	25	0	67	33	0	0	0	0	8

Additionally some more conclusion can be drawn from the data. As shown in the figures and the table in this chapter pillar P3 shows the most reliable and accurate results. Obviously there are no shadowing effects and no multipath environment. For this environment the results are even better than described before. The standard deviations are below 2 cm for short and even long baselines at an observation time of 20 minutes. Reliability and availability problems do not occur. Pillars P1 (shadowing by trees) and P4 (shadowing by trees and assumed multipath) show results worse by factors of approximately 4 to 10.

6. SUMMARY AND OUTLOOK

The ongoing research documented in this paper shows encouraging post-processing results regarding low-cost GPS receivers like the u-blox LEA-4T. Up to now the combination of the software packages Wa1 and TEQC provides the most reliable results. A special adapter was constructed for centering the high-sensitivity module.

This paper presents the results of first investigations using the LEA-4T for geodetic applications. The observation period has to be at least 20 minutes. To get a higher reliability and accuracy 30 minutes have to be preferred. For a coordinate component the achieved accuracy levels are 8 cm. The baseline length is of minor importance. In a multipath and shadowing free environment the accuracy level is better than 2 cm at an observation time of 20 minutes. This is a level already usable for geodetic applications. These results have to be validated within the ongoing research.

The paper also shows a very high repeatability accuracy of the positions, even if some systematic errors may still be contained in the data. Thus, this type of receivers is especially suitable for monitoring tasks, since for this application the repeatability is of highest importance. Systematic effects, if they are identical or similar for e.g. the same day time or the same season, would not influence the quality of a monitoring task.

ACKNOWLEDEGEMENTS

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Finally the author thanks Mr. Martin Knihs of IAGB, who constructed the adapter described in section 3.1.

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