SMARTPHONE RTK AND MOBILE GIS

Andreas Hoscislawski
University of Applied Sciences Karlsruhe, Germany, Moltkestr. 30, 76133 Karlsruhe, M.Sc., research associate, tel: +49 (0)7219252586, fax: +49 (0)7219252586, email: andreas.hoscislawski@hs-karlsruhe.de, Web-Site: www.navka.de

Julia Diekert
University of Applied Sciences Karlsruhe, Germany, Moltkestr. 30, 76133 Karlsruhe, Dipl.-Ing. (FH), research associate, tel: +49 (0)7219252329, fax: +49 (0)7219252329, email: julia.diekert@hs-karlsruhe.de, Web-Site: www.navka.de

Reiner Jäger
University of Applied Sciences Karlsruhe, Germany, Moltkestr. 30, 76133 Karlsruhe, Prof. Dr.-Ing., Head of Geomatics Institute at IAF, tel: +49 (0)7219252620, fax: +49 (0)7219252597, email: reiner.jaeger@hs-karlsruhe.de, Web-Site: www.navka.de

Abstract English

The paper describes developments on mobile GIS algorithms and systems carried out in the frame of the B.W. RaD project described at www.navka.de.

In opposite to desktop GIS, mobile GIS covers an extended spectrum of applications. Mobile GIS is characterized by the use of smartphones and tablets. Here the availability of additional hardware-, communication- and software infrastructures, namely mobile internet access, the use of GNSS and MEMS-sensor data, and the implementation of respective positioning and navigation algorithms are essential. Based on the 15 parameter navigation state vector **y**(t) mobile GIS applications can be provided in terms of different kind of geo-referencing and identification techniques of objects. The state **y**(t) comprises the 3D position, velocity, orientation, acceleration, and further the rotation rates of the navigated body (b), e.g. a smartphone, and the sensor calibration parameters s.

As concerns the positioning part (x, y, z) of **y**(t), the paper describes at first the development of a low-cost high precise GNSS RTK system, implemented under Android for the use on smartphones and tablets as GNSS-controller, and the implementation of further mobile GIS features.

The second part deals with the development of the geo-referencing system component for the mobile GIS KALEO-Georeferencer™, developed together with teXXmo Mobile Solutions (www.texxmo.com). The geo-referencing component of the KALEO uses the full navigation state vector **y**(t), computed with the NAVKA-algorithms based on low-cost GNSS and MEMS sensor data, together with a laser distance-measurement unit. The respective KALEO mobile GIS system component enables the contact-free 3D geo-referencing or identification of objects by their position, stored in the GIS database, as well as all kind of mobile GIS applications, related to the logging, administration, modelling, visualization and analysis of precise 3D-positions of objects and data.

Key words: Smartphone RTK, Low-Cost GNSS, MEMS, Multisensor Navigation Platforms, Mobile GIS, Android, Geo-referencing, RtkLib, NAVKA-Algorithms

1. MOTIVATION

Smartphones and other tablet computers from different manufacturers are on the market since 2007. Most of them have positioning modules for location based service applications (LBS) on board. Apples iPhone for example has a GPS module in since 2008 and is able to track additionally GLONASS signals since 2011. This enhances the reliability of a position solution indeed, but not the global positioning accuracy, which is in the range of multiple meters. One can assume that this will remain in the near future, too.

One reason is certainly, that the device manufacturers are not yet focused on high precise positions and further not on enhanced mobile GIS solutions, which can be based on the use of the full navigation state vector **y**(t). From their point of view the current position accuracy meets the requirements for most of the mass market applications on mobile devices (apps), like car and pedestrian navigation or LBS. Also the widely extended usability of mobile systems making use of GNSS/MEMS/Camera integration, and so the full navigation state vector **y**(t) ("navigation is more than positioning") are still - but not always (www.ikegps.com, www.navka.de) - underestimated. But things will change, and e.g. with the upcoming GALILEO system and the improvement of the GNSS-signal quality and multi-signal availability, also a technical redesign of the hardware can be expected. In that context the paper proves, that mobile GIS with smartphones and tablets is possible already right now by GNSS/MEMS integration, and expected to reach the mass-market soon.

As GNSS OSR (observation space related) and SSR (state space related) correction data is needed for a high accurate positioning and navigation state vector **y**(t), mobile devices like smartphones and tablets are highly predestined for mobile GIS, as they can receive that data via mobile internet (NTRIP standard), as well as by Wi-Fi in case of a local GNSS-reference station.

Due to the limitation on the size of precise "geodetic" antennas, it is not yet possible to integrate geodetic-grade a GNSS antenna with good signal-reception characteristics directly into a smartphone, although smartphones are already equipped with MEMS sensors to compute high precise navigation state vectors **y**(t). So, in order to set up a full operating navigation system for positioning and orientation, a smartphone has to be mounted together with geodetic-grade GNSS antenna on a common platform frame, which is of course possible. Else, a pure smartphone however can always be used as a GNSS-controller for processing the GNSS-data received e.g. via Bluetooth-communication from a nearby GNSS-receiver with high precise geodetic-grade GNSS antenna (fig. 2.1). So "smart-phone RTK" has been borne, and has been realized for mobile GIS-applications, as shown in that contribution.

In opposite to a smartphone, a MEMS-sensor equipped tablet can technically be upgraded with a medium-precise (3 cm of phase center variation) helix antenna. So GNSS/MEMS tablets, like the developed KALEO-Georeferencer™ (fig. 6.2) are able to produce the full navigation state **y**(t) and enable, equipped with a laser distance measurement unit, extended mobile GIS applications. These are related to the contact-free 3D geo-referencing or identification of objects by their position, stored in a mobile GIS database and further all kind of mobile GIS applications, which are concerned with the logging, administration and analysis of 3D-precise positions of objects and data.

2. SMARTPHONE RTK - EXEMPLARY SYSTEM DESIGN

Smartphone RTK has been developed by the NAVKA RaD team at the University of Applied Sciences Karlsruhe in the frame of the joint Baden-Württemberg RaD project “GNSS-supported LowCost Multisensor Platforms and Algorithms for Navigation and Georeferencing (NAVKA)” (www.navka.de).

The so-called navigation state vector parameters

$$\mathbf{y}(\mathrm{t}) = \left[x^e y^e z^e | \dot{x}^e \dot{y}^e \dot{z}^e | r_b^e p_b^e y_b^e || \ddot{x}^e \ddot{y}^e \ddot{z}^e | \omega_{eb,x}^b \omega_{eb,y}^b \omega_{eb,z}^b | \mathbf{s}\right]^T \quad (2\text{-}1)$$

to be computed in the NAVKA multisensor-multiplatform algorithmic concepts from GNSS and MEMS sensor data enable, besides various navigation applications for people and vehicles, also mobile GIS applications, related to different kind of geo-referencing and identification techniques of objects. The state $\mathbf{y}(\mathrm{t})$ (2-1) comprises the 3D position, velocity, orientation (roll (r_b^e), pitch (p_b^e) und yaw angle (y_b^e)), acceleration in the earth fixed frame (e), and further the rotation-rates of the navigated body (b), e.g. a smartphone, and finally the sensor calibration parameters $\mathbf{s}$.

As concerns the developed demonstrator system for a high precise RTK solution for smartphones and tablets for mobile GIS applications, some decisions regarding hard- and software had to be made to get a flexible and optimized system regarding costs and benefits at the same time.

Samsungs table Galaxy Note 10.1 was selected to be GNSS processing, communication and user interaction unit at same time . It has a Quad-Core Cortex-A9 1.4 GHz processor, 2 GB LPDDR2 RAM, which has enough power for GNSS processing and a 10.1″ display, which is large enough for mobile GIS applications. WiFi and HSPA+ are included and can be used for correction data reception. Its Bluetooth module can be used to connect a GNSS receiver without need of cable connection. The operating system is Googles Android 4.0.4 ”Ice Cream Sandwich”. Androids market share is at 81% in 3rd quarter 2013 and thus already in possession of many users. This means that no additional investment is necessary for most of user.

In order to get an accurate position solution in the centimeter range, the carrier-phase and Doppler observations of a GNSS receiver have to be processed together with the data of one or more reference stations. For this purpose a GNSS processing software is needed which is low priced, has a certain functional range and is yet reliable. While own RTK algorithms are also under development by the NAKA team, the basic requirements for “Smartphone RTK” were regarded in first instance to be fulfilled by the open source processing engine RtkLib 2.4.2 (Takasu, 2009). It is written in ANSI C (C89) and their functionality can be compiled for many operating systems like Windows or Linux. For Linux the RtkLib includes a command line program named RtkRcv which can be easily built with a given makefile for the GNU Compiler Collection (GCC) on Linux. Due to the fact that Googles Android operating system is based on Linux kernel and the Android NDK uses GCC, the RtkRcv can be compiled for Android. Further advantage of using RtkLib is that it supports various positioning modes for standard and precise positioning in real-time or post-processing. It supports additionally many GNSS receivers' proprietary messages like NovAtel, u-blox or Javad. The receiver interface allows to include additional receiver messages, which was done for the Septentrio AsteRx1 receiver as example. The RtkRcv build for Android is not restricted on one type of receiver hardware and one or more carrier frequencies can be used. For RTK measurements the RtkLib supports many standard formats and protocols for GNSS like RTCM, NMEA and NTRIP.

For a first evaluation of the system an u-blox LEA-6T L1 GNSS receiver was chosen. It delivers the raw GNSS observations (pseudorange, carrier phase and Doppler) and has a update rate of 5Hz. It is one of the cheapest consumer-grade receivers whose development kit is available for about 300€ and was already successfully used for short baseline observation in geodetic monitoring application (Zhang, 2013) with lengthes less than 500m. The power supply is realized with a mobile power bank. It costs about 25€ and has 6000mAh with loading status indicator (fig. 2.1).

The data communication between the receiver and the Galaxy Note is realized by a RS232 to Bluetooth adapter (about 150€) which has his own accumulator in. For the data transfer of the raw observations (RAW) and subframe data (SFRB) from u-blox receiver to the tablet less than 5 kbit/s are needed with an observation rate of 1 Hz. Thus, even at a higher observation rate a Bluetooth 1.0 with 732 kbit/s would be sufficient.

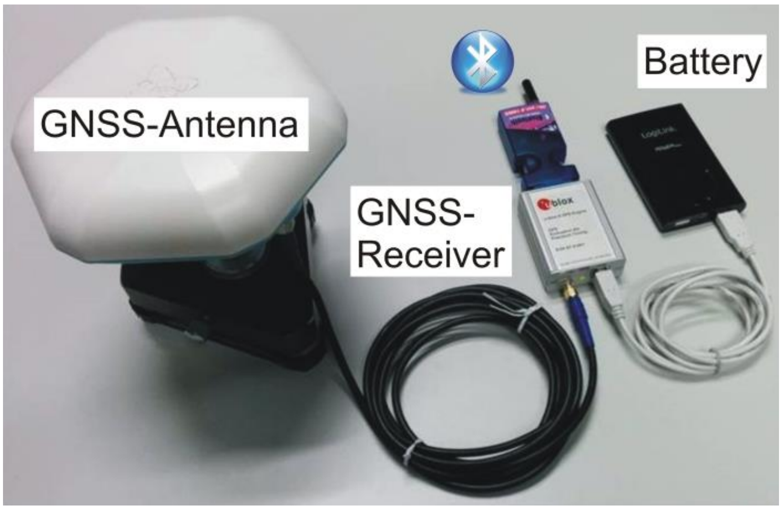

Fig. 2.1: Example system design with 3G+C antenna from navXperience

Fig. 2.2: Trimble Bullet III antenna

In the selection of antennas two different models came into question. One is the Bullet III antenna from Trimble, a hemispherical low-cost GNSS antenna which was already used successfully in monitoring applications. It is a cost-saving solution, due to the low price of about only 100€, but it needs a initialization phase of about 10-20 minutes in static application to fix the ambiguities (Zhang, 2013). To solve this shortcoming Takasu (2008) proposes to improve the time-to-first-fix (TTFF) by replacing the low-cost antenna with a geodetic-grade one. In our case the 3G+C antenna from navXperience was chosen. It has according to the manufacturer an excellent multi-path reduction and very low phase center variation. The costs are about 1800€ pre-tax. For both antennas a CLF 200 (50R) cable with SMA to TNC connectors are used for about 25€.

Therefore the hardware equipment for a low-cost single frequency RTK system without a local base station and including a tablet and Bullet III antenna is available for about 800 €, a system with a geodetic-grade antenna for about 2300 €.

3. SMARTPHONE RTK - SOFTWARE DESIGN AND IMPLEMENTATION

As already pointed out in chapter two it makes sense to use the RtkLib to generate a low-cost RTK solution on Android devices. RtkLib provides a command line version named RtkRcv. It can be controlled via telnet protocol and is initialized with a configuration file. For research purposes this allows the selection of different positioning settings and receiver types dependent on the tests requirements and the necessary communication. Thus, for the study of various systems and applications, the configuration can easily be modified without recompiling the RtkRcv again. For use in commercial software the initialization via setting file can be omitted.

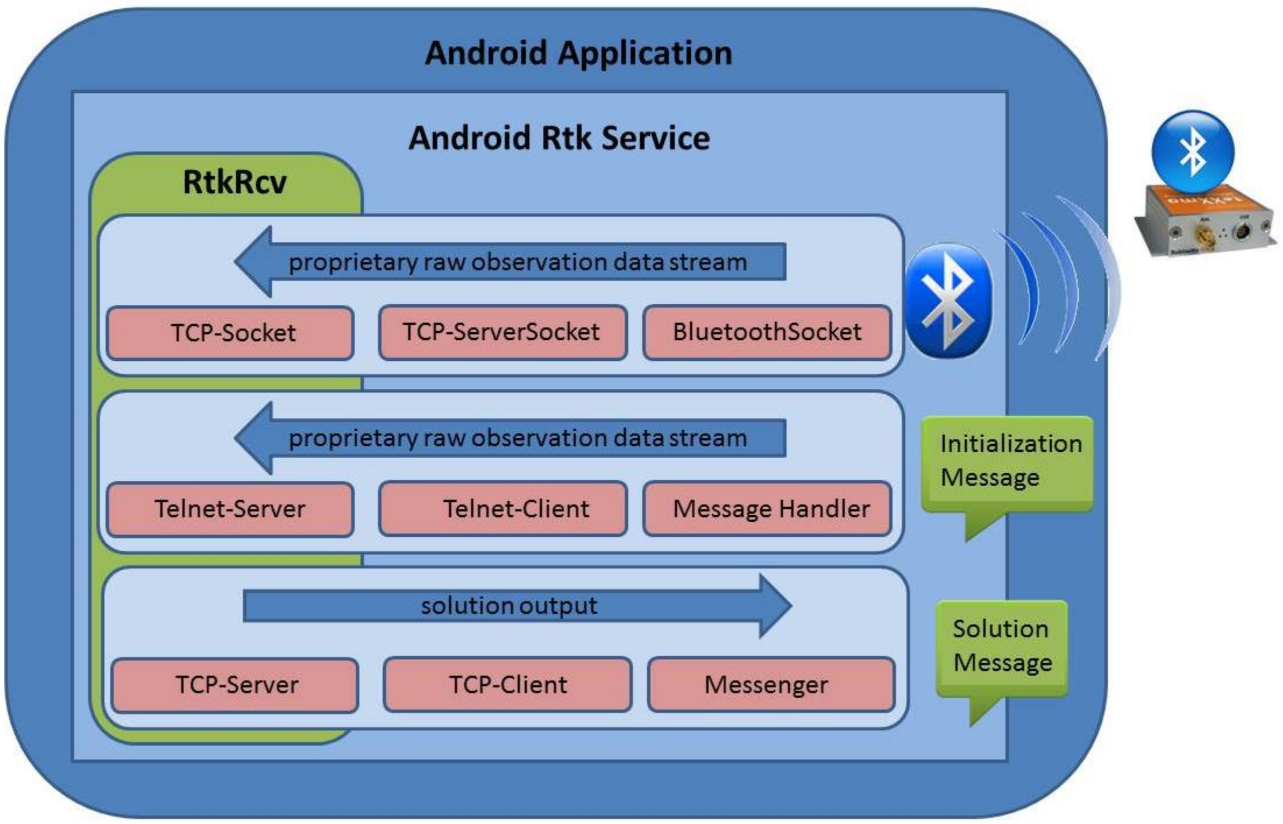

Fig. 3.1: Android smartphone or tablet computer based RTK service and data communication (left) with the GNSS receiver (right)

With the Android Native Development Kit (NDK) the RtkRcv sources can be cross-compiled for different Android device architectures such as ARM, x86 or mips. For this, only an Android makefile, similar to a classical makefile for the GCC, has to be generated.The Android NDK creates a shared library for each type of architecture. To use these libraries a so-called wrapper class has to be implemented using the Java Native Interface (JNI). It loads the RtkRcv libraries and serves as interface between the Java based Android app and the RtkRcv written in C.

In order to make the RtkRcv run properly on Android not only the sources have to be cross-compiled but also the data communication has to be implemented. Thus a bound Service was implemented. This is an application component that can perform operations in background even if the user switches to another app as long as one or more apps are bounded to the service. It can easily be integrated in different Android applications without much effort. The Service incorporates several functions:

At first the service (fig. 3.1) provides a bidirectional communication interface between itself and the applications by using a Messenger based on Handler class. This allows the client, in our case the specific application, to send commands to the Service using Message objects, but also the Service can send Messages to the application. One of the most important messages you can send to the Service is for example MSG_INITSERVICE, which defines the address of the Bluetooth GNSS receiver or the ports for the socket connections.

Secondly the Service establishes a Bluetooth connection between the Android device and a Bluetooth capable GNSS receiver and forwards the observation data stream via TCP-Socket connection to RtkRcv. RtkRcv uses a TCP server to output the position solution. This solution can be received from any app by establishing a TCP client or it uses the Message system of the Service, which runs an intern TCP client. This client sends a solution message to all applications which are bound to the Service once a new solution is available. The solution Message contains not only the position, but also additional parameters which can be used for integrity checks by the main app. These are e.g. the ambiguity fixing ratio between first and second best solution or the number of valid satellites. Additional messages are sent to the applications to inform about connection status of the Bluetooth and TCP connections within the Service.

Furthermore the Service handles the communication with the RtkRcv via telnet and configures and executes the RtkRcv server.

4. SMARTPHONE RTK – GEOREFERENCING CONCEPT

Typical geodetic applications, for example in monitoring projects or mobile GIS, require object geo-referencing of single points or complete buildings in the earth-centered earth-fixed (ECEF) coordinate system of a predefined geodetic datum and epoch. In low-accuracy location based services down to a meter level, the ITRF-related geodetic datum-transition (4-1) and -dynamics (4-2) can be neglected. But if the desired accuracy reaches the decimeter or centimeter level, as in the case of precise smartphone RTK and mobile GIS, they have to be taken into account. The ITRF dynamics is, besides the small parts of a datum change (4-1) and datum drift, mainly caused by crustal movements of the tectonic plates (4.2). Respective parameters of (4-1) and (4-2) are based on the re-adjustment of the International Terrestrial Reference Frame (ITRF), or its regional pendants like the European counterpart ETRF, by IERS or EUREF every couple of years.

Therefore also all real-time measurements have to be transformed to the corresponding geodetic ITRF of the relevant geodetic infrastructure for spatial geo-referencing of objects (e.g. INSPIRE in Europe, or SIRGAS in South America), that are stored in the GIS database. So, the first step in mobile GIS consists of geo-referencing existing buildings or structures. If a footprint of the building exists, it is not necessary to determine all points of interest in the specified datum. Instead of that, it is only required to determine at least three positions in the local coordinate system of the footprint (= the source coordinate system) and in the desired geodetic datum of the database (= destination coordinate system), (Jäger, 2010). With this point set the parameters **R**, σ and **t** of the so-called 7-parameter transformation can be calculated, typically in an adjustment process, and with the resulting transformation parameters, the complete building can be transformed, see eq. 4-1.

$$\mathbf{x}(\mathrm{t})_{\mathrm{ITRFzz}} = \sigma \cdot \mathbf{R}(\varepsilon_x, \varepsilon_y, \varepsilon_z) \cdot \mathbf{x}(\mathrm{t})_{\mathrm{ITRFyy}} + \mathbf{t} \tag{4-1}$$

$\mathbf{x}(\mathrm{t})_{\mathrm{ITRFzz}}$	Coordinates in the destination coordinate system
$\mathbf{x}(\mathrm{t})_{\mathrm{ITRFyy}}$	Coordinates in the source coordinate system
$\mathbf{R}(\varepsilon_x, \varepsilon_y, \varepsilon_z)$	Rotation matrix, based on angles $\varepsilon_x, \varepsilon_y, \varepsilon_z$
σ	Scale factor
$\mathbf{t}$	Translation

Differential GNSS measurements can be used to measure single points, in which the geodetic datum and epoch of the measurements correspond to that of the reference station or reference station network, for example in the datum ITRF2008, with epoch 2008. To transform these measurements to another datum, for example the ITRF2000 and another epoch, the 15-parameter transformation, that allows for a combined datum and epoch transformation can be used, see eq. (4-2).

$$\begin{aligned}\mathbf{x}(\mathrm{t})_{\mathrm{ITRFzz}} = {} & \sigma \cdot \mathbf{R}(\varepsilon_x, \varepsilon_y, \varepsilon_z) \cdot \mathbf{x}(\mathrm{t}_0)_{\mathrm{ITRFyy}} + \mathbf{t} + (\mathrm{t} - \mathrm{t}_0) \\ & \cdot \left[\dot{\sigma} \cdot \mathbf{R} \cdot \mathbf{x}(\mathrm{t})_{\mathrm{ITRFzz.t_0}} + \sigma \cdot \dot{\mathbf{R}}(\dot{\varepsilon}_x, \dot{\varepsilon}_y, \dot{\varepsilon}_z) \cdot \mathbf{x}(\mathrm{t})_{\mathrm{ITRFzz.t_0}} + \dot{\mathbf{t}}\right] \\ & + (\mathrm{t} - \mathrm{t}_0) \cdot \mathbf{v}_{\mathrm{zz,PL}}\end{aligned} \tag{4-2}$$

$\mathbf{x}(\mathrm{t})_{\mathrm{ITRFzz.t_0}}$	Coordinates in the destination coordinate system at epoch t_0
$\mathrm{t} - \mathrm{t}_0$	Time difference between destination and reference epoch
$\dot{\mathbf{R}}(\dot{\varepsilon}_x, \dot{\varepsilon}_y, \dot{\varepsilon}_z)$	First derivative of the rotation matrix, based on angles changes $\dot{\varepsilon}_x, \dot{\varepsilon}_y, \dot{\varepsilon}_z$
$\dot{\sigma}$	First derivative of the scale factor
$\dot{\mathbf{t}}$	First derivative of the translation

Parameters for datum and epoch transformations of the ITRF can be found at ITRF website: http://itrf.ensg.ign.fr/ITRF_solutions/.

As concerns the transformation of the ITRF-related position into other, conventional user target-systems for the plan and height position, either the RTCM 3.x transformation-messages, as a service from GNSS-positioning services can be used (see www.moldpos.eu). Alternatively NTV2 grids or other transformation databases for the plan and height transformation to classical geodetic datum systems and height reference surfaces can be used on the mobile smartphone or tablet computer (Jäger et al (2012a, b)).

5. SMARTPHONE RTK - SYSTEM TESTS

To evaluate the performance of the smartphone RTK system described in chapter three, kinematic tests with both antenna types and different reference stations were carried out on the roof of building B at University of Applied Sciences Karlsruhe (HSKA).The rover was put on point P1 (fig. 5.1). After a necessary period of time to the first fix of the ambiguities the rover was moved from P1 to point P4 in a distance of about 23 m. If a fixed solution could be calculated the receiver was moved back to the previous point, and so on. The tests (tab 5.1) were executed on three different days for at least 45 min each. Once a local base station with a 3G+C antenna on point P2 was used to process the data, the other time the data of a EPN station (Bruyninx, 2004) in Karlsruhe (KARL) were used as base station at a distance of about 1500 m.

Fig. 5.1: Roof of building B at HSKA with observation pillars

For the tests the observations were logged with the log stream of RtkLib for post-processing. The binary observation files of the local base and the receiver station were converted to RINEX 3.0 format with RtkConv from RtkLib.
The data for the EPN station KARL were downloaded from the IGS server of BKG: ftp://igs.bkg.bund.de/EUREF/highrate.

For the post-processing the position mode was choosen to be kinematic and the elevation mask was set to 15°. Only GPS observations were used. Apart from that the standard configuration of RtkPost was kept.

Session	Rover station	Antenna	Reference station	Total Fixing Ratio	Fixing Ratio after TTFF
K11 2014/02/21 15:27:02 –16:34:33 (67min)	P1-P4	3G+C	P2	61.0%	60.9%
K12 2014/02/21 15:27:02 –16:34:33 (67min)	P1-P4	3G+C	Karl	6.0%	6.6%
K21 2014/02/21 16:45:53 –17:51:49 (66min)	P1-P4	Bullet	P2	11.9%	13.5%
K22 2014/02/21 16:45:53 –17:51:49 (66min)	P1-P4	Bullet	Karl	25.1%	33.4%
K31 2014/02/24 13:11:34 –13:57:03 (46min)	P1-P4	3G+C	P2	78.6%	92.0%
K32 2014/02/24 13:11:34 –13:57:03 (46min)	P1-P4	3G+C	Karl	72.0%	80.6%
K41 2014/02/24 14:02:10 –14:47:13 (45min)	P1-P4	Bullet	P2	46.1%	54.1%
K42 2014/02/24 14:02:10 –14:47:13 (45min)	P1-P4	Bullet	Karl	20.5%	23.3%
K51 2014/02/25 13:05:30 –13:50:33 (45min)	P1-P4	3G+C	P2	83.8%	99%
K52 2014/02/25 13:05:30 –13:50:33 (45min)	P1-P4	3G+C	Karl	69.4%	83.5%
K61 2014/02/25 13:57:14 –14:44:07 (47min)	P1-P4	Bullet	P2	51.2%	89.9%
K62 2014/02/25 13:57:14 –14:44:07 (47min)	P1-P4	Bullet	Karl	57.5%	96%

Tab. 5.1: Observation epochs and system configuration

The objective of these tests is to check whether a low-cost antenna like the Bullet III, used successfully e.g. in static monitoring projects, can also be used for RTK applications, or if a geodetic-grade antenna like the NavXperience 3G+C has to be used, because there is a big difference in costs and dimension between both.

First of all it is well known that there is a initialization phase for static L1 carrier frequency observations to solve the ambiguities. These initialization epoch should be as short as possible for RTK applications. So, if the results from the Bullet antenna are compared with the 3G+C, it can be seen that there is a significant difference between both, see fig. 5.5 (K51) and 5.6 (K61). With the 3G+C you need less than 10 min to get a stable solution wherelse you need 25 min with the Bullet III. Of course there are fixed solutions before or within that span of time, but you see that the fixed status is lost very fast. This means that the ambiguity solution is not very robust yet and you can not work in field with such a unstable solution. This is why the time to first fix (TTFF) makes no sense to use here for the comparison, too. In figure 5.1 you see a positive spike where the 3G+C has already a fixed solution after 2 min. Figure 5.3 confirms the initialization epoch of 10 min for 3G+C. The Bullet III solution in fig. 5.4 is a bit better than in fig. 5.6 but confirms the trend that it needs a longer initialization phase until you get a robust solution. However, also negative spikes are possible. In figure 5.2 e.g. the ambiguities are never satisfying solved.

The results of K12 K22 K32 K42 K52 and K62 confirm the result for a more distanced base station (KARL). With a geodetic-grade antenna one needs about 10min of initialization and with a low-cost antenna a bit less than 20min.

In summary this means: With a geodetic-grad antenna the initialization phase is less than 10 min, wherelse with a low-cost antenna of the bullet III type (fig. 2.2) more than 20 min are needed. For the Helix antenna type (fig. 6.2), the time for the initialization is in between, using for all tests the GNSS processing engine RtkLib. So for a daily use of low-cost smartphone RTK, it is recommendable to make at present an investment to a geodetic-grade antenna, or alternatively to a L1/L2 ”medium-cost” receiver with fast fixing, controlled by a smartphone RTK-controller. All in all, an option directed to the future, is to consider the next generation of GNSS-algorithms for one-frequency low-cost receivers, like these, which are presently developed by the NAVKA RaD team at IAF/HSKA.

The above results are confirmed by the total fixing ratio. For the NavXperience 3G+C antenna the total fixing ratio is much higher than for the Bullet III in most cases. To make sure, that the positive result in the fixing ratio is not due to the shorter initialization phase of the 3G+C, the fixing rates were calculated again only for the solutions after the initialization epoch. For results with 3G+C a mean initialization phase of 10 min and for the Trimble Bullet III of 23 min was assumed. The mean of the fixing ratio after TTFF is presented in table 5.2. One can see, that the fixing ratio of the 3G+C is about 20% higher than for the Bullet III and the results processed with a local reference station are much better than with the KARL station.

Antenna	Reference station	Epochs K11-K62	K31-K66
3G+C	P2	84.0%	95.5%
3G+C	Karl	56.9%	82.0%
Bullet	P2	52.5%	72.0%
Bullet	Karl	50.9%	59.6%

Tab. 5.2: Mean of Fixing Ratio after TTFF

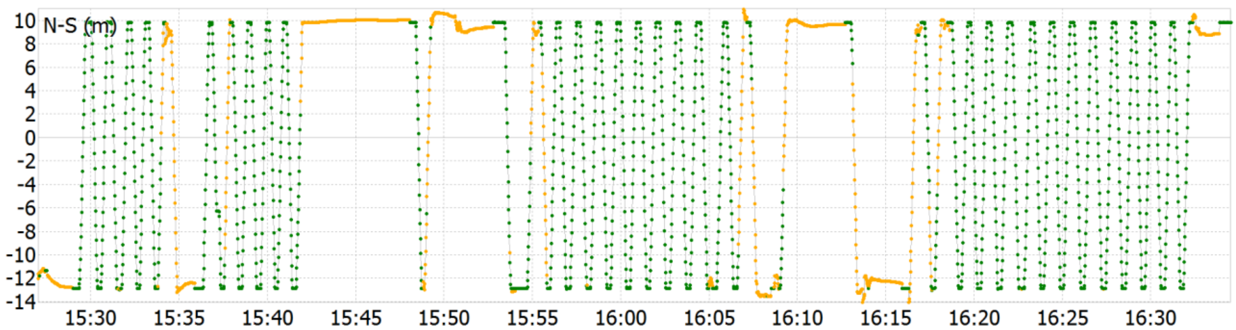

Fig. 5.1: Session K11 with 3G+C and local base, orange float, green fixed

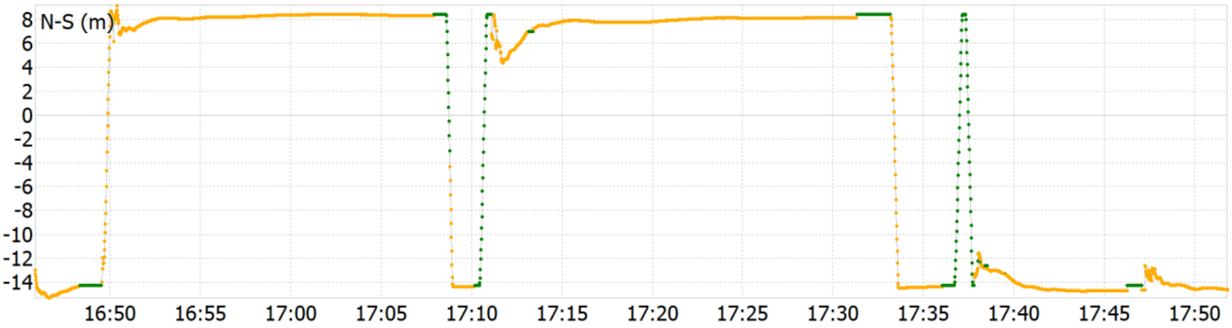

Fig. 5.2: Session K21 with Bullet and local base, orange float, green fixed

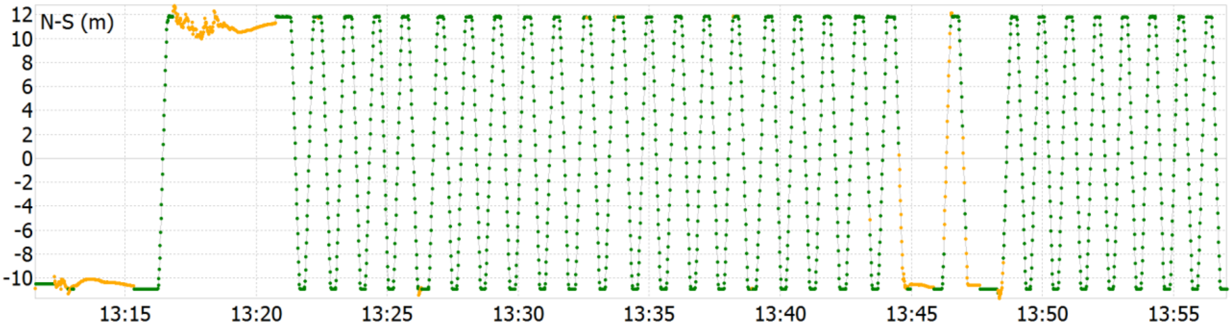

Fig. 5.3: Session K31 with 3G+C and local base, orange float, green fixed

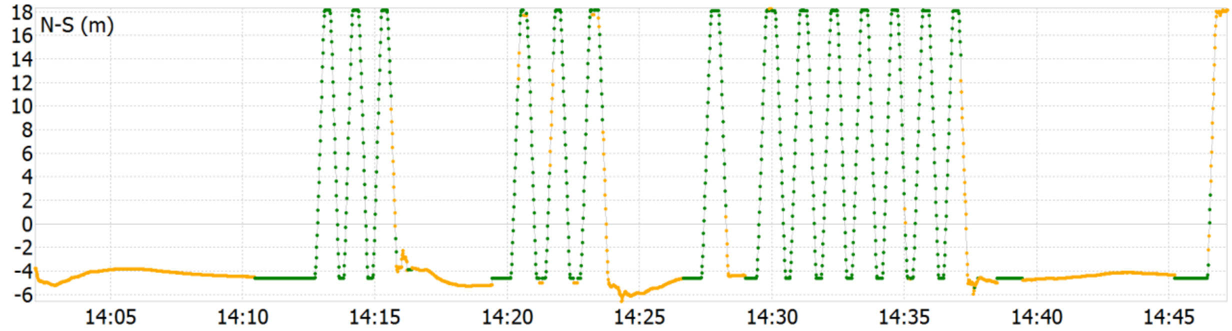

Fig. 5.4: Session K41 with Bullet and local base, orange float, green fixed

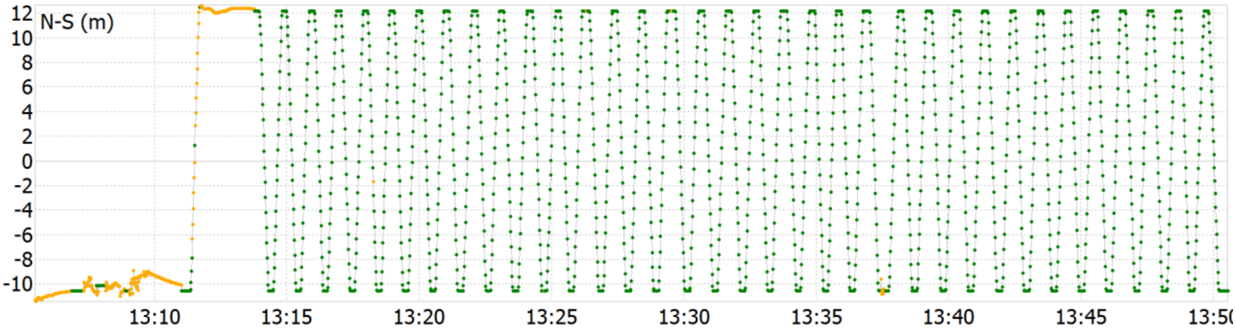

Fig. 5.5: Session K51 with 3G+C and local base, orange float, green fixed

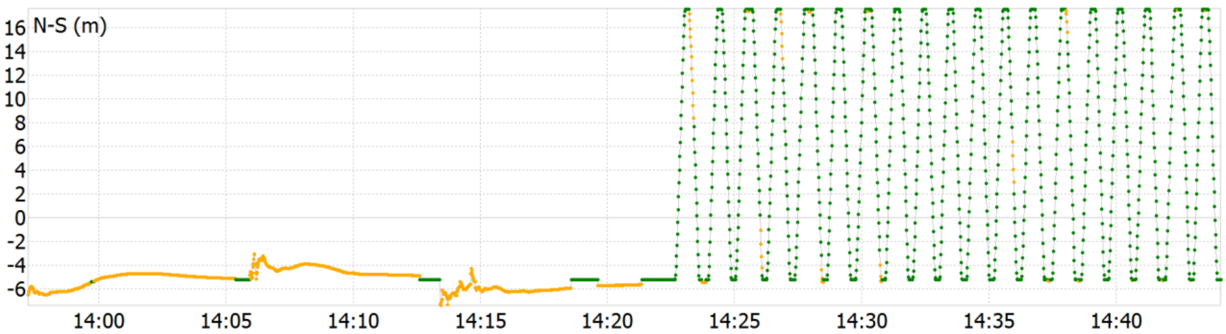

Fig. 5.6: Session K61 with Bullet and local base, orange float, green fixed

A further and much promising data set is presented in figure 5.7. The NavXperience 3G+C antenna was tested with an kinematic run similar to session K11 again, but this time the correction data of a reference station network, in our case SAPOS, was used in the VRS (virtual reference station) mode with a virtual station defined on point P2. The initialization phase needs less than 10 min again. The Total Fixing Ratio and the Fixing Ratio after TTFF are as good as session K51 with a local reference station. In figure 5.8 the result for same configuration but with a Bullet III antenna instead of the 3G+C is shown. The initialization phase is only about 3 min longer than with the 3G+C, but at the end of the epoch you see, that the Bullet III has no fix anymore. That means, that the performance on RTK of the Bullet III seems to be not as stable as with the 3G+C anntenna.

Session	Antenna	Reference station	Total Fixing Ratio	Fixing Ratio after TTFF
S11 2014/02/25 14:56:18 – 15:41:00 (45min)	3G+C	P2	81.6%	99.6% (10min)
S12 2014/02/25 15:47:50 – 16:34:26 (46min)	3G+C	Karl	63.1%	76.3% (13min)

Tab. 5.3: Observation epochs and system configuration

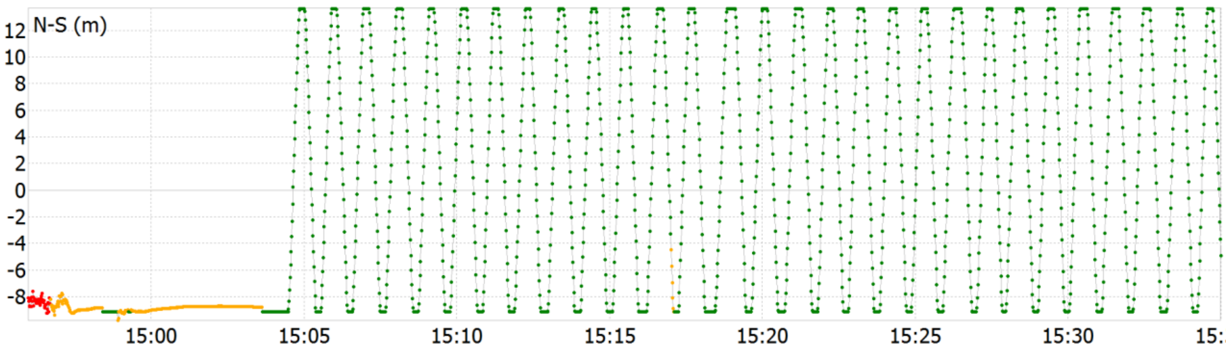

Fig. 5.7: Session S11 with 3G+C and SAPOS, orange float, green fixed

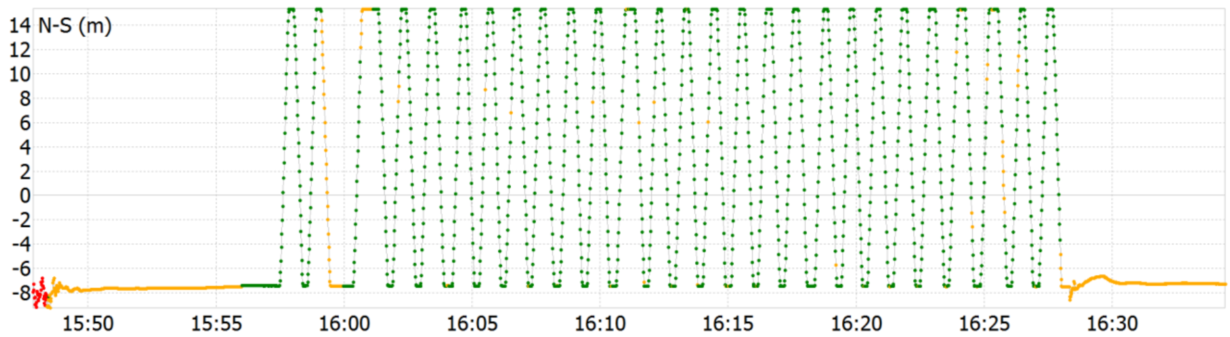

Fig. 5.8: Session S12 with Bullet and SAPOS, orange float, green fixed

A basic commercial standard RTK rover-equipment with a L1/L2 GNSS receiver (fast initialization) and a control unit is presently available for the prize about 20000 €, or with an additional receiver as reference station for about 30000 €. Since normally no EPN or IGS station is near by, the user normally uses a local reference station, or the data of a commercial GNSS positioning service provider. Although further investigations are still necessary to strengthen the present results, one can state the following: In contrast to such a high-end L1/L2 receiver, for a low-cost single frequency receiver with a geodetic-grade antenna

- an initialization phase of about 10 min has to be accepted.
- Within the good observation epochs K32 and K52 for a baseline with 1.5 km length the Fixing Ration after TTFF is about 80%. To work reasonably well the baseline should not be longer.
- For applications which need constant position like excavator control for example a simple one frequency low-cost solution is not sufficient. Even under good conditions with a geodetic-grade antenna there can be gaps in the fixed solution of more than one minute (K31 13:44:30 or K11 16:09:00). So a medium cost L1/L2 receiver is presently recommended for smartphone and tablet computer RTK application.
- Working with a reference station network could be an alternative, if one does not want to work with a local GNSS base station, or if one does not want to invest the double amount of money for an additionally GNSS reference station. For a rover only, the low-cost smartphone RTK system costs (without software) and including the smartphone in between 850.-EUR (Helix antenna, Fig 6.2) up to 2600.- EUR (high precise geodetic antenna, 1800.-EUR) plus the fee for the correction data services. The price for a local base & rover station equipment would be double.

Finally one has to remark, that the three sessions were observed under good conditions conerning multipath and satellite view. The Bullet III antenna has shown, that it is possible to get a fix also over a longer period of time, but it loses the fix more often than with a geodetic-grade antenna. For RTK work under worse conditions the Bullet III is probably more a pain than a workable solution or RTK, while the Helix type (fig. 6.2) shows a better performance concerning the ambiguity fixing, but generally has a lower accuracy (1-3) cm.

6. ENHANCEMENT OF SYSTEM DESIGN

The function volume of the smartphone RTK system, as described above, can be extended, if in addition to GNSS, the data of MEMS sensors (gyroscopes, accelerometers, magnetometers) are exploited, in order to get - besides the position (x,y,z) as in case of smartphone RTK - the full navigation state vector **y**(t). Respective algorithms for a tight and deep coupling of the GNSS/MEMS data have been developed in the frame of the NAVKA RaD (Jäger, 2014). The navigation state vector **y**(t) information can by used together with the distance d observatioon of a laser distance meter. With that system, which can be completely be implemented on a tablet (fig. 6.1, fig. 6.2), a contact-free 3D polar tracking of the 3D position **p** of objects can be done. The different coordinate systems on the device (fig. 6.1) have to be considered, because the MEMS-sensors, GNSS and the laser are mounted at different positions and orienations on the body (b) of the tablet. The different location and orientation of the MEMS-sensors and GNSS is already considered in the frame of the computation of the navigation solution **y**(t) of the body (b) by the multisensor-multiplatform concept of the NAVKA-algorithms (www.navka.de; Jäger (2014)). The distance meter observation d in the distance meter sensor coordinate system (s) can be set in relation to the body (b) with eq. 6-1. The the rotation matrix $\mathbf{R}_s^b$ is known from the mounting and the calibration of the laser distance meter. Finally, an observed point position **p** has to be transformed from the body system (b) to the ECEF (e-frame) with eq. (6-2). The rotation matrix $\mathbf{R}_b^e$ is known from the integrated GNSS/MEMS navigation solution **y**(t) computed by the NAVKA-algorithms (www.navka.de).

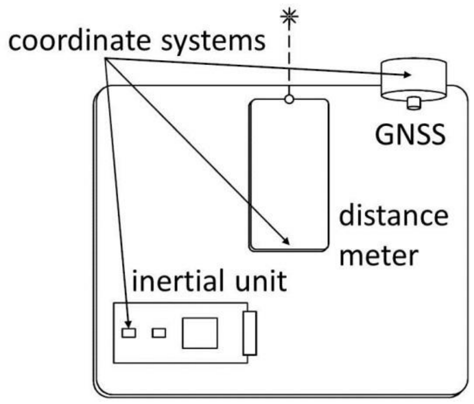

Fig. 6.1: Mobile tablet computer device and platform (p) with local sensor frames (s)

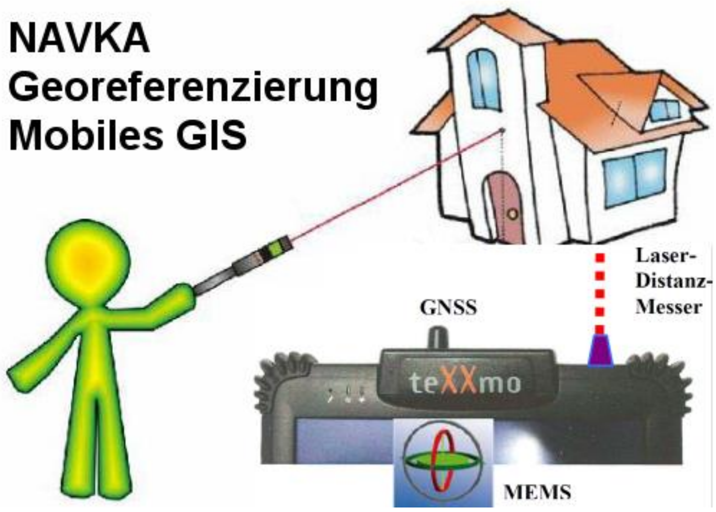

Fig. 6.2: Contact-free Georeferencing principle in mobile GIS (left) and KALEO-Georeferencer (bottom, right)

$$\mathbf{p}^b = \mathbf{R}_s^b \begin{pmatrix} d \\ 0 \\ 0 \end{pmatrix}^s + \begin{pmatrix} t_x \\ t_y \\ t_z \end{pmatrix}^b_{laser} \tag{6-1}$$

$$\mathbf{p}^{e} = \mathbf{R}_{b}^{e}(r,p,y)\mathbf{p}^{b} + \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{body}^{e} \quad (6\text{-}2)$$

The mobile GIS system (fig. 6.1) was implemented in the Windows based mobile GIS system KALEO-Georeferencer(TM) in a cooperation of the NAVKA RaD team and teXXmo Mobile Solutions GmbH (fig. 6.2). Fig. 6.2 (left) shows the principle of contact-free 3D polar tracking of object positions **p** (6-2) in the earth-fixed frame (e). Fig. 6.2 (bottom, right) shows the mobile GIS KALEO-Georeferencer, which is based on a tablet equiped with MEMS,GNSS and a laser distance meter.

7. SUMMARY

In this article a low-cost smartphone RTK system for direct non contact-free positioning, and an enhanced contact-free 3D object georeferencing system based on a tablet are presented. Both can be used for various mobile GIS applications. External low-cost GNSS (fig. 2.1) is due to single frequency (L1) mass market receivers. As shown in that contribution, the complete data communication and processing is done with standard smartphone and tablet computer hardware, in our case Android smartphones and tablets, as well as Windows mobile tablets.

MEMS is already available both in smartphones and in tablets, or - together with GNSS - available in complete navigation boxes (e.g. www.robinette.de). It was pointed out in that contribution, that full capacity for mobile GIS applications requires both - GNSS and MEMS sensors - and accordingly a full navigation state vector **y**(t) based on the respective raw sensor data.

Generally there is a need of transformation-algorithms and parameters due to the dynamics of the earth (e.g. datum-changes, datum-drift and plate-movements). The parameters and respective transformation parameter databases, or external services for datum transitions to classical geodetic frames and a change to a physical height reference system as the final target systems, have to be provided as well for mobile georeferencing and GIS.

The presented system developments on smartphone RTK and enhanced 3D contact-free georeferencing are both open for the use of other hardware-components, e.g. L1/L2 GNSS receivers, instead of L1-technology, in order to reduce the initialization time for the ambiguity resolution. Alternatively improved GNSS-algorithms can be integrated, which are under development in the NAVKA RaD team at HSKA. These are e.g., a modified ambiguity function algorithm for an ambiguity parameter and cycle-slip free positioning, implying the abolition of any initialization time, especially for L1 only. Further improvements are expected in the area of online precise point positioning (OPPP) using SSR products and corrections (e.g. from IGS-RTS) in combination with code- and carrier-phase observation combinations. Here the improved code measurement accuracy of the GALILEO signals will help to reduce the influence of ionosphere in high precise low-cost GNSS/MEMS-based system developments for mobile GIS and other navigation applications.

8. ACKNOWLEDGEMENT

The research and development on the topic of the article was funded at the Institute of Applied Research (IAF) in the frame of the joint B.W. research project “GNSS-gestützte LowCost Multisensorsysteme zur mobilen Plattformnavigation und Objektgeoreferenzierung” by the Ministerium für Finanzen und Wirtschaft Baden-Württemberg and a consortium of industrial partners (www.navka.de). The industrial partners teXXmo Mobile Solution und an Bernot IT were concerned with developments on low-cost positioning and georeferencing systems based on smartphones and tablets. The support of teXXmo with the respective hardware of the tablet based mobile GIS and georeferencing application KALEO-Georeferencer for research and development and thesis at IAF/HSKA is acknowledged.

REFERENCES

[1] Bruyninx C. (2004): *The EUREF Permanent Network: a multi-disciplinary network serving surveyors as well as scientists*, GeoInformatics, Vol 7, pp. 32-35

[2] Jäger, R. (2010): *Geodätische Infrastrukturen für GNSS-Dienste (GIPS).*Festschrift zur Verabschiedung von Prof. Dr.-Ing. G. Schmitt. Karlsruhe Institute of Technology (KIT). ISBN 978-3-86644-576-5. Seite 151 – 16

[3] Jäger, R., Kälber, S., Lagutina, E. and T. Gorokhova (2012a): *Determination of Transformation Parameters between the ITRF and the State Coordinate System on the Territory of the Novosibirsk Region* (In Russian). Proceedings of Interexpo GeoSiberia 2012, April 2012. Siberian State Academy of Geodesy (SSGA) ISBN 978-5-87693-512-0 (T.2). p. 195-203

[4] Jäger, R., S. Kälber and Ghadi Younis (2012b): *The New RTCM 3.1 Transformation Messages – Declaration, Generation from Reference Transformations and Implementation as a Server-Client Concept for GNSS-Services*. Bolletino di Geodesia e Science Affini (BGG). Journal of Istituto Geographica Militare. Vol. LXIX. No. 2-3. Firenze, Italy. P. 267 – 295

[5] Jäger R. (2014): *Navigation mit verteilten GNSS/MEMS Sensoren - Mathematische Modelle, Algorithmen und Anwendungspotenziale*. Horizonte. Forschungsmagazin der Hochschulen Baden-Württemberg. ISSN 1432-0174. Pages 7 -10

[6] Takasu, T., Yasuda, A. (2009): *Development of the low-cost RTK-GPS receiver with an open source program package RTKLIB.* Proceedings of international symposium on GPS/GNSS, Jeju, Korea

[7] Takasu T., Yasuda A. (2008): *Evaluation of RTK-GPS Performance with Low-cost Single-frequency GPS Receivers,* http://gpspp.sakura.ne.jp/paper2005/isgps2008_paper_ttaka.pdf

[8] Zhang Li, Schwieger V. (2013): *Monitoring mit Low-Cost GPS Empfängern – Chancen und Grenzen,* Beiträge zum 124. DVW-Seminar am 14. Und 15. März 2013 in Karlsruhe

BIOGRAPHICAL NOTES

Prof. Dr.-Ing. Reiner Jäger

Professor for Satellite and Mathematical Geodesy, Adjustment and Software Development at Karlsruhe University of Applied Sciences (HSKA)

Head of the Laboratory of GNSS and Navigation at IAF/HSKA (www.goca.info/Labor.GNSS.und.Navigation/Labor_fuer_GNSS_und_Navigation.htm) and the Institute of Geomatics at IAF and of the joint RaD project "GNSS-supported Low-Cost Multisensor Platforms for Navigation and Object Geo-referencing" (www.navka.de)"

Member FIG Commission 5 WG 5.4 Kinematic Measurements

CONTACTS

M.Sc. Andreas Hoscislawski
University of Applied Sciences – Institute of Applied Research (IAF)
Moltkestraße 30
76133 Karlsruhe
Germany
Tel. +49 (0)721 925-2586
Fax +49 (0)721 925-2927
Email: Andreas.Hoscislawski@HS-Karlsruhe.de
Web site: www.navka.de