GBAS-Technologies for High Precise Safety-Critical Maritime Navigation

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Abstract

As a result of the high quality of positioning and timing service, satellite navigation becomes the primary means of navigation for most of civil applications, worldwide. The trend of integrating satellite navigation with other technologies to obtain very precise and reliable position and time information is highly promoted by the development of the future European satellite navigation system Galileo and the modernization of GPS. In the future a large variety of safety-critical maritime applications will depend on this infrastructure.
This paper presents the DLR activities for the development of a maritime ground based augmentation system (GBAS). GBAS in general are focused on users who need assurance of high precise positioning service performance (decimetre) in real-time. In the maritime sector, due to IMO requirements, these are applications as: automated docking, dredging, hydrographical surveying, cargo handling, etc…
The paper starts with a brief overview of the ALEGRO project, the frame of this research and development activity. The project has been initiated in 2006 by DLR under the support of the Government of the German Federal State Mecklenburg Western Pomerania and aims for the further development of state-of-the-art real-time kinematic (RTK) technologies towards a maritime GBAS, taking into account the services of the future Galileo.
Subsequently, the paper describes the hard- and software architecture of the ALEGRO environment in Rostock, currently consisting of a single Monitoring and Control Station embedded in a data and processing network named EVnet. The description includes details about the service that can be provided to the user of the Test Environment within the vicinity of the port of Rostock.
The final section of this paper shows the recent results of the validation activities carried out at the port of Rostock and the results of the algorithm development. The validation activities performed within the project were followed by extensive analysis of the data to identify and evaluate signal disturbances in the port surrounding. These activities have been the base for the design and validation of algorithms for the detection of environmental and atmospheric propagation effects. As discussed in the paper, such effects - decreasing the signal quality and availability - with a strong impact on position and integrity can be a critical issue for the operation and the use of a continuous reliable GBAS service.

Introduction

Visual aids, radar aids and radio navigation systems are the main types of navigation systems and services used for civil maritime navigation. Since the DECCA system has been shut down and superseded by the American GPS in 2000, global satellite navigation systems (GNSS) are the only remaining systems, enabling the achievement of high accuracies of absolute position fixing in all weather conditions and at all times.
At present stand-alone GPS with a specification of 100 meter global position accuracy (95%) is acceptable for many navigational situations, and since SA has been turned off in 2000, stand-alone GPS accuracy has improved significantly (cf. [5]). Nevertheless, to meet the requirements for demanding applications, such as dredging, hydrographical surveying, mobile offshore drilling, safety of life applications, etc. (cf. Fig. 1), *differential GPS* techniques (DGPS) have to be applied in order to improve the accuracy of GPS position data (cf. [7]).
DGPS or, more general, DGNSS applications are using reference receivers with a known position to generate and transmit differential corrections to the users. Under unperturbed conditions (open sky, low multipath, no ionospheric perturbations …), DGPS user position accuracy in the vicinity of the reference station can be within the range of meter. But the main benefit of DGPS for mariners is the integrity information in the correction message of the reference station. Due to their known position, DGNSS stations have the ability to detect satellite anomalies and provide respective integrity information that is not being offered by stand-alone GPS (cf. [7]).

Concerning accuracy, integrity, continuity and availability [4] a number of safety-critical maritime applications have very stringent performance requirements, and an apparent analogy exists between

	System level parameters				Service level parameters			
	Absolute Accuracy	Integrity			Availability % per	Continuity % over	Coverage	Fix interval² (Sec)
	Horiz (metres)	Alert limit (metres)	Time to alarm² (Seconds)	Integrity risk (per 3 hour)	30 days	3 hours		
Ocean	10	25	10	10^{-5}	99.8	N/A¹	Global	1
Coastal	10	25	10	10^{-5}	99.8	N/A¹	Global	1
Port App & restricted waters	10	25	10	10^{-5}	99.8	99.97	Regional	1
Port	1	2.5	10	10^{-5}	99.8	99.97	Local	1
Inland waterways	10	25	10	10^{-5}	99.8	99.97	Regional	1

Notes: *1: Continuity is not relevant to ocean and coastal navigation*
2: More stringent requirements may be necessary for ships operating above 30 knots

Fig. 1: Minimum maritime user requirements for general navigation [2]

maritime navigation and aviation. The problems regarding the use of satellite-based navigation in inland waterways and port areas are almost comparable to precision approaches and landings of aircrafts. In the aviation sector, DGNSS-based landing systems that provide on a local basis differential corrections and integrity monitoring, are named Ground Based Augmentation Systems (GBAS) (q.v. [9]). Even if not completed, the development of these systems is far advanced and some of the GBAS technologies, especially for the integrity determination, may by transferable to provide high accurate and assured position information in the vicinity of a port.
For this reason and on base of the assumption that the development of the future European satellite navigation system Galileo and the ongoing modernization of GPS will increase the application of satellite-based applications also in the maritime and intermodal port logistic sector, DLR has initiated the project ALEGRO. The main aim of the project is the further development of state-of-the-art real-time kinematic (RTK) technologies towards a maritime GBAS for High Precise Safety-Critical Maritime Navigation, taking also into account the services of the future Galileo, having already been defined. Details of the project will be given in the following.

The ALEGRO Project

The name ALEGRO stands for “Installation of a local maritime augmentation system to support high precision application and service of Galileo within the Rostock Research Harbour”. It is one of the pilot projects in the context of the *Research Port Rostock (http://www.forschungshafen.de),* an initiative of the Federal State of Mecklenburg-Western Pomerania to set up and operate a test environment to develop maritime applications for Galileo and to test prototype applications in the port area of Rostock.

The project has been started in 2006 and will be finished at the end of 2008. It is led by DLR and, as already mentioned above, aims for the further development of state-of-the-art real-time kinematic (RTK) technologies towards a maritime GBAS, taking into account the services of the future Galileo. In more detail - the main objectives of ALEGRO are:

- Development of the infrastructure of the *Research Port Rostock* towards a *maritime test bed* for novel GNSS technology by the provision of a DGNSS service within the vicinity of the harbour;

- Support of regional business companies, university and non-university research institutions, developing new applications and services in the maritime sector, by the provision of high precise positioning and availability information for validation and verification tasks.

- Development of novel real-time kinematic technologies (RTK) and services, considering already the new characteristics offered by Galileo: increased accuracy and integrity, certified services and high availability;

- Support of the demonstration and certification of new products and services that rely on satellite positioning;

- Provision of an extended DGNSS service that enables the development of marketable and functional products/applications in the maritime sector that rely on the availability of high position accuracy and reliability.

Additional information about the ALEGRO project can be found in [1] and on the websites of the Research Port Rostock: “http://www.forschungshafen.de/projekte/Alegro/”.

ALEGRO-GBAS-Architecture

The internal processing, archiving and distribution of the ALEGRO GBAS reference station data is based on EVnet (Experimentation and Verification network), a combined hardware and software system developed by DLR together with the German company Jena Optronik. EVnet is a network based on modular configurable and adaptable hardware and software components supporting the near real-time data acquisition and processing. EVnet is furthermore a suitable research and development infrastructure enabling an efficient development, implementation and validation of algorithms and techniques used for the verification of existing and future GNSS systems (cf. [8]). The EVnet software has been chosen for this project, because it gives the opportunity to transmit the data of all installed sensors to a central processing and control facility. Additionally, new sensors, e.g. meteorological sensors or additional receivers, can easily be implemented in the system. And finally EVnet enables the monitoring and observation of data streams, to command the sensor station and all sensors in remote control and to process the data in real time.
To obtain GNSS measurements for the ALEGRO GBAS reference system, two high rate Topcon NetG3 GNSS receivers are used. Both receivers are installed in a building in the centre of the Rostock port (cf. Fig. 2) and share one antenna. The first receiver is operating in standard RTK mode to generate off-the-shelf RTCM correction messages. The second is operating in a high acquisition mode (20 Hz) to generate the input values for the ALEGRO processing routines. At present these routines create also standard RTCM but the software is fully open for, and controlled by the DLR research team, which enables the opportunity to create the next generation of correction messages based on RTCM3.

Fig. 2: Images of Rostock Port (Google Earth), the site of the ALEGRO reference station GHRO (Google Earth) and the antennas of the GPS reference receiver (red circle) and the UHF transmitter for the correction message (yellow circle).

An overview of the EVnet based architecture of the planned ALEGRO GBAS prototype is shown in Fig. 3. As mentioned above, high-rate GNSS receivers are used at the reference station and user site to get dual-frequency GNSS code and carrier phase observations with high temporal resolution.
The kernel of the whole system is the so called A-GPAF (ALEGRO-GBAS Performance Assessment Facility), which contains all processing modules to check the received raw data, to generate corrections and integrity parameters and to build correction message information that can be broadcasted to the user via the RTK Message Generator. At present all data received and processed are archived mainly to provide a data base to the system developer. The interface for the configuration, commanding and controlling of the whole system is the A-CCF (ALEGRO Command and Control Facility), which provides a number of GUIs to operate the system, to give status information and to visualize outcomes of the different processing modules.
The GNSS Information System, an interface to the communication network of the *Research Port Rostock* and the processing modules for the rover (left side in Fig. 3.) are still under development. To obtain the user position, off-the-shelf software is currently used.

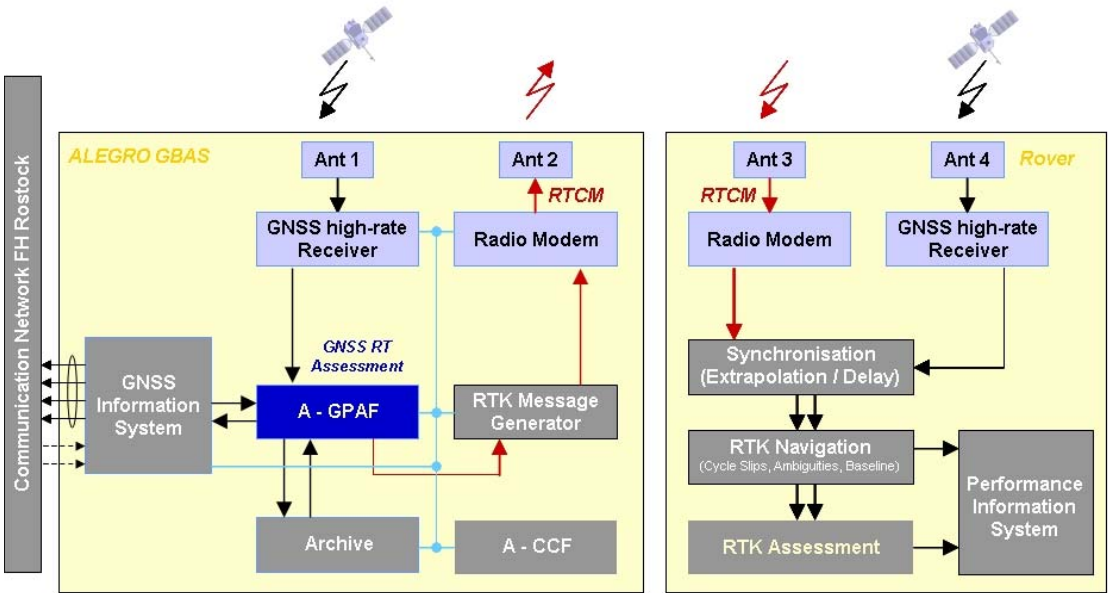

Fig. 3: Architecture design of the ALEGRO GBAS station

Development and Validation Activities

The aim of the development of GBAS-Technologies for high precise safety-critical maritime navigation is to provide a system, which enables real-time sub-meter positioning with very constraint integrity requirements. From already existing DGPS navigation and positioning systems it is known, that there are at least two main problems:

- In constricted waterways and during hydrographical surveying DGPS navigation is often unavailable and /or unreliable, due to signal masking (cf. [11]).

- Blunders in maritime navigation can be caused by extreme ionospheric phenomena and multipath effects (cf. [11]).

It is obvious that dynamic positioning in the sub-meter domain, normally done by the application of real-time kinematic (RTK) techniques (cf. [3]), suffers at least the same problems. The fulfilment of stringent integrity requirements for dynamic users in a port environment is also a very challenging task. To solve these problems by the development of new methods for the detection of errors in the signal characteristics and the development of new positioning and integrity algorithms, data are needed, that are representative for a port environment. Hence two measurement activities have been initiated in an early stage of the ALEGRO project. Results of these activities are given in the following.

The first measurement activity for the ALEGRO project took place in the port of Rostock (city harbour, ferry terminal, cargo terminal) at the end of January and beginning of February 2007 (cf. Fig. 2). The aim of the activity was to validate different GNSS based standard technologies related to their achievable positioning accuracy and to identify local disturbances and their influence on the raw data and positioning performance.

To enable the use of RTK a reference station has been installed at the ferry terminal. This reference station was configured to track signals of GPS and GLONASS systems. The data were evaluated to identify disturbances and transmitted as supplement information via wireless modem to the research vessel "Professor Albrecht Penck".
On board the "Penk" three receivers have been installed, connected to the same antenna. Each receiver has used a different positioning method: Combined GPS and GLONASS, GPS with the EGNOS service (European Geostationary Navigation Overlay System), RTK.
All data recorded at the "Penck" and data from the IGS station Warnemünde have been post-processed with the Trimble Total Control software to calculate a reference trajectory for estimating absolute positioning errors with centimetre accuracy
As this paper focus on high-precise positioning in the sub-meter range, only the RTK results will be discussed here. More detailed information about the whole activity can be found in [1].
Regarding the absolute position accuracy the analysis of the NMEA-files from the RTK-receiver at the "Penck" led to the following results:

- RTK (with all phase ambiguities fixed) resulted into ~2-10 cm accuracy (68%).
- The RTK-float solution led to ~1-10 m accuracy (68%).
- The maximal HDOP (Horizontal Dilution of Precision) during the whole period has been 2.2., which means that the spatial satellite distribution has been excellent all the time.

Beside the visibility of the GNSS satellites also the receiving conditions for the corrections from the reference station have a strong impact on the quality of the RTK solution. If no corrections are received, e.g. due to shadowing effects, the last received corrections are used by the receiver for a period up to 20 seconds. Fig. 4 and Fig. 5 show results of the analysis of the accuracy of RTK taking into account the age of the received correction message. Both figures show horizontal positioning errors retrieved from the RTK solutions obtained during the measurement activities at 31.01.2007 in the Rostock ferry and cargo terminal.

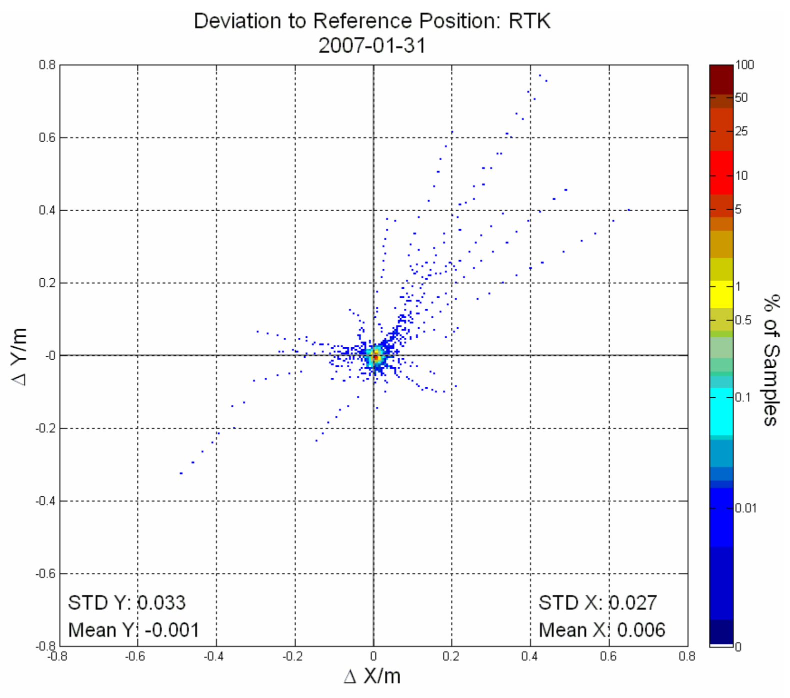

Fig. 4: Deviation of the RTK-position from the reference position

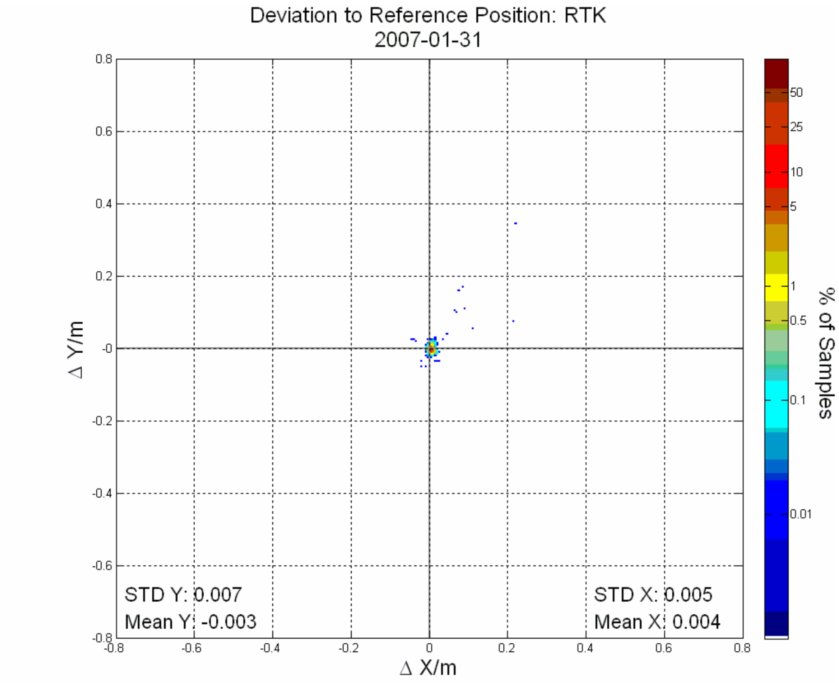

Fig. 5: Deviation of the RTK-position from the reference position, only for cases where the correction message age is 1 sec

Unlike Fig. 4, where all RTK-fix data obtained during the measurements are plotted, Fig. 5 shows results only from RTK solutions on base of correction messages with a maximal age of 1 second. The influence of the correction message age for the RTK can easily be seen in the differences of the standard deviations and the number of outliers in both plots.

The second measurement activity took place in June 2007. The aim of this measurement activity has been, to investigate RTK performance in-between the port facilities and on the docks in the Rostock port. For this activity a test and measurement car equipped with a TOPCON RTK receiver and the permanent ALEGRO reference station in the port of Rostock (see Fig. 2) have been used. As already described above, Trimble post-processing software has been used to generate reference positions to analyse the data. Examples of the obtained RTK performance are given in Fig. 6, Fig. 7 and Fig. 8. :

- Fig. 6 shows a projection of the different RTK-position modes on the true position of the car. The figure shows that even in the vicinity of the reference station RTK-fixed solutions have not been obtained at all times, sometimes even no position solution at all has been available (e.g. at mark 1 in the plot). An analysis of the total loss of data that occurred in the marked regions 2 and 3 identified receiver software problems as the reason.

- A closer look to the RTK-performance in the industrial harbour of Rostock is given in Fig. 7. Detailed analysis showed that the cause for the switching of the positioning modes and the total lost of positioning has been mainly due to shadowing effects by cranes, oil tanks, pipelines, bridges and halls in the dock area.

- Fig. 8 is a typical example how shadowing effects influence the RTK positioning. While driving under a belt-conveyer, the receiver switches from the RTK-fix mode (green) to the RTK-float mode (dark blue). Moments later, when driving under a second conveyer-belt the receiver, still in the RTK-float mode, turns in the stand-alone mode.

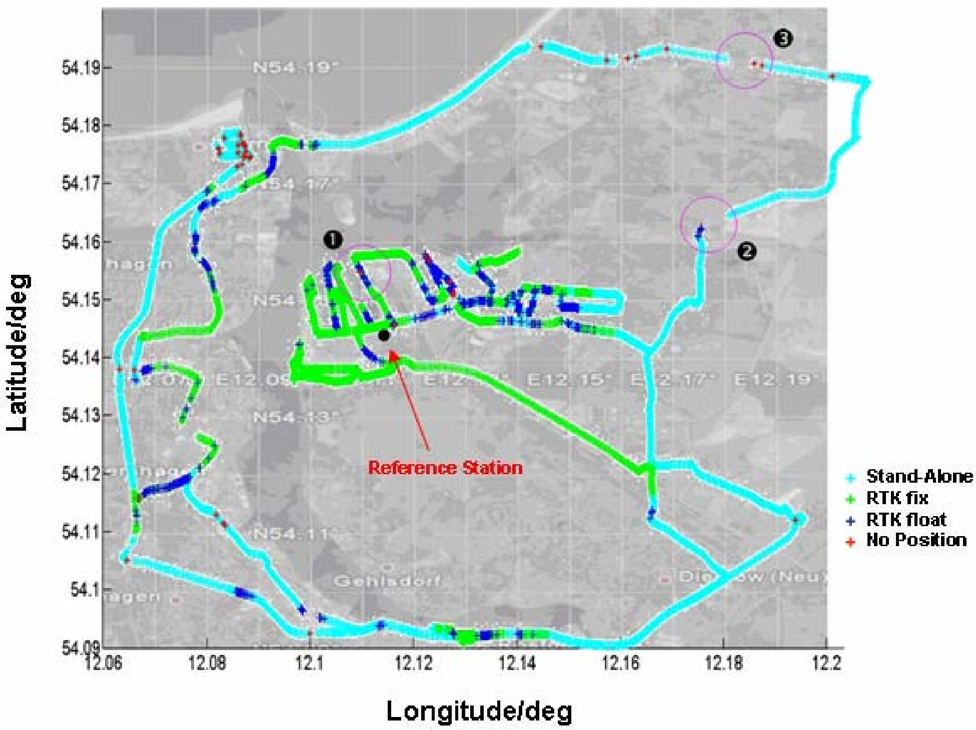

Fig. 6: Different RTK-position modes (colour coded) obtained during the measurement activity in the area of Rostock, Germany

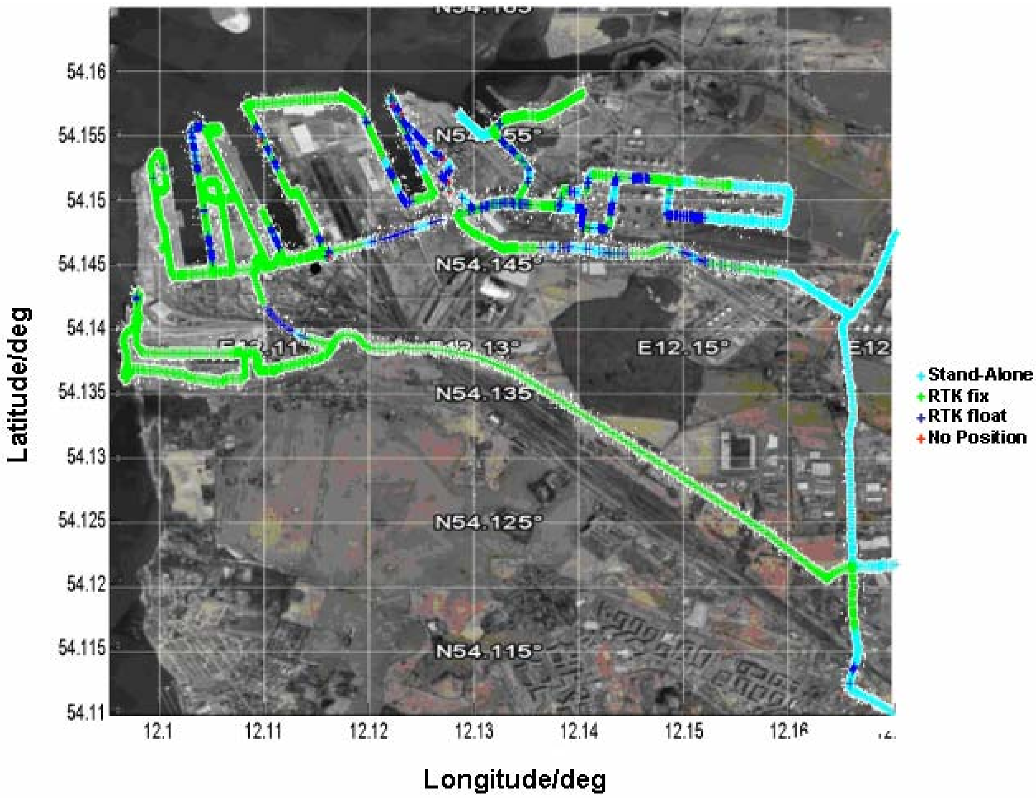

Fig. 7: Different RTK-position modes (color coded) obtained during the measurement activity in the port of Rostock, Germany

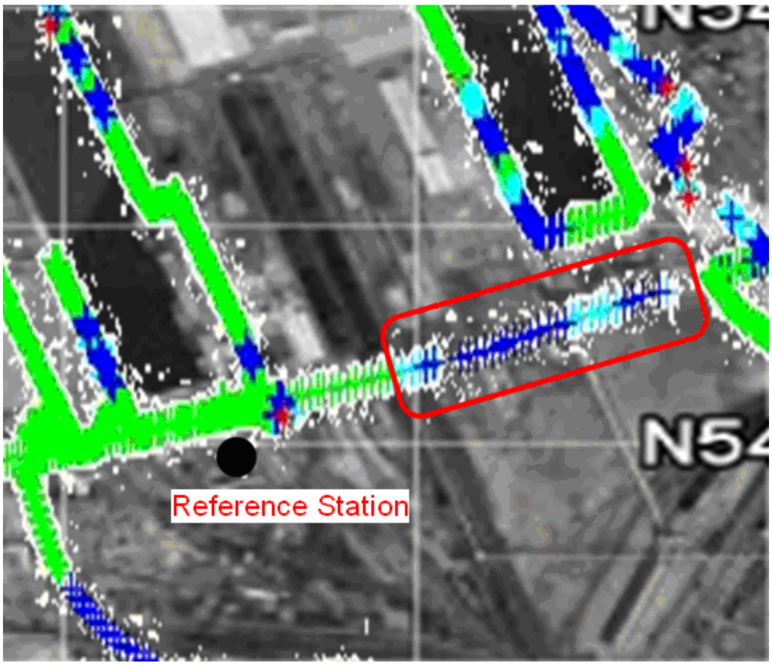

Fig. 8: Example: RTK drop out while driving under a band-conveyer (red rectangular)

Summary

For a number of years GNSS technologies has been used to get accurate position fixes in ocean and coastal waters all over the world. Speed, heading and distance to waypoints can also easily derived from the GNSS data, and already today all this information can be employed in association with electronic charts, and integrated shipboard navigation systems. Now, and in analogy to the present activities in the aviation sector, to develop GBAS systems for precise landing operations, the next challenging step in the evolution of maritime GNSS technology will be the development of locally assisted systems for high precise safety-critical operations. This paper illustrates the first steps of the DLR development team towards such a maritime GBAS performed in the project ALEGRO. Within the project DLR has designed and built up the soft- and hardware infrastructure for the further development of state-of-the-art RTK technology. Furthermore first GNSS measurement activities have been performed by ship and by car in the port of Rostock in 2007. The data are currently used to develop new improved positioning and integrity algorithms.
In addition, the analyses of the data has shown that off-the-shelf RTK-technology is not sufficient to provide the needed accuracy for high precise applications in the terminal and dock areas of the Rostock port at any time. In contrast to airports, ports are full of obstacles that influence (interference, multipath) or shadow the radio waves from the GNSS satellites and also from the UHF transmitter of the reference station.

Future Work

While integrity is a main justification for local augmented GNSS, the most important step for the further development of the ALEGRO-system in the near future will be the implementation of components for the real-time integrity monitoring, including self-monitoring of the GBAS reference station and self-monitoring at the user side. Further working activities will be the early integration of Galileo measurements in the GBAS for a combined use of GPS and Galileo.

As shown above, for high-precise GNSS applications a port is a difficult environment where satellite signals become blocked by local obstructions such as cranes, oil tanks, ships and other obstacles. Here technology specialized for a specific application may be the only option, e.g. the integration of inertial navigation with GNSS [6].

Due to the modernization of the American GPS and the Russian GLONASS and the expected full availability of the new European satellite navigation system Galileo in about 6 to 7 years it is obvious that multi-carrier signal processing will play the important role in safety-critical positioning in the future.

Last but not least, the development of specifications for maritime GBAS will be an urgent task for the near future to support product development in the maritime industry.

Acknowledgments

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