siNafa: safety Navigation for shipping (9181)

Dirk KOWALEWSKI and Frank HEINEN, Germany

Key words: GNSS, Jamming, Spoofing, RTK, Moving baselines

SUMMARY

The project siNafa - safety navigation for shipping, is a joint project of navXperience, Raytheon Anschütz, DLR (German Aerospace Center) and the Technical University of Berlin. It was funded by the German Federal Ministry for Economic Affairs and Energy and had a volume of € 1.3 million. The DLR has done research on the jamming and spoofing of GNSS signals, Raytheon Anschütz has provided her newly developed gyro in this project and has integrated our developments into the on-board system. NavXperience has developed a 3-antenna GNSS receiver system and the TU Berlin has developed the calculation software for all six degrees of freedom and accelerations at each location. The following document describes the development and features of the three antenna system from navXperience.

ZUSAMMENFASSUNG

Das Projekt siNafa – sichere Navigation für die Schifffahrt, ist ein Verbundvorhaben von navXperience, Raytheon Anschütz, DLR und der Technischen Universität von Berlin. Es wurde gefördert vom Bundesministerium für Wirtschaft und Energie und hatte ein Volumen von 1,3 Mio. €. Das Deutsche Zentrum für Luft- und Raumfahrt hat Untersuchungen zum Jamming und Spoofing der GNSS Signale gemacht, Raytheon Anschütz hat Ihren neuentwickelten Gyro in diesem Projekt zur Verfügung gestellt und unsere Entwicklungen in das Bordsystem integriert. NavXperience hat ein 3 Antennen GNSS Empfänger System entwickelt und die TU Berlin die Berechnungssoftware für alle sechs Freiheitsgrade und die Beschleunigungen an jedem Ort entwickelt. Das folgende Dokument beschreibt die Entwicklung und die Eigenschaften des drei Antennensystems von navXperience.

siNafa: safety Navigation for shipping (9181)

Dirk KOWALEWSKI and Frank HEINEN, Germany

1. MOTIVATION

The Global Navigation Satellite Systems (GNSS) will be expanded in the next few years and their importance and application areas will increase significantly. Fully usable are the American GPS (Global Positioning System) and the Russian GLONASS (Globalnaja nawigazionnaja sputnikowaja sis-tema, translated: Global satellite navigation system). As of 2018, two more globally available GNSS systems will be operational and fully operational by 2020. The European Galileo and the Chinese BeiDou. With four fully functional satellite navigation systems, the application capabilities, reliability and importance of this technology will increase enormously. Every second year, the GSA (European Global Navigation Satellite Systems Agency) makes a market report on the growth opportunities of GNSS technology in Europe. The study predicts growth of 8% in general and 5.5% in the maritime sector (GSA, European Global Navigation Satellite Systems Agency, March 2015). The GSA provides the Market Report 2015 for download at the following link: http://www.gsa.europa.eu/2015-gnss-market-report.
Nearly all GNSS base technology manufacturers in the precise market segment come from North America. Here are companies like Trimble, Navcom, Topcon and Javad from the USA, as well as Hemisphere and Novatel from Canada. Recently, the Chinese company ComNav has been attracting attention with its GNSS board development. In Europe, there is the Belgian company Septentrio, founded in 2000 as a spin-off of the University of Leuven, which deals exclusively with GNNS receiver technology development, GNSS antenna technology is purchased.

NavXperience was founded in November 2009 to develop, produce and distribute GNSS technologies from Germany. Since the end of 2010, our 3G + C antenna technology is on the market, which can receive all past and future GNSS signals. The patented process is developed in Germany by the Fraunhofer Institute IIS. An important milestone of navXperience, which has the sole exploitation right of this patent. The 3G + C antenna technology is characterized by its high accuracy and the reception of all past and future GNSS signals, making it a future-proof product. Since January 2014, we are also developing receiver technology, which will be launched in September 2018 This makes us the only manufacturer in Germany for precise GNSS technology.
As a small and young company, we need to gain competitive advantage by not following the big ones but using new technologies to serve niche markets. The open architecture of our GNSS board (LINUX operating system) distinguishes extraordinarily to the closed systems from our competitor. The siNafa project will help us to further develop our GNSS board into a novel measuring system.
We see the need to accurately and reliably determine the 6 degrees of freedom by determining the accelerations at each location for survey passenger and container vessels, and to make the

functional patterns and software developed in siNafa into one product. The same applies to the detection and detection method developed by DLR against Jamming and Spoofing.

2. STATE OF the SCIENCE

2.1 GNSS Receiver

All commercial GNSS receiver manufacturers develop closed systems. Manufacturers like Novatel, Septentrio and Javad gives Programming guides out and allow the user also commands via the command level. As a result, the receivers can be controlled via self-developed software and retrieve data. There is only the possibility to process the data in the predefined formats and none to access the absolute raw data. Other manufacturers, such as Trimble and Topcon, do not provide information on how to control your GNSS boards. Their aim is to bring complete systems for the surveying or machine control in the market and thus to control their markets. One example is the construction equipment market, where Trimble and Topcon have no noteworthy competition.

There are more and more precise GNSS applications where access to the absolute raw data and the installation of proprietary software on the GNSS board are necessary. That's exactly what the OSR receiver from navXperience is all about. We installed an open LINUX operating system here and created access to the raw data via our Open GNSS Receiver Protocol (OSRP). According to our research, there is no such multi-frequency GNSS receiver except for navXperience. There was a project called GPL-GPS from the year 2008, which has since been discontinued. Here they have tried to develop their own operating system and not used a standard LINUX. After a short time, the hardware was so outdated and no longer available that a completely new development would have been necessary. The same wents with the Namuru V1 receiver from the University of New South Wales. This receiver platform was used in the course of a DLR project (Grillenberger, et al., 2008). There were further developments of the Namuru receiver V2 and V3 but they are also not available anymore. The DLR project was trying to develop a world-class GNSS receiver and not a precise GNSS receiver for exact applications. The computing power would not have been enough.

On the scientific level, there are also Software Defined Radios (SDRs). It will s. G. Front-Ends are used to receive the analog GNSS signals and to perform the signal processing and processing with a conventional PC. These approaches are not suitable for commercial use. Not only the size, weight and power consumption, but also the slow processing speed do not allow a use in siNafa. Only by using the OSR platform from navXperience can Raytheon Anschütz carry out the important work package 3400 “analysis and pre-control of the GNSS control loops” and install the software directly on the receiver. There is no comparable technology from any other manufacturer that offers the user these possibilities.

2.2 Multi-antenna systems

In the shipping industry, there are two hands full on 2 GNSS antenna systems, named GPS compass. They are typical manufacturers of marine technology such as Furuno, Simrad and Hemisphere. These systems have nothing to do with our intended development. The systems are equipped with low-cost one-frequency GNSS receivers and you can measure the roll, pitch and yaw angles with an accuracy of 1.5 to 0.5 °. We have found two manufacturers offering a three antenna system, Japan Radio Co. Ltd and NaviStar from Northop Gumman. But here too, only single-frequency GNSS receivers are used and only all 6 degrees of freedom with an accuracy of 0.5 °.

For the multi-frequency receiver manufacturers, there are three providers of s. G. Heading Receivern the Belgium company Septentrio, the Canadian manufacturer Novatel and the market leader Trimble from the United States of America. In these technologies, one antenna is used for accurate 3D position determination and the second determines the direction. This technology is mainly used in the control of machines, the largest application is the control of excavators. Occasionally there are also systems in maritime applications.

Septentrio has two heading receivers, the first is called AsteRx2eH and has a multi-frequency board for GPS and GLONASS satellites. The accuracies relevant for the project are given in the brochure as follows: with 1 m antenna spacing, rolls and pitch 0.6 ° and yawing with 0.3 °. The accuracy of the speed measurement is given as 0.008 m / s (0.03 km / h). The second model is the AsteRx4 and is a multi-frequency receiver for GPS, GLONASS, Galileo and BeiDou. The accuracy for rolls and trunks is specified at 0.2 ° and for yawing at 0.1 °, much more accurate than the AsteRx2eH. The accuracy of the speed measurement is given with 0.01 m / s (0.04 km / s), much less accurate than the older model. The question arises for us why one can measure the angles with the newer model more accurately than the first derivative. At this point it becomes clear how much paper is paper.

3. GNSS RECEIVER

3.1 Developing GNSS Technology

The challenge in this work package is to change the open source receiver (OSR) board of navXperience so, that three boards can be easily synchronized over a clock and thus all GNSS receivers have the same time. The development of the motherboard with the memories and computers is done by us, the design and manufacture of the hardware is doing together with external companies. Testing of time standards and synchronization is the most important development for the accuracy of the complete system. A circuit diagram and the individual components are selected by us and then given to our manufacturer for production. We will commission two functional samples. One will be bought by the TU Berlin, this one will be installed on a boat of the BSH. The other one was installed on the Basle Express.

3.2 Six Dots of Freedom GNSS

In the work package, we first have to adapt and test our OSRP to the requirements of the TU Berlin. Then we will develop one software to control the three GNSS receivers over a clock. This adaptation will be crucial for our accuracy requirements. If we succeed here we can become more accurate and faster (higher data rate) than our competitors and thus have an innovation advantage.

The next step is the implementation of the vector phase tracking of GNSS carrier signals. We want to determine the relative position of the two rover antennas to the master antenna with millimeter precision. We will continuously determine these with the GNSS receivers in a phase locked loop. The previous technology is to consider the carrier phase of each satellite and each frequency separately. However, the spectral and spatial correlation is not used and a small error in the phase tracking immediately has a negative effect on the accuracy. The patented method (Henkel, et al., 2009) involves vector phase tracking, which processes the carrier phases of all visible satellites jointly on all available frequencies and thereby exploits the spatial and spectral correlation of the measurements. The coupling of the measurements is carried out by a projection of the phase errors in position, clock and atmospheric errors and their filtering. The complexity is only slightly higher than with a separate processing. The method allows a continuous, jump-free tracking of the main phases, even if the signal strength (S / N) of individual satellites breaks in by 20 dB.

4. INSTALLATION

4.1 Deneb

The following photo shows the installation of the three antennas on the Deneb, a German surveying vessel from the BSH[1]. The master antenna is mid-ships and the two rover are starboard and portside. We made the installation and the exact surveying of the antenna positions in the shipyard.

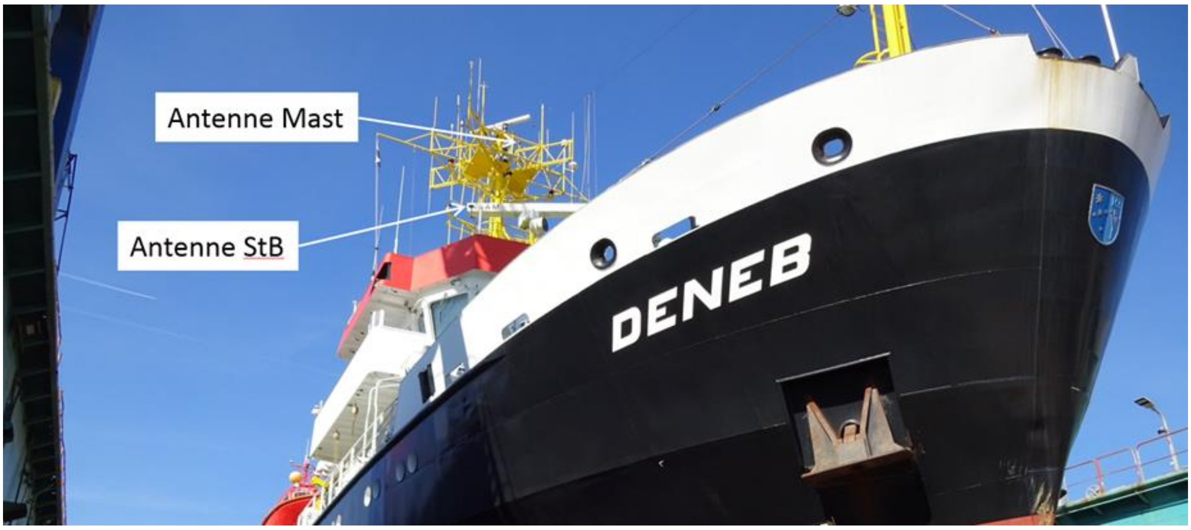


Figure 1 Deneb in the shipyard

It is not easy to find good places for GNSS antennas on a vessel. The problem is that everybody like to have a good place for his antenna and you have to find a compromise between the safety and the functionality. We find a good solution with long baselines.

Punktnummer	X in m	Y in m	Z in m
GNSS - Antenne	4.358	-1.099	22.100
NavXperience port	12.980	-3.287	11.976
NavXperience starboard	12.892	3.645	11.945

Figure 2 sheet antenna positions

4.2 Basle Express

Figure 4 Wheelhouse Top over the navigation bridge

Figure 3 Masterantenna

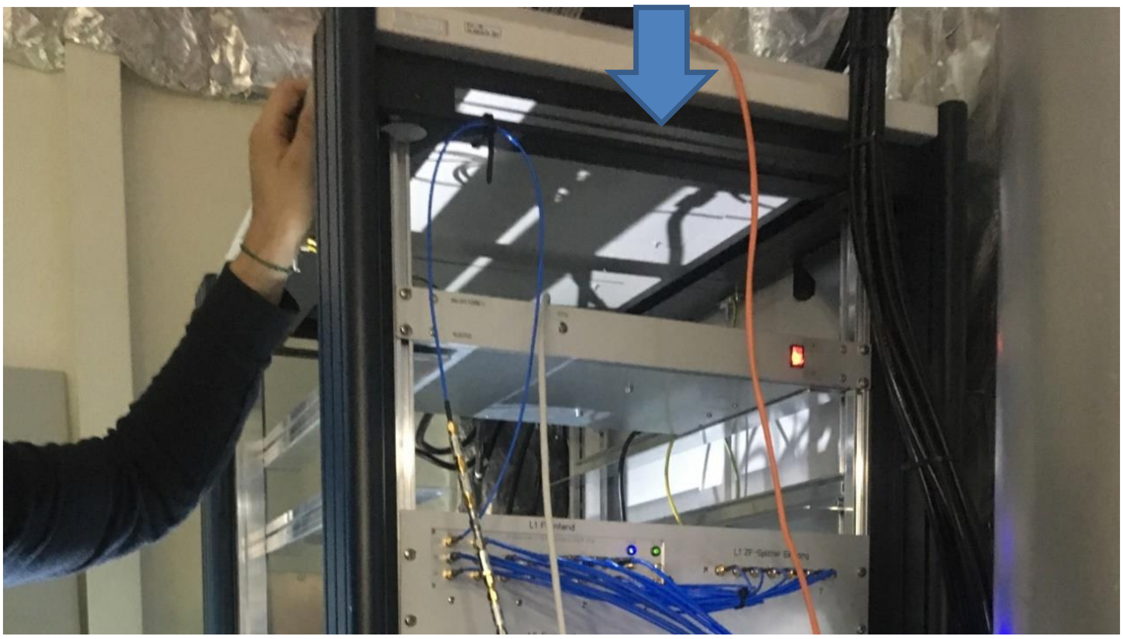
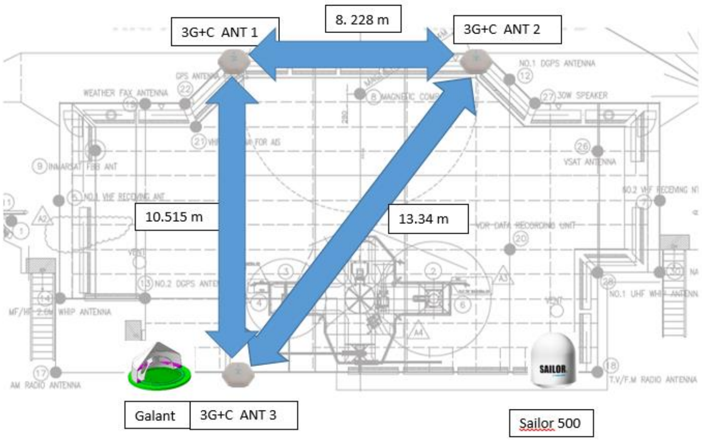


Figure 5 3 antenna receiver from navXperience

Over the bridge we find very good conditions and places for our antennas. We make the installation parallel to the vessel axis using a right angle between the baselines.



5. VECTOR TRACKING

In the project we tested a patent from Technical University of Munich, Vector tracking. The idea is to calculate vectors between every received satellites. If we lost a satellite we can make a pre-calculation to this satellites. This help us in difficult conditions and we don't lost the fixing and the accuracy.

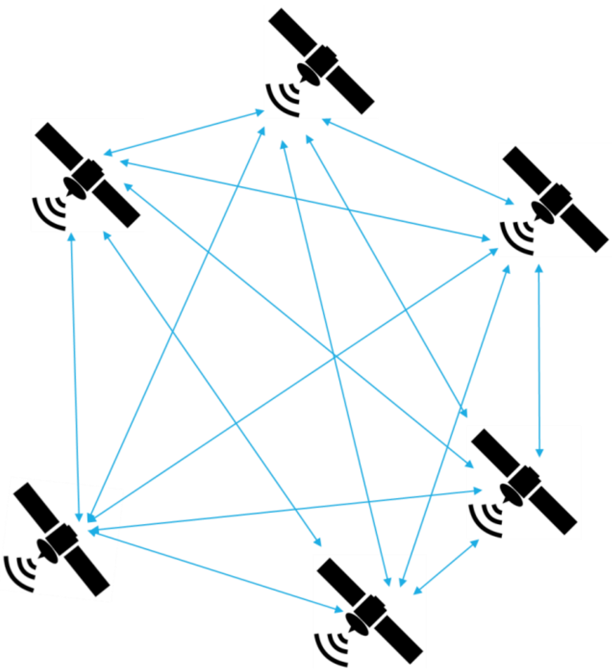


Figure 6 good conditions

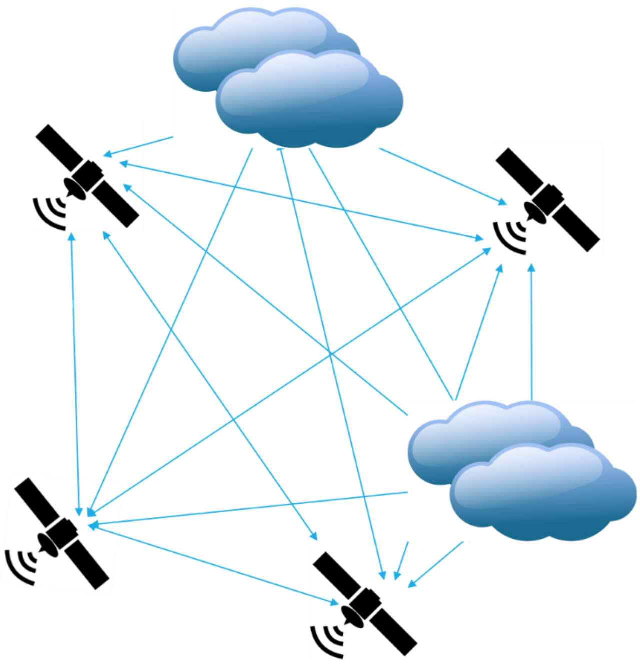


Figure 7 bad conditions

We find out that these patent helps a lot to have more accuracy and a longer fixing time. Now navXperience is the owner of the patent and we implement the technology in all GNSS receivers. This is a very good result of our research project.

6. RESULTS

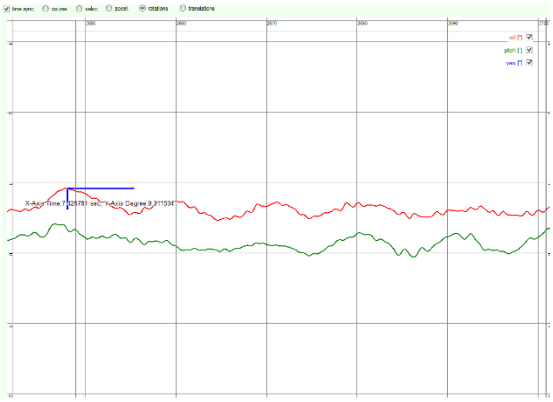


Figure 8

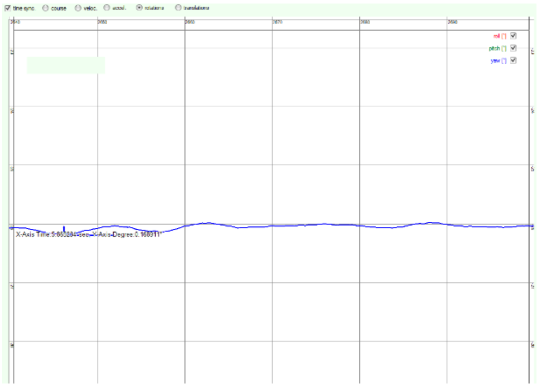


Figure 9

The figure 8 shows the roll and pitch and figure 9 the heading at the same time. This our first results. We see that we need around 20 seconds to get good results, better than 0.1° accuracy. This was not bad, but we like to have more accuracy. This was our first step.

6.1 Web interface

In the project we develop a web interface to use the system easy and comfortable. With the web interface you can create and manage projects, automatically measure the baselines and arange these relative to the vessel axis.

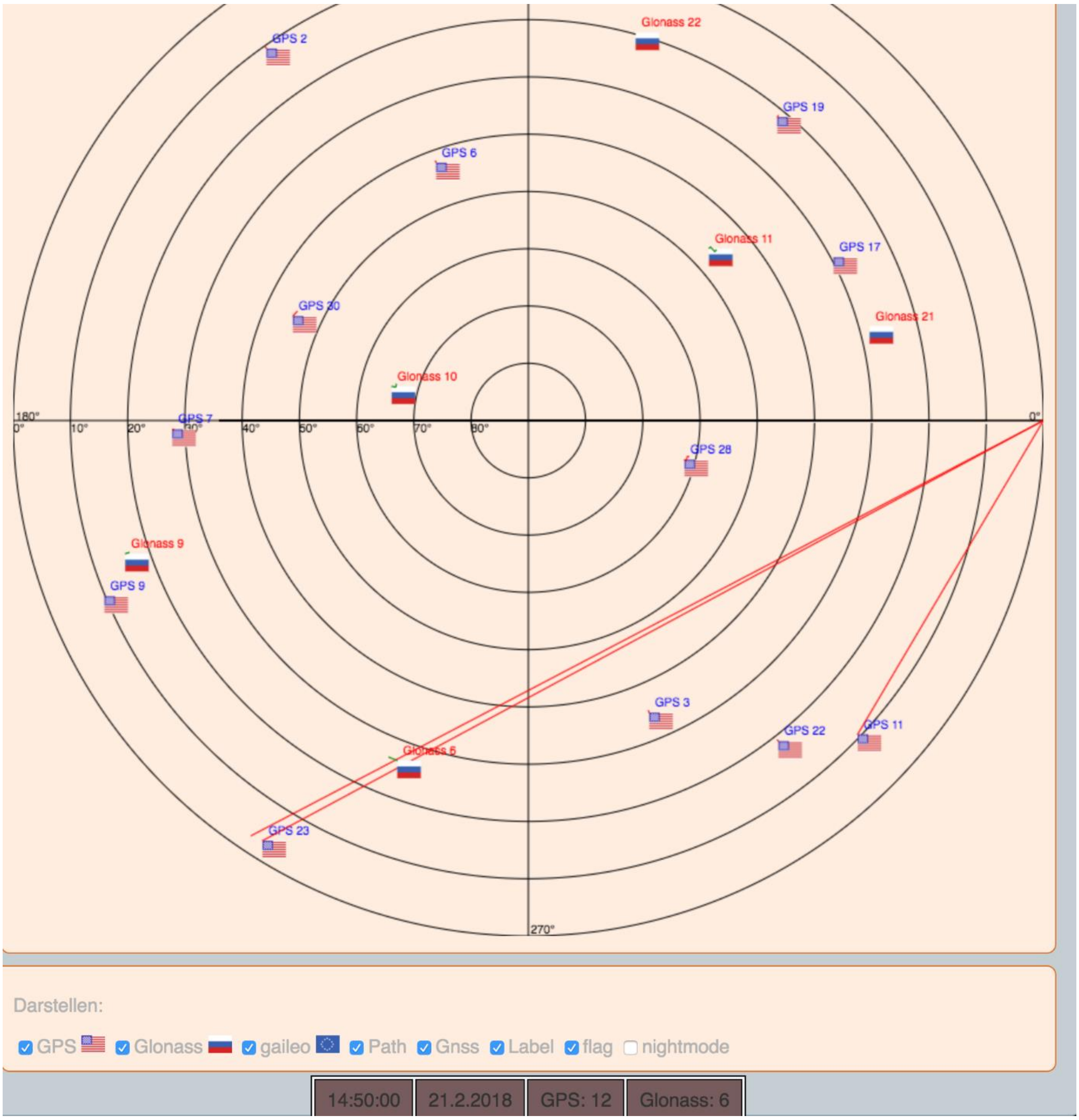


Figure 10 Skyplot with GPS and GLONASS

The skypolt is ready for Galileo and Beidou.

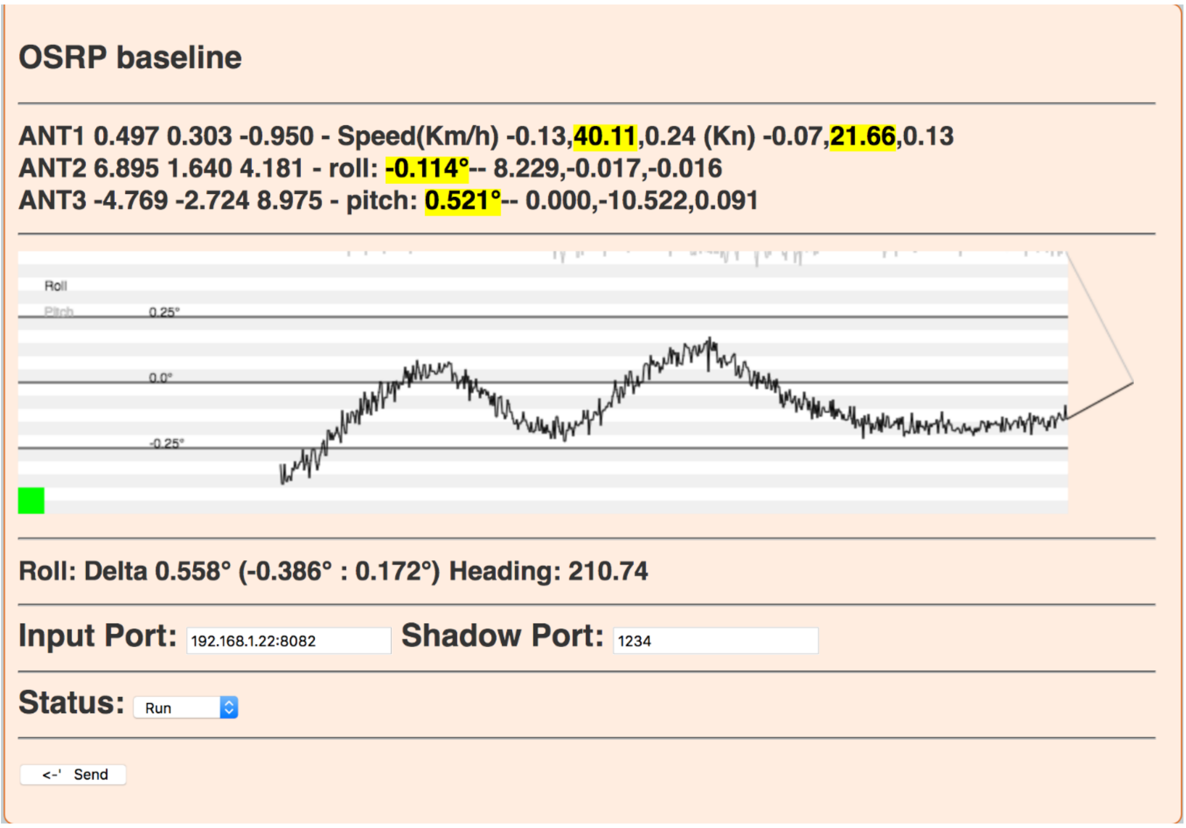


Figure 11

The figure 11 shows the results of our actuell baseline calculation. The calculations based upon the Baselineconcept that was already used in the MoDeSh project but now we increased it with hardware processed dopplerdata and got better results. Also the calculations went simpler and produces less calculation related inaccuracies.

Now we have an accuracy of 0.02° for roll pitch and heading. The screenshot is from a measurement on board the Basle Express a 366 m long container vessel, it was in conditions with a very quiet sea with no waves. The roll was very low at a speed of 21.66 knots (40.11 km/h). In this screenshot the data from the roll angle is without a filter. We make tests with different Hz data output and we get the best results with 10 Hz.

The figure 11 shows unfiltered realtime data (just the hardwarelatency). We expect to get a better accuracy by optional online filtering with the cost of a little bit more latency.

7. CONCLUSION

Our project give us a lot of good results:

- High precision realtime derivation of the six degrees of freedom
- The open architecture concept allowed the embedding of external developments on the device
- The open software concept allow to get all parts of rawdata and all parts of processed data by TCP/IP
- Using the Dopplerdata allowed to implement very good full automatic “einmessen” of fresh installed Antennaequipment

The next steps are further Softwaredevekopment and than to test the system on the surveying vessel Deneb. We compared our measurements with Gyro and Compass on Board of the Basle Express and we got better results. A three antenna GNSS System have the big advantage in Comparison with an IMU[2], we have no drift and always the same accuracy. After a successful tests on the Deneb, we will develop the three antenna GNSS for surveying vessels, but we think there are a lot more application, where you can use the system. For example a very interesting one, is to provide data for the calculations for leveling helicopter platforms.

8. FURTHER OUTLOOK

We are prepared for Galileo and Beidou. We expect increasing accuracy when these systems are online.
We hope to proof our open architecture concept together with a lot of costumers with different plugins and usages.

[2] IMU Inertial Measure Unit

REFERENCES

[1] T. Pany, Navigation Signal Processing for GNSS Software Receivers, Artech House, 2010.

[2] D. Dötterböck, S. Ko and B. Eissfeller, "Multi-Constellation RTK with a Software Receiver," in *Proceedings of the ION GNSS 2011*, Portland, Oregon, USA, 2011.

[3] "Network Time Protocol," Wikipedia, 5 March 2014. [Online]. Available: http://en.wikipedia.org/wiki/Network_Time_Protocol.

[4] J. Hahn and E. Powers, "A Report on GPS and Galileo Time Offset Coordination Efforts," in *Proceedings of TimeNav'07*, Geneva, Switzerland, 2007.

[5] B. Eissfeller, T. Pany, R. Biberger and T. Schueler, "Instantaneous Ambiguity Resolution for GPS/GALILEO RTK Positioning," *Journal for Gyroscopy and Navigation (Russian)*, vol. No. 3 (38), pp. 71-91., 2002.

[6] B. Eissfeller, C. Tiberius, T. Pany and G. Heinrichs, " Real-Time Kinematic in the Light of GPS Modernisation and Galileo," *Galileo's World,* pp. 28-34, Fall 2002.

[7] J. Avila-Rodriguez, G. W. Hein, S. Wallner, J.-L. Issler, L. Ries, L. Lestarquit and A. de Latour, "The MBOC Modulation: The Final Touch to the Galileo Frequency and Signal Plan," in *Proceedings of ION GNSS 2007*, Fort WOrth, Texas, USA, 2007.

[8] Dybek, J.; Böder, V.; Wirth, H. und Seeber, G. (1998): Optimierung der hydrographischen Positions- und Lagebestimmung. Gemeinsamer Schlussbericht zum BMBF-Vorhaben FKZ MTK 590 A und MTK 590 B. Koblenz und Hannover, 1998.

[9] Böder, V. (2009): Untersuchung von Lagewinkelsensoren. Beiträge zum 89. DVW-Seminar Hydrogra-phie – Neue Methoden von der Erfassung zum Produkt. Schriftenreihe des DVW 58/2009. Wissner-Verlag, Augsburg, 2009.

[10] IALA Recommendation R-129 on GNSS Vulnerability and Mitigation Measures, Edition 2, Dez. 2008.

[11] N. Ward, G. Shaw, P. Williams, A. Grant, "The Role of GNSS in e-Navigation and the Need for Resilience", European Navigation Conference ENC GNSS 2010, Braunschweig, Germany, October 2010.

[12] A. Grant, P. Williams, N. Ward, S. Basker, "GPS Jamming and the Impact on Maritime Navigation", The Journal of Navigation, Vol. 62, No. 2, April 2009, pp. 173-187.

[13] T. Kraus, R. Bauernfeind, B. Eissfeller, „Survey of In-Car Jammers – Analysis and Modeling of the RF signals and IF samples (suitable for active signal cancellation), Proc. Of ION GNSS 2011, 20-23 Sept. 2011, Portland, OR, USA, pp. 430-435.

[14] D. P. Shepard, J. A. Bhatti, T. E. Humphreys, "Drone Hack, Spoofing Attack Demonstration on a Civilian Unmanned Aerial Vehicle", GPS World, Aug. 2012.

[15] S. Rounds, „Jamming Protection of GPS Receivers. Part 1: Receiver Enhancement", GPS World, Jan. 2004, pp. 54-59.

[16] T. Willems, W. De Wilde, "Theory and Practice of the Interference Mitigation Technology (AIM+) in Septentrio Receivers". Proc. ION ITM 2013, 27-29 Jan. 2013, San Diego, CA, USA, pp. 835-842.

[17] F. Leveau, S. Boucher, E. Goron, H. Lattard, "Anti-Jam Protection by Antenna", GPS World, Feb. 2013, pp. 30-34.

[18] M. Cuntz et al., „Architecture Design and First Results of Multi-Antenna GNSS Navigation Receiver", Navitec 2008, Dec. 2008, Noordwjik, ESA-ESTEC.

[19] A. Konovaltsev et al, "Performance Analysis of Joint Multi-Antenna Spoofing Detection and Attitude Estimation", Proc. ION ITM 2013, San Diego, CA, USA.

[20] M. Sgammini et al, "Blind Adaptive Beamforming Based on Orthogonal Projections for GNSS", Proc. ION GNSS 2012, Sept. 2012, Nashville, TN, USA.

BIOGRAPHICAL NOTES

Dirk Kowalewski

He received his Dipl.-Ing. of Geodesy from the TFH Berlin in April 1991. He started his career as a specialist in CAD Software, total station from Zeiss and Topcon and a GNSS specialist for Trimble, Ashtech and Topcon. He worked in these jobs for different companies about 10 years. In March 2001 he started with his own business and he was the founder and the director of Geo.IT Systeme GmbH. The next milestone was the foundation of navXperience together with Franz-Hubert Schmitz. With navXperience they started the developing of our 3G+C GNSS antenna technology in the beginning of 2010. They started the sales in the end of 2010. From 2009 to 2011 they worked together with Frank Heinen at the research project MoDeSh. The development was a six dots of freedom Software for the measurement of movements and deformation on vessels. In 2013 the idea of the OSR receiver was born and since 2015 navXperince, Gutec and Datagrid works together on this project. Since 2012 he is a member of the working group AK 3 “Measurement method and Systems” DVW Germany.

Frank Heinen

Dipl. -Ing. of Electronics at the University of Duisburg in 1989.

He developed operating systems for acoustic discharge measurement hardware till 1991 and then went for 11 years to Ziegler Informatics and get a specialist in CAD Software development.

After that he went to IVC-AG and TRIGIS as a GIS-Software specialist. In December 2004 he get freelancer in the Fields of GEO, GIS and CAD. Since 2005 he worked with GeoIT. Together with GeoIT he developed an OS that enhance an existing TOPCON device and give it a WEB-Interface that maps the whole settings area and give a lot add-ons. With GeoIT he worked at the research project MoDeSh. Since the foundation of navXperience he also works with and later for navXperience. There he worked on the GOOSE Project and for siNafa.

CONTACTS

Dipl.-Ing. Dirk Kowalewski
navXperience GmbH
Querweg 20
13591 Berlin
GERMANY
Tel. +49 30 375 896 7-0
Fax + 49 30 375 896 7-1
Mail: dirk.kowalewski@navxperience.com
Webpage: www.navxperience.com

Dipl.-Ing. Frank Heinen
navXperience GmbH
Querweg 20
13591 Berlin
GERMANY
Tel. +49 30 375 896 7-0
Fax + 49 30 375 896 7-1
Mail: frank. heinen@navxperience.com
Webpage: www.navxperience.com