Driving Assistance Systems for Inland Vessels based on High Precision DGNSS (Research Project LAESSI)

by

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ABSTRACT

Inland shipping is an important key element of the German transport system. The growth in traffic, increasing ship dimensions, reduced maneuver space etc. place high demands on the responsible skippers. It is expected that future driving assistance systems can contribute to safe navigation.

The project LAESSI (Guiding and Assistance Systems to Improve Safety of Navigation on Inland Waterways) aims to develop efficient navigation assistance functions for inland waterway transport. Therefore, nautical information like position, height and heading has to be determined. One main task of the project is the development of a bridge collision warning system, which could provide a timely alert to the skipper, whenever the vessel, particularly the wheelhouse or radar mast, will not safely pass the bridge.

A feasibility study has identified Global Navigation Satellite System (GNSS) technologies as basis for the reliable height determination for such a bridge collision warning system. This approach requires information about the vertical clearance of the bridge superstructure as well as precise height information at least 300 m before the vessel will pass the bridge. The high accuracy level of less than 10 cm in the vertical position requires the use of high precision DGNSS.

The paper will present the derived requirements for inland waterway assistance functions as well as an overview about the overall system architecture. In addition the paper provides information about the high accuracy positioning system, which is based on real-time kinematic (RTK9 technology including integrity information. The correction and integrity data together with other waterway information will be broadcasted using the new frequency bands offered from VDES (VHF Data Exchange System). Finally the paper will describe first results gained in demonstration areas at the Moselle and Main Rivers.

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1. INTRODUCTION

Inland navigation plays an important role in transportation of goods in Germany. Although inland navigation is a relatively safe mode of transport, accidents like collisions of wheelhouses with a bridge superstructures happen from time to time and can have dramatically consequences. It is expected that this type of accident can be reduced by a system warning that is generated when the ship's height is too large for the bridge passage. In addition, even the daily navigation of a large ship, e.g. a 185 m push tow, in confined waters is a demanding task for a scipper and indicates the need for support.

The aim of the project LAESSI is to support the skipper in his tasks of navigating a vessel and thus make inland shipping safer and also more efficient. To reach this goal, LAESSI makes use of latest GNSS navigation technology and data transmission developments. Within the project LAESSI research was done to add elaborated integrity information to the result of GNSS processing. Providing high precision navigation data with high reliability is a prerequisite to set up advanced driver assistance functions.

The joint research initiative LAESSI will be pursued in a unique combination of core competences from in-innovative navigation GmbH, Alberding GmbH, Traffic Technologies Centre of German Waterways and Shipping Administration (WSV) and DLR (German Aerospace Center) and Institute of Communications and Navigation.

The paper will provide information about the derived requirements for inland waterway assistance functions as well as an overview about the overall system architecture. In addition the paper informs about the high accuracy positioning system, which is based on RTK technology including integrity information. The correction and integrity data together with other waterway information will be broadcasted using the new frequency bands offered from VDES (VHF Data Exchange System). Finally the paper will present first results gained in demonstration areas at the rivers Moselle and Main.

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2. THE CONCEPT OF LAESSI

2.1 Assistance functions

The project focuses on the development of:

- A Bridge Collision Warning system providing a timely alert signal to the skipper, whenever the vessel, particularly the wheelhouse or the radar mast, will not safely pass under a bridge.
- A Mooring Assistance providing an accurate display of the actual situation, in particular, highly accurate distances to quay walls and other vessels.
- An Automatic Guidance System reducing stress on the skipper during on route navigation. Highly accurate and integrity tested positioning and heading information is the basis for this functionality, especially on narrow waterways.
- A Conning Display presenting clearly the motion of the ship. For this purpose it is also important to incorporate information from the propulsion systems as well as the influence of wind and water currents.

2.2 System requirements

In the following table accuracy as well as integrity requirements are listed for the different assistance functions. The basic idea of a bridge collision warning is to compare the geodetic height of the vessel with the geodetic height of a bridge. This results in requirements for the height measurement. The algorithm will further be divided into two parts, a long distance part starting about 10 minutes before the bridge passage and a close up part within the last two minutes. The first lines in Table 1 in column bridge collision warning refer to the close up part. A warning in the close up part requires immediate action of the skipper, higher integrity requirements have to be taken into account there. Also the time to alarm is lower there.

Position and heading are used as a basis for prediction of the ship´s movement in the close up part. High requirements for position and heading accuracy are necessary for the mooring assistant. These are based on the requirement that each point on a 185 m convoy shall be known with 30 cm accuracy. The integrity risk is based on the assumption, that one non detected error within three years of normal operation can be tolerated. The time to alarm requirement takes into account, that on the one hand mooring is a critical operation for the skipper. On the other hand the vessel is moving at low speed in this situation.

	Bridge collision warning	**Automatic guidance**	**Mooring assistance**	**Conning display**
Position accuracy [cm]	20	30	10	20
Height accuracy [cm]	10	not relevant	not relevant	not relevant
Heading accuracy [°]	0,3	0,17	0,07	0,1
Integrity risk	$10\ 10^{-5}$ / 2 min $30\ 10^{-5}$ / 8 min	$0{,}55\ 10^{-5}$ / 3 h	$18\ 10^{-5}$ / 10 min	$18\ 10^{-5}$ / 1 h
Time to alarm [s]	4 6	2	6	6

Table 1: Accuracy and integrity requirements of assistance functions

Quite similar are the requirements for the conning display. Here the vessel operates in confined waters, but most times not close to walls or other vessels. Thus accuracy requirements are lower. Also the time of using a conning display is longer than a typical mooring situation.

For automatic guidance of the vessel no especially high accuracy is required. In contrast to the other assistance functions, the skipper is not part of the control and action loop. His functions are monitoring the system as well as tactical trajectory planning. Jumps due to errors in the position measurement might have immediate impact on the rudder commands. Thus the function has to be very reliable. Basis for the proposed integrity risk is the assumption that within one year on 100 vessels only one case of not detected integrity problems may occur. Also a very short time to alarm is required.

2.3 Overall system architecture

The required level of accuracy (dm – cm) cannot be achieved by currently used code based positioning techniques. Therefore phase based GNSS positioning (RTK) needs to be applied. Furthermore exact and valid electronic charts, as well as information regarding the actual situation in the navigational area (e.g. temporary restrictions at construction sites) are required.

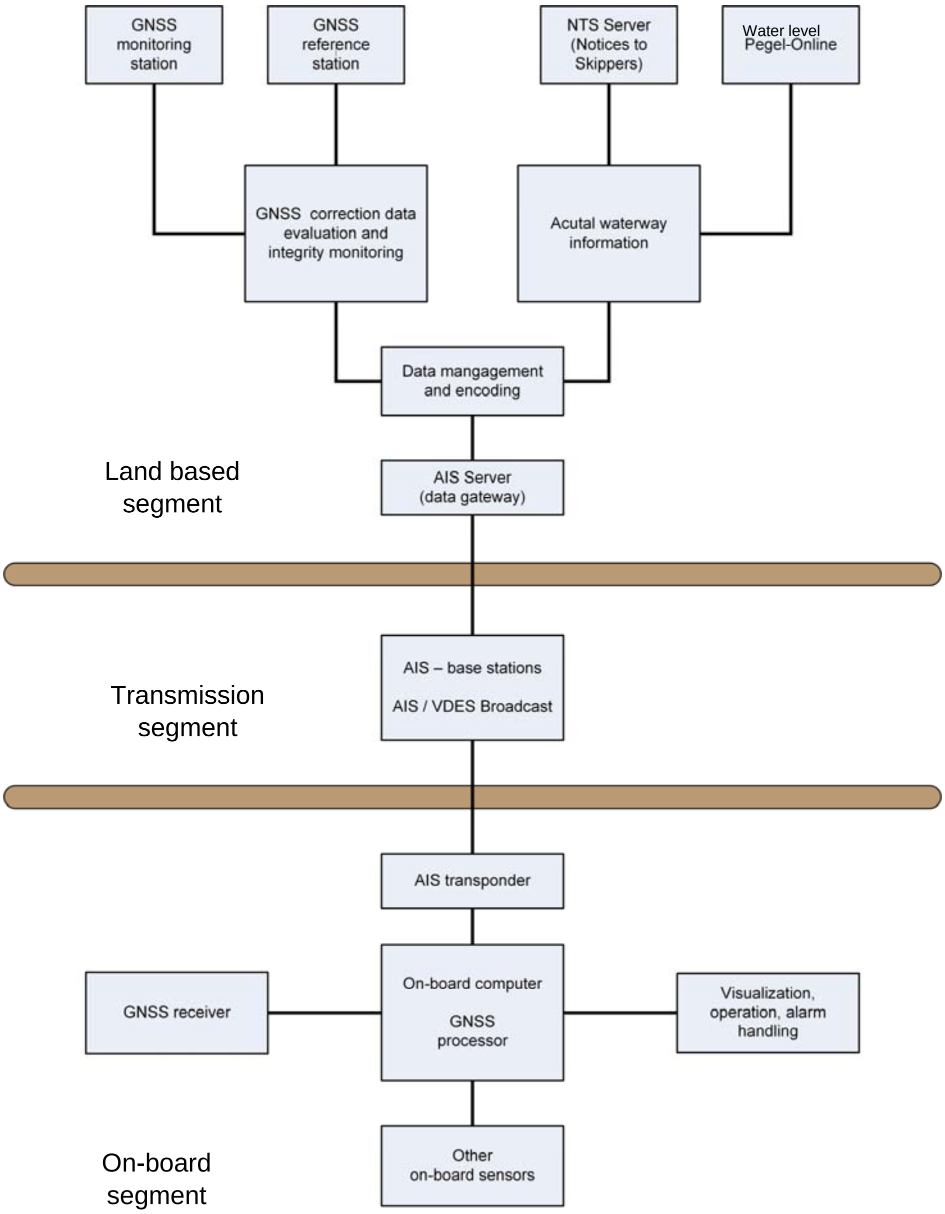

Figure 1: Overall system architecture

Fig. 1 shows a schematic overview of the system architecture of the project LAESSI. The land based segment provides GNSS correction data necessary for the RTK processing on-board the vessel. These correction data are integrity checked before they are transmitted. Any problems are reported to subsequent processing steps and are the first step of the integrity control framework of this project. Also information about actual waterway conditions is prepared. Here it is important to provide up-to-date information about waterway restrictions, e.g. construction works at bridges. Such information should be provided timely and to the appropriate locations.

Transmission of these data to the vessels shall be done by AIS and its future enhancement VDES. Finally the on-board segment realizes the assistance function. A GNSS receiver, augmented by the correction data generated in the land segment provides high precision GNSS solutions. Processors on the vessel monitor the integrity of the solution and realize the assistance functions. Further on-board sensors are inertial measurement unit (IMU), rate of turn indicator, radar, laser distance scanners etc.

3. DATA PROCESSING AND TRANSMISSION

3.1 Land based data processing

The on-board assistance functions, which shall support the skipper in a reliable manner, require on the one side precise position information but also actual water way information. This information will be generated and collected by the land based service and broadcast to the vessel. An overview of the design of the service is given in Fig. 2.

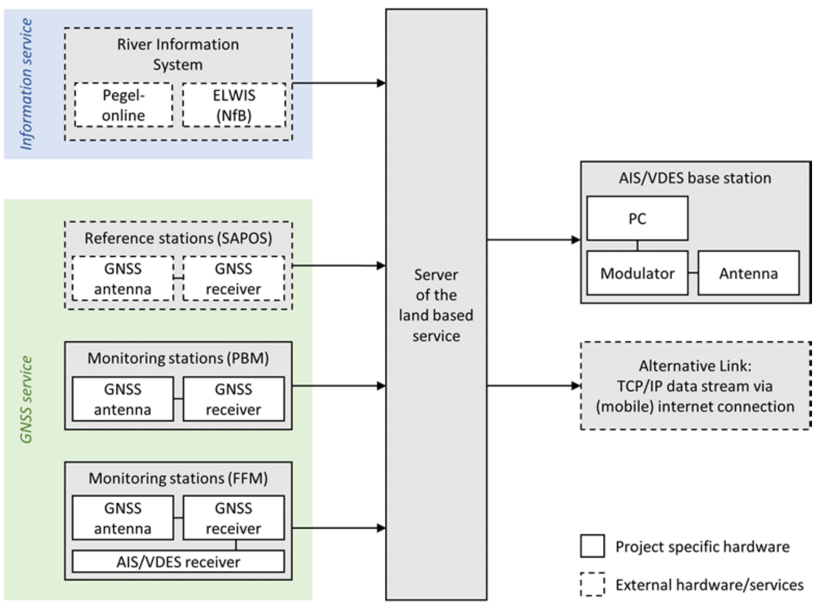

Figure *2*: Design of the land site service

The use of GNSS signals and appropriate measuring techniques for precise positioning is well-established in geodesy. For this purpose the real-time kinematic (RTK) technique will be applied to achieve cm-level position accuracies based on carrier phase GNSS observations and on the corresponding correction data.

Therefore, a network of permanent GNSS reference stations is needed to derive RTK correction data. This network should have an appropriate spatial distribution and the data should be accessible in a standardized way for the central processing server. A state-of-the-art network RTK data processing algorithm will derive the GNSS correction data for the vicinity of the current position of the vessel. As the project aims to support safety critical applications, these GNSS corrections will be checked for their integrity before they will be broadcasted (Pre-Broadcast Monitoring) to the vessel via a standardized communication channel, implemented along the inland waterways. The result of this integrity check will also be transmitted to the user to have a full quality assessment of the service and correction data at the vessel.

Additionally a verification of the calculated corrections will be conducted at some Far Field Monitoring stations, which will processed the received corrections. In addition these monitor sites may also provide performance indicators of the communication system to the service providers.

The requirements to the shore based GNSS service are derived from the needs of the assistance functions:

- The accuracy of the calculated GNSS position on-board shall be below 10 cm for the horizontal and height component.
- The service shall detect erroneous satellite ephemeris/clock or correction data within a certain limit of time and transmit this integrity information to the vessel.
- The availability of the service shall follow the definition of IMO standards (IMO Res. A.953 (23). Furthermore the service has to ensure, that the integrity data transmitted to and via used communication system is free from errors (checksum).
- The broadcast GNSS correction data shall refer to the latest realization of the ETRS89 coordinate reference system, as it is also used in the official German surveying and mapping administrations. Due to this, a homogeneous data basis can be established and the comparison to external surveying data like bridge shapes and harbour maps is ensured.

Besides the precise position the skipper is interested in up-to-date notices about the water ways, like temporarily closed sections, construction work at a bridge or provision of the water level. This information is provided in Germany via web-based portals like ELWIS or PEGELONLINE. From these web services the information needed will be requested, checked for plausibility and broadcasted to the skipper as Application Specific Messages (ASM) via AIS/VDES. This broadcast will be issued in a regional specific manner, so that only relevant notices are transmitted in an area, which is covered by an AIS/VDES base station.

3.2 Data transmission

As described above phase based GNSS corrections together with integrity information need to be broadcasted to ship site users to fulfill the high accuracy requirements of the intended LAESSI driver assistance applications. Such data are based on carrier phase observations for GPS and GLONASS. The amount of data is expected in a range of about 7 Kbit using an update rate of 1-2 seconds. In addition to the GNSS corrections so called waterways information data will be broadcasted to provide the assistance functions with up to date information of water level and notices to skippers (NTS).

The NTS data include information of present restrictions of the navigable water as well as information of present bridge clearance. The GNSS corrections as well as the waterway information should be broadcasted to dedicated areas.

To summarize the following requirements for the data transmission could be deviated:

- Data rate: > 9600 bit /s enabling an update rate of < 2 sec
- Coverage: complete coverage (partly overlapping) along inland waterways
- Standardization: international standardized communication is required to enable harmonized data transmission

AIS (Automatic Identification System) are already standardized in the maritime and inland waterway domain to exchange navigational data between ships, between ship and shore and shore to ship. For this purpose a number of countries have already installed shore side networks to enable data exchange. The German WSV has installed an AIS network which covers the coast as well as major inland waterways. In connection with a mandatory carriage requirement AIS is a viable candidate for the planned transmission of corrections and waterway information. Nevertheless, the existing AIS is limited within its data capacity. Especially the high demand on the update rate would cause a significant AIS data load. At present an AIS message type #17 is standardized for the transmission of code based GPS corrections. However, this message cannot be used for RTK messages. Accordingly within the LAESSI project VDES (VHF data exchange system) is considered for data transmission from shore to ship. VDES provides additional terrestrial frequency channels within the same frequency band and can provide higher data capacity.

Another possibility is the use of GSM which is nowadays a standard for mobile data transmission. GSM would be a feasible candidate but we have to take into account that GSM has not a full coverage along inland waterways and may not be usable under certain circumstances (e.g. when a large number of users is blocking the network). Thus the availability of this service may not fulfill the requirements. However GSM will be used within LAESSI as a backup to AIS (VDES).

The driver assistance applications were tested in selected areas at Moselle and Main Rivers. Inside these areas the existing AIS infrastructure has been modified to enable a simulation of the future VDES. For this purpose future available VDE frequency channels will be allocated for a number of AIS shore sites in the test bed areas. This system concept enables the use of standard AIS equipment at land and on-board using future frequency channels and prevents from any adverse effects with the operational AIS system during the test periods. The use of AIS technique means limiting the data rate to 9600 Bit/s. It is planned that the new developed ASM will be used to support the current development of such messages aligned to the ongoing international standardization process of VDES.

Due to the limited coverage along waterways and the general availability GSM mobile communication was only used as a backup to AIS (VDES) within LAESSI. The concept of VDES comprises the functions of the existing AIS, an additional communication link for the exchange of ASM and an additional communication link enabling higher capacity VHF digital data exchange (VDE).

4. SHIPBORNE INTEGRITY MONITORING

4.1 Carrier phase processing

Usually code-based techniques (like IALA Beacon DGNSS) are used for inland waterway navigation and achieve accuracies of few meters or less. However, the described assistance functions indicate significantly higher requirements. As a consequence a transition of code observations to the more accurate phase observations (by a factor of 100) is necessary. The challenge by using carrier phase observations is to solve the unknown number of waves phase cycles, the ambiguities. If the ambiguities can be estimated as float values, a dm-accuracy of the position can be achieved. If the carrier phase ambiguities are fixed to integer numbers, cm accuracy is reachable.

Several influences like signal interruptions, multipath, cycle slips and measurement noise affect the ambiguities resolution of the carrier phase and consequently the determination of positioning and velocity information. These special station dependence effects cannot reduce by the land based correction data. Furthermore the atmospheric effects coming from the ionosphere and troposphere can impact the positioning solution, depending on distance between land based station and the remote station on the vessel. Nevertheless, to provide high accurate (less than 10 cm in horizontal and vertical position) and reliable PNT data a tightly-coupling of the GNSS observations (phase and code) with other sensors like inertial measurement unit (IMU), rate of turn etc. in an Extended Kalman Filter (EKF) is required. This combination has the advantage that on the one side short GNSS outages due to obstacles like bridges and buildings near the ship path can be bridged. On the other side more sensor data and the combination of all sensors outputs enable higher integrity information.

4.2 3-stage integrity concept

Fig. 3 explains the desired integrity concept on ship-side that consists of three components. At first only the parameters from the EKF-based RTK processing were analyzed. This includes a validation of the fixed ambiguities and the variances from the adjustment algorithms. In the next step similar output data like length of the antenna baseline, velocity, heading and height difference from different sensors or procedures will be compared. Furthermore the integrity information from the land based service is used to evaluate the position accuracy on the ship. All individual parameters have specified thresholds based on the assistance function requirements. Only if all parameters are below their thresholds, the integrity for this event will be assessed positively and the PNT data can be considered as reliable.

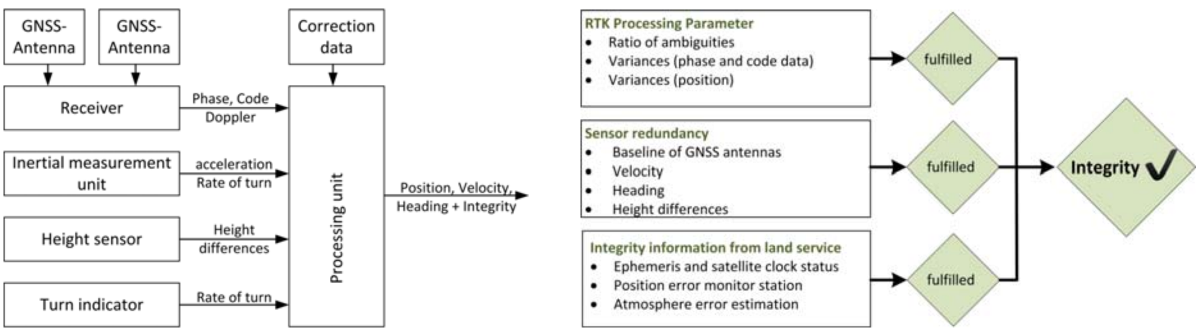

Figure 3: **On board processing with RTK algorithm and additional sensors (left). 3-stage integrity concept (right)**

5. PERFORMED TEST AND RESULTS

As described in the previous sections four main areas of development were conducted within the LAESSI project:

- New driver assistance functionalities,
- An on-board PNT unit which provides the required accuracy and integrity for 3D position and heading,
- Soft- and Hardware to provide integrity monitored GNSS corrections (RTK) and waterways information and
- a communication channel for transmitting the high data rate GNSS data and waterway information over a modified AIS shore network

For testing and validation of the system concept two test areas were implemented. One test bed was installed in Koblenz along the Moselle River for first tests of system components and a second one at the Main River in the area of Würzburg for system integration and investigations over a longer part of the waterway, including several locks and bridges. Further tests were performed using a commercial 180 m long inland vessel (El Niño) which cruises between Rotterdam in the Netherlands and Linz in Austria. These tests should provide information how the system works on a regular trip and gain information and feedback from the skipper in the daily use of the system.

5.1 Performed test

First tests regarding the performance of various sensors, technologies, data transmissions and communication were performed in the Koblenz test bed. Here the project team could validate that the several system components were working as planned and that they provided the expected performance. In a second step full system integration were accomplished at the Main test bed using a larger measurement campaign on the MV Naab in October 2017. One part of this measurement was a performance test of the new communication system based on modified AIS land sites. The results will be explained in the following sub sectors. During this test campaign a lot of other aspects were analyzed. They will be published in separate papers.

5.2 Test of communication equipment

Beside a lot of other measurements (e.g. analysis of the possibility to solve for high position accuracy and heading information) the test campaign enabled the test of the modified AIS transmissions on co-located frequency channels which will be usable with the currently developed VDES standard. As showed in Figure 4 altogether five AIS land stations were equipped with this additional functionality.

This configuration enabled the project team to test the availability of overlapping AIS shore sites in a test area of roughly 100 km. Fig. 5 shows a measurement of the signal propagation in the test area and indicates the good overlapping of the AIS and the “simulated VDES system”. Between the shore sites of Erlabrunn (Main km 240) and Steinbach (Main km 200) two AIS shore sites were not installed. The coverage gap was accepted in order to test the switch over to a GSM communication as a backup and to identify the usage of this commercial communication system.

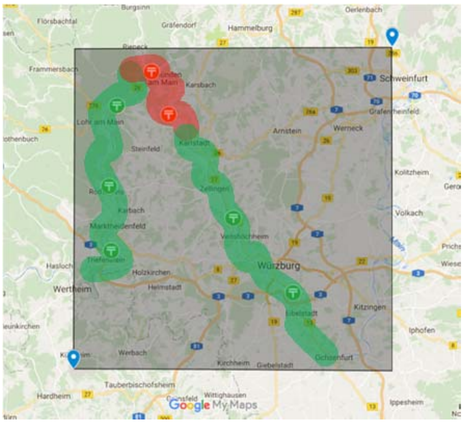

Figure 4: Test bed Main River with additional AIS land sites transmitting on new VDES frequency channels (green) and area for GSM connection (red); Dark grey, reginal area for frequency channels 2025 and 2026

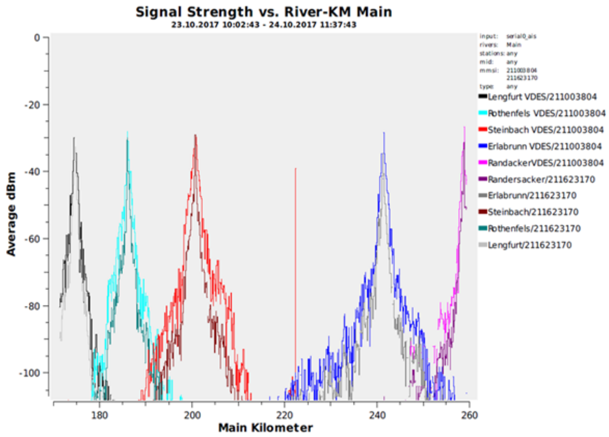

Figure 5: Coverage measurements for AIS and VDES frequencies along Main River, MV Naab 10/2017

A first analysis of the data received shows the difficulty to provide the data capacity, which is needed for a valid RTK fix. As shown in Fig. 6 a RTK fix solution was possible in most parts of the test bed (with exception of the north east part, which was not equipped with AIS). Nevertheless the data age was too high in many parts along the Main River test area. The reason for this is the limited data capacity of the AIS channel. It should be noted that for the test period only transmissions on AIS channel A were used. With a combination of using channel A and channel B a better result could be expected.

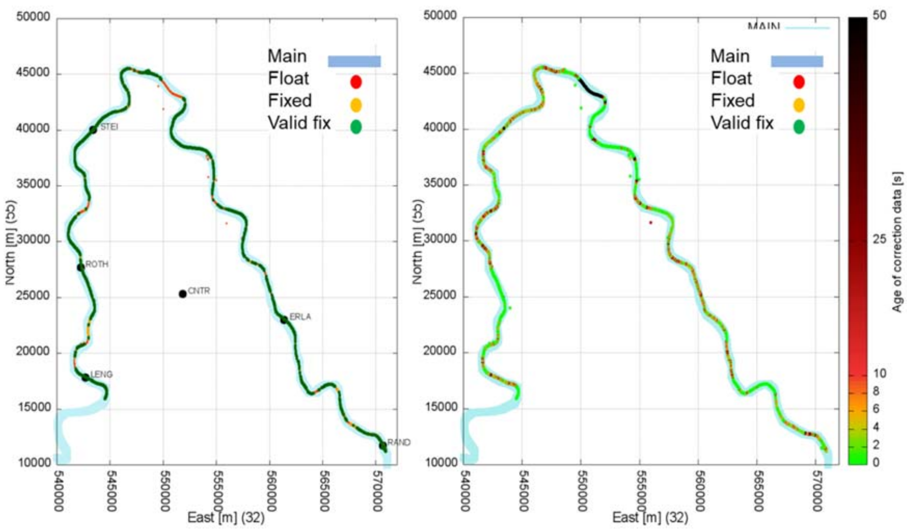

Figure 6: data analysis (fix solution and data age) for AIS and GSM at Main test bed, Naab 10/2017

296 Day		Valid KD	Float	Fixed	Fixed+ (4 s)	Fixed+ (2 s)
	Via GSM	92,5	14,1	83,8	79,7	79,3
	Via AIS	77,7	28,2	71,6	60,3	53,5

296 Night		Valid KD	Float	Fixed	Fixed+ (4 s)	Fixed+ (2 s)
	Via GSM	100,0	3,7	96,3	95,9	95,9
	Via AIS	99,8	2.2	97,8	96,8	96,5

297 Night		Valid KD	Float	Fixed	Fixed+ (4 s)	Fixed+ (2 s)
	Via GSM	100,0	0,1	99,9	99,8	99,8
	Via AIS	100,0	1,9	98,1	97,0	97,0

297 Day		Valid KD	Float	Fixed	Fixed+ (4 s)	Fixed+ (2 s)
	Via GSM	92,9	10,8	86,5	82,3	81,9
	Via AIS	70,1	22,5	77,4	55,3	46,2

Figure 7: Availability analysis for various types of RTK fix for modified AIS and GSM, MV Naab, 10/2017

Fig. 7 provides a detailed overview about the availability of the tested communication options along the test area. As expected the availability of the modified AIS transmissions was only in a range of 80% due to transmissions only on AIS channel A and the limited data capacity of AIS in contrast to GSM or the future VDES.

However, the test further shows that there is a need for more investigations in the methods how the data should be packed and coded before they will be transmitted. Both will be possible when real VDES technology with a much higher data rate becomes available.

5.3 Further achievements

As mentioned before a lot of other activities, measurements, results and achievements were conducted within LAESSI. The following part will summarize some of the main results of the project. The main goal of the project was to develop and test first driver assistance functionalities for bridge warning, automatic track control, mooring and conning. All this functionalities could be successfully implemented and tested from innovative navigation GmbH. Fig. 7 provides some examples for the bridge warning and conning display.

As a basic element to provide reliable and integrity checked position, navigation and time data as input to the new applications, the German Space Agency (DLR) could implement and test a prototype PNT (Position, Navigation, Timing) data processer unit (Fig. 8).

On the land site the Alberding GmbH has developed and tested new shore site services, based on the concept shown in Figure 1. Various software modules to provide the RTK corrections and the waterway information to the AIS shore infrastructure were developed. The WSV was responsible for the setup of the communication channels for the test areas. Within the project a first VDES simulation could be performed and tested using AIS transmissions on new frequency channels. Here the WSV has gained important results for the ongoing standardisation process of VDES, e.g. AIS and VDES transmissions on co-located frequency channels.

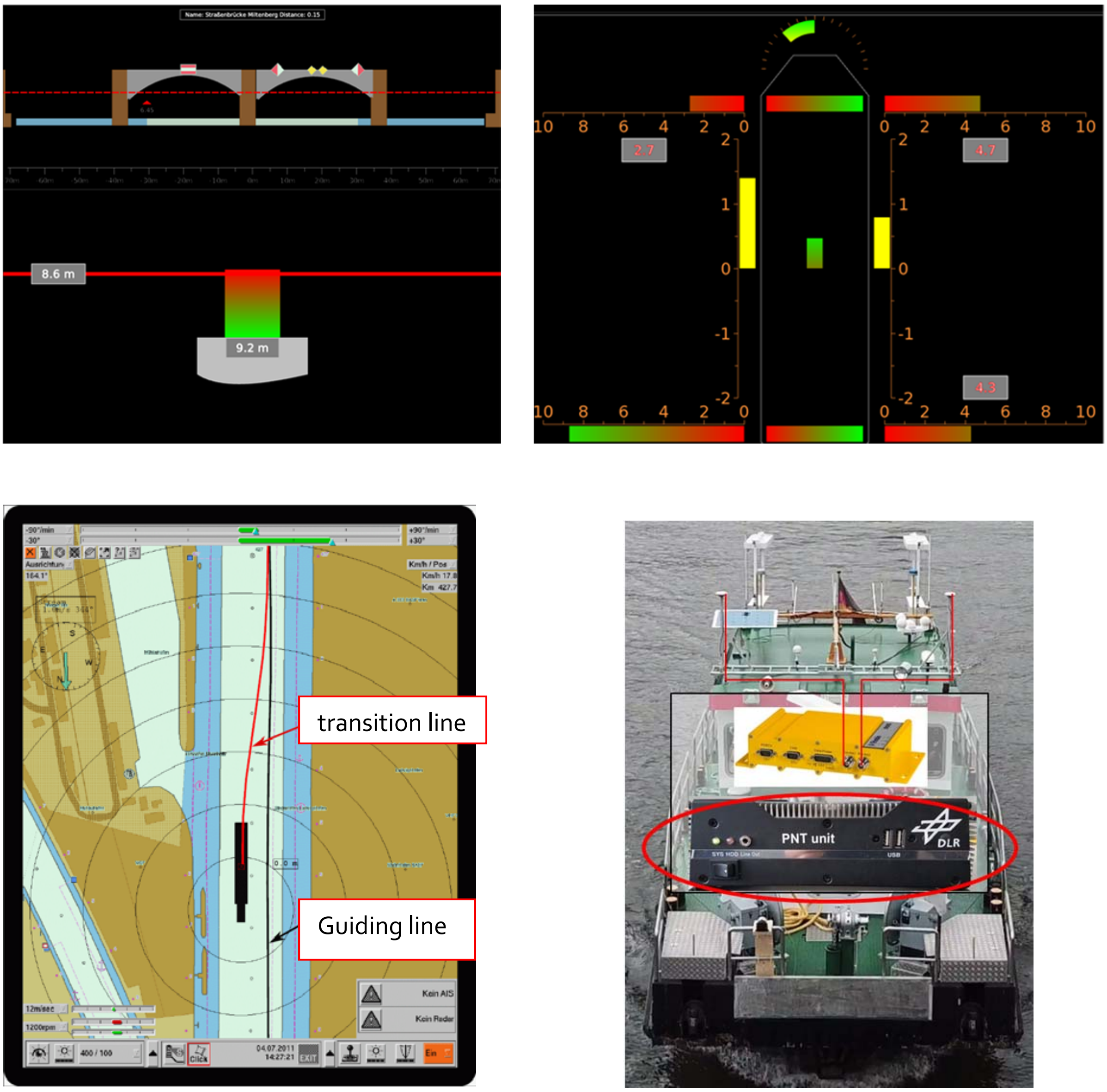

Figure 8: Examples of visualisation displays, bridge height warning (top left), conning and and mooring assitance (top right), automatic guiding system (reference: ISR, Stuttgart University, down left), example of prototype PNT unit developed within LAESSI (down right)

CONCLUSIONS

The results gained in the LAESSI project are a first step into a driver assistance supported shipping of inland vessels. The tested functions, e.g. the bridge warning system can contribute to the safety of navigation on inland waterways. The first reactions by skippers according to functions and display of assistance data were very positive. The developments in LAESSI will provide basics for autonomous shipping in future. Relevant results could also be achieved which help to amend international standardization of river information services and systems, communication standards and data protocols.

The members of the LAESSI project team consider to further develop the system technology towards new on-board applications (e.g. enabling automatic navigation of inland ships into a lock), to improve the provision of GNSS corrections (e.g. using PPP methods), the performance of on-board PNT and the used communication system (e.g. VDES). A follow-up research project is planned and may start in mid-2018.

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