Applications for a Hydrographic Multi Sensor System on Lakes and Rivers

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Key words: hydrography, multi sensor system, attitude determination, precise point positioning, gravimetry, archaeology, laserscanning

SUMMARY

Determining topographic features for the safety of waterways is one of the major, but not the only task for hydrographic surveys. As stated on the homepage of the International Hydrographic Organization (IHO, www.iho.org, visited on September, 19th 2009), *Hydrography is the branch of applied sciences which deals with the measurement and description of the physical features of oceans, seas, coastal areas, lakes and rivers, as well as with the prediction of their evolution, for the primary purpose of safety of navigation and all other marine purposes and activities, including economic development, security and defence, scientific research, and environmental protection*.

The laboratory Hydrography at the HafenCity University Hamburg (HCU) tries to find future applications or applications that should be newly investigated for hydrographic platforms. For testing we use our equipment onboard our survey vessel Level-A. The following paper presents the HCU-Hydrographic Multi Sensor System (HCU-HMSS) and describes some applications in archaeology, gravimetry, and laserscanning. Additionally the precision of attitude senors and the use of precise point positioning without any reference stations will be taken into acount.

The precise point positioning shows accuracies on the dm level. Attitude sensors investigated did not meet the accuracy specifications. In archaeology high precision and resolution DTM or point clouds assists in finding underwater objects.

A short insight in not yet finished investigations with gravimeter and laserscanner measurements will be given in the report.

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1. Introduction

Determining topographic features for the safety of waterways is one of the major, but not the only task for hydrographic surveys. The following paper presents the HCU-Hydrographic Multi Sensor System (HCU-HMSS) and some applications in archaeology, gravimetry, and laserscaning. Additionally the precision of attitude senors and the use of precise point positioning without any reference stations will be further described.

2. The HCU-Hydrographic Multi Sensor System (HCU-HMSS)

The core of the HCU-HMSS is based on different sensors for positioning and attitude determination of the ship and depth measurement or determining features under water, mostly onboard our survey vessel *Level-A*. Figure 1 gives an overview of the system.

Looking to inland applications of the HMSS in Germany the system is capable of using own reference station data or the SAPOS reference station system of the German surveying authorities (Satellitenpositionierungsdienst der deutschen Landesvermessung). The SAPOS system offers correction data in the RTCM format that leads to an accuracy of better than 5 cm in real time. Both GPS and GLONASS data can be used with the Leica RTK System or four GNSS Javad receivers working with the real time software system GNNET/GNATTI from Geo++. GNNET/GNATTI is based on a modular software system that can be used to determine ships position and attitude and combine the data with other defined sensor data (using NMEA o other specific data formats), synchronized with GPS time. The main attitude determining sensor is the IXSEA OCTANS III motion sensor with a standard deviation of 0.1° secant (latitude) for the heading, and 0.05° for roll and for pitch. Heave is measured with 5 cm or 5%, whichever is the larger value.

Multi beam depth measurements are carried out by the echo sounder RESON SeaBat 8101, serving 101 beams with a frequency 240 kHz, an opening angle of 1.5° per beam and a measuring maximum data rate of 40 Hz in shallow water. Further to this single beam echo sounders Fahrentholz Litugraph with 15 kHz, 100 kHz, 210 kHz, and 700 kHz are implemented in the system. Subbottom profiling and side scan operations are carried out with the Innomar System SES-2000 and one side scan sonar from Klein Associates. A magnetometer is used to measure the effects of iron features in the Earth magnetic field (Marine Magnetics Mini Explorer, accuracy 0.2 nTesla).

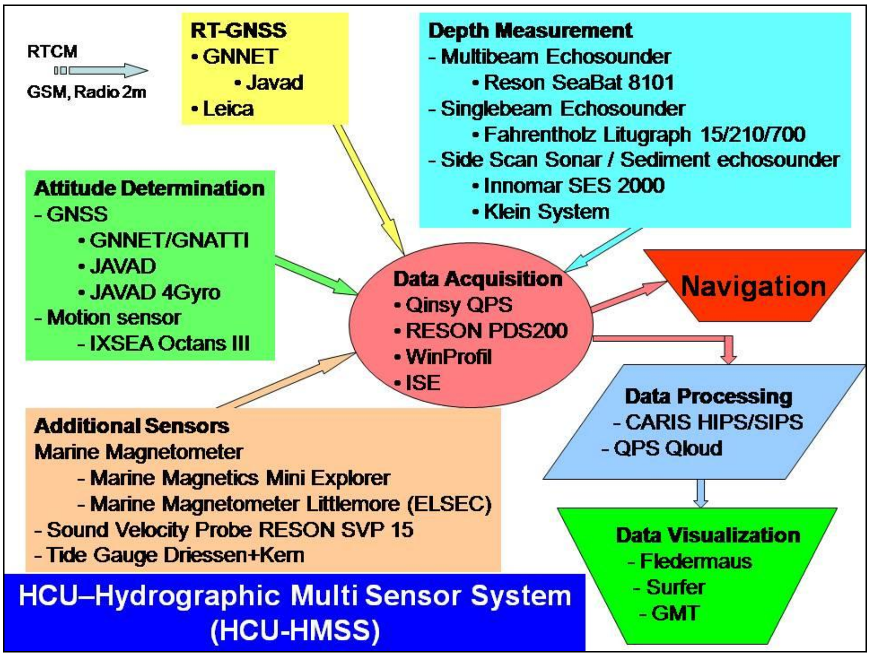

Figure 1: The HCU-Hydrographic Multi Sensor System

The software system Qinsy from QPS is used for combining positioning and attitude determination with the multi beam depth measurements over LAN and RS interfaces. However it is possible to integrate any other sensor with a NMEA-standardized data structure. Single beam measurements are sampled and processed with the WinProfile software of HydroSupport. The results are modeled and presented mainly with the software SURFER or FLEDERMAUS.

3. Investigation of Precise Point Positioning (PPP)

GNSS Precise Point Positioning (PPP) is based on the accurate modeling of the orbits and clocks of the GNSS satellites. The accuracy for real time broadcast orbits reach around 160 cm, the satellite clocks are given with the accuracy of 7 ns. The International GNSS-Service (IGS) provides after 13 days final orbits with an accuracy of better than 5 cm and satellite clocks models accurate to 0.1 ns and better (IGS 2009). Additionally absolute phase center variations (PCV) of the GNSS antenna and transformation parameters between the user coordinate system and the basic GNSS coordinate system have to be applied. Appropriate software uses these corrections from the IGS in post processing and calculate PPP positions.

Four GNSS antennae were installed onboard the Level-A on a trip over 40 km on the Elbe river between Wedel and Freiburg. Because of hardware problems not all GLONASS satellites could be used in post processing. The post processing was carried out by Lambert Wanninger and Anja Heßelbarth from the Technical University of Dresden with the software modules Wapp and TripleP. The comparison between the real time RTK positions onboard of the Level-A and the PPP solution are described in the following.

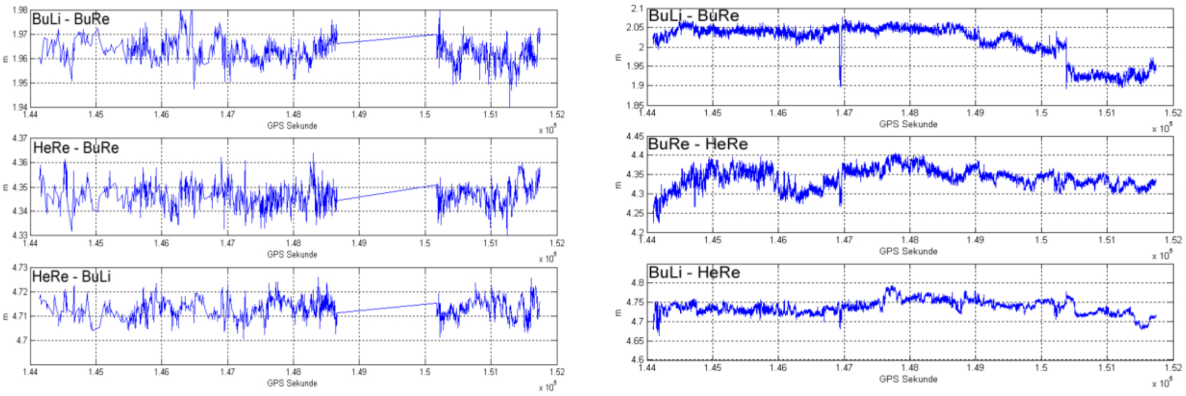

Fig. 2: Distances between GNSS antenna onboard the Level-A. Left: determined with RTK positions, right: determined with PPP positions. Different scales used.

The distances between the GNSS antennae were calculated from the 3D coordinates for every second. Figure 2 shows the results of three antenna combinations, BULI-BURE (starboard to portside, bow; mean 1.963 m), HERE-BURE (starboard from bow to stern; mean 4.346 m) and HERE-BULI (starboard to portside from bow to stern; mean 4.713 m). The left panel shows the RTK distances, on the right the distances derived by he PPP solutions. The standard deviation of all distances were determined with a standard deviation of 4-5 mm. The right graphic presents the results from the PPP solution. The mean of the distances reach in BULI-BURE 2.015 m (difference to RTK: 5.2 cm), in HERE-BURE 4.340 m (difference to RTK: 0.6 cm), and in HERE-BULI 4.737 m (difference to RTK: 2.4 cm). The standard deviations of the distance determination range from 1.8 cm in HERE-BULI to 4.5 cm in BULI-BURE.

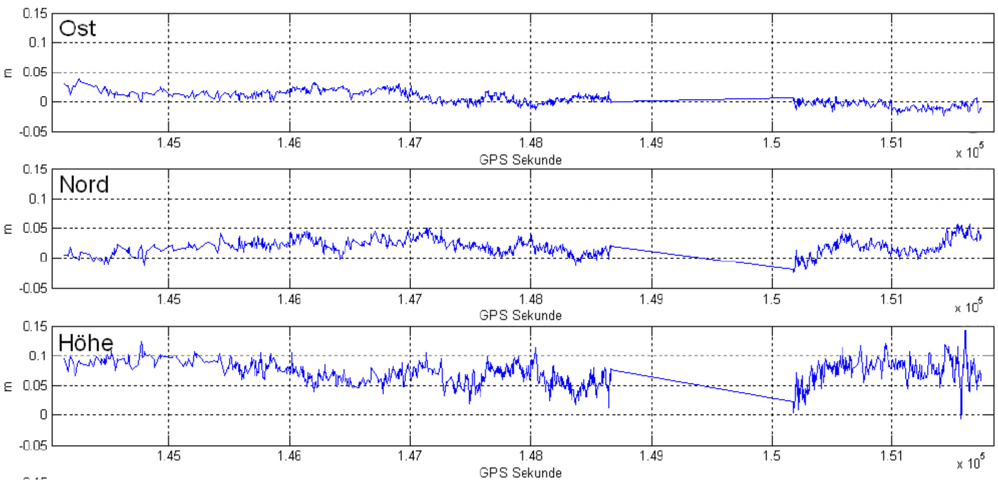

Fig. 3: Difference between RTK and PPP solution in East (Ost), North (Nord) and Height (Höhe) in the balance point of the four antennae.

The difference between the RTK and the PPP solution of the balance point of all 4 antennae is shown in Figure 3. The mean of the difference in the east component is calculated to 13.4 cm (σ=3.5 cm), in north 3.1 cm (σ=6.6 cm), and in the height 19.2 cm (σ=9.4 cm).

The accuracy of the PPP solution meets all necessary accuracy requirements on the ocean and in several other hydrographic applications. More details about the used software can be found in (Heßelbarth and Wanninger 2008). The results above were obtained in the bachelor thesis of Jörg Münchow, a student of the HCU.

4. Investigation of attitude sensors

Properly working attitude determination is important for the transformation between GNSS antenna and hydrographic sensor (e.g. echo sounders) and for the correction of the sensor data itself (e.g. multi beam echo soundings). Usually three different types of attitude sensors are used in a hydrographic environment:

- inertial sensors (gyros, accelerometer)
- GNSS supported gyros
- GNSS multi antenna systems.

The combination of inertial and GNSS based systems seems to be the best solution, as far as the GNSS antenna can be mounted without or with less shading of the signals (*Böder 2002*).

Onboard the Level-A, an inertial motion sensor (IXSEA OCTANS III) and a multi-antenna system is installed. Figure 4 shows the possible configuration.

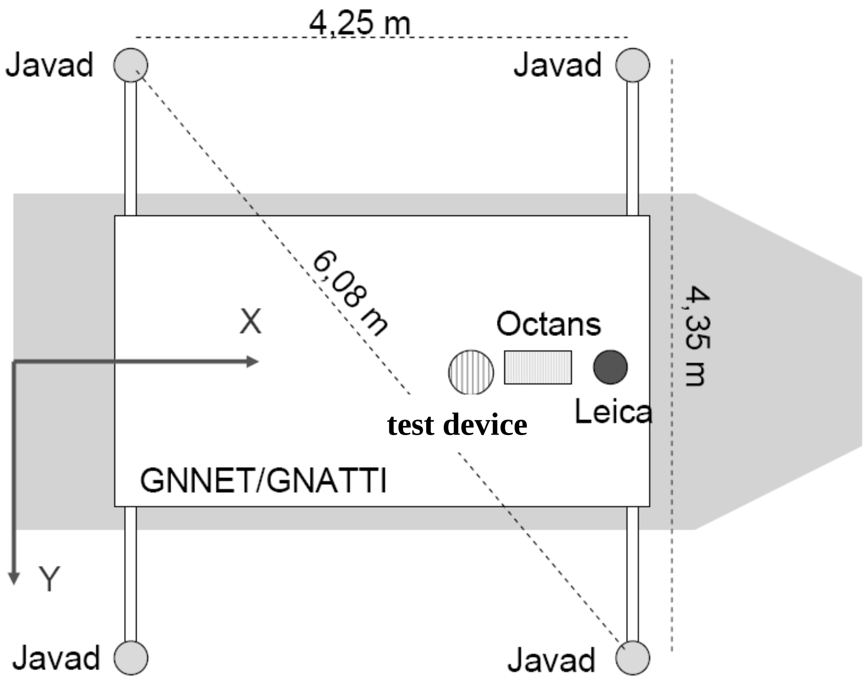

Figure 4: Possible configuration for an investigation of attitude sensors

The GNSS attitude determination is carried out by the software GNNET/GNATTI. The longest effective baseline length for the attitude components roll and heading are given with

4.35 m perpendicular to the ships X-axis, the baseline length for the pitch reaches 4.25 m. Approximate accuracy estimates for the accuracy of the GNSS attitude determination are given by the following rules of thumb:

- Heading accuracy
  - 0,3 [° m] / effective baseline [m],
- Roll and pitch accuracy
  - 0,5 [° m] / effective baseline [m].

This holds for two receivers. A better accuracy is obtained from a system build of four antennae. With the given GNSS antenna configuration onboard the Level-A an accuracy of about 0.05° for the heading and 0.10° for roll and pitch is reached.

Figure 5 presents the differences between the ships system and a well known attitude sensor used in hydrography with a specified standard deviation of 0.35° for roll and pitch. The name of the sensor is made anonymous (X). The measurements were carried out onboard Level-A.

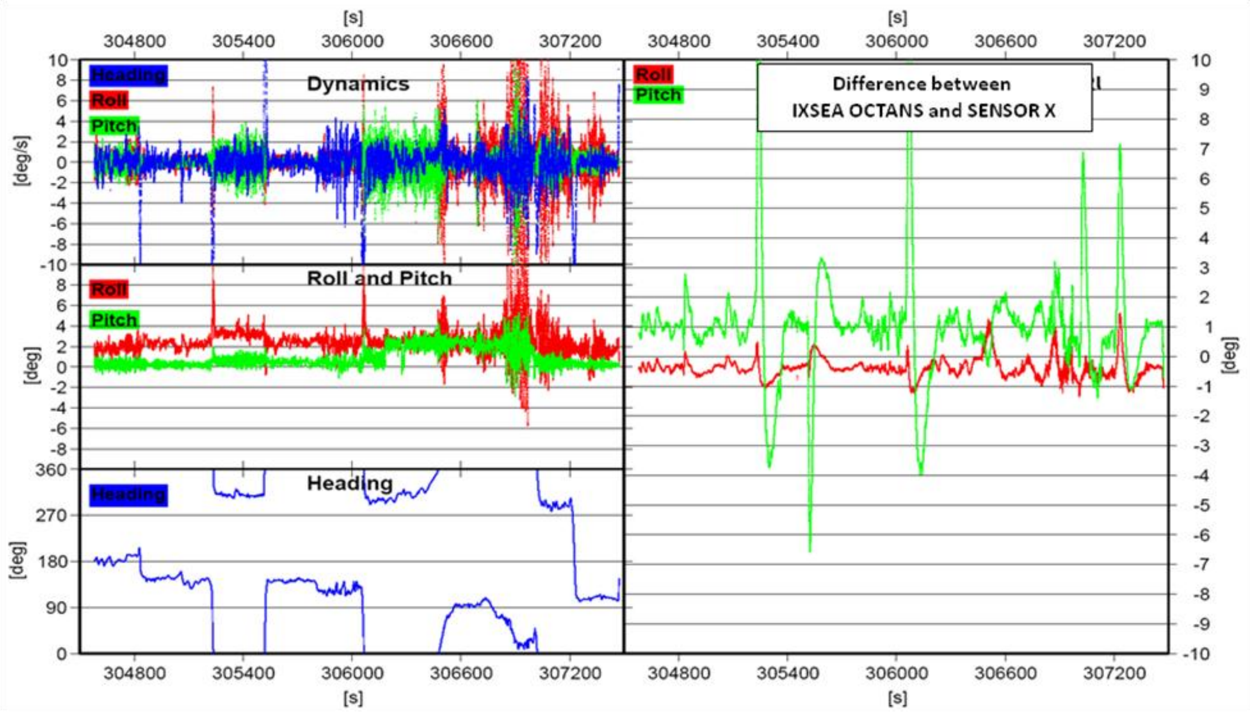

Figure 5: Left: Dynamics in heading, roll and pitch [deg/s]; roll, pitch, heading in [deg]. Right panel: Difference between IXSEA OCTANS III and attitude sensor X in [deg].

The ship was going on “normal” survey lines for depth measurements. The ships attitude is presented in the left panel of Figure 5. The investigation shows that the roll component meets all specifications (right panel of Figure 5). The calculated standard deviation amount to 0.35°, whereas the standard deviation of the pitch differences reaches 2.03° with maximum differences of about +10° and -6.5°.

These and other investigations show that not all attitude sensors in hydrography fulfill the specifications. It is possible to test these sensors onboard the Level-A, and also onboard of another vessel with the HCU-HMSS, see also (Böder 2002, Böder 2006, Böder 2009).

5. Investigation of pockmarks

In terms of measurements in a hydrographic campaign on the Lake Constance (between Germany, Austria, and Switzerland) the single beam echo soundings revealed bubbles coming out from crater structures. Figure 6 on the left presents the results when investigating those structures with the parametric subbottom profiler Innomar SES 2000. Here one can see structures looking like small volcanoes, some active and some without bubbles. The penetration in that case reached around 2 m, in other part up to 10 m and shows some parallel layers of sediment. The behavior of the bubbles in the water column is interesting for geophysics research, e.g. for the detection of resources. It can be investigated by acoustic methods. Figure 6 shows on the right side the multi beam echo sounding results (Reason SeaBat 8101) from a part of the investigated area by means of a digital terrain model (DTM). The area in figure 6 is 500 m x 300 m, the depths vary between 10 m and 30 m. The diameter of the largest crater in this figure ranges to 20 m with a depth of about 4.5 m. More details are discussed in *Böder and Wessel (2008)*.

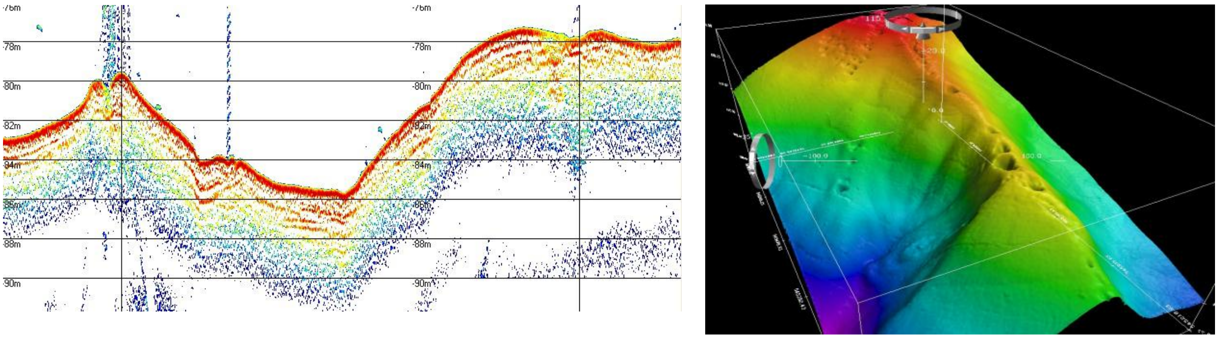

Figure 6: Pockmarks in the Lake Constance. Left: Subbottom profiling of active and inactive pockmarks, Innomar SES 2000. Right: Multi beam echo sounding DTM (from: *Böder and Wessel 2008*)

6. Gravimetry

Another geophysical but also geodetic application was tested in the Elbe river near Glückstadt. In order to observe the fine structure of the Earth gravity field a former Russian submarine gravimeter (Chekan AM) from the German company Gravionic was installed onboard the Level-A. The positioning of the gravimeter was carried out with the SAPOS RTK solution and the IXSEA OCTANS III. Depth measurements were carried out simultaneously in order to calculate the Bouguer anomalies.

The goal of the measurements was to derive geoid information for a high precision GNSS-height transfer (mm-accuracy over a distance of 2.4 km) between left and right bank of the river, see *Hirt at al. (2008).*

The processing at Gravionics has not been finished until the final reading of this paper.

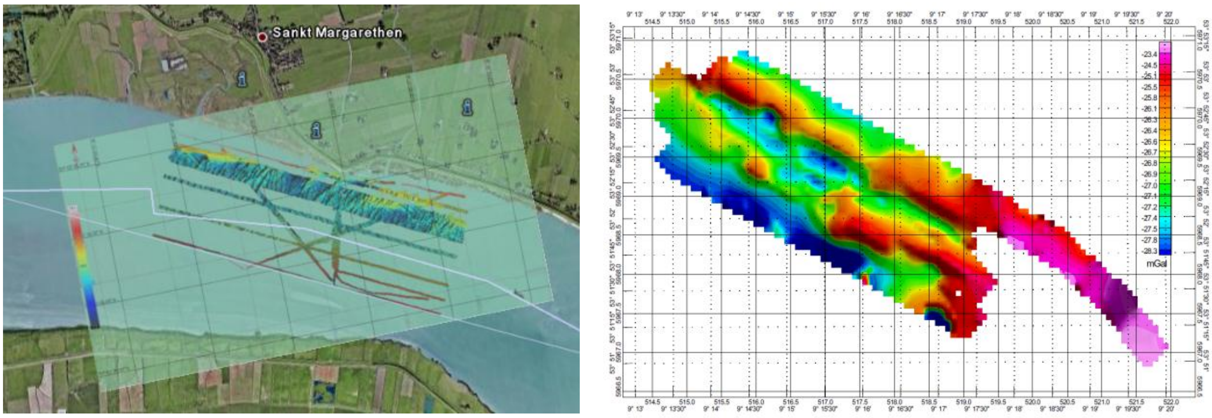

Figure 7: Profiles (left) and free air anomalies (right) measured with the HCU-HMSS and the gravimeter CHEKAN AM from Gravionic.

7. Archaeology

Detecting and visualizing archaeological objects and structures under water with high resolution and accuracy requires a well optimized system. Visualization of high resolution depth measurements helps the archaeologists to find objects and their functions in a medium in which the visibility reaches only a few decimeters. Divers sketches may help in that case, however high precision and high resolution depth measurements should be made at first.

In 2008 several investigation of archaeological objects have been carried out in the German fjord Schlei near the ancient Viking city Haithabu, where several wrecks and the so called ”Seesperre” (sea barrier, around 800 AC) was measured. In the Lake Constance several areas of archaeoligcal interests, for example ancient remains of lake-sided villages of pile dwellings and in the Elbe river military wrecks from 2nd World War and an old boat from the Middle Age (around 1630) have been observed.

In the following the problems of precision and high resolution depth measurements shall be presented by means of two examples. Figure 8 shows a topographic structure in the Lake Constanze. Archaeologists from the canton Thurgau, Switzerland, found wooden pillars on this structure in shallow water around 250 m away from the shoreline. By looking at the map it can clearly be seen that the underwater structure consists of an artificial triangle with a side length of around 35 m. In the north eastern side the remaining of the island eroded in the same way as it is seen from other structures in that region.

In figure 8 small artificial structures caused by uncertainties of the measurements (RTK over long distances) can be seen in the southern part of the underwater island. In case of a less resolution DTM these effects will be filtered out however here a recalibration of each profile will be necessary in order to find the best solution.

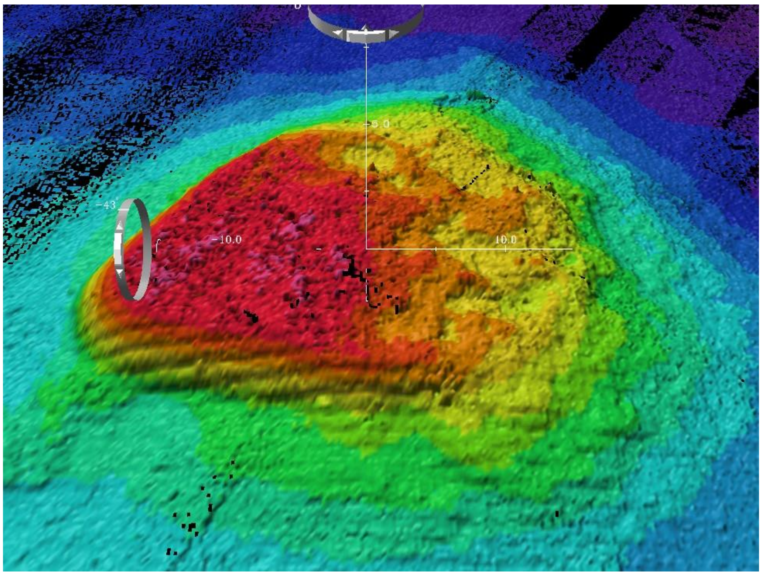

Figure 8: Archaeological structure in the Lake Constanze. Middle Age.

Figure 9 shows a 12 m wooden boat in the river Elbe from the years around 1630. The keel points upwards. In the figure it seems that the planking can be seen in the visualization. However in this case the "planking" is caused by the grid width of 50 cm at the edges of the flat bottomed boat. The analysis of the type of boat varies here with the grid width.

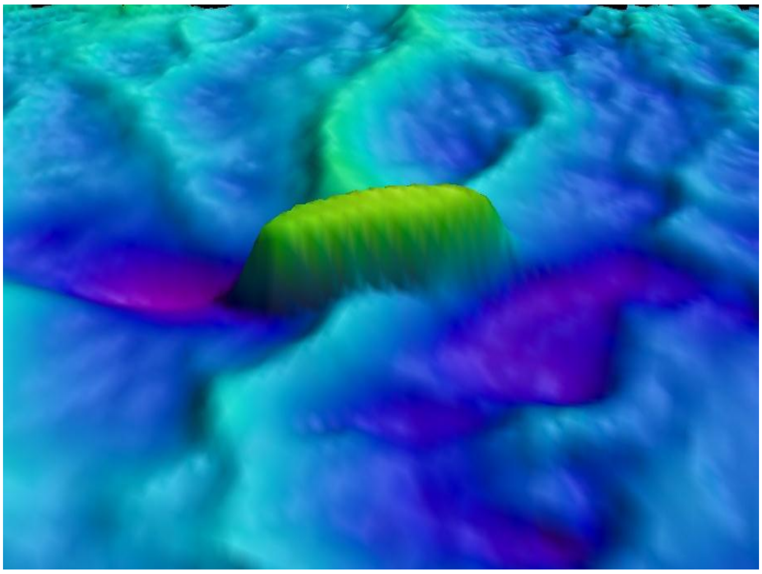

Figure 9: Wooden boat from the Middle Age, River Elbe, 50 cm grid.

Detailed information can be generated out of point clouds with a high resolution and high precision. However the hydrographic surveyor should be aware of the quality of his data and the visualization methods.

8. Marine-terrestrial Laserscanning

In cooperation with the company Dr. Hesse and Partner (DHPI), Hamburg, an terrestrial laserscanner from Zoller&Froehlich has been installed onboard the Level-A. The positioning and attitude determination was carried out with the SAPOS RTK solution and the IXSEA OCTANS III. Figure 10 shows the installation onboard, the results are still under construction at DHPI.

This implementation of the scanner will help to measure features above the waterline, like quay walls, shoreline, construction sites, and tidelands. In the near future the HCU will buy an own laser scanner for kinematic purposes.

Figure 10: Installation of a terrestrial laserscanner from Zoller&Froehlich (owner: company DHPI) onboard the Level-A

In this application the accuracy highly depends on the accuracy of the motion sensor. A heading error of 0.2° leads to a position error of around 35 cm in a distance of 100 m. This leads us back to the demand that the sensors and software for positioning and attitude determination have to be optimized in a hydrographic multi sensor system.

9. Conclusions

The use of a hydrographic multi sensor system is not restricted to the determination of depths in waterways. A lot of applications may be opened on the market if all sensors are well synchronized and optimized onboard the survey vessel. The paper shows some possible applications from projects at the HCU in 2008 and 2009.

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BIOGRAPHICAL NOTES

Volker Böder graduated in geodesy from the University Hannover in 1994. His doctoral thesis from 2002 is about precise positioning and attitude determination in marine applications. He received his Assessor Degree from the Government of the Federal State of Lower Saxonia in 2005. Since 2005 he is professor for practical geodesy and hydrography at the HafenCity University, Hamburg.

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