HCU-HMSS: A Multi Sensor System in Hydrographic Applications

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Abstract
Machine guidance and control is only one task to be accomplished in hydrographic applications. On water nearly all measurements has to be carried out in kinematic mode. In this paper the Hydrographic Multi Sensor System of the HafenCity University Hamburg (HCU-HMSS) will be described. Although the navigation and control of the ship is part of hydrographic work, this paper presents the positioning and attitude determination and some applications in a hydrographic environment.

Inertial measurement systems and later GNSS satellite navigation in the late 1980’s led to a better accuracy and availability of the ships’ positions. The use of multibeam echo sounder (MBES) in the 1990’s was accompanied by an extended importance of attitude determination. Additionally the huge amount of data has to be processed: in order to be more efficient, the operator has to eliminate or reduce errors and data in real time on board without extending the expensive ship time.

One aim is to visualize all measurements in real time for quality control. The hydrographic engineer sets and modifies all necessary parameters for filtering uncertain measurements of the multibeam echo sounder. All depth measurements will be corrected and reduced to the selected reference system, using the data of attitude sensors such as inertial measurement units or GNSS systems.

A multi sensor system has to be well optimized and calibrated in order to fulfil all requirements. All sensors like GNSS, motion and depth determining sensors have to be synchronized in a well defined time scale like the one given with the GPS reference time.

The HCU-HMSS offers the possibility to examine the proper functioning and accuracy of attitude determination systems in a kinematic environment. The systems have to be installed onboard the HCU survey vessel Level-A or can be examined in the environment of alternate boat. The accuracy of the onboard GNSS attitude system is limited by the lengths of the effective baselines between the GNSS antennas. In the near future the possibilities of using terrestrial laserscanning and gravimetry on board will be investigated in details. The HCU-HMSS offers a wide range of research topics.

Keywords
GNSS, inertial measurement unit, Hydrography, multi sensor system, positioning and attitude determination

1 INTRODUCTION
Machine Guidance and Control is only one task to be accomplished in hydrographic applications. The survey vessel, namely a ship, boat, Remotely Operated Vehicle (ROV) or Autonomous Underwater Vehicle (AUV) usually has to be guided on a survey line or directed to an object under water. On water, nearly all measurements have to be carried out in kinematic mode, although the ship is fastened at quay walls, normally wind, currents and waves move the vessel in a way that hardly can be modeled in real time with simple equations.
In the following the Hydrographic Multi Sensor System of the HafenCity University Hamburg (HCU) will be described. Although the navigation and control of the ship is part of hydrographic work, this paper presents the positioning and attitude determination and some applications in a hydrographic environment. The sensors usually are installed on board the HCU-survey vessel Level-A, however the modular concept in general allows the integration on various platforms: not only at sea.

In the middle of the last century the positioning of depth measurements was carried out with one or two sextants on board a survey vessel, trying to obtain a simultaneous fixing of landmarks or celestial objects in order to fix to lines of position (LOP) in the nautical chart and combine this information with the depth measurements. Radio navigation (Syledis, LORAN-C, etc.), inertial measurement systems, and subsequently GNSS satellite navigation in the late 1980’s led to a better accuracy and availability of the ships positions. The use of multibeam echo sounder (MBES) in the 1990's yielded to an extended importance of attitude determination. Additionally the huge amount of data has to be processed: in order to be more efficient the operator has to eliminate or reduce errors and data in real time on board without extending the expensive ship time.

On board the Level-A the goal is to visualize all measurements in real time for quality control. The hydrographic engineer sets and modifies all necessary parameters for filtering uncertain measurements of the multibeam echo sounder. All depth measurements will be corrected and reduced to the selected reference system, using the data of attitude sensors like inertial measurement or GNSS systems.

2 THE HCU HYDROGRAPHIC MULTI SENSOR SYSTEM (HCU-HMSS)

The core of the HCU-HMSS based on different sensors for positioning and attitude determination of the ship, depth measurement or determining features under water, mostly on board our survey vessel Level-A. Additionally a magnetometer is used to measure the effects of iron features in the Earth magnetic field (Marine Magnetics Mini Explorer, accuracy 0.2 nTesla).

For inland applications of the HMSS in Germany the system is able to use its own reference station or the SAPOS reference station system of the German surveying authorities (Satellitenpositionierungsdienst der deutschen Landesvermessung). Because reference stations only can be installed on land and usually not on the water, and because the measurement areas sometimes are large, the distance to a fixed reference station could increase to several kilometres and more. The use of a reference station network which reduces the distance-dependent errors like errors in satellite orbit, ionosphere and troposphere offers correction data in the RTCM format that leads to a 3D-accuracy of better than 5 cm in real time over distances of a few tens of a kilometre. One of the greatest problems sometimes are the gaps in the coverage of the communication system using GSM or UMTS. Particularly on water the typical telecommunication services have less interest to fill these gaps with additional transmitting stations, because the number of customers at sea is rather small. In case of data gaps because of missing data link the GNSS raw data can be saved as RINEX data for post processing (with precise point positioning (PPP) or PDGPS software). First results can be found in section 3.
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 the Geo++ GmbH, Garbsen. GNNET/GNATTI is based on a modular software system that can be used to determine real time position and attitude and combine the data with other defined sensor data (using NMEA or other specific data formats), synchronized with GPS time. Both systems can be used with their own reference station (using 2m radio data link) or with the SAPOS reference system.

The main attitude determining sensor on board 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%, depending on which value is higher. The OCTANS is a strapdown inertial measurement unit with three accelerometers and three fibre-optic gyroscopes, and a real time computer. The light (4.3 kg) and compact instrument is easy to install and shows a minor settling time of 5 min under normal sea conditions. This unit cannot be supported by GNSS data.

Multibeam depth measurements are carried out by the echo sounder RESON SeaBat 8101, serving 101 beams with a frequency of 240 kHz, an opening angle of 1.5° per beam (150° opening angle of swath) and a measuring data rate of maximum 40 Hz in shallow water.
Additionally single beam echo sounders Fahrenholz 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.

The software system Qinsy from QPS serves to combine positioning and attitude determination with the multibeam depth measurements over LAN and RS interfaces in real time. However it is possible to integrate any other sensor elements using NMEA or a free ASCII format as output. All incoming data streams receive a time stamp, which is synchronized over a pulse-per-second (PPS) TTL-pulse generated by the GNSS unit with GPS time.

Single beam echo sounder measurements are sampled and processed with the WinProfile software of the company HydroSupport. The results are modelled and presented mainly with the software SURFER or FLEDERMAUS.

In order to receive reliable data from multibeam echo sounding the system components have to be calibrated with respect to

- positioning delay,
- pitch offset,
- azimuthal offset,
- roll offset.

The calibration is carried out by comparing a combination of different pairs of survey lines which has been running

- with different or same speed
- over a well defined object or inclined or horizontal plane
- in one direction or reciprocal.

The processing takes only a few minutes before starting the project, so that all measurements should be well calibrated in real time.

3 INVESTIGATION OF PRECISE POINT POSITIONING (PPP)

Precise Point Positioning (PPP) with GNSS based on the accurate modelling of the orbits and clocks of the GNSS satellites. The accuracy of real time broadcast orbits is about 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 a modelling of the satellite clocks with better than 0.1 ns. Additionally absolute phase centre variations (PCV) of the GNSS antennae and transformation parameters between the user coordinate system and the basic GNSS coordinate system have to be taken into account. Appropriate software uses these corrections from the IGS in post processing and calculates PPP positions.

In order to investigate the possibilities of using PPP in hydrographic applications four GNSS antennae were installed on board the Level-A on a trip over 40 km on the river Elbe 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 (Heßelbarth and Wanninger, 2008). The comparison between the real time RTK positions on board of the Level-A and the PPP solution are described in the following.
The difference between the RTK and the PPP solution of the balance point of the antenna array is shown in Figure 3. The mean of the difference in the east component is calculated to 0.5 cm ($\sigma=1.1$ cm), in north 1.9 cm ($\sigma=1.4$ cm), and in the height 6.9 cm ($\sigma=2.1$ cm).

As a next step it has to be investigated if the PPP solutions can be integrated into the hydrographic system by using existing high precision RTK solutions to calibrate the PPP coordinates in order to fill gaps of positioning.

The accuracy of the PPP solution meets the necessary requirements on the ocean and in several other hydrographic applications. More details about the software used can be found in (Heßelbarth and Wanninger, 2008). The results above were created in the bachelor thesis of Jörg Münchow in 2009.

4 INVESTIGATION OF ATTITUDE SENSORS

Properly working attitude determination is important for the transformation between GNSS antenna and hydrographic sensor (like echo sounder) and for the correction of the sensor data itself (for example multibeam echo soundings). Usually three different types of attitude sensors are used in an hydrographic environment:

- inertial units (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).

On board the Level-A an inertial motion sensor (IXSEA OCTANS III) and multi-antenna system is installed. Figure 4 shows the possible configuration.
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. An approximation for the accuracy of the GNSS attitude determination is given by the following rules of thumb:

- **Heading accuracy**
  - \(0.3 \,[° \text{ m}] / \text{effective baseline [m]}\),

- **Roll and pitch accuracy**
  - \(0.5 \,[° \text{ m}] / \text{effective baseline [m]}\).

This is true for two receivers, a better accuracy can be achieved with a system based on four antennae. The possible GNSS attitude accuracy on board the Level-A is 0.05° for the heading and 0.10° for roll and pitch.

Figure 5 presents the differences between the ship’s system and a sensor often used in hydrography with a specified standard deviation of 0.35° for roll and pitch, here called sensor X. The measurements were carried out in a usual hydrographic environment on board the Level-A.
The investigation shows that the roll component meets all specifications. The calculated standard deviation amounts to 0.35°, whereas the standard deviation of the pitch differences reaches 2.03° with maximum differences of about +10° and -6.5°, even when the ship was traveling on a survey line for depth measurements.

These and other investigations are indicating that the improper use of attitude sensors onboard may yield to errors in depth measurements. It is possible to test sensors onboard the Level-A, and also onboard of other vessels with the HCU-HMSS, see also (Böder 2002, Böder 2006, Böder 2009).

5 RESEARCH APPLICATIONS OF THE HCU-HMSS

In 2008 and 2009 several research institutes asked for assistance in geophysical and archaeological issues. In Böder and Wessel (2008) the investigation of pockmarks in the Lake Constance has been presented. In terms of a project single beam echo soundings were showing bubbles coming out of crater structures. Using MBES and subbottom echo sounding these structures, some active and some without bubbles have been investigated. The diameter of the craters reaches up to 20 m with a depth of about 4.5 m. The behaviour of the bubbles in the water column is interesting for geophysics research, they can be investigated by acoustic methods. More details are discussed in Böder and Wessel (2008).

Another geophysical but also geodetic application has been tested in the river Elbe near Glückstadt. In order to receive an higher resolution of the Earth’s gravity field a former Russian submarine gravimeter (Chekan AM) from the German company Gravionic was installed on board 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 gain a better information about the geoid for a high precision height determination (mm-accuracy over a distance of 2.4 km) between left and right bank of the river, see Hirt et al. (2008).

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 a meaning in a medium in which the visibility reaches only a few decimeters. Divers sketches may help in this case, however high precision and high resolution depth measurements should be made in the first place.

In 2008 several investigations of archaeological objects have been carried out in the German fjord Schlei near the ancient Viking city Haithabu in the course of the International Hydrography Summer Camp 2008, where several wrecks and the so-called “Seesperre” (sea barrier, around 800 AC) was measured. In the Lake Constance several areas of archaeological interest, for example ancient remains of lake-sided villages of pile dwellings and in the river Elbe military wrecks of the 2nd World War and an old boat from the Middle Age (around 1630) have been observed. Detailed information can be generated from point clouds with high resolution and high precision. However the hydrographic surveyor should be aware of the quality of his data and the visualization methods.

In cooperation with the company Dr. Hesse and Partner (DHPI), Hamburg, an terrestrial laserscanner from Zoller&Froehlich was installed on board the Level-A. The positioning and attitude determination was carried out with the SAPOS RTK solution and the IXSEA OCTANS III. Figure 6 shows the installation onboard, the analysis of the results is still under progress at DHPI.

This implementation of the scanner will help to measure features above the waterline, like quay walls, shoreline, construction sites, and tidelands. Recently the HCU acquired the laser scanner Riegl VZ-400, which will be implemented onboard in the near future. The sensor reaches up to 500m in the long range mode (42,000 measurements per second) and 300m in the high speed mode (125,000 measurements per second), both with an accuracy of 5mm (1σ).
In this application the accuracy highly depends on the accuracy of the motion sensor. The uncertainty of the IXSEA Octans III, especially in heading (0.17° at the latitude of Hamburg), leads to positioning errors up to 1.5m at a distance of about 500m. This leads us back to the requirement that the sensors and software for positioning and attitude determination have to be optimized in a hydrographic multi sensor system.

CONCLUSIONS
Modern hydrographic systems offer a range of new applications. A multi sensor system has to be well optimized and calibrated in order to meet all requirements. All sensors like GNSS, motion and depth determining sensors have to be synchronized in a well defined time scale like the one given with the GPS reference time.

The HCU-HMSS offers the possibility to examine the functioning and accuracy of attitude determination systems in a kinematic environment. The systems have to be installed on board the Level-A or can be examined in the environment of another survey vessel. Using our GNSS attitude system the accuracy is limited by the length of the effective baselines.

In the near future the possibilities of using terrestrial laserscanning and gravimetry on board will be investigated in more detail. The HCU-HMSS offers a wide range of research topics which has not been investigated yet.

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