INITIAL EXPERIENCE WITH THE INTEGRATION OF A TERRESTRIAL LASER SCANNER INTO THE MOBILE HYDROGRAPHIC MULTI SENSOR SYSTEM ON A SHIP

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Commission I, WG I/4

KEY WORDS: echo sounder, GNSS, multi beam, sensor integration, terrestrial laser scanning, vessel

ABSTRACT:

Hydrography is the science and practice of measurement and representation of the parameters necessary to describe the condition and shape of the sub-water surface, its relationship with the land surface, and the condition and dynamics of the water. To fulfil the requirements of many hydrographic applications a mobile multi sensor ship, which is able to measure all necessary parameters, must be available. Due to special conditions in the harbour of Hamburg and along the river Elbe, which is the most essential entrance for the economy of Hamburg, the monitoring of sedimentation in the harbour and the documentation of the docks is of major interest for the Hamburg Port Authority. However, these tasks require a multi sensor system, which is able to measure simultaneously above and below water.
In this paper initial experience of the integration of two terrestrial laser scanning systems, IMAGER 5006i from Zoller + Fröhlich and Riegl VZ400, into the mobile hydrographical multi sensor system will be presented. These systems have already been installed on two different ships in Hamburg. In a first pilot study the ship Level-A (length 8m, width 3.5m, draught 0.35m) from the HafenCity University Hamburg (HCU), which is well-suited for operations in shallow water areas, has been used in cooperation between HCU and the engineering office Dr. Hesse and Partner (DHPI), Hamburg to test the terrestrial laser scanner IMAGER 5006i from Zoller + Fröhlich in combination with the hydrographic sensors onboard. The second pilot study was carried out with the terrestrial laser scanner Riegl VZ400, which had been installed on the ship Deepenschriewer III (17.2m length, width 4.9m, and draught 1.4m) from the Hamburg Port Authority. For testing the sensor integration of these two multi sensor systems two objects were scanned in two selected test areas of the harbour of Hamburg and Wedel to demonstrate the performance of each system. To verify the accuracy of the kinematic laser scanning system on the ship some reference data has been scanned with static laser scanning. The system integration and test procedures including first results are described in the paper.

1. INTRODUCTION

Three-dimensional geodata are digital information to which a specific spatial location can be assigned on the earth's surface or in the water. These geodata provide a substantial part of the knowledge existing in the modern information and communication society, and which is increasingly needed on all levels in administration, economy and science, and by individual citizens. They are the basis of planning-related actions and their availability is a requirement for location and investment decisions. Thus, there is an increasing need for geodata which meets high requirements such as efficient data collection (up-to-date and economical data) and extensive availability (fast, simple, complete, area-covering and large scale).

Therefore, mobile sensor systems (or MMS - Mobile Mapping Systems) offer an optimal solution for efficient 3D data acquisition in the air (airplane, helicopter), on the ground (vehicle) and on the water (ship). In this contribution, mobile multi sensor systems on two ships in Hamburg with which 3D geodata can be simultaneously acquired above and below water are presented. However, the paper focuses on the integration of terrestrial laser scanning systems (TLS) on the two ship-based multi sensor systems, which are equipped with navigation and hydrographical sensors. This system integration and some initial investigations with these two special multi sensor systems have been carried out in a co-operation between the HafenCity University Hamburg (HCU), the Northern Institute of Advanced Hydrographics (NIAH) GmbH, and the engineer's office Dr. Hesse und Partner Ingenieure (dhpi), and Hamburg Port Authority (HPA). For the first pilot study the terrestrial laser scanner IMAGER 5006i from Zoller+Fröhlich has been installed on the HCU/NIAH boat “Level A” in co-operation with dhpi. In a second pilot project the terrestrial laser scanner Riegl VZ-400 was used on the surveying ship “Deepenschriewer III” of HPA, in order to test the system in typical HPA applications.

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2. MOBILE MULTI SENSOR SYSTEMS

Mobile multi sensor systems have been in use for nearly two decades in airplanes and on vehicles. In particular mobile mapping vehicles with integrated terrestrial laser scanners have become successfully established in the market within the last five years. Thus, among others, several authors report on the land-based operation of such mapping systems in different countries: Talaya et al. (2004), Gajdamowicz et al. (2007), Graefe (2007), Kremer & Hunter (2007), Gandolfi et al. (2008), Kersten et al. (2009). Hesse (2007) describes an approach for the sensor integration of a terrestrial laser scanner on a mobile platform. In recent years the potential of terrestrial laser scanners for hydrographical applications on multi sensor vessels has also been recognized. Alho et al. (2009) report of the use of a terrestrial laser scanner on a boat for the measurement of rivers in Finland, while Van Rens et al. (2007) describe the application of a Riegl LMS-Z420i in combination with RTK-GPS and the Applanix inertial system POS MV 320 in the harbour of Norfolk (Virginia, USA).

Modern multi sensor systems on a ship can be equipped as follows: terrestrial laser scanner for 3D data acquisition above water, multi beam echo sounder for measurement of structures under water, GNSS for kinematic positioning of the laser scanner and echo sounder, and inertial measurement unit (IMU) for determination of the orientation (roll, pitch, heading) and for supporting GNSS. The spatial vectors between the individual sensor systems are determined very precisely in a ship coordinate system by geodetic measuring procedures so that all measurements can be transformed into the super-ordinate coordinate system.

3. SURVEYING SHIPS & THEIR ONBOARD SENSORS

The multi sensor systems on board the two surveying ships “Level-A” (HCU) and “Deepenschriewer III” (HPA) are similarly designed. The GNSS correction data for the generation of precise real-time positioning (networking solution) is provided by an external service (“Level-A”: SAPOS, “Deepenschriewer III”: Trimble VRS-NOW). Both systems use an IMU from IXSEA although the HPA’s system generates a more precise course angle and can also support positioning. The data fusion is accomplished in both systems using the acquisition and processing software QINSy from the company QPS (Zeist, the Netherlands). Further information on the hydrographical multi sensor system of the HCU (HCU HMSS) is summarised in Boeder (2010). Fig. 1 shows an overview of the onboard sensors.

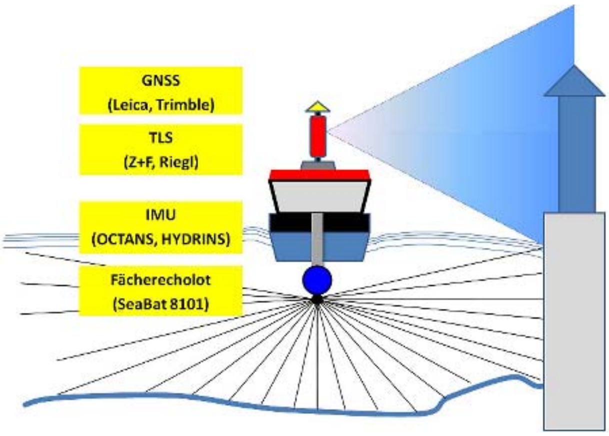

Figure 1: Schematical overview of the sensors used on board “Level-A” and “Deepenschriewer III”.

3.1 Ships

The “Level-A” (see Fig. 2, left) is an aluminium boat, which is used in research and teaching at the HafenCity University Hamburg (HCU). The boat (length 7.5m and width 2.5m) is characterised by a relatively small draught (about 0.5m) for applications in shallow water areas (of rivers, lakes, and coast). With a modular structure and with modern hydrographic sensors (echo sounder, magnetometer, flowmeter, etc.) the multi sensor ship can be used flexibly and economically. It can be transported on a trailer and it can be rented by third parties via the Northern Institute of Advanced Hydrographics GmbH (NIAH).

Figure 2: Surveying ships “Level-A” from HCU/NIAH (top) and “Deepenschriewer III” from HPA (bottom).

The surveying ship “Deepenschriewer III” (Fig. 2, right) is a steel ship, which is used by Hamburg Port Authority (HPA) for hydrographic measurements of the river Elbe and areas of Hamburg harbour. In particular the monitoring of the water depth as well as the bathymetry of the waters regarding geomorphologic changes and finding obstacles are major tasks for this ship. With a length of 17.2m, a width of 4.9m and a draught of 1.4m the ship is well suited to almost all applications in the harbour. Due to its size the ship is more smooth in the water than the “Level-A”.

3.2 GNSS Positioning

The positioning on board is carried out by GNSS systems in real time using the above-mentioned data correction services. In order to achieve high availability of precise positioning, as many satellites as possible must be included in the measurements. This is guaranteed by the hybrid use of the systems NAVSTAR GPS, GLONASS and the forthcoming GALILEO. Occasionally disturbances occur during the transmission of the correction parameters on large waters. However, no such significant disturbances near houses and industrial plants were noticed for the projects presented.

On board the "Deepenschriewer III" a Trimble SPS851H GNSS receiver with Zephyr 2 antenna is operating. The correction data are provided by the service Trimble VRS-NOW (VRS net solution). The measuring rate is up to 20Hz per second; a PPS output is available. The accuracies of the Trimble VRS-NOW correction data service can be estimated to 1-2cm in position.

RTK positioning data are integrated into the IXSEA HYDRINS solution (see section 3.3) using data from the inertial sensor. According to the manufacturer's specification the integrated positioning is more precise than the available GNSS solution by a factor of three. However, this statement requires an independent investigation. The combined solution is then transferred in real time via RS232 or LAN to the hydrographic processing software QINSy for the integration of all sensors.

On board the "Level-A" the RTK system Leica GPS500 with a AT502 antenna was operated during the first campaign. The 2-frequency GPS receiver obtains the reference station data from the data correction service SAPOS of the German Ordnance Survey. The measuring rate is up to 10Hz per second with the data being transferred via RS232 interfaces. The system does not provide a PPS output; the PPS signal on board is read out by an additionally operating Javad 2-frequency receiver. The SAPOS HEPS data correction service guarantees an accuracy of 1-2cm according to the information from the service provider. In combination with the GPS500 system such accuracy can be approximately obtained under optimal conditions. Nevertheless, the instrument will be replaced by a new GNSS system in August 2010.

3.3 IMU-determination of roll, pitch and heading

In the investigations represented in this paper two different inertial measuring systems from the IXSEA company have been used. For hydrographic applications in particular the systems OCTANS, HYDRINS and PHINS of the IXSEA product series (Tab. 1) are established in the market. All systems are based on accelerometers and fibre-optical gyroscope systems.

	OCTANS	HYDRINS	PHINS
accuracy of orientation angles (*route mean square*, RMS)			
heading	0.1° secant (φ) Hamburg: 0.17°	0.02° secant (φ) Hamburg: 0.034°	0.01° secant (φ) Hamburg: 0.017°
roll/pitch	0.01°	0.01°	0.01°
accuracy of position and translation determination			
Heave/ surge/ sway (RMS)	5cm or 5%, whichever is greater	2.5cm or 2.5%, whichever is greater	5cm or 5%, whichever is greater

Table 1: Main technical specifications of IXSEA IMUs (manufacturer's data). Notations: φ: geog. latitude, secant (φ) = 1/cos(φ), for Hamburg secant (53.5°)=1.68.

The three IXSEA systems are represented in Tab. 1 with their main specifications which are relevant for the investigation. All systems can be connected via Ethernet and RS232/RS422 with other systems. The data delivery will be made using the format NMEA0183, but in addition, other ASCII and binary formats are also available. All measured data can be time-synchronized with PPS signals. For the models HYDRINS and PHINS the accuracies of the GNSS positioning and the data rate are further improved by the integration of the inertial measuring data. The data rates can be selected between 0.1 Hz and 200 Hz for all three models. On the "Level-A" the determination of the orientation angles can be made with the support of an array consisting of four GNSS antennas (Boeder 2009).

3.4 Terrestrial Laser Scanner Z+F IMAGER 5006i

According to manufacturer specifications the Z+F IMAGER 5006i uses visible light (658nm) with a beam divergence of 0.22mrad (0.014°) with a spot size of 3mm, which corresponds to one footprint with a diameter of 21mm at 79m. The maximum scan distance is 79m; however measurements up to 50m are practical. The horizontal and the vertical fields of view are 360° and 310°, respectively, but for the range from 0-50° scanning is not possible. However, a tilting mount can be installed on the system.

Vertical and horizontal resolution of the scanner are indicated as 0.0018° in each case, which corresponds to 3mm at 79m distance. The vertical and horizontal accuracy is given as an RMS value of 0.007°, which equates to 1cm at 80m distance. The scanner noise for distances up to 50m for a reflectivity $\rho \geq 10\%$ is given as approximately 7mm, and at $\rho = 100\%$ as 1.8mm. The data acquisition rate is 508,000 pixels per second. The rotation speed of the mirror has a maximum of 50 rotations per second (rps) but usually operates at 25 rps. Thus, the boat speed of 6 kn (about 3 m/s) generates vertical lines with an interval of 6cm as a result (with 50 rps).

Based on this information the standard deviation of each coordinate component can be estimated with a higher precision than 1cm at the maximum range of 79m. In these investigations the horizontal angle of the system has not been changed during scanning. The data transfer on board to other computers or sensors can be accomplished via LAN and USB, while the time synchronization is realised over a PPS (pulse by second). Investigations into the accuracy of the IMAGER 5006i are published in Kersten et al. (2009).

3.5 Terrestrial Laser Scanner Riegl VZ-400

The terrestrial scanner Riegl VZ-400 uses near-infrared light with a beam divergence of 0.3 mrad (0.017°), which corresponds to one footprint with a diameter of 30mm at 100m according to the manufacturer's specification. The field of view of the VZ-400 ranges from +60° to -40°, which gives a viewing angle of 100°. Using these angle values a vertical measuring range of 17.3m over and 8.4m below the instrument horizon at a distance 10m can be determined. However, an additional tilting mount can support other elevations of the scanning system.

The difference angle between two sequential measurements in the vertical is adjustable within the range of $0.0024° \leq \Delta\varphi V \leq 0.288°$, while for the horizontal angle variations between $0.0024° \leq \Delta\varphi H \leq 0.5°$ are possible. Therefore, the distance between two scan lines is, at minimum, 4mm in horizontal and vertical directions at a distance of 100m.

For the distance measurements a standard deviation of 5mm at 100m distance is specified using Riegl´s test conditions. The resolution of horizontal and vertical angles is given as 0.0005°, which corresponds to a lateral deviation of 4mm at a distance of 500m. Based on this information the standard deviation of each coordinate component can be estimated with a higher precision than 1cm at a distance of 100m. In these investigations the horizontal angle of the system has not been changed during scanning, although this is possible in principle.

In the *Long Range Mode* the maximum distance is 500m for good natural reflectors (reflectivity ρ ≥ 80%) and 160m for reflectors with ρ ≥ 10%. The effective measurement rate is 42,000 measurements per second with a pulse repetition rate (PRR) of 100kHz, while this can be speeded up by a factor of three in the *High Speed Mode* (125.000 measurements/second, PRR of 300kHz). Here, the operating range is only 300m, about 60% of the *Long Range Mode* using natural reflectors with a reflectivity ρ ≥ 80% and 100m with ρ ≥ 10%.

The scanning speed is indicated as 3 to 120 lines per second in the vertical. As a consequence an interval of 3cm for vertical lines can be achieved with a speed of the boat of 3m/s using a scanning speed of 100 lines/s.

The data transfer on board and the time synchronization is solved similar to the IMAGER 5006i. The integration of the Riegl VZ-400 into the software QINSy had been established without any problems using the special Riegl driver.

3.6 Reson SeaBat 8101

The multi beam echo sounder Reson SeaBat 8101 measures distances in the water with an acoustic frequency of 240kHz. Such a frequency already causes reflections at first sediment layers, so that the signal penetrates negligibly little into the ground. Via a projector sound energy is transferred into the water, reflected by the ground or other obstacles, and received over an array of several hydrophones. The beam forming mechanism generates signals from the received energy with an opening angle of 1.5° in both the sensor direction and perpendicular to it, corresponding to a footprint with a diameter of 2.61m at a water depth of 100m. However, for coastal and riverside applications, which shall be connected to data from terrestrial laser scanners, depths of approximately 10-20m can be expected. Therefore, the beam diameter is 26cm at a depth of 10m, which is larger by a factor of 100 compared to the laser spot of the laser scanner.

Due to a system expansion the opening angle of the entire multi beam echo sounder (SeaBat 8101) on the “Level-A” is 210° crosswise and 1.5° lengthwise to the ship’s longitudinal axis. Thus, the sensor measures not only downward, but also to the side. A tilting of the sensor is feasible by an additional mounting plate. The difference angle between the beams amounts to 1.5° and causes a point distance of approximately 26cm at a 10m distance. With a boat speed of 3m/s and a maximum scanning rate of 40Hz a strip with up to 141 beams is measured in an interval of 7.5cm. Thus, a maximum of 5,640 measurements per second are possible. On board of the “Deepenschriewer III” the system is equipped with 101 beams as the standard option using an opening angle of 150°. The maximum range for measurements is 300m using the available SeaBat 8101.

According to the manufacturer’s specifications the resolution of the depth measurements is given to 1.25cm. The accuracy of a depth measurement essentially depends on the accuracy of the determination of temperature and salinity of the water in the different sediment layers. In water depths of 10m accuracies of better than 10cm are attainable, but rarely better than 5cm.

The data can be processed in different post-processing programs, usually the program QINSy is used on board of the “Level-A” using a LAN interface for data transfer to the computer.

Despite apparently worse characteristics concerning point measurements in comparison to laser scanners multi beam echo sounder of good quality are significantly more expensive than good laser scanners. Here, the less favourable conditions of the underwater measurements with hydro-acoustic techniques are considered. In Fig. 3 two terrestrial laser scanners and the multi beam echo sounder are illustrated.

Figure 3: Z+F IMAGER 5006i (left), Riegl VZ-400 (centre) and Reson SeaBat 8101 (right)

4. SCANNING OF AN INDUSTRIAL DOCK PLANT IN WEDEL USING LASER SCANNER IMAGER 5006I ON BOARD OF THE LEVEL-A

A first test with the multi sensor ship “Level-A” had been carried out on the river Elbe in front of the power station in Wedel in 2009, where the industrial dock plant with a mobile embarking crane and a factory hangar is located directly at the water’s edge (Fig. 4).

Figure 4: Partial view of the power station in Wedel with embarking crane (left) and factory hangar (right).

In addition to GNSS positioning (Leica GPS 500), inertial orientation angle layer (IXSEA OCTANS) and multi beam echo sounder (Reson SeaBat 8101) the laser scanner Z+F IMAGER 5006i was carried on board the “Level-A”. The laser scanner was stably installed on a tight mounted tripod on the foredeck in the ship’s longitudinal axis at approximately 1m distance from the GNSS antenna (Fig. 5), while the inertial measuring system OCTANS is installed in the boat approximately 2.5m below the GPS antenna.

Figure 5: Installation of the terrestrial laser scanner Z+F IMAGER 5006i on a tight mounted tripod on board of the “Level-A“.

The new sensor position has been determined in the ship’s coordinate system with a spatial resection by scanning all existing control points on board and by measuring the points in the laser scanning data. Therefore, six control points were well distributed on board (Fig. 6, bright circles).

Figure 6: Spatial resection for the determination of the scanner position in the coordinate system of the “Level-A” using control points (bright circles). The image is presented as intensity values.

During scanning the boat was driven at approximately 2m/s parallel to the dock plants, while the pitch angle varied about ± 1°, the roll angle about ± 3° and the heading changed during one profile by about 40°. The data from the multi beam echo sounder and the laser scanner were recorded simultaneously. In Fig. 7 the trajectory of the boat (marked with an arrow) is clearly visible as a line in front of the dock plants. The trajectory is a result of the same points, which were measured on the driving boat.

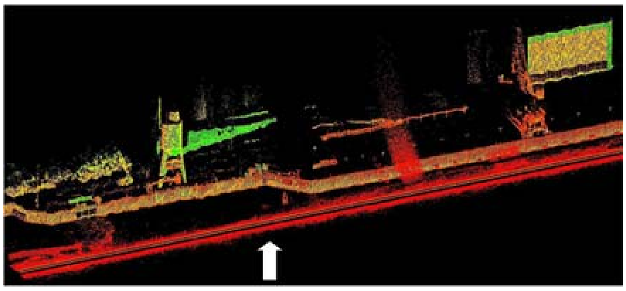

Figure 7: Kinematic scanning of the power station Wedel with the illustration of the boat trajectory parallel to the dock plant.

The scanned data were evaluated in the engineering office dhpi in a post-processing mode. After a pre-processing the Z+F scan profiles were merged with the IMU data in the evaluation software SiRailScan, which was developed for 3D laser scanning data by the company Technet in Berlin, in order to generate a rectified point cloud.

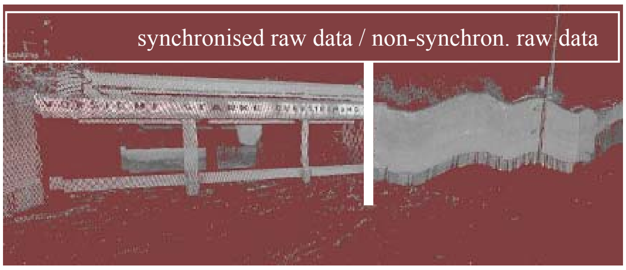

Figure 8: Results of measurements with compensation (left) and without compensation of the inertial measured orientation angles (right) for the outlet structure of the power station Wedel.

Fig. 8 demonstrates the comparison between raw data with compensation by inertial measuring data (left) and raw data without compensation (right) in which the ship’s dynamics (in particular heading, roll and pitch) still affect the coordinates as undulations. In the representation of the intensity values the inscription over the outlet structure is clearly visible in the left part of the figure.

After IMU compensation the laser scanning data are combined with the multi beam echo sounder data, which are already compensated in real time. In Fig. 9 a section of the measurements of the quay wall is illustrated, presenting the quay wall and the river ground including a zoom as DEM (top) and as a cross section (bottom).

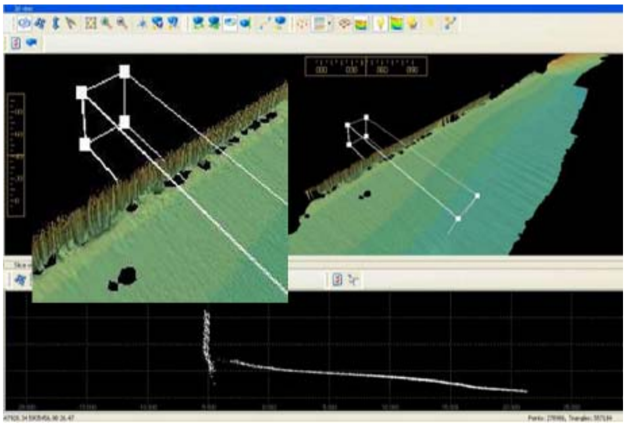

Figure 9: Section of the measurement results from the echo sounder representing the power station Wedel after processing with the program Qloud (QPS): perspective view with a zoom part (top) and a cross section (bottom).

With these measurements kinematic hydrographic laser scanning was realised on board the “Level-A” for the first time. However, it became clear in this pilot study that the range of the laser scanner of 79m at the maximum is not sufficient for many hydrographic applications. Nevertheless, accuracies of a few centimetres at close range were achieved. Here, the barely sufficient accuracy of the heading angle determination with the OCTANS (0.17°) or 0.24cm clearly affects the measuring accuracy of the coordinates in 79m distance. Such systematic effects can, in most cases, be calibrated. However these were not performed in this investigation.

5. SCANNING OF GRASBROOKHAFEN IN THE HAFENCITY OF HAMBURG USING LASER SCANNER RIEGL VZ-400 ON BOARD OF DEEPENSCHRIEWER III

The hydrographic data acquisition software QINSy provides an interface for the Riegl VZ-400, so that the data could be merged e.g. on board the “Level-A”. But, the software is also available on board the “Deepenschriewer III”, where the 3D positions and the orientation angles are directly measured with the inertial sensor IXSEA HYDRINS in combination with a TRIMBLE SPS851H. Thus, the object coordinates are determined in real time in the software QINSy.

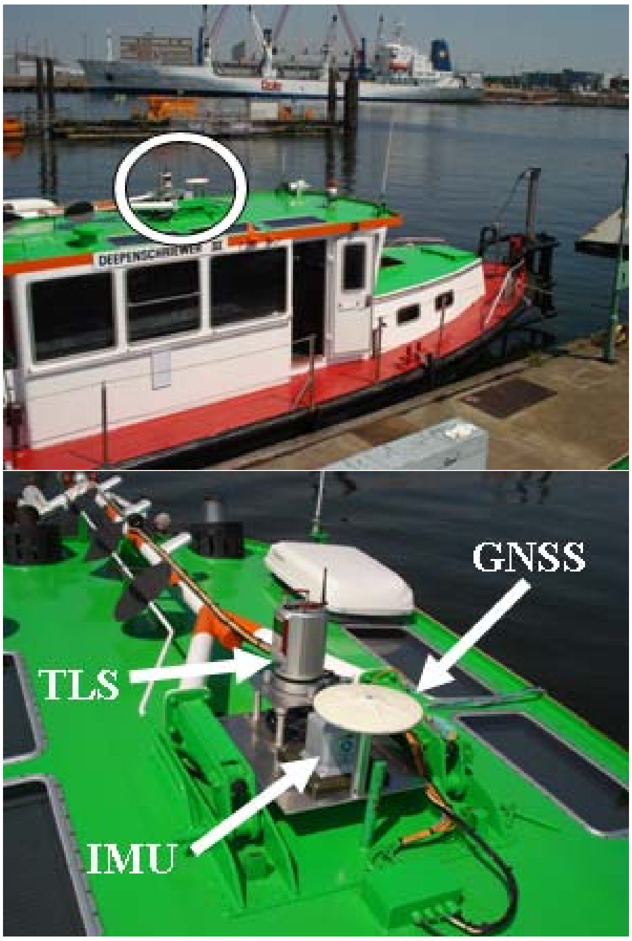

Fig. 10: Installation of TLS Riegl VZ-400 onboard the “Deepenschriewer III”.

Fig. 10 shows the structure of the multi sensor system on the roof of the “Deepenschriewer III”. GNSS antenna, IMU and TLS were installed on a plate along the ship’s axis with a distance of 30cm between each sensor. The close proximity of each sensor reduces possible error influences from the geodetic sensor determination and from the fusion of the measuring data.

The following presented investigations are based on the first measurements in the Grasbrookhafen in the HafenCity of Hamburg on July, 16th, 2010. The scanning area is illustrated in Fig. 11 in an outdated aerial photograph of Google Earth. The harbour basin is about 450m long in east-west and 60m to 110m broad in north-south direction. With the exception of the old dock warehouse A of the future Hamburg Philharmonic Hall no buildings shown on the aerial photograph remained at the time of survey. However, the northern and the eastern area of the Grasbrookhafen are today already fully developed and in use. The lower image in Fig. 11 shows a perspective view of the scanned data in the Grasbrookhafen.

In the first investigations the “Deepenschriewer III” drove at about 20m distance from the quay wall, in order to be able to also scan the dock plants up to the water line. Three profiles were successively scanned and later analysed. The profiles 3 and 5 begin on the northern bank from west to east and conclude with east-west profile on the southern bank. Profile 4 begins on the northern bank from west to east and ends on the southern bank with an east west profile. The two marks A and B are selected in Fig. 11 and will be investigated more in detail in the following.

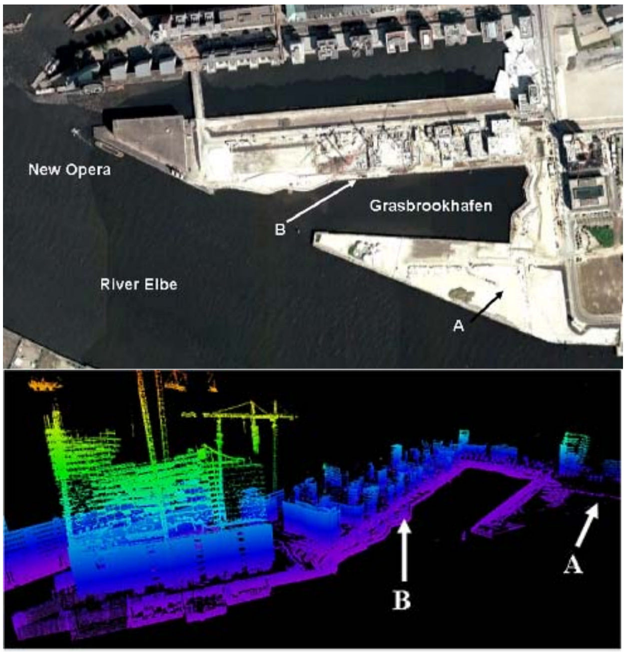

Fig. 11: Outdated aerial photograph of the Grasbrookhafens (source: Google Earth) in Hamburg HafenCity (top) and perspective view of the scanned data (bottom).

Mark A shows a scanned hoarding (see Fig. 12). The lateral frameworks of the elements consist of 4cm thick pipes, while the upper and lower frameworks are 2.5cm thick pipes. The hoarding wire has a thickness of 3mm and is built as 10cm x 25cm rectangles. The hoarding is clearly identifiably in all profiles; also a part of the thin wires is clearly recognisable. The comparison of the coordinates, which were determined for this hoarding, showed that the results of the west-east profiles 3 and 5 deviate from each other by approximately 1-2cm in XY position and in height. This is a very good result; the differences are barely discernible in the representations of the point clouds. However, the east-west profile 4 shows a deviation of 7cm in the XY position and of 5cm in the height in comparison to the other two above-mentioned profiles.

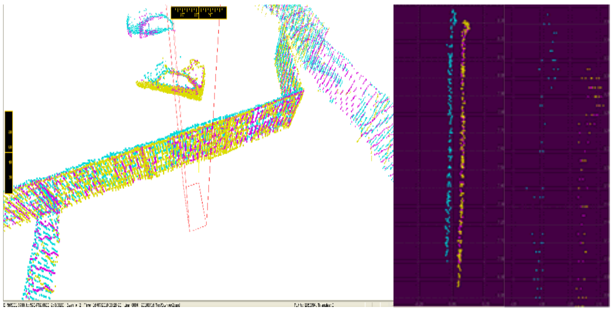

Figure 12: Accuracy analysis by reference to a building fence on the southern bank of the Grasbrookhafen (mark A in Fig. 11): 3D presentation of the scanned points (left) and representation of the measurement results in a cross section (right).

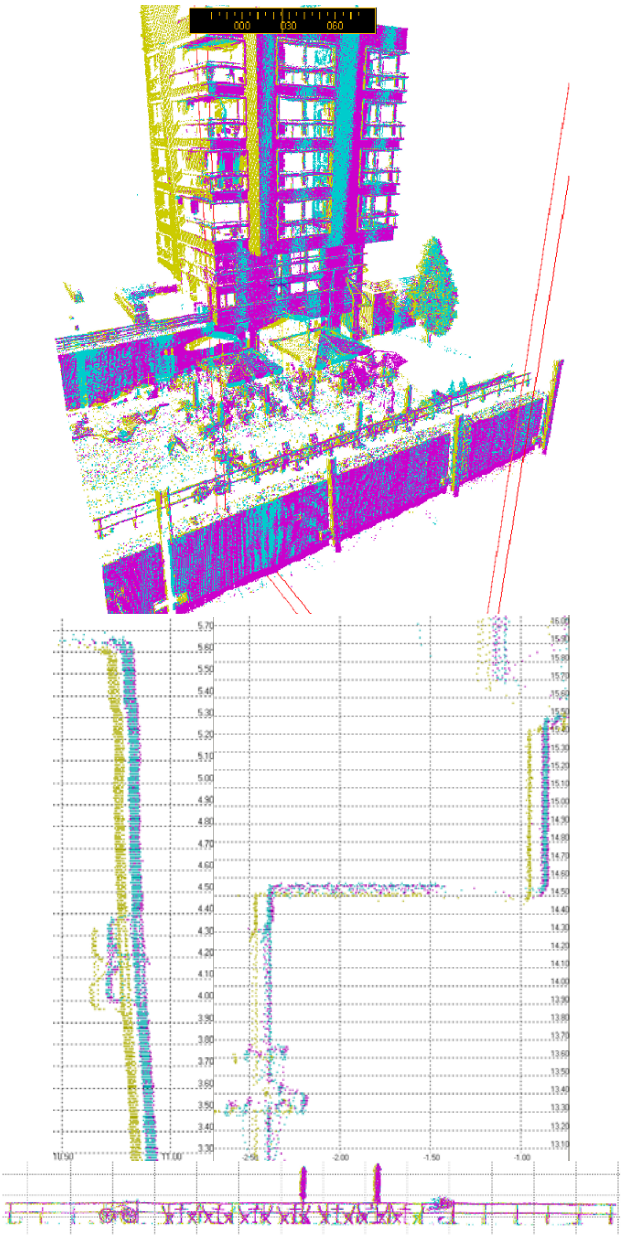

Fig. 13: Accuracy analysis at a building (top) and at a quay wall (centre) in the Grasbrookhafen (mark B in Fig. 11) and representation of the scanned points at the railing (bottom).

These deviations could be also verified for mark B at the northern bank in Fig. 13. Here, analyses could be completed both at the back-positioned house front (Fig. 13 top) and at the quay wall (Fig. 13 centre), which showed comparable results in each case (7cm in XY, 4cm in Z) to the southern bank. Additionally, the coordinates of the deviating profile 5 were continuously further distance from the ship, thus it can be assumed that systematic effects occur in this profile. This could have been caused for example by a deviation of 3.5cm in the determination of the sensor positions on board across the longitudinal direction of the ship. Nevertheless, it should be possible to calibrate this effect in the later post-processing of the data.

The deviation of the orientation angle determination and/or an inaccurate alignment of the sensor axes respectively, could be analysed in the representation of long linear structures alongside to the ship's driving direction at different distances to the TLS. A good example seems to be represented in the light curved pipes of the railing in the lower part of Fig. 13. However, during a field reconnaissance it was noticed that these curved variations are actually present in the railing meaning that a more exact analysis must still be carried out.

Further precision statements can be accomplished by analysing surfaces and linear structures in different profiles (e.g. from normal vectors). For these investigations different software packages, e.g. RiScanPro from Riegl, should be used. Generally it must be noted, that the identification and measurement of objects cannot usually be carried out at clearly defined points and breaklines, since these points are scanned at a regular grid spacing.

At the time of the writing this paper analyses of the data are not yet finished. Reference data which were acquired by static laser scanning with the Riegl VZ-400 on August 13th, 2010 will permit more precise statements about the accuracy of mobile scanning in comparison to be made.

6. CONCLUSIONS AND OUTLOOK

The first investigations into the use of terrestrial laser scanner systems on board of surveying ships in Hamburg show that data acquisition by such systems can be integrated into the hydrographic multi sensor systems (HMSS) both in post-processing mode and in real-time. The high speed of data acquisition, the abundance of information (3D coordinates, reflecting characteristics) and the accuracy of the acquired point clouds within the centimetre range offer good conditions for the use of this new technology for many applications at and on the water.

For the investigations at HCU and NIAH the software for data acquisition QINSy plays a crucial key role for the integration of terrestrial laser scanners in real time. The integration of the Riegl VZ-400 could be successfully accomplished. In addition both pilot studies showed that the pure accuracy of the inertial measurement units significantly affects the accuracy and quality of the kinematic laser scanning data. In comparison of the two laser scanners used on board the surveying ships the Riegl VZ-400 already has a clear advantage due to its technical specifications concerning scanning range, accuracy and resolution, making the use of this laser scanner very reasonable economically. In the near future further investigations with the system will be carried out in the harbour of Hamburg, in order to examine in detail the system accuracy on the basis of reference data and to also be able to calibrate systematic errors. Furthermore investigations will focus on how useful this scanned 3D data is for modelling and visualisation of structural objects (Kersten et al. 2008). First approaches to object recording and automated modelling have already been published in Hesse and Neumann (2007).

By system integration and extension of terrestrial laser scanners on board surveying ships the range of applications can be increased. Potential applications are, for example, the documentation and inspection of structural dock objects and dyke plants, as well as in harbour and coastal areas, the topographic survey of coastal and river banks and drying-falling tideland areas. Additionally, the observation of ship dynamics such as the determination of trim behaviour (squat and settlement), for example, represent a further possible specific application.

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