Comparison of laser bathymetry with single-beam and multibeam data

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This article summarises a Master Thesis devoted to the task of evaluating the LIDAR bathymetric systems of Chiroptera and Hawkeye developed by the Swedish company AHAB. The LIDAR bathymetric data was compared against two reference data sets, single-beam and multibeam echo sounder data, which were evaluated beforehand in order to avoid any bias in the comparison. Different comparisons were made over the data to obtain the inner precision, outer accuracies as well as wreck search abilities of the systems under analysis. The reference used for classifying the systems on a specific performance level was the IHO S-44 standard.

LIDAR bathymetry | S-44 standard | DTM comparison | DTM accuracy | Chiroptera | Hawkeye

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1 Introduction

In its inception, LIDAR applied to the underwater environment was a technology developed in the Cold War for the primary purpose of submarine detection. The first application as a hydrographic tool was presented by Hickman and Hogg (1969). Afterwards, its capabilities for bathymetric measurements as well as water column data retrieval were investigated and new equipment was developed accordingly. LIDAR bathymetric systems were developed in two types of sensors suitable for shallow and deeper coastal waters. However, the Hawkeye III system was precisely replacing these two sensors normally installed separately into a sole device with several lasers installed with the ability to cover the whole range of depths.

The assessment of the performance of LIDAR equipment was introduced mainly by companies and governmental agencies whose main interest was to ascertain the ability of these systems to complement or even replace the well-established multibeam echo sounder (MBES) and single-beam echo sounder (SBES) technologies. The need to define the quality of the LIDAR data led to a variety of tests showing that most of the systems achieved figures exceeding the IHO Order-1 standard at 95 % confidence level for the vertical accuracy. Such was the case of the SHOALS system with a figure of 0.28 metres (Riley 1995), LADS Mk II with 0.24 metres (Perry 1999) or the Hawkeye system with a similar performance as the one showed by SHOALS (Steinvall and Koppari 1996).

There are different kinds of measures that describe the quality of the LIDAR systems such is the case of the already mentioned vertical accuracy, the horizontal accuracy, the point density, the distribution and the footprint size. Therefore, the quality of the final product delivered by any system is influenced by the combination of these factors, the type of sea-floor surveyed (roughness) as well as the type of DTM used to represent the data (Li 2004).

The accuracy values given by former LIDAR assessments do not show the influence of the reference data sets on them. Therefore, increasing the overall amount of error and decreasing the expected reliability of the systems analysed.

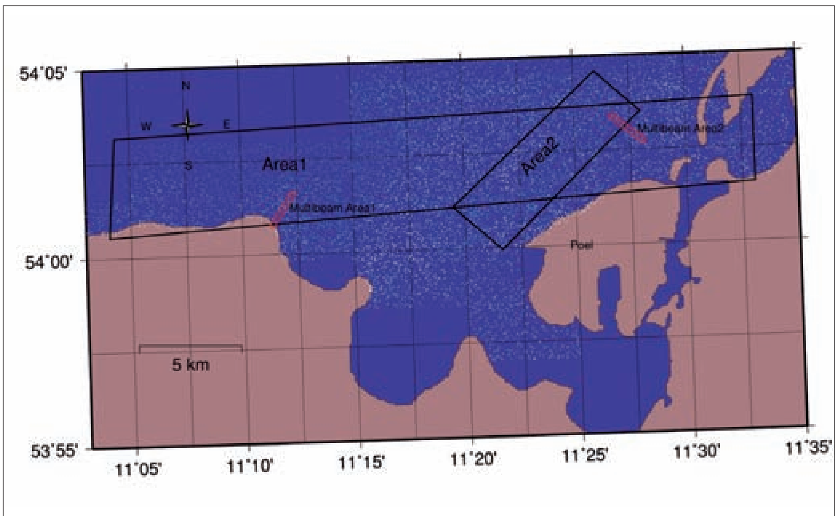

Fig. 1: SBES data (blue dots), MBES (red) and LIDAR acquisition areas

2 Site description and instrumentation

The main study areas, where MBES and SBES as well as Chiroptera and Hawkeye data were collected, are located in the north of the city of Wismar. There are two further calibration sites located in the north of Rostock. These two calibration areas are composed by different elements such as obstacles, wrecks or concrete blocks among other elements. The SBES sensor covered a huge area comprising all the other data sets with a point spacing of approximately 30 to 40 metres. On the other hand, the MBES data gathered for the analysis comprised two rectangular areas as well as the calibration sites. The MBES collected data in a wide range of depths for the sake of upholding a thorough analysis of the LIDAR data set (see Fig. 1).

The LIDAR sensors were installed separately in the aeroplane. The aeroplane positioning was made with different systems. On the one hand, the positioning system for Chiroptera was made by the company IGI using GrafNav as processing software. On the other hand, for the Hawkeye sensor the positioning system was the Applanix POS AV using POSPac as processing software.

These programs are able to blend the post-processed aircraft position given by the GPS antenna with the attitude data delivered by the INS sensor in order to obtain a high-resolution position for the aircraft.

The Chiroptera system was able to collect around 140 million points while the Hawkeye collected almost 7 million. Furthermore, the Hawkeye sensor acquires points using a semicircular pattern in water depths up to 6 metres whereas the Chiroptera acquires data using an elliptical pattern in water depths up to 14 metres. The depth values displayed are only given as an approximation. The real depth limit for these sensors depends mainly on the water turbidity.

3 Methodology

The data provided by the company was divided in files conforming to the LAS format, each file representing a flight strip. Inside each LAS file there are different classes of points representing water surface, sea-floor or water obstacles. These data files were processed in a first stage with the program LAStools which allowed to arrange all the information divided by flight strips in several files that represented the different survey areas. The program also allowed to extract exclusively those classes that were interesting for the analysis, which was the case of the sea-floor or underwater obstacles classes.

Once the data was preprocessed with LAStools, the new LAS files were used as input to the GISMO software, where the comparison was carried out using the comparison tool available in this program. The last step in the procedure of comparison was to perform all the statistical analysis over the difference models with the OCTAVE program. OCTAVE is a tool similar to MATLAB and runs with scripts and functions developed for the purpose at hand.

The first decision taken regarding the comparison with the data was to use the densest model to perform the comparison operations in order not to lose information in the process. Therefore, the LIDAR data was used to perform the comparison operations. The data model used for representing the geographic data set was a TIN. Regarding these two facts, and also considering that the comparison will be a local operation (Tomlin 1990), it is possible to take into consideration the spatial data model conversions for numerical data and the rules for combining different spatial data models given by Kemp (1993).

The main approach, considering the spatial data model conversion, is to transform the TIN spatial model to an irregular grid by using point interpolation as specified by Kemp (1993). The destination model is the irregular grid because this is the spatial structure of the SBES data set and the MBES data set. Moreover, when considering the rules for combining different spatial data models the data set with the bigger density will be used for the operations, otherwise one would lose precision during the operations (Kemp 1993), therefore the LIDAR data set for performing the point interpolation operations should be used.

The general procedure for the comparison was performed using the following steps:

1. Generation of a TIN from LIDAR data.
2. Point interpolation on the TIN data model.
3. Generation of irregular grid from interpolated points. (These irregular grids will correspond with the positions of the SBES and MBES data).
4. Comparison between generated irregular grid and reference data (SBES or MBES data sets).
5. The different data sets were divided using depths with intervals where the lower limit was included and the higher limit was excluded.
6. Statistical analysis of the generated difference grid in OCTAVE.

Finally, an absolute vertical accuracy assessment was performed based on the entire information given by the different data set comparisons. The approach was to assess each DTM accuracy by isolating it from the influence of the second data set used in the comparison (Ben-Haim et al. 2013). This assessment was performed building a set of equations that expressed the various comparisons made along this study and solving this system using least squares adjustment.

4 Results and discussion

4.1 Reference data sets

The SBES data set was considered to be free from bias when compared with itself in a simulation process where 400 randomly taken points were compared against the entire sample of SBES points composed of approximately 350,000 points (Li 2004). After the analysis, the standard deviation of SBES data set was considered to be 0.156 metres. The MBES data set was also considered to be free from bias while its standard deviation was deemed to be 0.05 metres. When comparing both reference data sets there was a large bias of –0.22 metres caused by the shallower measurements given by the SBES technology.

Finally, it is worth mentioning the similar values between the SBES accuracy estimation and the estimation of the SBES DEM error obtained after removing the MBES influence from their comparison (0.156 metres the former and 0.154 metres the latter one).

4.2 LIDAR inner precision

The inner precision analysis showed the consistency of the LIDAR Chiroptera data while the Hawkeye system exhibited a clear bias in some of the results, especially in the overlapping areas. This bias was due to a tilt that showed its maxi-

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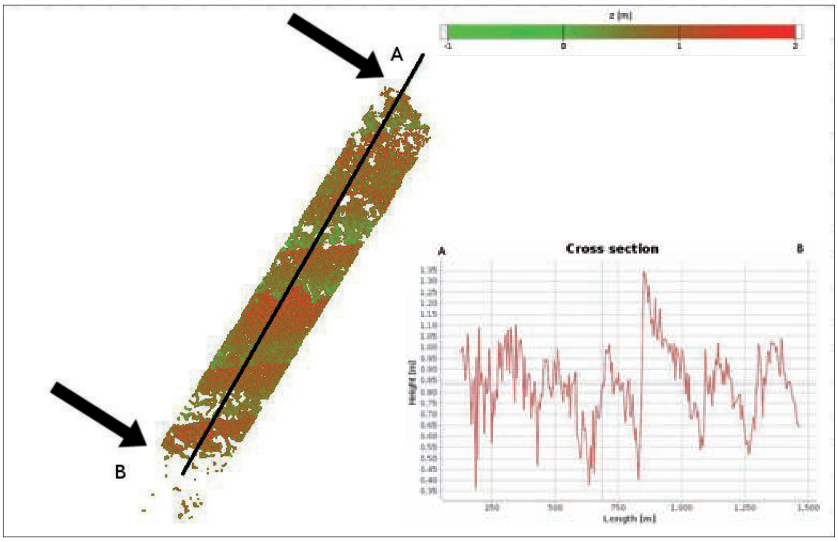


Fig. 2: Comparison MBES area 1 and Hawkeye system, profile showing the inclination and differences among flight strips

mum difference on the sides of the flight strips (see Fig. 2 and 3).

The comparison of Chiroptera and Hawkeye sensors revealed a bias between them. The source for this bias between sensors could be precisely the mentioned bias caused by the tilt in the Hawkeye system.

4.3 Comparison between LIDAR and reference data sets

The comparison between SBES data and LIDAR data revealed a bias of approximately 0.60 metres which was caused by a mistake in the geoid undulation interpolation. The comparison also showed an increasing trend for the standard deviation with depth.

Fig. 3: Comparison SBES and Chiroptera system area 1

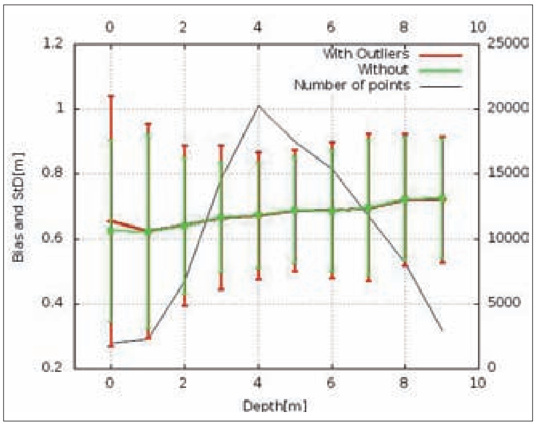
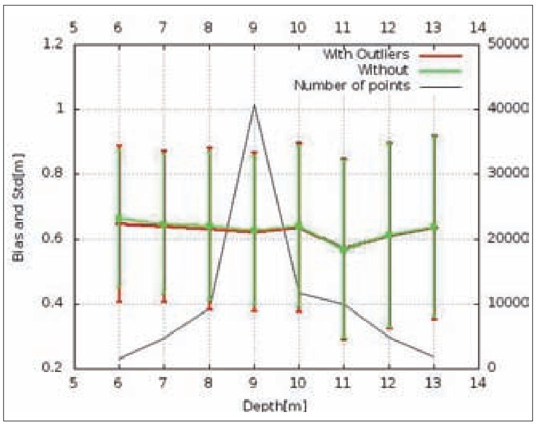


Fig. 4: Comparison SBES and Hawkeye system area 1



On the other hand, there exists a noticeable increase of precision with depth at the shallower values reaching an optimal depth at around 4 to 5 metres for the case of Chiroptera and between 7 to 10 metres for the case of Hawkeye. This is caused by the presence of outliers in the shallower regions which disappear and allow for such increase of accuracy (see Fig. 3 and 4, and the tables).

Comparison	Bias	StD
Chiroptera vs SBES	0.681 m	0.218 m
Chiroptera vs MBES	0.776 m	0.177 m
Absolute accuracy Chiroptera		0.093 m

The comparison of MBES and LIDAR supports the results obtained with the SBES data set. It is worth mentioning the improvement of the standard deviation in the case of the MBES comparisons due to the better quality of the MBES data set with respect to the SBES data set.

Comparison	Bias	StD
Hawkeye vs SBES	0.620 m	0.255 m
Hawkeye vs MBES	0.831 m	0.211 m
Absolute accuracy Hawkeye		0.190 m

The least squares estimation revealed also the influence of the reference data sets on the comparisons. This is the case with the Chiroptera sensor whose standard deviation decreased in almost half the value of the one obtained with the MBES comparison. This effect is also noticeable, but to a lesser extent, in the case of the Hawkeye standard deviation results.

4.4 Wreck search capabilities

The first wreck analysed was located in the MBES area at an approximate depth of 4 metres protruding from the seabed up to 3 metres. The wreck was not retrieved by the sensor and hence there is hardly any point protruding from the overall Chiroptera DTM surface. On the other hand, the wreck is easily noticeable in the MBES DTM model.

The detection probability of such a wreck, taking into consideration the bad water clarity conditions, goes to a value of at least 80 % (Guenter et al. 1996). This fact leads us to think that this wreck should have been detected by the LIDAR system.

The second wreck analysed, only detected by Hawkeye, is located in Nienhagen reef and was the only one available among the other obstacles placed in both calibration areas. The Hawkeye model represents the shape of the object. However, there is a decrease of precision of the system in the region where the obstacle lies.

The results of the wreck analysis are not conclusive and it would be necessary to perform more thorough and complete assessment of the behaviour of the LIDAR data in those places with underwater obstacles. Moreover, these results seem to be contradictory when analysing the data sets system-wise, e.g. surprisingly the Chiroptera system does not detect the wreck, whereas the Hawkeye does it with some difficulties.

5 Conclusion

The analysis of the two LIDAR systems, Chiroptera and Hawkeye, together with the analysis of the reference data sets used for the comparison allowed, first, to give an insight into the real accuracy and behaviour of the LIDAR data and, secondly, to guarantee that the information given as a reference could be used as such.

The Chiroptera system showed an overall good performance with relatively good values for the standard deviation of the data. This behaviour was supported by the results of the inner precision analysis, where the sensor showed strong coherence with minor systematic errors present in the analysis of the overlapping areas. The results of the comparison with the SBES and MBES data sets illustrate how the Chiroptera sensor was able to comply with S-44 Order 1 requirements when considering the bias present in the data set.

The Hawkeye system showed a lower performance when compared with its Chiroptera counterpart. This fact was noticeable both in the inner precision analysis and in the MBES and SBES comparisons. The inner precision analysis showed a system with a consistent performance in terms of standard deviation. This analysis showed also the presence of a further systematic error in the Hawkeye sensor, which was observed as an inclination of the flight strips. The results of the comparison with the SBES and MBES data sets show how the Hawkeye sensor decreases its performance slowly with depth. Furthermore, when considering the bias present in the data sets, most of the depth regions were compliant with the S-44 Order 1 standard.

This study leaves several questions open. The first being related with the analysis of the performance of the LIDAR data under different types of sea-floors (ranging from flat to rough). This factor could have a strong influence on LIDAR performance as suggested by Ben-Haim (2013) and therefore should be addressed in further research. The second issue to tackle in a future analysis is the ability of the LIDAR system to detect underwater obstacles, therefore giving a better insight in the system's ability to reach S-44 Order 1b or Order 1a requirements. This question remains open due to the lack of wreck data or its low quality if present in the data sets. ⚓

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