New techniques in capturing and modelling of morphological data

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Since 2014 the techniques of LiDAR bathymetry have been used for capturing morphological data in Schleswig-Holstein. Round 2000 km² have already been surveyed with these techniques. Data gaps only occur locally in tide ways or low-lying areas, which are needed to be filled by hydrographic surveys. But compared with the bathymetric LiDAR, these surveys have a substantially lower density of points. Hence, it is difficult to merge these data to a morphological model. As a consequence it is necessary to densify the hydrographic data to create a homogeneous model. The mathematical method of Coons patches is suitable for this purpose. The gaps inside the area of hydrographic survey are filled with data points in desired density. The bathymetric information is then calculated using bilinear interpolation. As a result a data set which has a similar point density as the bathymetric LiDAR is created. After the preparation a homogeneous morphological model can be generated by triangulation, based on bathymetric LiDAR on the one hand and hydrographic surveys on the other hand.

coastal protection | LIDAR bathymetry | morphological data model | Coons patches

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1 Introduction

Schleswig-Holstein, the most northern state of Germany, is called »the land between the seas« because it is placed between the Baltic Sea with a coastline of approximately 640 kilometres on the east side and the North Sea with a coastline of approximately 550 kilometres at the west side of the state (Fig. 1).

This location between the seas justifies that coastal protection is a main task. Without buildings of coastal protection, 25 % of the area and 12 % of the inhabitants of Schleswig-Holstein would be threatened of storm surge and floods.

For coastal protection knowledge about the development of the morphology of the coastal areas is necessary. Therefore, an area-wide survey above and below the mean sea level has been conducted and an analysis of the acquired data has been done.

Fig. 1: The state Schleswig-Holstein

2 Previous survey

Both seas have different conditions which are considered by implementing a survey. The Baltic Sea is stamped by the last ice-age with fjords and shallow shore areas. A nearly constant water level in the height of the mean sea level is predominant. Variations are only in the impact of wind. The North Sea is stamped after the last ice-age by the growth of the Wadden Sea offshore the coastline which is daily formed by two tides. The water level varies between round three metres from the high tide to the low tide.

Both coastal regions are shallow water areas. In focus of coastal protection are the areas between the coastline and seawards the depth line of ten metres below the mean sea level. Because of these natural conditions an area-wide survey is seen to be difficult.

The region of the North Sea, including the Wadden Sea, has been primarily surveyed by ships until now using the high tide completed by airborne LiDAR scanning at the low tide.

The region of the Baltic Sea until now has been primarily surveyed by ships and boats with a small draught following by terrestrial survey on feet up to the waterline and then completed by airborne LiDAR scanning.

3 LiDAR bathymetry as a new method of survey

Since 2014 the Schleswig-Holstein Agency for Coastal Defence, National Park and Marine Conservation (LKN.SH) has been using the method of LiDAR bathymetry for the survey of the coastal regions above and below the mean sea level. Only lower areas are additionally hydrographical surveyed by ships.

The known method of airborne LiDAR scanning applies red LiDAR light, which is able to capture terrain and water surfaces. The technique of LiDAR bathymetry uses additional green LiDAR light, which is able to penetrate into the water body and capture the seafloor (Fig. 2).

3.1 Expected depths

For the depth of penetration the turbidity of the water body is decisive. This is declared as Secchi depth. Also the power of the systems is important which is described as a factor of the Secchi depth.

On the coast of the Baltic Sea the Secchi depth varies between three metres at the fjords and five metres at the open sea.

On the coast of the North Sea the values of Secchi depths varies at the Wadden Sea between nought and one and a half metres and seaside the Wadden Sea nearly three metres.

In spite of the small Secchi depth the technique of LiDAR bathymetry is very suitable because the ground of all water areas left on the tide land at the low tide are captured.

This is not possible by using airborne LiDAR scanning. The red LiDAR light cannot penetrate into the water body.

The systems of LiDAR bathymetry on the market are divided into two categories. The one system is able to reach the one to one and a half (1 : 1.5) of the Secchi depth, the other system is able to reach the two and a half to three (2.5 :3) of the Secchi depth.

With this information of the manufactures and the knowledge of the Secchi depths of the areas the reachable depths of the survey are estimated (Fig. 3).

3.2 Results of LiDAR bathymetry in coastal areas

Between 2014 and 2016 around 2,000 km² have been covered by LiDAR bathymetry. The whole coastal area of the Baltic Sea with 650 km² and approximately 50 % of the Wadden Sea with 1,350 km² have been captured until now.

In all regions the expected depths are nearly reached.

The following examples of the west coast of the island of Sylt, the Wadden Sea and a coastal area of the Baltic Sea show this:

- At the west coast of the island Sylt the whole sand reef down to eight metres is captured (Fig. 4).
- At the Wadden Sea the ground of all water areas on the tideland is captured (Fig. 5).
- In the Baltic Sea detailed under-water structures down to five metres are captured (Fig. 6).

3.3 Accuracy of data of LiDAR bathymetry

The accuracy of data of LiDAR bathymetry are defined by comparison with terrestrial and hydographical surveys realised nearly at the same time. The results are nearly between one and two decimetres in height, which conforms with the ac-

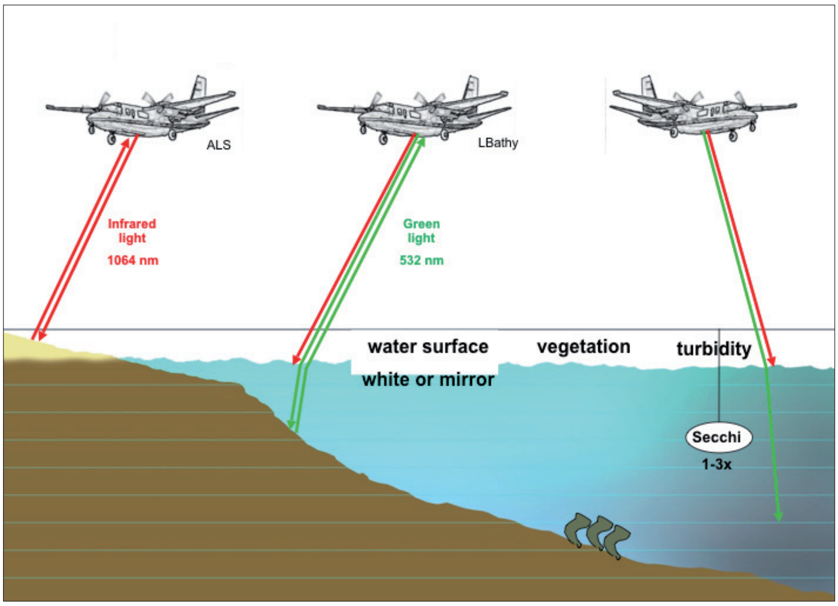


Fig. 2: Principle and limitations of LiDAR bathymetry

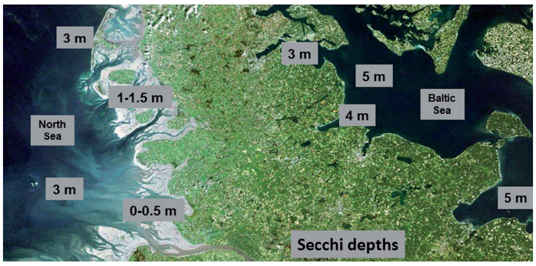


Fig. 3: Secchi depths at the North Sea and the Baltic Sea

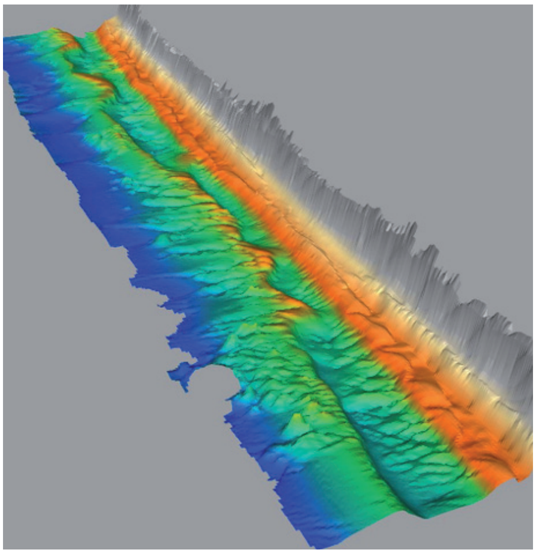


Fig. 4: Results of LiDAR bathymetry down to eight metres at the west coast of the island Sylt

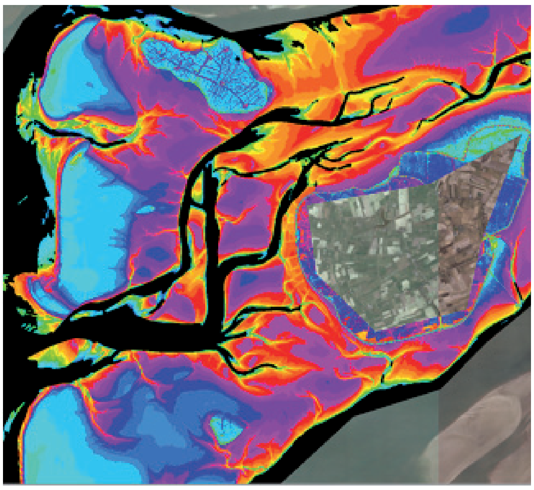


Fig. 5: Results of LiDAR bathymetry of the Wadden Sea, the most turbidity area. Only the tide ways are not captured

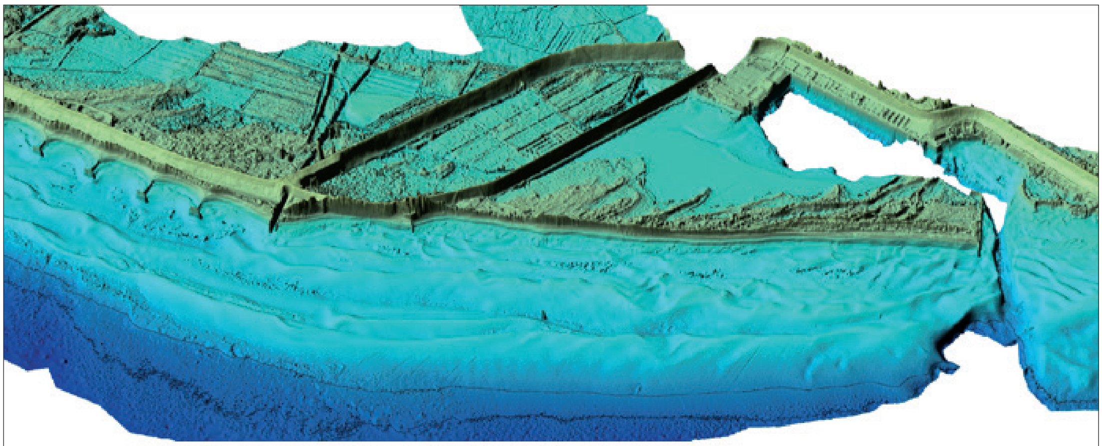


Fig. 6: Results of LiDAR bathymetry down to five metres of the Baltic Sea

curacy of the hydrographic survey as Fig. 7, 8 and 9 show.

4 Modelling of line-based survey data

After a first implemented survey by LiDAR bathymetry at the shallow water areas the remaining deeper channels of the tide ways are hydrographically surveyed by using a single-beam system.

The LiDAR data are area-wide homogeneous spreaded with at least one point per squaremetre. These data are unproblematically converted into a plausible morphological model.

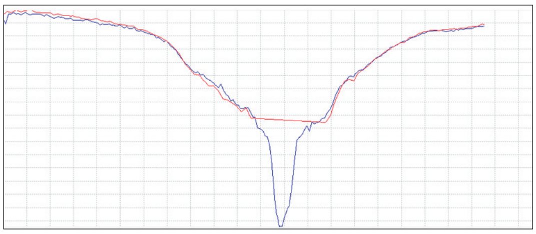


Fig. 7: Accuracy of LiDAR bathymetry (red line) in the Wadden Sea in comparison with hydrographic survey data (blue line)

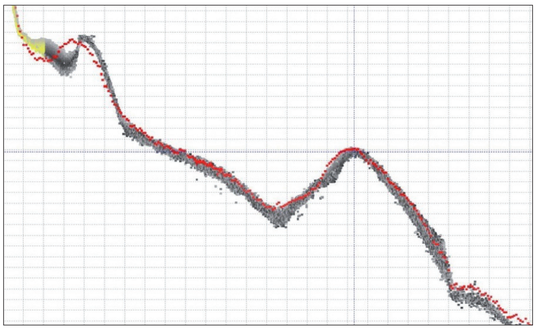


Fig. 8: Accuracy of LiDAR bathymetry (grey points) at the west coast of Sylt in comparison with hydrographic survey data (red points)

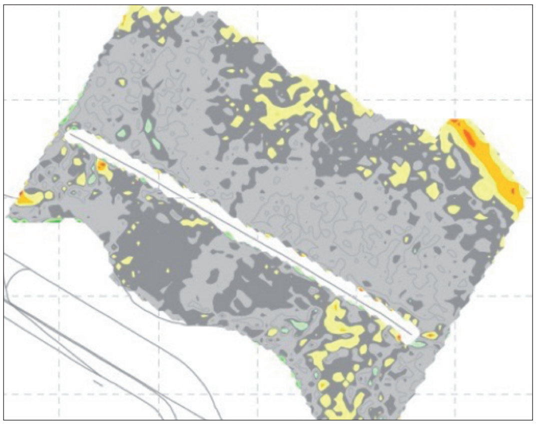


Fig. 9: Accuracy of LiDAR bathymetry depicted in a difference model LiDAR bathymetry vs. hydrographic/terrestrial survey. Grey: 0 to 10 cm, dark grey: 10 to 20 cm

The line-based hydrographical data with an usually line distance of one hundred metres and one data point per running metre is very problematically converted into a plausible morphological model because of the inhomogeneous data distribution.

Therefore, it is a goal of the LKN.SH to create a homogeneous data distribution of line-based surveys and to generate a plausible morphological model.

This is possible by using Coons patches.

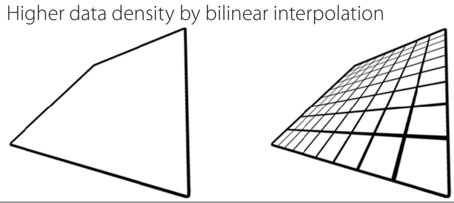
4.1 Coons patches for higher data density

Especially the car industry needs algorithms to generate free formed surfaces by CAD (Krömker 2008).

Approximation algorithms of Bézier curves and Bézier surfaces are known. These were developed by P. Bézier at Renault.

Steven Anson Coons (1912 to 1979) was a pioneer of developments in computer graphics. He worked among others at Ford. His developed Coons patches are based on an interpolation algorithm (Bungartz et al. 2013, p. 91). Inside of mostly four squared polygons a higher data density takes place by bilinear interpolation (Fig. 10).

Fig. 10: Method of Coons patches. Higher data density by bilinear interpolation



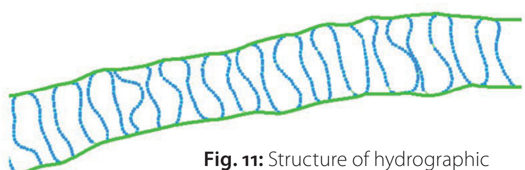


Fig. 11: Structure of hydrographic survey. Cross lines together with the hull produced for squared areas

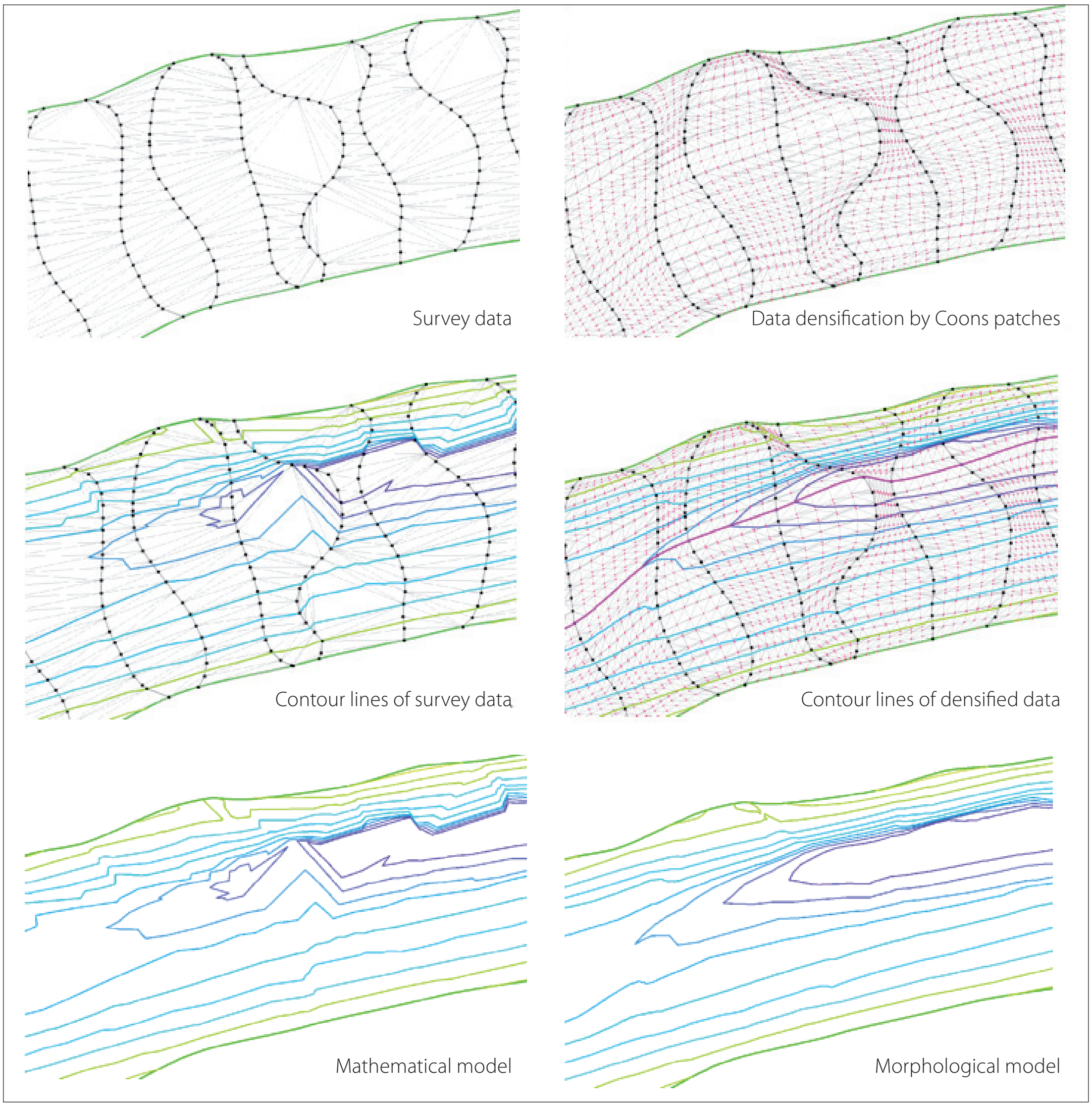


Fig. 12: Comparison of the mathematical model with only the survey data (left) and the morphological model additional with the Coons data (right)

References

Krömker, Susanne (2008): Skript Computergraphik II, SS2008, Kapitel 6 Splines; www.iwr.uni-heidelberg.de/groups/ngg/CG2008/Txt/Kapitel6.pdf, last access 19.09.2016

Bungartz, Hans-Joachim; Michael Griebel; Christoph Zenger (2002): Einführung in die Computergraphik – Grundlagen, Geometrische Modellierung, Algorithmen; Vieweg+Teubner-Verlag, 344 p.

4.2 Transfer to line-based survey of channels

In the survey of channels the definition of the measuring lines are perpendicular to the direction of flow.

The hull line, composed of the ending points of each measuring line, encloses the area which is represented by the inside-placed data points.

Thus, four squared polygons are produced which allow bilinear interpolation inside. The algorithm of Coons patches are utilised here (Fig. 11).

An improvement of the polygonal partitioning is given by embedding morphological structure lines like the deepest line of the channel bed or lines of change of inclination. These optimise the morphological accuracy of the model.

4.3 Using of Coons patches

As a result virtual data will be formed with a homogeneous data distribution and assigned high information by bilinear interpolation of the surveyed data.

By using the original data and the Coons data a plausible morphological terrain model is generated. Fig. 12 and 13 illustrate the differences between mathematical and morphological model.

5 Conclusions

For an area-wide survey of shallow water areas along the coast the technique of LiDAR bathymetry is very effectively usable. This method replaces the difficult realisation of hydrographic survey which is only necessary as addition in deeper areas.

In a hydrographic survey with single-beam technique it is possible to generate a homogeneous data density by using Coons patches. More plausible morphological terrain models are creatable. ⚓

Fig. 13: Demonstration of the difference between the mathematical model and the morphological model at a part of the River Eider