First steps towards developing a risk-based hydrographic surveying policy.

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ABSTRACT: Developing a risk-based hydrographic surveying policy requires predicting depths with available bathymetric data. Previous research used the methods of Inverse Distance Weighting (IDW) and kriging using a regular grid for interpolation. The aim of this paper is to investigate the use of quadtree decomposition applied to bathymetric data to define a new grid as the basis for improved interpolation and risk assessment. The quadtree approach allows to adapt the resolution of the grid depending on the variability and data availability such that grid sizes may vary with location. A case study will be tested where the seafloor is relatively flat or sloping versus an area where sandwaves are present. The resulting grid will be the basis for developing a risk-based probability map for which the accuracy of the interpolated depths is important for assigning resurvey frequencies for the Netherland Continental Shelf (NCS).

1. INTRODUCTION

For purposes of safe navigation and in keeping with the Safety of Life at Sea convention (SOLAS) developed by International Maritime Organisation (IMO), there is a need for hydrographic surveys to be managed efficiently and kept up-to-date. The two entities responsible for conducting hydrographic surveys are the Netherlands Hydrographic Office and the Rijkswaterstraat (RWS). They work together and abide by the S44 standards but also developed their own Hydrographic Survey Policy and as such added to the S44 International Standard for the NCS. The current Hydrographic Survey Policy assigns survey frequencies of areas of the NCS which are not based on a comprehensive risk-based assessment.

In addition to the busy shipping lanes, the NCS is characterized as having a shallow seafloor with dynamic seabed formations, especially sandwaves that vary temporally and spatially. This is a concern since the navigable depths have to be maintained and managed efficiently to account for the factors that affect the seafloor depths and hence maritime safety. This research will aim to create an automatic tool which can be used to assign resurvey frequencies more efficiently using geostatistical analysis. It is essential to be able to make a risk-based assessment focused on expected depths and grounding risks due to sandwave dynamics, objects on the seafloor (such as wrecks and unknown objects), human intervention activities (such as maintenance dredging, sand mining, construction on the seabed, laying of pipelines and cables and land reclamation projects) and extreme storm events.

This paper therefore focuses on the preparation step in the development process to create a dynamic digital elevation model (DEM), which covers the complete NCS (except areas where no hydrographic data is available) with homogeneous accuracy. The single beam echosounding (SBES) and multibeam echosounding (MBES) datasets will be the input for the spatial interpolation analysis procedures. The dynamic DEM should also include for each grid cell, the variability in time, such that predictions of depth changes can be made. For those predictions an elaborate approach based on deformation analysis as described by Dorst (2009) will be explored. Once new hydrographic survey data becomes available for certain areas, the dynamic DEM must be automatically updated using the new survey data.

The dynamic DEM will at first only consider data-based predictions assuming certain hypotheses for the dynamics of the sand waves. In a later stage, additional factors such as human intervention activities, storm events and objects on the seafloor will be considered to assess grounding risks.

2. BACKGROUND

Differences in mapping techniques such as single beam echosounding and multibeam echosounding to map the seafloor of the NCS results in data being heterogeneous in time and space: previously some areas were mapped using only SBES, other areas longer records of both SBES and MBES surveys.

In VanDijk (2011) a 25x25 meter grid was chosen to guarantee sufficient data density in all areas and was considered to be sufficient resolution to reveal the bedforms at the scale of sandwaves. However, the trade-off is that in areas with much higher data density it would be possible to obtain higher resolution results with high accuracy. This would be the areas that are also most interesting in terms of sand wave dynamics. VanDijk (2011) used the deterministic interpolation method inverse distance weighting (IDW) which is simpler and claims more consistency. This method is based on the theory that closer data points have more correlation and similarities than further data points and hence this interpolation method depends on the distance and closeness of the neighbouring data points.

Dorst (2009) used Kriging interpolation technique which considers the distance and direction between all the pairs of observation data points and uses these values to compute the variability in the sandwave field. It is assumed that for sandwave fields, anisotropy in scale can be assumed that maximum variability is orthogonal to minimum variability. Maximum variability is defined as the direction perpendicular to the sandwave crest and minimum variability as the direction which is assumed to be perpendicular to the direction of maximum variability. This method as compared to the IDW, provides better weighting of the data but is more complex and requires blocks of homogenous sandwave characteristics. To provide an accurate, continuous and homogenous bathymetric map of the entire NCS there is a need for a robust interpolation method that can solve the problems presented above, that is to provide a grid that is small enough to detect the variability in the sandwaves (scale of the sandwaves) without compromising the processing speed of the data for the complete NCS. The aim of this contribution is to solve these issues by considering the potential of the quadtree grid structure as the basis for interpolation of the bathymetry with appropriate data weighting and the foundation for creating the probabilistic map for the NCS.

3. METHOD

3.1 Quadtree Approach

Quadtree decomposition methods have been demonstrated before using bathymetric observations and other related applications such as in Borthwick (2001), Welstead (1999), Mixon (2011) and IDON Technologies (2010). However for this application the quadtree algorithm is designed specifically for the purposes of creating a dynamic DEM as the first step towards creating a probabilistic map which will determine the hydrographic survey frequencies for the NCS. The Quadtree decomposition method will be applied to bathymetric data observations to guarantee homogeneous accuracy and variability. This approach will guarantee higher resolution in areas of large variability and at the same time allowing for data reduction in cases of very high density MBES data in areas of low variability.

The quadtree algorithm is based on initially subdividing an area into four equal quadrants; for each of these quadrants the data density over time and signal variability will be assessed. If both are exceeding a certain predefined threshold, the quadrant will be split into four new sub quadrants recursively, until convergence or until a certain minimum grid size is reached. This will lead to a decomposition of the DEM into blocks, with each having a low standard deviation. Hence each newly subdivided quadrant will have more or less equal variation.

Depending on the application, the algorithm is flexible in terms of the criteria for splitting the quadrants and choice of associated thresholds. For this specific application the variability (depth variations with respect to a fitted plane) will be the most important criterion. Therefore this algorithm is specifically designed to investigate the best way for which the variability can be computed and represented. In some areas of the NCS, the availability and data density of the depth observations are very low. It is assumed that in these areas depths do not reach a critical value where it affects the safety of navigation and also exhibits the least dynamic behaviour. Therefore in these areas where variability is not critical, a larger grid size is acceptable here for interpolation, especially if the dynamic depth is set equal to the shallowest depth in the corresponding area. Figure 1. shows an example of how the quadtree decomposition may work. Note however, that in reality the decomposition would have continued until an even finer resolution, for example 5 meters.

The added value of the quadtree algorithm will be shown based on a case study for a specific area, with different sea floor characteristics which includes flat or sloping seabed versus areas where sandwaves are present, represented by different data densities. The case study also comprises an analysis of the interpolation results for the depths based on the newly defined grid produced from the quadtree decomposition approach. For the weighting function of kriging, the same variability measure will be used as for the quadtree decomposition. The results are compared to those obtained with the interpolation methods from the previous studies by Dorst (2009) and Van Dijk (2011), to show that the new approach resolves the issue of data availability versus requested accuracy and computation time. Furthermore the results of the quadtree approach can be used as a GIS (Geographic Information System) tool where the newly developed grid can be integrated with the dynamic bathymetric DEM. The time series of bathymetric data sets can be stored in each grid cell for further analysis.

The approach will first use synthetic data for the interpolation. The resulting interpolated values will be compared with the ground truth data which is already known since the simulated dataset is based on the known bathymetry. Subsequently, real data will be used for cross validation which is possible to some extent by comparing the interpolated values at locations where observations are also available. MBES data can also be used where a subset of data is selected at a track spacing similar to SBES data in order to have same data density as the SBES.

4. CONCLUSION

This quadtree decomposition approach provides optimal use of the available bathymetric data for the NCS. Depending on the seafloor characteristics for example areas with sandwaves, the variability is accounted for by improving the sampling density of the data points which leads to better weighting for interpolation of the depths. Appropriate weighting for accurate interpolation will improve the creation of a dynamic DEM as the basis for developing a probabilistic map which assigns the hydrographic survey frequencies of the NCS.

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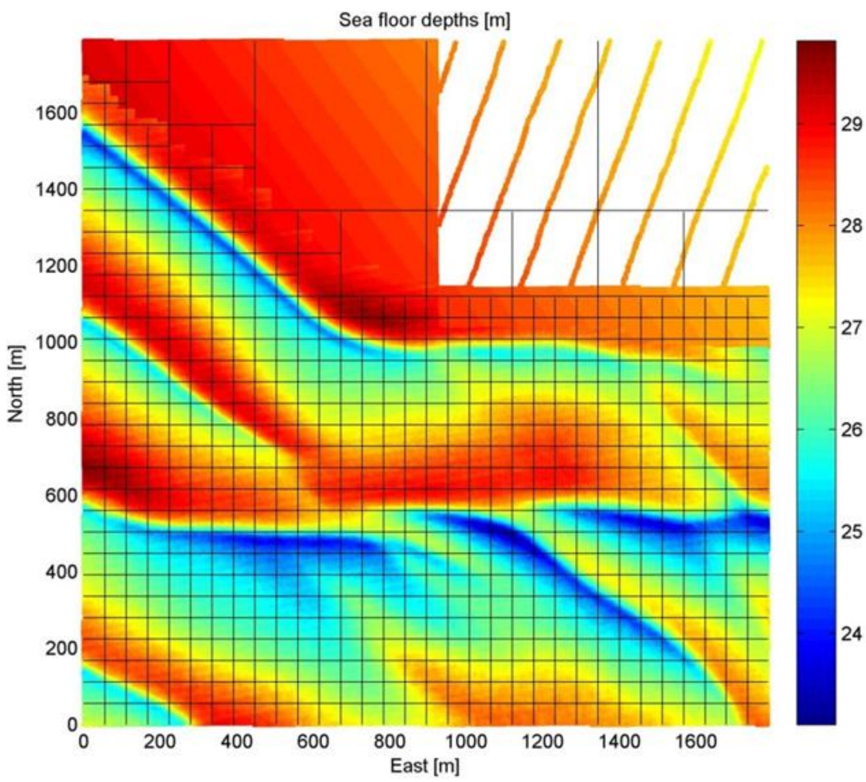

Figure 1. Example of quadtree decomposition for bathymetric data.