

Problems, methods and technologies of combined 3D model construction for underwater and above-water relief

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Abstract. In the article we describe the methods for construction of underwater 3D relief (bathymetry) and combining it with the corresponding ground relief (terrain) when the bathymetry information is of much lower quality than that of terrain. We have developed an algorithm for combining the low quality underwater relief with the higher quality ground relief using Delaunay triangulations. The resulting combined 3D model of relief has no noticeable artifacts and can be used to solve various hydrological tasks, such as computation of the HPP reservoir water level in dependence to the water discharges of the hydroelectric power plant. We have tested the technology for building combined relief 3D model in several scientific projects intended to estimate the changes in the coastline under various water flow scenarios in the basins of Angara River and Lake Baikal.

1. Introduction

The river bed of the Angara River on its more than 100 km stretch from the dam of the Irkutsk Hydroelectric Power Station (IHPS) to the start of the Bratsk Reservoir has rather complex structure with many islands, backwaters, channels and inflow junctions. The most dangerous from the point of view of potential flooding is the 67 km long area from the dam of IHPS to the end of the city of Angarsk. About 1 million people live here and the area contains the largest enterprises of the Irkutsk region. To consider the risks of flooding of urban areas caused by increased water discharges through the dam of IHPS and the other river Angara inflows due to extreme weather conditions it is necessary to build the relief models to determine potential zones of flooding. Regular space monitoring of the specified area may be used to measure the coastlines with the accuracy of several meters but it is a costly affair [1-9].

By using sufficiently accurate relief model it will be possible to estimate the dependence of potential flooding boundaries on the water discharges. Moreover, in conjunction with the period of extreme low water that began in 2014 in the basins of lake Baikal and river Angara the problem of estimating the boundaries of shallowing of the lower pool of the IHPS and the Bratsk reservoir is of great current interest.

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Thus, we need the river bed relief model. The model should take into account the shape of the river bottom. While the ground relief is represented by topographic vector electronic maps of various scales and various global DEMs (e.g. SRTM, ASTER), the information about the underwater relief of the Angara River is not available electronically. There exist some electronic bathymetry data for navigators, but they are fragmented and very imprecise. The only useful sources of the underwater relief information are the pilot charts, which are available in paper form only. To use the pilot charts we have to vectorize them (Fig. 1).

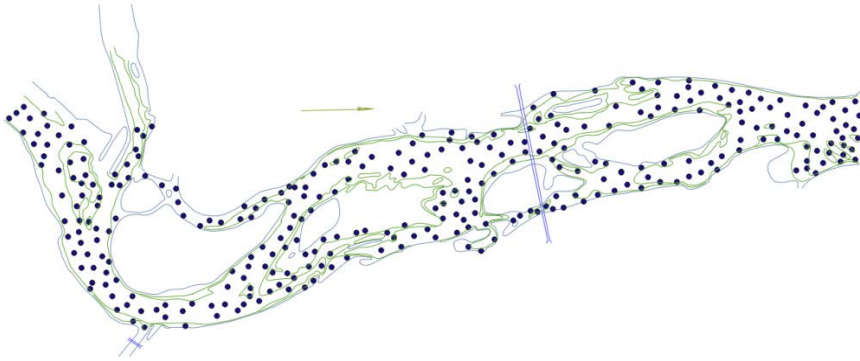


Fig. 1. The results of vectorization of the underwater relief of the Angara River.

2. Models and methods

To digitize the pilot charts we use the free version (7.99) of the tool Easy Trace. From the pilot charts we digitize the following objects: water depth contour lines, depth marks, some engineering structures and the coastline.

All the sheets of the pilot charts have arbitrary north direction, because they were rotated to place the sheet most effectively along the correspondent fragment of the river. Thus, after vectorizing we have to rotate and shift the sheets back to their positions on the topographic map. To find and perform the coordinate transformation we have developed a small utility, that takes several pairs of coordinates of some distinctive points on the both maps (it is required to specify at least two points), computes the transform parameters using the least squares method, and transforms the source map (pilot chart) to the coordinates of the target map.

After performing the coordinate transformation it turns out that the vectorized coastline strongly mismatch the more precise coastline of the topographic map and it is impossible to match these lines by just turning and shifting (Fig. 2).

To build a visually consistent digital terrain model using the water depth data of low quality we have developed an original approach, which uses digital map morphing (transformation) algorithms.



Fig. 2. Comparison of the coastlines on the pilot chart (blue) and on the topographic map.

The problem of matching map layers of different precision is quite common. It can also arise, for example, when trying to use some thematic map layers, which are based upon a topographic map of low scale, together with the map layers of higher scales. The resulting map will have evident artifacts such as contour lines, forest areas or roads in water. To improve the result we have developed a method of map morphing and software to perform the morphing. The main idea of the method for the underwater data is that first we should find a transform to match the coastlines. In fact we don't need the coastlines from the pilot chart themselves at all, because the topographic map version is much better and we can always use it. But we need the transform of the coordinate plane, that matches the coastlines: we will use the transform for the bathymetry layers to avoid intersection with the topographic map coastlines and get visually consistent results without noticeable artifacts.

To specify the contour matching parameters we have implemented a special task in our electronic map viewer program IrkGV (Fig. 3). Using the task operator sets correspondence between some distinctive points of the source (inaccurate) and target (more precise) maps. The correspondence may be set between individual points (green arrows, rarely used) as well as between contour parts (red arrows). The red arrows, which are adjacent on both contours, specify the match of the contour parts between them. And sometimes it is also required to suppress matching between some contour parts (for example, when one of them has some surplus details, which would make the resulting transform too complex) – to do it we use black arrows.

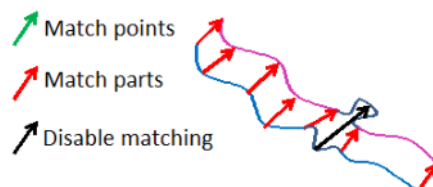
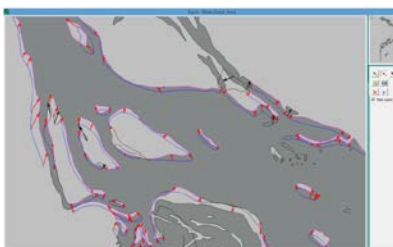


Fig. 3. The map morphing parameters task window. The arrows specify correspondences between individual points of the maps and between the contour parts.

The mapping of the points of the matched contour parts is performed using the linear transformation of the parametric coordinates of the curves. If the resulting transform will fail to match some distinctive points of the contours, it will be required to explicitly set correspondence between the points by red arrow and repeat the transformation. After setting all the matches between the maps we generate the displacement file which, besides from the explicitly set displacements (by the arrows) contains the displacements computed for the intermediate points of the matched contour parts.

To transform the source data we have developed a special tool using constrained Delaunay triangulation algorithms [10]. It takes the displacement file and builds a constrained Delaunay triangulation, which contains the displacement vectors in each of its vertices. The segments of the matched contour line parts of the source map are the constraints (hard edges) of the triangulation. For any point of the coordinate plane in the area of interest we can find the triangle, to which it belongs, and compute the displacement vector for the point using linear interpolation of the displacement vectors of the triangle vertices. So, the triangulation specifies transform of the coordinate plane, that we use for all the other low quality layers.

Finally we build the triangulation, which represents the combined relief. The map layers used for triangulation construction may play distinct roles: ground relief, water level marks, contours of coastlines, underwater relief. The underwater relief depth is measured from the water level, so we first use information about the water level marks to build an auxiliary triangulation, which is then used to determine the water level in each underwater data point.

While performing morphing for combining the underwater and ground reliefs we obtain a continuous transformation of the coordinate plane which can match the inaccurate contours of the coastlines with the more accurate ones. The transformation is then applied to the other layers of the underwater relief map (isobaths and depth marks). The map layers obtained as a result of the morphing are consistent with the information about the ground relief.

4. Results and discussion

We have applied the approach considered for the fragment of the Angara river on the 135 km stretch from the IHPS to the city of Svirsk. As a result we have obtained the digital 3D model of combined relief (Fig. 4). A digital terrain model of this kind was obtained for the first time and has no analogues.



Fig. 4. Final digital model of the Angara River (surface relief combined with underwater) from IHPS to the Bratsk reservoir (Svirsk).

The same approach was used for selected regions of the Bratsk reservoir (Fig. 5,6). The Bratsk reservoir is extremely large, so we have created the combined relief 3D models for more than 50 areas of interest, but not for the whole reservoir.



Fig. 5. A fragment of the resulting map for the Bratsk reservoir near the Kamenka settlement. The bathymetry contour lines were obtained from pilot charts.

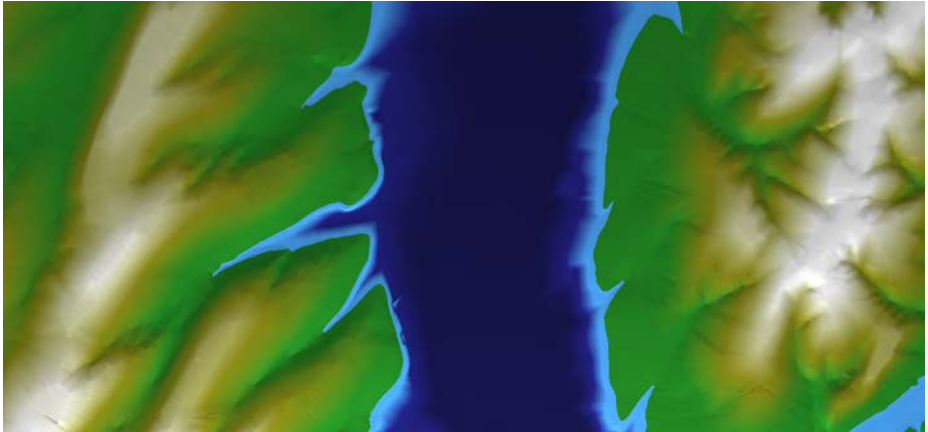


Fig. 6. A fragment of the combined relief model for the Bratsk reservoir.

We have also an experience of creating combined relief models without morphing, when all the data used have sufficient spatial precision. Thus, during implementation of a project for assessment of anthropogenic impact the digital terrain model of the area of Listvyanka village was created (Fig. 7) based on a high-resolution satellite image (WorldDem, 10 meters per pixel).

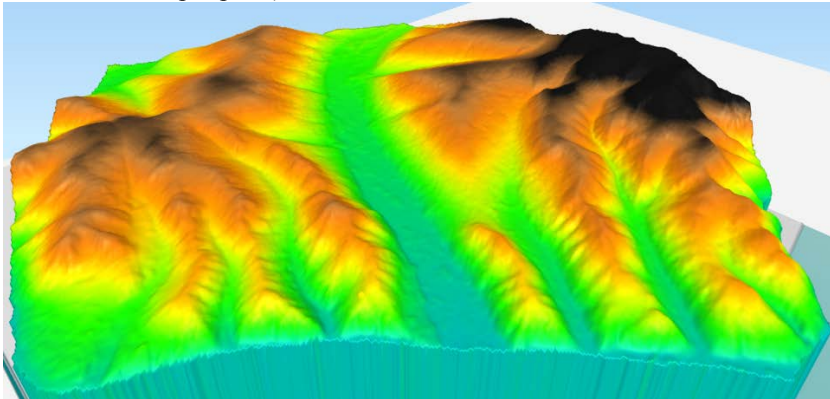


Fig. 7. Digital terrain model of the ground relief in the area of Listvyanka.

The underwater relief was obtained from the echo sounder measurements of the bottom relief near the edge zone of Listvennichny Bay. The resulting combined relief is shown on Fig. 8.

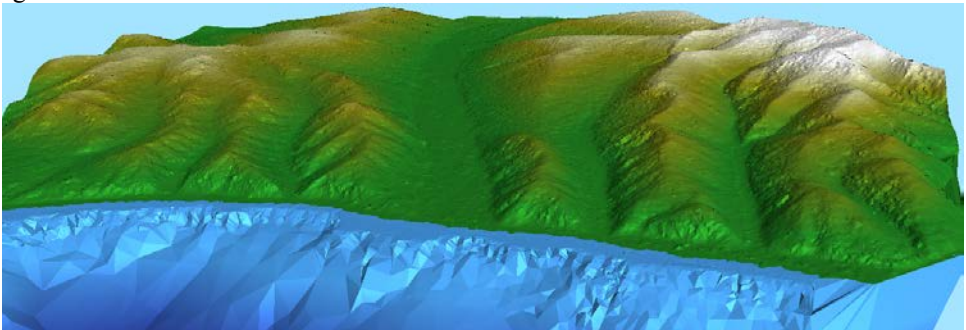


Fig. 8. The combination of the surface part with the underwater part (the ground relief is based upon a WorldDem satellite image, and the bathymetry was obtained by echo sounder measurements).

Conclusion

The combined 3D models of ground and underwater relief make it is possible to solve various hydrological tasks for reservoirs, lakes and rivers. The technologies and methods described in the article have been tested on a number of projects and have shown their effectiveness.

The combined reliefs were used to assess changes in the coastline under various scenarios of water availability in the water basins of Angara and Lake Baikal. The created 3D models of relief were used as a part of hybrid geographic information system that allows you to simulate various scenarios of changes in the water level and to determine the zones of the coastline change.

This work was performed with partial financial support of the Russian Foundation for Basic Research (Grant No. 17-47-380005).

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