Abstract

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Title of the PhD thesis: Method for bathymetric monitoring of the coastal zone based on the fusion of multimodal geospatial data obtained using on-board sensors of unmanned measurement platforms

This PhD thesis focuses on developing an innovative method for creating a numerical model of the coastal zone based on geospatial data recorded using various sensors. The developed method places particular emphasis on obtaining high-quality depth data up to 1 m, which is a challenge due to the excessive draft of manned hydrographic vessels. The aim of the doctoral dissertation was to develop a method for bathymetric monitoring of the coastal zone based on the fusion of multimodal geospatial data obtained with the use of on-board sensors of unmanned measurement platforms. The thesis of the dissertation is based on the assumption that the proposed method will enable obtaining the data quality required for the International Hydrographic Organization (IHO) Special Order. These requirements are particularly important in the coastal zone, where precise measurements of the seabed are crucial for the safety of navigation.

To implement the main aim of the PhD thesis, an original method for bathymetric monitoring of the coastal zone was developed based on the fusion of multimodal geospatial data obtained using on-board sensors of unmanned measurement platforms, such as: Single Beam Echo Sounder (SBES) and MultiBeam EchoSounder (MBES), photogrammetric camera, as well as Light Detection and Ranging (LiDAR) from airborne and mobile laser scanning. As part of this method, bathymetric and photogrammetric data were processed with the use of three modules: processing depth data, processing shallow water data and determining the coastline. Once the geospatial data is processed, it is then integrated using an original weighted average data fusion method, in which weights for individual data sources are determined based on the measurement accuracy. It is worth emphasising that the author's method uses a shoreline extraction method with the use of LiDAR data and the Support Vector Regression (SVR) method, which allows obtaining shallow water depths of up to 1 m based on the Structure-from-Motion (SfM) point cloud from Unmanned Aerial Vehicle (UAV) data.

For the purposes of this PhD thesis, bathymetric and photogrammetric measurements were carried out using unmanned flying and floating measurement platforms in two representative waterbodies: sea and inland. The developed method was used on data recorded during five measurement campaigns, one of which was a comprehensive campaign during which all data were obtained on the same day, which made it possible to eliminate the influence of variable hydrometeorological conditions on the measurement results. For each campaign, a separate weighted average data fusion model was created, which took into account the characteristics of the studied waterbody. The created models were then subjected to detailed quantitative analysis. This analysis allowed for verification of the effectiveness of the developed fusion method.

Based on the research conducted, the following conclusions were drawn:

- The developed coastal zone monitoring method based on multimodal data fusion enables the reduction of excessive geospatial data;

- This method has been verified in both marine and inland areas, which was confirmed in five measurement campaigns;
- The method for bathymetric monitoring of the coastal zone is a parametric method. Its effectiveness depends on the selection of parameters when processing individual data and creating a fusion model;
- The increase in the power exponent in the bathymetric monitoring method of the coastal zone does not affect the accuracy of the developed weighted average data fusion model;
- Depth data obtained using the SVR method allowed for very large data coverage in hard-to-reach places. However, they have the worst depth measurement accuracy of all the sensors used;
- Based on the developed weighted average data fusion models, it was found that all measurement points with depth determination errors exceeding 0.25 m were generated with the use of the SVR method;
- LiDAR data from Airborne Laser Scanning (ALS) and Mobile Laser Scanning (MLS) processed using a modified shoreline extraction method that takes into account the presence of terrain obstacles near the boundary between land and water should be supplemented with additional data. Therefore, the method for determining the coastline based on an orthophotomap is considered the main source of data about its course;
- Research has shown that the proposed shoreline extraction method allows for much more accurate determination of its natural course using MLS than ALS;
- The weighted average depth method can not be used on coastline points because they always have the same depth (0 m). For this reason, it was decided to use the weighted average method of plane rectangular coordinates for these points;
- Based on data recorded during a comprehensive measurement campaign, a weighted average data fusion model was developed with a depth accuracy of 0.111 m (p=0.95). The tests have proven that the proposed method can definitely meet the minimum accuracy requirements for the IHO Special Order;
- Decentralized fusion is used to create the model, because in the case of this type of data, constant supervision of the integration process is necessary.

The quantitative analysis performed did not provide grounds to reject the thesis that the proposed bathymetric monitoring method will enable obtaining the data quality required for the IHO Special Order.

Keywords: bathymetric monitoring, coastal zone, data fusion, geospatial data, Unmanned Aerial Vehicle (UAV), Unmanned Surface Vessel (USV)