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Abstract. One of crucial problems in the process of precise Port Electronic Navigational Chart (Port ENC) production is the seabed objects charting. General knowledge about the underwater objects is very important for the improvement in navigational safety, especially important in harbour areas. The article presents the concept of hierarchical hydrographic data fusion from different hydrographical sources for seabed object`s detection. Simultaneous processing of 3D seabed model obtained by measuring the water depths, sonar mosaicked images (illustrating the seabed characteristic) and the magnetic anomalies map could be remarkably helpful for discrimination of ferrous features, establishing their highly precise positions and to determine their placing characteristics. An attempt to integrate all the above is expected to provide a significant enhancement of the interpretation of the whole context of the seabed situation. The image obtained from hydrographic data will be much more helpful than considering all acquired information separately as individual data sets. This approach is believed to be of great importance for Port ENC production process.

Keywords: hydrography, data fusion, electronic navigational chart.

1 Introduction

The purpose of this paper is to present the possibilities of fusion data obtained from various hydrographic sensors and to use them for the production of ENC. The authors objective was to present the concept of hierarchical hydrographic data fusion, especially useful for a delivery of fused data for precise Port ENC production. To achieve this goal it is very important to use as accurate data as possible. Some aspects of bathymetric data processing for the ENC production and data reduction were presented in [1,2].

Modern approach to a precise chart production not only needs to be more and more accurate but also more and more complex as well. It should also include hydrographic information about objects hidden under the see bottom. The well-known approach to detect objects lying on the seabed or buried underneath it is to identify magnetic anomalies. Magnetometers are commonly used in marine environment to collect geodata about bottom objects like sunken vessels, unexploded ferrous ordnance and mines,

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cables, pipelines and much more, also about underwater archaeological sites. Aspects of magnetometer applications are described in [3,4].

The magnetometer most widely used for marine survey is a proton passive magnetometer. A complex version of this magnetometer is a gradiometer, constructed by using at least two magnetometer`s heads. Using more than two magnetometers allows to obtain much more precise data, taken as the difference between single magnetometer sensors. Another advantage of the gradiometer is that it can detect the location of the target by a comparison of both sensors positions.

Several geometrical configurations of gradiometers (planar or vertical) are possible to use. Some aspects of gathering data by a gradiometer were presented in [5]. A configuration with at least three sensors has a possibility to additionally assess the burial depth of an object. The idea which seems exceedingly interesting is to implement a gradiometer sensor to an Autonomous Underwater Vehicle (AUV) for objects detection close to the seafloor [6].

A very modern and perspective approach to spatial data processing is to use artificial intelligence (AI) methods, especially artificial neural networks (ANN) [7]. Some of them were used to analyse magnetometer [8], gradiometr and also radar spatial data for the marine environment [9, 10, 11, 12] with the idea of ANN implementation [13, 14, 15]. The General Regression Neural Networks (GRNN) application was an especially interesting solution [16, 17, 18, 19].

Various accurate methods of Digital Terrain Model (DTM) construction [20, 21, 22, 23, 24] may be applied in building 3D bathymetric bottom models [25, 26] which could be used during the data fusion process [27, 28, 29].

Often, magnetic data is acquired to crosscheck it with side scan sonar data [30, 31]. Data from one source is complement to other sources in the process of data mining [32, 33, 34].

The proposed data fusion process is divided into two parts: a local data fusion and a global data fusion. The first one assumes a multi-sensor fusion takes place in hydrographic systems: main hydrographic data with reference to navigational data, such as the position, course and data from motion unit sensors. The second includes fusion of final processed hydrographic product, such as bathymetry, sonar mosaicked image and magnetic anomalies distribution map.

The article consists of three sections. Section 2 contains description of a background of a hydrographic data fusion and a commonly used fusion. Section 3 illustrates the concept of multi-sensor hydrographic data fusion in order to obtain more informed interpretation about the subsurface view. The paper ends with conclusions and overview of future work.

The data fusion of different sources like bathymetric data, sonar image and magnetometer survey is a perfect solution for a system where very precise information is required.

2 Background of Research

The data fusion is a widely ranging subject that is extensively applied to many various research areas such as image processing, and intelligence systems [35, 36, 37]. Generally, the data fusion can be divided into three main categories: a multi-sensor fusion, an image fusion and an information fusion [38]. In the hydrographic data fusion we deal with data gained from different hydrographic sensors. In such case the concept of multi-sensor fusion is presented. A pixel and a feature fusion is the next step. The last one is the information fusion which affects the decision-making process. The data fusion from different sources like bathymetry, sonar mosaicked imagery and marine magnetometer survey is an excellent idea for systems where very high precision information is required.

2.1 Hydrographic Data Characteristic

The main issue in hydrographic data fusion lies mainly in characteristics diversity of data gathered by different hydrographic sensors. Proposing the concept of hydrographic data fusion, the authors make use of the data obtained from a high resolution side scan sonar, a bathymetric swath system and a marine magnetometer.

Side scan sonar (further SSS) waterfall views, merged into one mosaicked imagery, illustrate the seafloor bottom characteristic and provide detection of potential surface obstructions. A side scan sonar system consists of a recording device, an underwater sensor – towfish. Transmitted acoustic waves interact with the seafloor and most of their energy is reflected. The returning echoes are transmitted up the tow cable to the recorder, which processes these signals, calculates their proper position converting into the right value pixel by pixel, and then visualizes these echoes on the monitor screen [39]. The inaccuracy in positioning of the towfish is a major issue during the side scan data collecting. The position is calculated from the layback value and offsets the towpoint from the positioning system antenna. For the purpose of object detection and its precise identification, fusion with bathymetric data is commonly used. In the concept of presented hydrographic data fusion, mosaicked imagery is used for further processing flow.

Data collected by bathymetric sensors - multibeam systems (further MBES), provides very precise full seafloor search depth values. The final processed product contains depth areas, points of depths and contours. To provide precise measurements several issues must be taken into consideration. Firstly, the echosounder must be calibrated. During the measurements, a surveyor continuously needs to control the sound speed values. Also, the beam patterns, ping length`s and the whole water area characteristic need to be accounted. The processing procedure is time-consuming. Major benefit of this data is a fact that in such bathymetric system a full seafloor search is obtained with high resolution and very precise positioning at the same time.

Marine magnetometer data illustrates the magnetic anomalies distribution map, which provides detection of a potential submerged or buried ferrous-feature. For successful magnetic anomalies measurements, the surveyor should determine the smallest volume of the ferrous-feature expected to detect. This needs to be also related to the magnetic field intensity that can be reliably detected. Generally, it is 5nT value [39]. Also, several distortions of the signal due to vessel`s hull and towing cable or interference with other high-frequency navigational equipment, need to be taken into account. The magnetometer transducer is towed overboard on the cable, which determines inaccuracy in positioning of the towfish – the same as in SSS measurements. The results are graphs with the magnetic field changes distribution. To improve interpretation, a common practice is to use the magnetic anomalies chart as a texture of magnetic anomalies contour map to bathymetric grid or as a magnetic anomalies 3D plot to sonar mosaicked imagery. For the concept of data fusion, the authors take into further consideration the magnetic anomalies 3D plot.

All of the mentioned hydrographic measurements methods are used to collect the data representing information about the seabed situation required in production of precise electronic navigational chart: depths values, surface obstructions and buried features.

All of these data vary in the processed hydrographic final product. It means that the sonar mosaic imagery, the digital depth model, and the magnetic anomalies distribution 3D plot cannot be easily combined.

2.2 Existent Hydrographic Data Fusion

For the purpose of this section, the authors surveyed the literature on commonly used hydrographic data fusion. Firstly, let us discuss fusion of high resolution side-scan sonar mosaic imagery and bathymetric data (Fig. 1). This kind of integration is commonly used as an aid to more informed interpretation of subsurface view context. A big benefit is completion of another one, e.g. an improved slant-range correction of a side-scan image or removal of topographic effects from sonar back-scatter intensities [40]. Also, it provides full identification of potential surface obstructions: detection, precise positioning and full measurements: depth clearance above the highest point, high above the surface and its dimensions. A high resolution side-scan sonar mosaic and magnetic anomalies distribution data (Fig. 2) is the next type of hydrographic data fusion. This helps to comprehend the context of the seabed situation, especially if there is a need to detect a seabed cable, pipeline or another potential submerged ferrous-object. This data integration is realized in computer software as an image matching result. In general it illustrates seafloor and subsurface geological conditions – by sonar mosaicked imagery – as a background of visualization and magnetic anomalies contour map or 3D plot of ferrous-magnetic objects. The second one is used as a texture layer. In fact, it visualizes the subsurface situation which consists of two different separated data sets. The last type of hydrographic data fusion is an integration of bathymetry and magnetic anomalies distribution map (fig. 3). The knowledge of depth values in the research area is used as a source of information about the laying characteristic and depth situation above and in the vicinity of a ferrous-magnetic object. This fusion type is realized in standard software dedicated to visualization of the data.

The concept of the authors` research work is to integrate all mentioned above hydrographic data into one data set. This approach is assumed to ensure significant enhancement of the interpretation of the whole context of the seabed situation. It will also provide a number of benefits to the user of Port ENC. The major one is a more informed interpretation about the depth clearance and the surface or subsurface potential obstruction. Also, it supports decision making, while safe navigation in harbour areas is guaranteed.

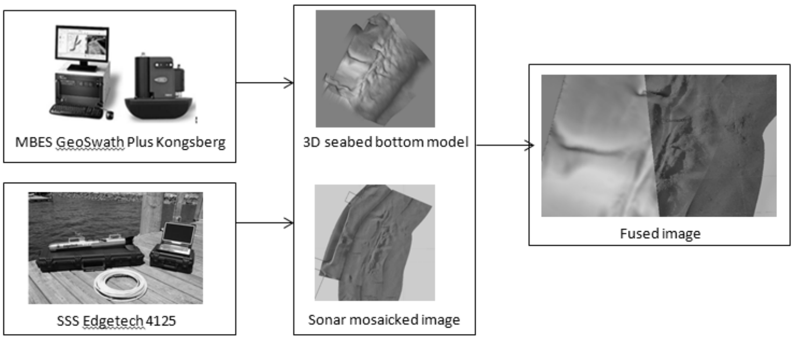

Fig. 1. Image integration: 3D seabed model with side scan sonar image [own studies]

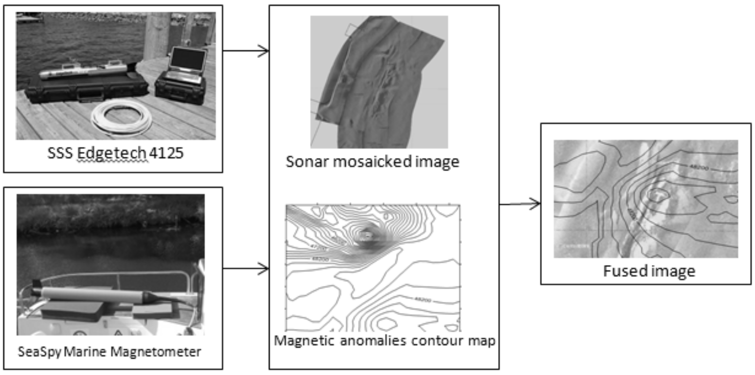

Fig. 2. Image integration: side scan sonar image and magnetic anomalies contour map [own studies]

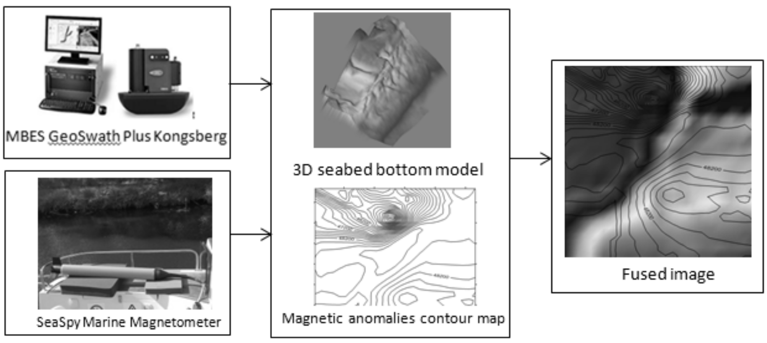

Fig. 3. Image integration: 3D seabed model and magnetic anomalies contour map [own studies]

3 Concept of Hierarchical Hydrographic Data Fusion

The data fusion means any process of data aggregation from multiple sources into a single composite with a higher information quality [38]. Most common branches of data fusion are [35, 38]:

- multi-sensor fusion – fuses the data from various sensors to integrate them into one enhanced in quality information;
- image fusion – uses images of the same area gained by the same sensor, at different times and with various factors, etc.; it corresponds to pixel and feature fusion;
- information fusion – falls on decision making.

Figure 4 illustrates author`s concept of hierarchical hydrographic data fusion. The following sub-sections describe all fusion categories mentioned above with hydrographic aspects.

3.1 Multi-sensor Fusion

The main goal of a multi-sensor fusion is to integrate hydrographic data collected by different sensors and to combine them into one representation. This approach uses statistical methods, such as Kalman filters and probabilistic techniques – Bayesian networks [38]. Such fusion is commonly used in hydrographic measurements systems, where the navigational – positioning system and hydrographic measurements meet. The authors concept considers the data from SSS, MBES and marine magnetometer.

3.2 Image Fusion

The main objective of image fusion is to fuse different images into an improved one. In general, this kind of fusion uses the multiplication of images. Image fusion algorithms consist of two categories: pixel based and feature extraction. The first one merges data pixel-by-pixel [38]. The second one segments the images and then fuses them into one. From the hydrographic point of view, the segmentation presumes feature detection, edge detection and area description. The segmentation provides, also, potential obstructions extraction with completion of the whole subsurface situation context. The algorithms proposed in literature are multi-resolution analysis, hierarchical image decomposition, pyramid techniques, Principal Component Analysis (PCA), wavelet transform and fuzzy rules [41, 42].

3.3 Information Fusion

The information fusion is a multi-level process of combining various data collected from different sources to create the fused information. Moreover, in this stage it is assumed to combine processed outputs of each source to create a new more informing interpretation [43]. The information fusion has two major aims: to support decision making and to improve understanding of the whole context about the area. From the hydrographic point of view, it is crucial, especially during conducting navigation in caution areas such as harbours. The knowledge about: depth and possibility to establish safety areas, dimensions of subsurface potential obstructions and buried pipelines or cables localization seems to be crucial for safe harbour manoeuvres.

The following figure 4 illustrates the concept of hierarchical hydrographic data fusion.

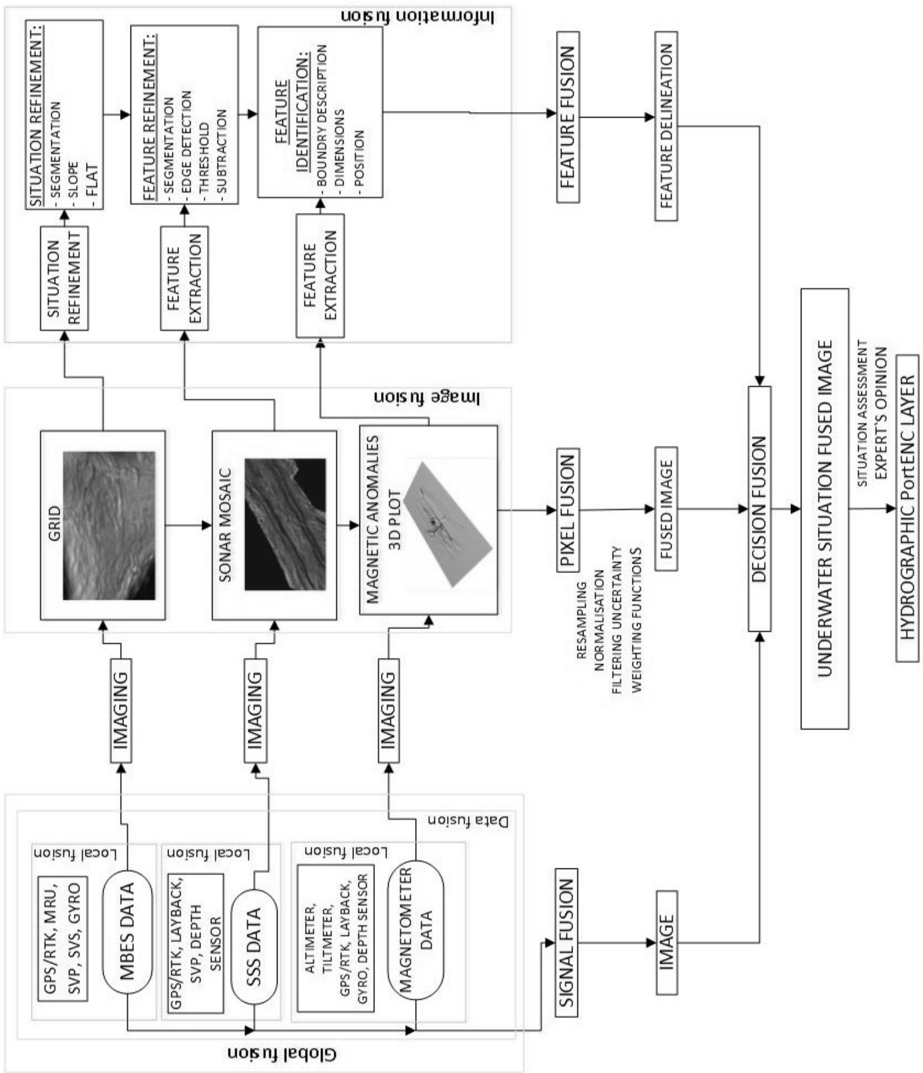

Fig. 4. Concept of hierarchical hydrographic data fusion [own studies]

4 Conclusions

The main intention of this paper was to present the concept of hierarchical hydrographic data fusion. It was achieved by surveying the literature on data fusion methods and handled by presenting schematic diagrams relevant to the nature of hydrographic data. A common analysis of spatial data from different hydrographical tools for data mining is presented. Marine magnetic, bathymetric and sonar data analysis fused together give a hydrographer a chance to obtain much more information than in another approach. An automated processing of images could be very effective during the data mining process with the whole three hydrographic data sources.

The hydrographic data fusion would be very useful during providing the navigation procedure. The fused, from hydrographic sensors, data should be presented on electronic navigational charts, especially for purposes of conducting maneuvering, using precise Port ENC.

The future work presumes acquiring the hydrographic data and using the concept of hierarchical multi-sensor fusion in the following steps: SSS with MBES, SSS with magnetometer and MBES with magnetometer.

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