Sensor Data Fusion Techniques for Environment Modelling

Conference Paper · June 2015

DOI: 10.1109/IRS.2015.7226263

2 authors:

Andrzej Stateczny
Gdansk University of Technology

Izabela Bodus
Maritime University of Szczecin

Sensor Data Fusion Techniques for Environment Modelling

Andrzej Stateczny*, Izabela Bodus-Olkowska**

* Marine Technology Ltd.,
Klonowica 37/5, 71-248 Szczecin, Poland,
e-mail:a.stateczny@marinetechnology.pl

** Institute of Geoinformatics, Maritime University Szczecin,
Waly Chrobrego 1-2, 70-500 Szczecin, Poland,
e-mail: i.olkowska@am.szczecin.pl

Abstract: *In the article data fusion techniques for underwater environment modelling are presented. For better understanding the problem, authors divided data fusion techniques into three parts, in reference to the output information that needed to be obtained.*

1. Introduction

The most important issue in the seabed bottom environment modelling is source of data. There are several sensors by which relevant information can be collected. Data, acquired by various hydrographic sensors, represents different in meaning references about seabed bottom [1]. Hydrographic echosounder collected points of depth in the area of interests. This sensor is using soundwaves to calculate the distance from echosounder`s transducer to the sea bottom. Output data, that hydrographer obtained through this sensor, are high density information consists of XYZ points [2] with very precise position from Global Positioning System Real Time Kinematics (GPS RTK) and very accurate depth value. Final products are Digital Terrain Modell (DTM) [3-8] or one of the Electronic Navigational Chart's (ENC) layers – bathymetry. The first mentioned processed output is taking into author`s further consideration.

Next hydrographic sensor refers to seabed bottom modelling is sonar. Sonar is also working on soundwaves, but information that is collected, represents returning signal strength. On the basis of the strength of the signal reverberation hydrographer is able to detect the objects laying on the seabed bottom and may mark them as a potential obstruction. Also, is it possible to measure the geometry of detected objects: length, width and its height. From environment modelling point of view, sonar image is useful not only for the detection and specification of the seabed lying object, which is of course the main purpose of this sensor. Final product, as an output of processed sonar data – sonar mosaicked imagery, is also used as a complex underwater geomorphological view of the area of interests. The modern sonars are working on high frequencies, so images that are obtained presents underwater views in high quality and with high resolution. Following hydrographic sensor which acquired data for seabed environment modelling is marine magnetometer. This one collected information about magnetic anomalies in the water area. By this kind of data, hydrographer can discriminate buried under the seabed bottom ferrous features such as pipelines or marine mines and so on. For further consideration of environment modelling, data representing magnetic anomalies need to be processed into the final product such is magnetic anomalies distribution 3D map or contour map. Sonar mosaicked imagery and magnetic anomalies map are usually supported by high density bathymetry, due to weak position determination techniques. Both of the sensors are usually towed overboard on the cable. This kind of acquiring data method is commonly used in hydrographic surveying. The issue is in inaccuracy in determination of the towfish position, which is obtained due to layback and offsets method. Inaccuracy in towfish positon refers to inaccuracy in the position of detected underwater seabed lying or buried objects. That is why high density bathymetry with very precise positioning measurements provides enhancement.

2. Data fusion techniques for environmental modelling

The main purpose of this paper is to present data fusion techniques for underwater environment modelling. For better understanding the problem, authors divided data fusion techniques into three parts, in reference to the output information that needed to be obtained. The first one is multi-sensor fusion, which fuses the data from various sensors. This integration is commonly used in complex hydrographic systems, where signal from positioning system, hydrographic transducers and other navigational and supported system met. All of the data are fused into one enhanced and completed information set. This fusion techniques is realized through statistic method such Kalman filters and probabilistic techniques such as Bayesian networks. Aspects of sensor fusion were presented in [9-11]. Apart from numerical method very often for navigational data processing are use Artificial Neural Networks (ANN) [12-18].
Next data fusion techniques is image fusion, which presumes integration of images of the same area. In the authors considerations this fusion will assume final products that are obtained from processed data sets from mentioned before hydrographic sensors – DTM from echosounder, sonar mosaicked imagery from sonar images and magnetic anomalies distribution 3D chart from marine magnetometer data. The image fusion consists of two categories: pixel images and feature extraction. Important is that information in pixel differs in meaning. In the DTM pixel represents information about depth; in mosaicked imagery, pixel illustrates signal strength, by which it is possible to discriminate the seabed lying objects; and on 3D magnetic anomalies map pixel points magnetic anomalies value, which corresponds with information about buried ferrous feature. It is believed that images obtained by different sensors, fused together through this techniques will provide significant enhancement in the interpretation of the whole context of the underwater view. By this fusion techniques, author`s shows the one of the method of underwater environment modelling. Image fusion supports also feature fusion. Considering three different sources of data, it is possible to extract exactly and completely, with full specification, the underwater and buried potential obstructions. In this paper feature fusion is also widely present. Knowledge about seabed bottom environment with all information consisted of geomorphological view, 3D terrain model and also complex specification of the underwater objects may support information fusion, which falls on decision making and improvement of understanding the whole context about underwater area. This fusion method combines processed outputs of each sensor to create new, more informed product. Taking into consideration 3D terrain model obtained from echosounder data, it is possible to establish the situation refinement: slopes or flat areas. Discussion about information fusion cannot ignore sonar mosaicked imagery and magnetic anomalies distribution 3D chart, by which it is possible to feature extraction by its refinement: edge detection, boundary description and subtraction. All of this allows to feature delineation with its specification, characteristic and dimensions. 3D charts are often use also for sensor planning tasks [19-24].

3. Hydrographic data fusion for environment modelling

Mentioned above data fusion techniques gives the opportunity to seabed bottom environment modelling. All of them: multi-sensor fusion, image fusion, feature fusion and information fusion composed of the underwater situation falls on decision fusion, situation assessment and experts' opinions. The whole concept of hydrographic data fusion is presented in [1]. For the purpose of this essay, authors focused on image and information fusion techniques for environment modelling. Image fusion presumes integration of different images of the same area. In the authors considerations this fusion will assume final products that are obtained from processed data sets, mentioned before – DTM, sonar mosaicked imagery and magnetic anomalies distribution 3D chart. Important is that information in particular pixel in every image differs in meaning. In the DTM pixel represents information about depth; in mosaicked imagery – pixel illustrates signal strength, by which it is possible to discriminate the seabed lying objects; and on 3D magnetic anomalies map pixel points magnetic anomalies value, which corresponds with information about buried ferrous feature. Further, authors demonstrate hydrographic data fusion concept divided into 2 steps: image fusion with feature fusion and information fusion

3.1. Image fusion

Image fusion algorithms should satisfy the requirements: preserve all relevant and important information in the fused image; suppress the noises and negligible areas of the image and minimise any inconsistencies in the fused image [25]. Image fusion is commonly and widely used in many fields of research areas, such remote sensing, medical imaging, avionics [26]. Image fusion can be considered as a pixel fusion and feature fusion. Pixel fusion presumes merging images pixel by pixel and fused image is combination of considered individual pixel values or small regions of pixels. Pixel-based fusion algorithms are widely described in [25]. Spatial image fusion is a method which combines pixel values of the input images in linear or non-linear way [25,27]. When images in grey scale need to be fused, colour fusion method can be used. In fused image, objects from input images will appear in other colours. For remote sensing imagery, such hydrographic imagery is, colour fusion uses Principle Component Analysis (PCA) techniques. Multi-resolution (MR) image fusion presumes transforming all input images from normal image space into other domain, applying an MR transform – such wavelets or pyramids. Input images are fused with usage of some defined fusion rules, and output image – fused image – is reconstructed [25,27]. Pyramid transforms, such Laplacian, contrast, Gaussian are based on the type of filters that they used. These method can show some problems with input images that are noisy, as a noise tends to have higher contrast [25,27]. Figure 1 illustrates a concept of pixel-based image fusion scheme using pyramids.

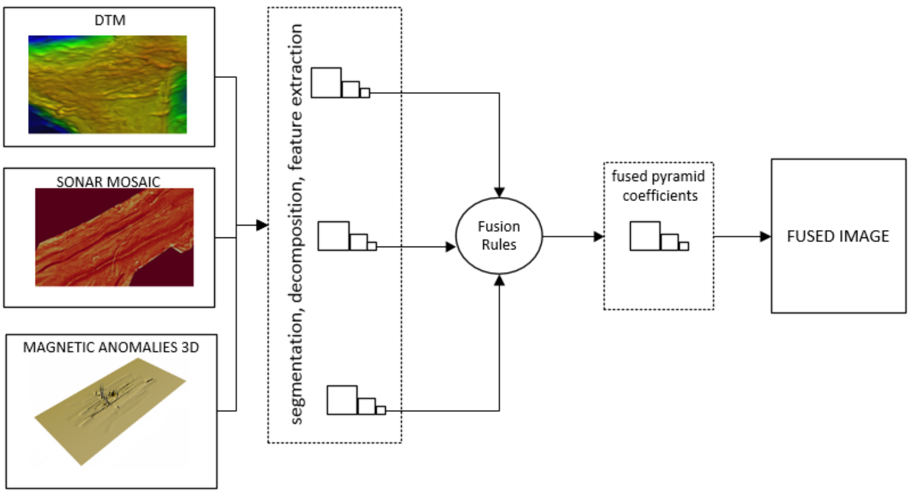

Figure 1.The pixel-based image fusion scheme using pyramids (source: own studies based on [25])

3.2. Feature fusion

Image fusion supports also feature fusion. Considering three different sources of data, it is possible to extract exactly and completely – with full specification, the underwater seabed lying and buried underneath the seabed, potential obstructions. For feature fusion opportunity, decomposition of every input image is needed. One, of this kind of fusion method, is wavelet based method. Its main concept is to discriminate and extract the details from one image and put it into another [28]. Wavelet algorithm presumes several levels of image decomposition such as joint, separate, segmentation, and then – using proper fusion rules composite fused image, relays on wavelet coefficients [25,27,28]. Figure 2 demonstrates the concept of feature fusion algorithm.

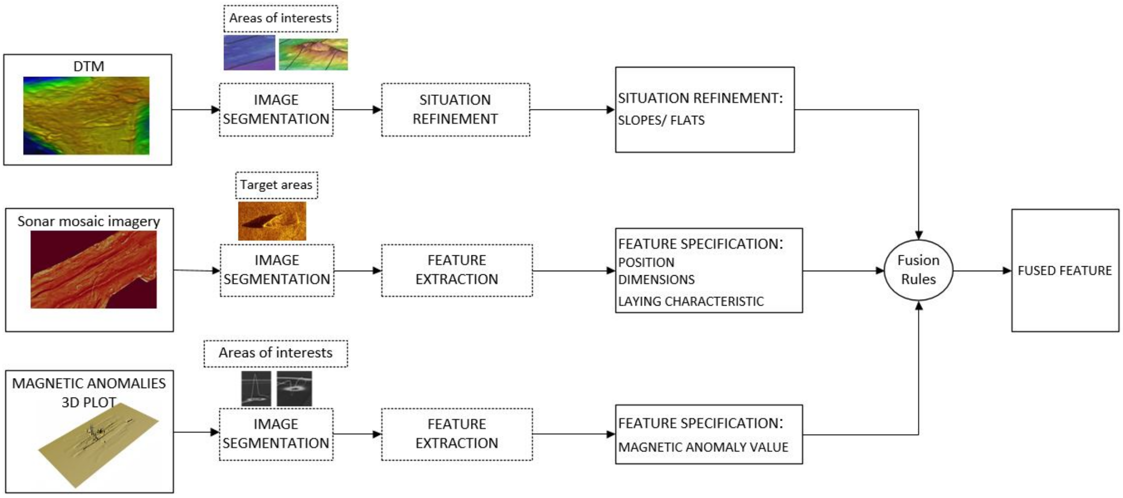

Figure 2. Feature fusion scheme (source: own studies)

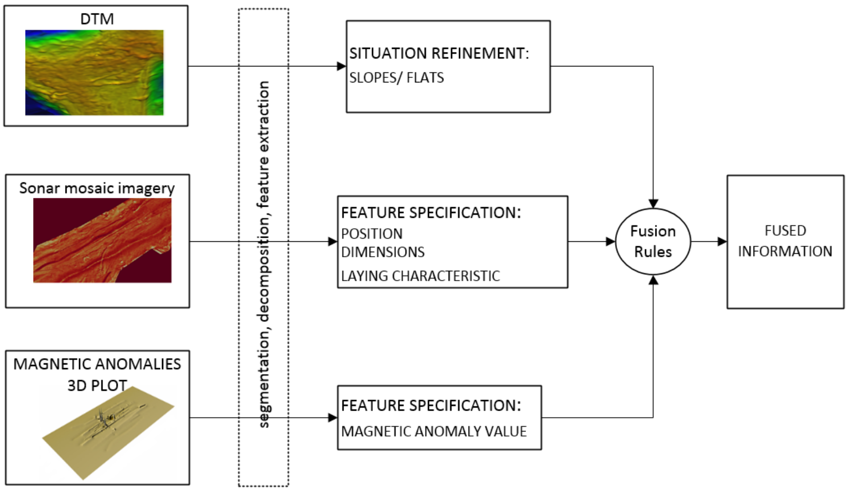

Figure 3. Information fusion scheme (source: own studies)

3.3. Information fusion

The main goal of information fusion is to combine various information to obtain a single composite of potential comparable alternative solutions that can be classified and ranked [29]. The concept of information fusion presumes, that the data must be comparable and numerical; inexactness in data must be taken into consideration; an appropriate aggregation function to integrate values into a single set must be selected [29]. Thus, information fusion is a multi-level process of combining different data to produce fused information. In information fusion which is mainly based on decision making, the pre-processed outputs of each single source are fused to create a new interpretation. Usually, for information fusion purposes ANN models is widely used. Neural networks require an input learning set to identify set of parameters of a network referred to as weight [28]. This technique is able to predict, analyse and interfere information from a given data without need of using mathematical solutions. This makes the neural networks very attractive as a technique of hydrographic image fusion as the nature of variability between images is subjected to change every time a new hydrographic sensor is used [28]. Figure 3 represents the scheme of information fusion proposed by authors.

4. Conclusions

The paper discusses the hydrographic data fusion techniques for underwater environment modelling. Hydrographic data fusion methods are single out into three steps: image fusion, feature fusion and information fusion. Knowledge about seabed bottom environment with all information, which is consisted of: geomorphological view, 3D terrain model and also complex specification of the underwater objects, may support information fusion, which falls on decision making and improvement of understanding the whole context about underwater area. Presented fusion method combines processed outputs – final products, of each hydrographic sensor to create new, more informed one. Image fusion takes into consideration three kind of hydrographic images: 3D terrain model obtained from echosounder data, it is possible to establish the situation refinement: slopes or flat parts of the area. Sonar mosaicked imagery and magnetic anomalies distribution 3D chart, by which it is possible to feature extraction by its refinement: edge detection, boundary description and subtraction. All of this allows to feature delineation with its specification: characteristics and dimensions. Mentioned above data fusion techniques gives the opportunity to seabed bottom environment modelling. It is believed that images obtained by different sensors, fused together through this techniques will provide significant enhancement in the interpretation of the whole context of the underwater view and for underwater environment modelling. All of them: multi-sensor fusion, image fusion, feature fusion and information fusion composed of the underwater situation falls on summarize information, extract useful information, support decision-making, situation assessment and experts' opinions.

References:

[1] A. Stateczny A., I. Bodus-Olkowska, "Hierarchical Hydrographic Data Fusion for Precise Port Electronic Navigational Chart Production", *Proc. of Telematics in the Transport Environment,* Ustron, Poland, 2014, *Communications in Computer and Information Science* 471, pp. 359-368.

[2] A. Stateczny, M. Wlodarczyk-Sielicka, "Self-Organizing Artificial Neural Networks into Hydrographic Big Data Reduction Process", *Proc. of Joint Rough Set Symposium*, Granada-Madrid, Spain, 2014, *Lecture Notes in Artificial Intelligence*, pp. 335-342.

[3] J. Lubczonek, A. Stateczny, "Concept of neural model of the sea bottom surface", *Proc. of Neural Networks and Soft Computing*, Zakopane, Poland, 2003, *Advances in Soft Computing*, pp. 861-866.

[4] M. Wlodarczyk-Sielicka, A. Stateczny, "Selection of SOM parameters for the needs of clusterization of data obtained by interferometric methods", *Proc. of 16th International Radar Symposium*, Dresden, Germany, 2015.

[5] A. Stateczny, "The neural method of sea bottom shape modelling for the spatial maritime information system". *Proc. of Maritime Engineering and Ports II,* Barcelona, Spain, 2000, *Water Studies Series*, vol. 9, pp. 251-259.

[6] A. Stateczny, "Artificial neural networks for comparative navigation", *Proc. of Artificial Intelligence and Soft Computing*, Zakopane, Poland, 2004, *Lecture Notes in Artificial Intelligence*, vol. 3070, pp. 1187-1192.

[7] W. Maleika, "Moving average optimization in digital terrain model generation based on test multibeam echosounder data", *Geo-Marine Letters*, vol. 35, Issue 1, pp. 61-68, 2015.

[8] A. Stateczny, "Methods of comparative plotting of the ship's position", *Proc. of Maritime Engineering & Ports III*. Rhodes, Greece, 2002, *Water Studies Series*, vol. 12, pp. 61-68.

[9] W. Kazimierski, A. Stateczny, "Fusion of Data from AIS and Tracking Radar for the Needs of ECDIS", *Proc. of Signal Processing Symposium*, Jachranka, Poland, 2013.

[10] W. Kazimierski, A. Stateczny, "Radar and Automatic Identification System track fusion in an Electronic Chart Display and Information System", *Journal of Navigation* 2015 (in press).

[11] A. Stateczny, W. Kazimierski, “Sensor Data Fusion in Inland Navigation”, *Proc. of 14th International Radar Symposium*, Dresden, Germany, 2013, vols. 1 and 2, pp. 264-269.

[12] J. Balicki, Z., Kitowski, A. Stateczny, “Extended Hopfield Model of Neural Networks for Combinatorial Multiobjective Optimization Problems”, *Proc. of 12th IEEE World Congress on Computational Intelligence*, Anchorage, USA, 1998, pp. 1646-1651.

[13] W. Kazimierski, A. Stateczny, “Optimization of multiple model neural tracking filter for marine targets”, *International Radar Symposium*, Warsaw, Poland, 2012, pp. 543-548.

[14] W. Kazimierski, G. Zaniewicz, A. Stateczny, “Verification of multiple model neural tracking filter with ship's radar”, *International Radar Symposium*, Warsaw, Poland, 2012, pp. 549-553.

[15] A. Stateczny, W. Kazimierski, “A comparison of the target tracking in marine navigational radars by means of GRNN filter and numerical filter”, *Proc. of IEEE Radar Conference*, Rome, Italy, 2008, vols. 1-4, pp. 1994-1997.

[16] A. Stateczny, W. Kazimierski, “Determining Manoeuvre Detection Threshold of GRNN Filter in the Process of Tracking in Marine Navigational Radars”, *Proc. of International Radar Symposium*, Wroclaw, Poland, 2008, pp. 242-245.

[17] A. Stateczny, W. Kazimierski, “Selection of GRNN network parameters for the needs of state vector estimation of manoeuvring target in ARPA devices”, *Proc. of the Society of Photo-Optical Instrumentation Engineers (SPIE)*, Wilga, Poland, 2006, vol. 6159, pp. F1591-F1591.

[18] A. Stateczny, “Neural manoeuvre detection of the tracked target in ARPA systems”, *Proc. of Control Applications in Marine Systems,* Glasgow, Scotland, 2001, *IFAC Proceedings Series* 2002, pp. 209-214.

[19] J. Lubczonek, A. Stateczny, “Aspects of spatial planning of radar sensor network for inland waterways surveillance”, *6th European Radar Conference*, Rome, Italy, 2009, pp. 501-504.

[20] A. Stateczny, J. Lubczonek, “Radar Sensors Implementation in River Information Services in Poland”, *Proc. of 15th International Radar Symposium,* Gdansk, Poland, 2014, pp. 199-203.

[21] A. Stateczny, J. Lubczonek, Kantak T., “Radar Sensors Planning for the Needs of Extension of River Information Services in Poland”, *Proc. of 16th International Radar Symposium*, Dresden, Germany, 2015.

[22] A. Stateczny, J. Lubczonek, “FMCW Radar Implementation in River Information Services in Poland”, *Proc. of 16th International Radar Symposium*, Dresden, Germany, 2015.

[23] W. Kazimierski, A. Stateczny, “Analysis of beam sharpening effectiveness in broadband radar on inland waters", *Proc. of 16th International Radar Symposium*, Dresden, Germany, 2015.

[24] T. Hyla, N. Wawrzyniak, W. Kazimierski, “Model of Collaborative Data Exchange for Inland Mobile Navigation*”. Proc. of. 2014 Soft Computing in Computer and Information Scienc*e, Miedzyzdroje, Poland, 2014, *Advances in Intelligent Systems and Computing 342*.

[25] J.J. Lewis, R.J. O`Callahgan, S. G. Nikolov, D.R. Bull, N. Canagarajah, “Pixel- and region-based image fusion with complex wavelets”, *Information Fusion 8 (2007) 119-130.*

[26] V. Petrovic, V. Dimitrijevic, “Focused pooling for image fusion evaluation”, *Information Fusion 22 (2015) 119-126*

[27] H. B. Mitchell, “Image Fusion: Theories, Techniques and Applications”, *Springer-Verlag Berlin Heidelberg, 2010.*

[28] A. Pappachen James, B. V. Dasarthy, “Medical image fusion: A survey of the state of the art”, *Information Fusion 19 (2014) 4-19.*

[29] R. Ribeiro, A. Falcao, A. Mora, J. Fonseca, “A fuzzy information fusion algorithm based on multi-criteria decision making”, *Knowledge-Based Systems 58, pp. 23–32 (2014).*