Exploiting performance measures from advanced SAS systems for autonomous MCM operations

T. O. Sæbø, Norwegian Defence Research Establishment (FFI)
P.O. Box 2025, NO-2027 Kjeller, Norway, Torstein-Olsmo.Sabo@ffi.no

Abstract — Many nations are in the process of replacing traditional mine countermeasures (MCM) vessels with unmanned systems. This implies that a critical component in future MCM operations will be autonomous underwater vehicles (AUVs) with advanced sensors and a high level of autonomy. Existing AUV systems have limited autonomy, basically performing pre-planned operations. Except for simple collision avoidance manoeuvres, they cannot adapt their behaviour to the sensed environment. In this paper we present a concept where several performance measures are estimated in-situ using advanced synthetic aperture sonar (SAS) systems, and forwarded as input to a performance evaluation tool, which again feeds the real time autonomy system.

1 Introduction

Future MCM operations will likely be based on unmanned systems, where the primary platform is AUVs with high level of autonomy [1]. A critical component in the AUV autonomy system is the access to relevant and accurate information about the environment and the status of the operation. This information has to be continuously updated during the mission, which has been a challenge using processing demanding SAS systems. Now many SAS systems come with real time processing, allowing for automated production of SAS images, seabed maps, and additional information related to the environment.

The Norwegian Defence Research Establishment (FFI) has together with Kongsberg Maritime (KM) developed the HUGIN family of AUVs. One such vehicle is shown in Fig. 1. FFI and KM have also developed SAS processing software for KM's series of SAS systems. In the SAS processing, several performance measures are estimated, combined and used as inputs to FFI's MCM Insite performance evaluation tool [2]. MCM Insite uses a system- and threat-dependent look-up table to estimate a MCM performance map. This map constitutes important input for operator support, but it is also an essential component in the autonomy system. By using information from MCM Insite to adapt the AUV pattern, the search part of the MCM operation can be conducted with a verified performance. In this paper we present advanced use of SAS combined with novel MCM performance estimation for future MCM operations.

Fig. 1. A HUGIN AUV operated from a Norwegian MCMV.

2 Synthetic aperture sonar

In contradiction to traditional sidescan sonar, which has a range- and frequency-dependent along-track resolution, SAS systems can achieve a fixed resolution in both image dimensions [3]. The principle of SAS is a coherent combination of pulses, which is challenging due to strict constraints on the navigation accuracy.

The SAS technology has recently matured to a commercial level, and combined with interferometric processing, SAS systems now produce images and bathymetries with extreme resolutions. Fig. 2 shows example data produced by a HISAS 1032 system, where image reflectivity and bathymetry are displayed as brightness and colour, respectively. The image resolution is 4x4cm, while the bathymetric resolution is 18x18cm.

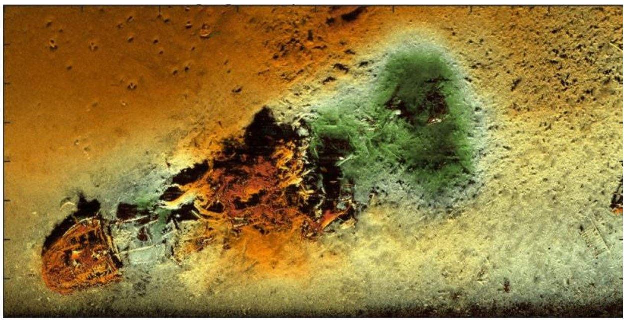

Fig. 2. Example SAS image of a 100 m long shipwreck. Courtesy of Norwegian Coastal Administration and FFI.

3 Advanced SAS products

Interferometric, multi-element sonars not only produce SAS images with extreme resolution, but they also output other useful products: Improved navigation, bathymetry, image quality and image complexity. The two latter are crucial for autonomous operations.

The image quality can be considered a measure of how well potential mines will be represented at each sonar image patch, and is based on coherence between the interferometric arrays and track linearity [4]. The image complexity measures the difficulty of recognizing potential mine responses given the local image intensity variations, and is a combination of anisotropy and multi-scale variance [2]. Fig. 3 shows an example SAS image with coherence, anisotropy and multi-scale variance.

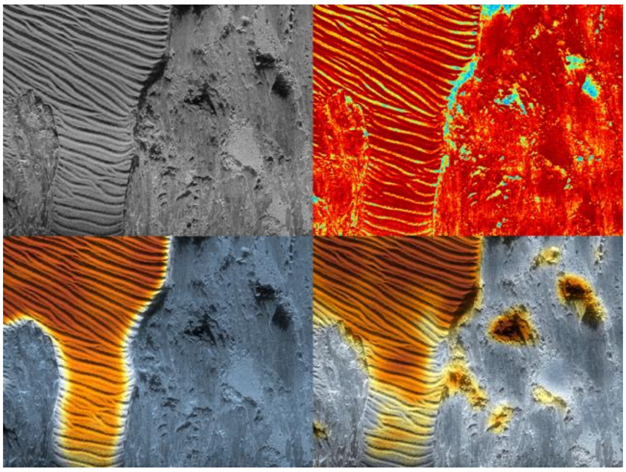

Fig. 3. Example SAS image (top left), coherence (top right), anisotropy (lower left) and multi-scale variance (lower right).

4 MCM performance evaluation

When unmanned systems with advanced sensors are used in MCM operations, traditional performance estimation algorithms are insufficient. To address this issue, we has developed a performance model combining through-the-sensor estimation with a-priori system specifications, named MCM Insite [2]. Image quality and image complexity are mapped into mine hunting performance, using a prior table learnt from an extensive sonar database with performance ground truth. Fig. 4 shows an overview of the data flow in MCM Insite.

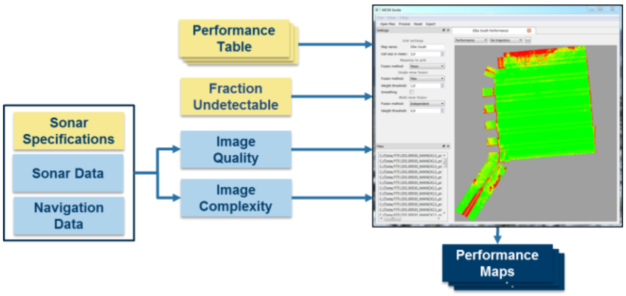

Fig. 4. Overview of the MCM Insite performance tool.

5 Autonomous MCM operations

Standard AUV MCM operations are today pre-planned. Typically, line spacing and line orientation are manually set. This means that if the sonar performance differs from the expected performance, one either misses data, or one operates less efficient than optimum. MCM Insite was originally implemented for post-mission analysis, but with the introduction of real time SAS, we have also implemented it as part of the AUV autonomy system. We have demonstrated autonomous MCM operations where the track separation is estimated in real-time using image coherence, and where sufficient data quality is ensured by estimating the MCM performance. If the MCM performance is below a preset threshold after a survey is finished, the AUV autonomously executes a new set of tracks perpendicular to the first ones. We have also implemented real-time ATR and an autonomous ID path-planner, and in the MANEX'13 sea-trial we ran SAS processing, adaptive line spacing, ATR, replanning and execution of an ID mission autonomously in single sortie [5]. The AUV then brought back sonar snippets and optical images of the detected mine-like targets. An example is shown in Fig. 5.

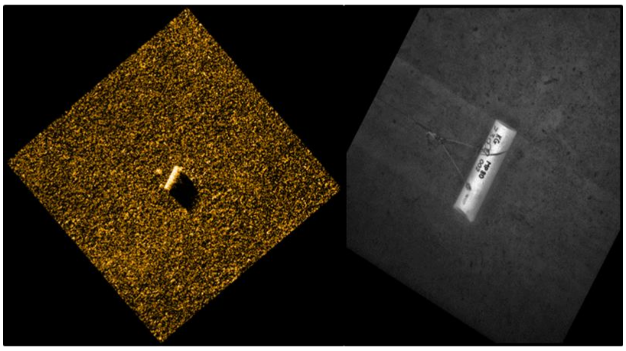

Fig. 5. Example SAS and optical image of a dummy mine.

6 Summary

In this paper we discussed the advantages of advanced SAS systems for AUV operations, and presented a concept for MCM performance evaluation, which can be used both as part of the AUV autonomy system and as an operator support tool. Since the MCM performance is degraded in regions with low coherence and/or high anisotropy and variance, we argue that real-time performance measures are a prerequisite for effective and efficient unmanned stand-off MCM operations.

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Author/Speaker Biographies

Dr. Torstein Olsmo Sæbø holds a Ph.D. in physics from the University of Tromsø, Norway. Since 2002, he has been at FFI, specializing in SAS systems. He is currently Research Manager for the underwater robotics development at FFI. Dr. Sæbø is an Associate Editor of the IEEE Journal of Oceanic Engineering.