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Towards integrated autonomous underwater operations for ocean mapping and monitoring

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A R T I C L E I N F O

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A B S T R A C T

The NTNU Centre for Autonomous Marine Operations and Systems (NTNU AMOS) is as a ten-year research program, 2013-2022, addressing research challenges related to autonomous marine operations and systems applied in e.g. maritime transportation, oil and gas exploration and exploitation, fisheries and aquaculture, oceans science, offshore renewable energy and marine mining. Fundamental knowledge is created through multidisciplinary theoretical, numerical and experimental research within the knowledge fields of hydrodynamics, structural mechanics, guidance, navigation, control and optimization. This paper gives an overview of the research at NTNU AMOS related to mapping and monitoring of the seabed and the oceans. Associated definition and requirements related to autonomy are also addressed. Results and experience from selected field trials carried out in the Norwegian coastal and Arctic waters will be presented. Integrating different sensors and sensors platforms such as Autonomous Underwater Vehicles (AUV), Remotely Operated Vehicles (ROVs), and ship-based systems will be shown.

1. Introduction

The vision of NTNU AMOS is to establish a world-leading research centre on autonomous marine operations and systems where fundamental knowledge is created through multidisciplinary theoretical, numerical and experimental research within the knowledge fields of marine technology, guidance, navigation and control. NTNU AMOS addresses the main application areas for ocean space science and technology (Fig. 1) including offshore oil and gas, maritime, fisheries, aquaculture, offshore renewable energy, marine science and marine mining. Cutting-edge interdisciplinary research involving technology, science and application knowledge will provide the needed bridge towards autonomous underwater operations in order to make high levels of autonomy a reality. This paper is an updated version of the work “Towards Integrated Autonomous Underwater Operations” by Sørensen and Ludvigsen (2015) presented at NGCUV in Girona, Spain.

Developments in technology platforms, sensors and control methods including autonomy have in many cases been driven by the needs in marine sciences as described in Bellingham (2014), Seto (2013), Williams et al. (2015) including contributions from several authors, Berge, Båtnes, Johnsen, Blackwell, and Moline (2012), Bingham et al. (2010), Clark et al. (2013), Ludvigsen, Sortland, Johnsen, and Singh (2007), Moline et al. (2005), Moline, Woodruff, & Evans (2007), Pizarro and Singh (2003), Singh et al. (2001), Singh, Whitcomb, Yoerger, and Pizarro (2000), Williams et al. (2012), and the references therein. The research group of Sousa (2010) at the Underwater Systems and Technologies Laboratory (LSTS), University of Porto, Portugal has done pioneering work in the development of software platforms for networked vehicle systems operating underwater, at the sea surface and in the air. In particular, they have been successful to support integrated operations using the open software package Neptus/DUNE tool set.

Another successful concept for autonomy of underwater vehicles is described in Hagen et al. (2009), making autonomous underwater vehicles (AUVs) truly autonomous. Here, more than 15 years of experience on the Hugin AUV concept is described. Sotzing and Lane (2010) and Insaurralde and Lane (2012) at Heriot–Watt University, Scotland have during several years been working with a hybrid control architecture with different control layers addressing autonomy. In addition to the mentioned references there is a vast and increasingly research activity on autonomous underwater vehicles in many other strong research groups around the world, e.g. Japan, US, Canada, Brazil, India and Europe.

In this paper, we will address various aspects of the on-going research activities at NTNU AMOS on underwater operations for

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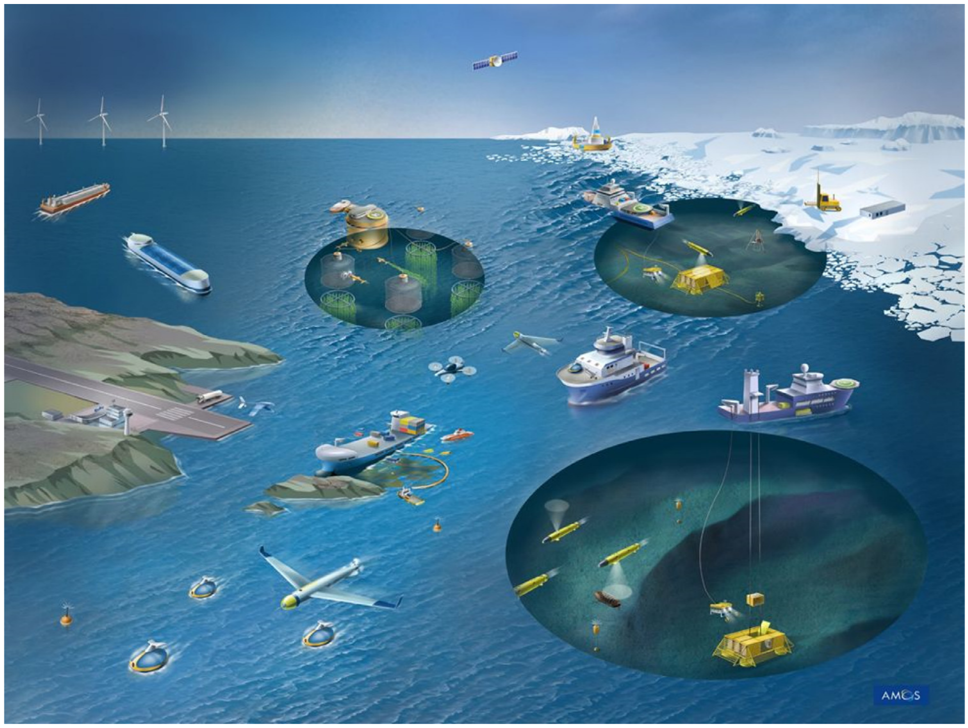

Fig. 1. Ocean space science and technology, illustration by AMOS/NTNU and Stenberg.

mapping and monitoring purposes. The main contributions of the paper are; evaluation of different technology platforms subject to spatial and temporal coverage and resolutions and a presentation of a control architecture considering a bottom-up approach towards autonomy. Selected results from field campaigns will also be shown.

The paper is organized as follows: In Section 2 integrated technology platforms and sensors will be presented. Autonomy aspects are discussed in Section 3. Examples from field campaigns are shown in Section 4. Future trends are discussed in Section 5, and finally the conclusions are given in Section 6.

2. Integrated platforms and sensors

2.1. Spatial and temporal coverage and resolution

Nilssen et al. (2015) proposed a concept for integrated environmental mapping and monitoring (IEMM) based on a holistic environmental monitoring approach adjusted to purpose and object/area of interest. The proposed IEMM concept describes the different steps in such a system from mission of survey to selection of parameters, sensors, sensor platforms, data collection, data storage, analysis and data-interpretation for reliable decision-making. In addition to measurements of essential parameters, the quality of the data interpretation is dependent on the spatial and temporal resolution and coverage of the data. Hence, the dynamics in both space and time have to be considered in the mission planning process. The temporal and spatial resolution and coverage capabilities for the relevant technology platforms are shown in Fig. 2 indicated by orders of magnitude. The spatial and temporal coverage and resolution needs will depend on the mission purpose (e.g. processes, organisms of different sizes) and the different decision-makers such as scientists, authorities, and industry may have individual needs and requirements. As suggested by Nilssen et al. (2015) the platforms' capabilities and limitations, mission purpose and object/area of interest are of importance as well as the ability to participate in integrated operations including

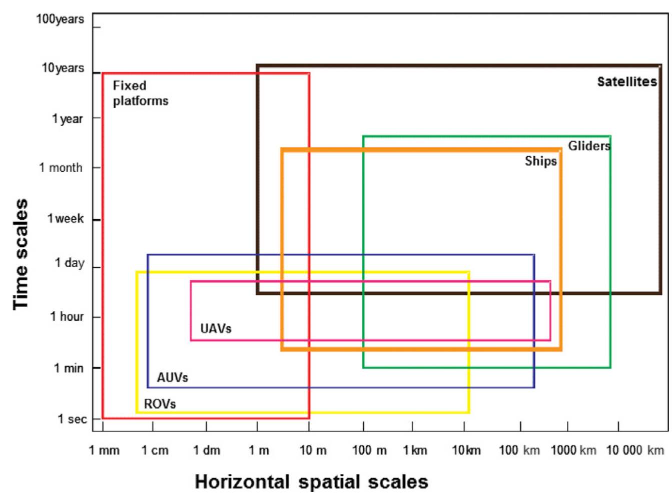

Fig. 2. Spatial and temporal resolution and coverage of different platforms, Nilssen et al. (2015).

also complementary platforms. In this context, underwater platforms may be landers or moorings, remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), and gliders. In order to be successful, improvements of the individual platforms as well as integration to different platforms in a network are of importance. As indicated in Fig. 1 this integrated approach does also include unmanned surface vessels (USVs), ships, unmanned aerial vehicles (UAVs), airplanes and remote sensing by satellites. Lately, research on unmanned aerial vehicles (UAV) and autonomy has increased the interest to apply low-cost UAV as sensors platforms and communication hubs between sensor platforms in the surface or the air and e.g. a mother vessel supporting AUV operations with some distance to the launching vessel.

For shipwrecks, the time constant of magnetic signatures and decompositions is in the order of years dependent on water depth,

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