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Towards Integrated Autonomous Underwater Operations

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Abstract: The Centre for Autonomous Marine Operations and Systems (AMOS) at NTNU (Norway) 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 AMOS related to underwater operations. 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.

Keywords: Automatic control, autonomous underwater vehicles, integrated operations.

1. INTRODUCTION

The vision of 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. 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 inter-disciplinary 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.

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 Williams et al. (2015), Bellingham (2014), Seto (2013) including contributions from several authors, Clark et al. (2013), Williams et al. (2012), Berge et al. (2012), Bingham et al. (2010), Ludvigsen et al. (2007), Moline et al. (2005, 2007), Pizarro and Singh (2003), Singh et al. (2000, 2001), 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.

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

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) 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.

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We will in this paper address various aspects of the on-going research activities at AMOS on underwater operations. The main contributions of the paper are; evaluation of different technology platforms subject to spatial and temporal coverage and resolutions and 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, Ødegård 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 to 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 order of magnitudes for temporal and spatial resolution and coverage capabilities of relevant technology platforms are shown in Fig. 2. The spatial and temporal coverage and resolution needs will vary dependent on 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, Ødegård et al. (2015) the platforms' capabilities and limitations, mission purpose and object/area of interest are of importance as well as the ability to run integrated operations using different 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 of 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), air planes 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.

2.2 Underwater platforms

Lander: For fixed platforms such as landers, moorings and ocean observatories, the temporal resolution can be high provided sufficient energy supply and data storage capacity. However, the spatial resolution will be limited to the coverage and range of the mounted sensors. Most sensors are point samplers, while others, such as active acoustics can cover a wide area. The range of active acoustics is dependent of the frequencies used, varying from meters to several kilometres (Godø et al., 2014).

Remotely operated vehicles (ROV): Mobile sensor platforms operating in the water column are normally deployed from a ship/floater. Recent ROV motion control systems (Fernandes et al., 2015; Dukan and Sørensen, 2014; Sørensen et al., 2012) provide manoeuvring capabilities with station keeping/hovering (dynamic positioning) and target and bottom tracking. High-resolution data from survey area can be provided with detailed seabed and sampling data with down to mm spatial resolution. The umbilical gives unlimited electrical power and high bandwidth communication.

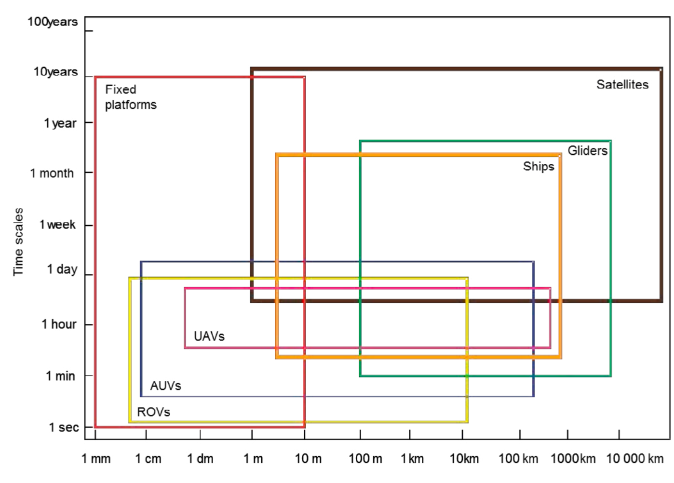

Fig. 2. Spatial and temporal resolution and coverage of different platforms, Nilssen, Ødegård et al. (2015).

Glider: Gliders' operational ranges and spatial coverage are high compared to AUVs and ROVs. The speed is rather low, following ocean current systems at a minimum of energy, using principles of buoyancy driven propulsion. Since the operation may go on for weeks, the spatial range is high. For measurements in the water column, the glider is good. However, the accuracy in navigation and control is limited. The ability for benthic surveys is also limited.

Autonomous underwater vehicles (AUV): AUVs may be divided into small AUVs rated to 0-100 m water depth and large AUVs (0-6000 m). Small AUVs may be operated from small boats and from shoreline. Torpedo shaped survey AUVs are mostly used in mapping providing good hydrodynamic and manoeuvring capabilities for tracking and path following (Moline et al., 2005). So far, there is limited access to AUVs with station keeping/hovering capabilities.