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The use of underwater hyperspectral imaging deployed on remotely operated vehicles – methods and applications

Geir Johnsen*, Martin Ludvigsen, Asgeir Sørensen**, Lars Martin Sandvik Aas*****

** Centre for Autonomous Marine Operations and Systems (AMOS), Dept. Biology, Norwegian University of Science and technology (NTNU), N-7491 Trondheim, Norway (Tel: +47 918-970-27; e-mail: geir.johnsen@ntnu.no).*
*** Centre for Autonomous Marine Operations and Systems (AMOS, Dept. Marine Technology, NTNU, N-7491 Trondheim, Norway (e-mail: martin.ludvigsen@ntnu.no, asgeir.sorensen@ntnu.no).*
**** Ecotone AS, Havnegata 9, N-7010 Trondheim, Norway (e-mail: lars@ecotone.com).*

Abstract: Currently a new underwater hyperspectral imager (UHI) have been deployed on Remotely Operated Vehicles (ROV) for a more automated identification, mapping and monitoring of bio-geo-chemical objects of interest (OOI). Sea floor maps based on UHI can be used to classify OOI based on specific optical fingerprints providing spectral upwelling radiance or reflectance with up to 1 nm spectral resolution in the visible range for each image pixel. Different habitats comprising soft bottom, deep and cold water coral reefs, sponge habitats, pipeline monitoring and kelp forest maps are examples for UHI-based mapping. Characterising material surface on man-made objects such as corrosion on pipelines and subsea structures and archaeological objects are other examples. The overall image quality and identification success of OOI can be optimized if movements of the ROV is controlled by a dynamic position (DP) system and corresponding speed, altitude, pitch, roll and yaw control. Likewise, illumination control is important to provide proper light intensity, spectral composition and illumination evenness of OOI to enhance data quality. The benefits of using UHI for seafloor habitat mapping can be evaluated by four categories of resolution. These are A) spatial resolution (image pixel size), B) spectral resolution (1–10 nm, 400-800 nm), C) radiometric resolution (dynamic range, bits per pixel), and D) temporal resolution for time-series and monitoring. These categories of resolution are discussed with respect to OOI identification and mapping using different case examples.

Keywords: Remotely Operated Vehicle (ROV), Underwater Hyperspectral Imager (UHI), mapping of seafloor, habitat mapping, habitat monitoring, ecosystem management and decision making

1. INTRODUCTION

Since most of the seafloor is optically deep (average world ocean depth of approximately 3700 m), underwater imagery must rely on artificial light as illumination source (Watson & Zielinsky 2013). Underwater images and maps of seafloor are often limited in spatial scale and mainly gives qualitative information, thus requiring time-consuming human interpretation. Obtaining high quality maps of features on the seafloor has been limited by *in situ* diver surveys, ship-based acoustics (echo sounders), benthic "grab" samples, epi-benthic sledges and beam trawl samples, underwater photography (including photo-mosaic) from boats and underwater robots (Boyd et al. 2006, Ludvigsen et al. 2007) or video towed from boat (drop camera, Buhl-Mortensen et al. 2010).

During the last decade, the use of hyperspectral imagers (HI, spectral resolution < 3 nm) has been deployed on airplanes and boats to generate objective and automated information of OOI on land and at sea-surface down to about 20 m depth (Klonowski et al. 2007, Volent et al. 2007, Johnsen et al. 2009, Dierssen 2013, Mouroulis et al. 2014). A prototype HI system was developed for use in airplanes, microscope, from mountains and by SCUBA divers (Volent et al. 2007, 2009, Johnsen et al. 2009) followed by an analog prototype UHI for underwater sea-floor mapping (Johnsen et al. 2013, Pettersen et al. 2013).

1.1. History of Underwater hyperspectral imaging (UHI)

For further development of UHI imagery of the sea floor, different UHI systems have been deployed on SCUBA based underwater tripods, underwater carts and on mobile underwater platforms, such as ROV (Figs. 1-3). Due to light limitation, underwater imaging techniques cannot rely on passive techniques using ambient light, and an active technique with own light source is needed (Johnsen et al. 2013). Also, to obtain spectral reflectance, R(λ), correction for lamp and Inherent Optical Properties (IOP) of dissolved and particulate matter in the water need to be accounted for (Fig. 4, see details below).

In April 2010 an analog UHI (prototype), attached to an underwater sliding cart, was used for mapping of OOI on seafloor at Hopavågen, Agdenes in Norway (Johnsen et al. 2013). In 2011 this UHI prototype was used by SCUBA divers in Eastern (Great Barrier Reef) and Western Australia (Shark Bay), operating the UHI attached to a sea-floor tripod with a scanning unit, providing panorama photomosaics of

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OOI of soft and hard corals at Great Barrier Reef and stromatolites and seagrass in Shark Bay (Figs. 1-2).

In April 2012, the first digital UHI, , was deployed on ROV, doing the first UHI seafloor mapping at the deep cold water coral reef at Tautra in Trondheimsfjord (Norway) at 60-80 m depth. The second UHI survey on ROV was performed 10-14 December 2012 down to 400 m depth in the Trondheimsfjord. In the following years four UHI models have been deployed on different types of ROV´s and sites (Figs. 5-9). Since 2013, UHI-based bio-geo-chemical mapping have been performed in the European and Canadian Arctic, the Atlantic, along the Norwegian coast and in the Pacific down to 4200 m depth looking for deep water manganese nodules.

Fig 1. An analog prototype of UHI at 5 m depth on Lizard Island, Great Barrier Reef, Australia, January 2011. The underwater tripod was equipped with a panorama scanning unit and two 35W halogen lamps (battery powered) for scanning of different colour groups of soft- and hard coral species.

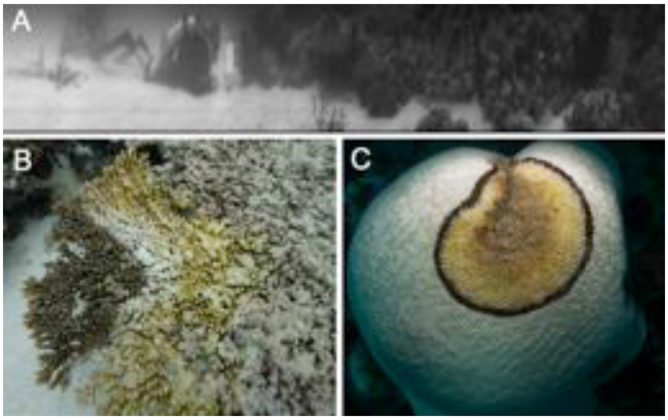

Fig. 2. Scuba operated UHI (analog prototype, set up in Fig. 1) scanning different colour groups and physiological state of corals, Lizard Island, January 2011. A) UHI image of 260 degree panorama scan of diver with reference plate and corals. B) Live coral (brown), dead coral (white), dead coral overgrown by green algae (green) and old dead coral (grey). C) Different physiological status of Brain coral (Mussidae) bleached (devoid of photosynthetic endosymbionts, white), sick tissue infected by bacteria (dark brown) and alive coral (bright brown).

The experience with and SCUBA-based UHI imaging (Figs. 1-2) provided the basis for sea-floor identification and mapping of coral reef habitats and general habitat mapping of OOI .

In December 2009 a spin-off company from NTNU, Ecotone AS, was formed to identify, map and monitor bio-geo-chemical OOI on seafloor for industry and environmental agencies. A new digital UHI sensor system, patented and produced by Ecotone AS (www.google.com /patents/ US8767205 B2) has been developed for ROV surveys and have been used the 5 last years to identify, map and monitor the seafloor for different OOI´s.

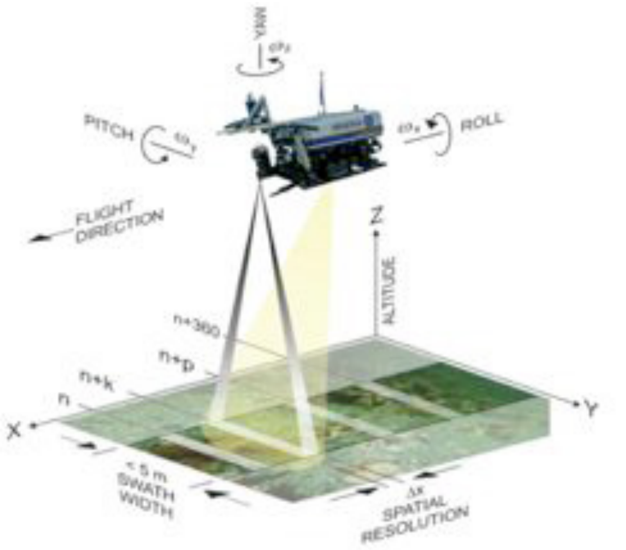

Fig. 3. Underwater hyperspectral imager (UHI) on ROV. The UHI and corresponding two 250 W halogen lamps has been used to illuminate the seafloor for UHI scanning of objects of interest (OOI). Redrawn from Johnsen et al. (2013).

Examples of UHI-based OOI identification, mapping and monitoring are seafloor habitats (minerals, soft versus hard bottom), seafloor pipeline inspection (type of material, cracks, rust and leakage), shipwrecks (type and state of wood, nails, rust and artefacts), deep-water coral reefs (species identification, area coverage and physiological state), deep-water sponge fields (species identification, area coverage and physiological state), and kelp forest (species identification, area coverage, physiological state and growth rates of benthic organisms). UHI-data output are such as areal cover, number of selected OOI and statistics.

By using UHI, giving hyperspectral information (digital counts, radiance or reflectance spectra) per image pixel, we can move towards automated seafloor identification and mapping based on optical fingerprints, in contrast to RGB cameras giving only 3-waveband information. Real-time computing methods of UHI data as input for mission planning and re-planning including navigation, guidance and control of ROVs and autonomous underwater vehicles (AUVs) are currently studied improving autonomy.