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A new method for underwater archaeological surveying using sensors and unmanned platforms

Øyvind Ødegård*, Asgeir J. Sørensen*, Roy E. Hansen, Martin Ludvigsen***

* Centre for Autonomous Marine Operations and System (NTNU AMOS),
Department of Marine Technology,
Norwegian University of Science and Technology (NTNU),
Otto Nielsens Veg 10, NO-7491 Trondheim, Norway.
(e-mail: oyvind.odegard@ntnu.no, asgeir.sorensen@ntnu.no, martin.ludvigsen@ntnu.no)

** Norwegian Defence Research Establishment (FFI), NO-2027 Kjeller, Norway (e-mail: roy-edgar.hansen@ffi.no)

Abstract: As most of the world's oceans are inaccessible to diving archaeologists, we must rely on advanced underwater technology and marine robotics to explore, map and investigate ship wrecks in these areas. New sensors and unmanned sensor platforms represent huge potentials for archaeological applications, but require a scrutinous look at how established archaeological methods and approaches must be adapted or rejected to optimize the results. Surveys done on a disintegrated wreck site with acoustic sensors like side scan sonar and synthetic aperture sonar, and optical sensors like stereo cameras, video and underwater hyperspectral imager, are compiled to serve as a case study to demonstrate the method. Challenges regarding guidance, navigation and control are discussed.

Keywords: Wreck, sensors, marine archaeology, underwater robotics, control, navigation

1. INTRODUCTION

Diving archaeologists are normally constrained to operate no deeper than 30-50 meters due to physiological limits and safety regulations. Since the average depth of the world's water bodies is approximately 3700 meters, this constraint considerably limits the reach of marine archaeology as a discipline based on diving only. One way to overcome this limit is to apply unmanned underwater vehicles such as remotely operated vehicles (ROVs) or autonomous underwater vehicles (AUVs). The tools used by marine archaeologists for the last couple of decades have been towed side scan sonar for detection and ROV with camera for inspection, although other sensors are also becoming more common (Plets, 2013). The integration of these technologies into marine archaeological methods has been very successful, and fundamental for providing knowledge of cultural heritage located beyond human diving capabilities. However, the methods have their limits – challenging bathymetry, currents, ultra-deep waters, and the need for a surface vessel to navigate freely limits the ability to reach some areas, and also the quality of the acquired data may suffer due to lack of appropriate sensors and control performance of the underwater vehicles. With the advent of more sophisticated underwater robotics in recent years, especially with regards to control and autonomy, the outlook for better investigations of areas and objects of interest on the seafloor is improving for all marine sciences – not least marine archaeology. Advances within sensor technology, control systems and computer science combined heralds great possibilities for extending the discipline's reach both physically and epistemologically. By adopting the concept of *Integrated Operations* different platforms and sensors can be used to complement each other, and data can be processed and used for planning and re-planning during a survey (Ødegård et al., 2012). Nilssen et al. (2015) proposes an Integrated Environmental Mapping and Monitoring (IEMM) model for dynamically selecting different sensors and platforms in iterations and feedback loops where sensor data is continuously compared to mission goal to guide operational decision making.

This paper will describe sensors and platforms relevant for seabed mapping tasks typical for marine archaeological surveys. We will show how data from one task can be used to plan and execute the next in a method for detecting, investigating and recording underwater cultural heritage (UCH) using underwater robotics. The sequential steps in the method will be exemplified with a case study from *the Reference wreck*, a site in Trondheimsfjorden, Norway (10°24'23E,63°27'12N), that has been investigated with a range of different platforms and sensors.

The main scientific contribution of the paper is the outline of a method for applying sensors and sensor carrying platforms for different tasks in typical marine archaeological surveys. The method is based on experiences from field work involving integrated operations and the IEMM model.

Section 2 describes the different sensors and platforms for marine archaeological surveying, and introduce three main mission objectives, detect, investigate and record, within the concept of the IEMM model. In Section 3 we present a case study with results from the Reference wreck obtained during several surveys using a range of sensors ad sensor platforms. In Section 4 we discuss the method, and finally, the conclusions are given section 5.

2. METHOD

A typical marine archaeological survey of previously unmapped areas could have the following mission objectives:

- Detect any possible wreck sites in the area;
- Inspect sites to determine if they really are wrecks;
- Record any established wreck sites.

With advances in technology and engineering the number of sensors and platforms available for seabed mapping is growing. They can be deployed in various combinations and configurations, and good planning and effective management

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of operations is becoming increasingly important to ensure good results. The IEMM model (fig.1.), proposes a method for selecting appropriate sensors and platforms to perform in different spatial domains iterated in a sensor data feedback loop until a set of pre stated mission objectives are satisfied (Nilssen et al., 2015).

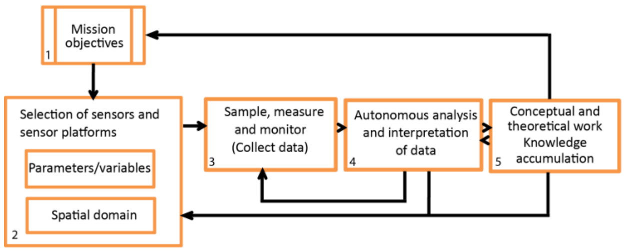

Fig. 1. Section of the IEMM model, modified to show sequences of operations in a marine archaeological survey.

Typically a general mapping of a survey area will initially use long range acoustic sensors providing bathymetry and imagery sufficient for a general characterization of the area. If the purpose of the survey is to detect and map any previously unknown objects or areas of interest within the survey area, the choice of the initial sensor must correspond to the resolution and data type expected to be necessary to detect such objects or areas. Depending on the mission objectives it may be necessary to deploy multiple sensors and platforms to acquire data that satisfies the mission objectives (Ludvigsen et al., 2014). Since range and resolution often are inversely proportional, the choice of platform can be very important as it can increase the data resolution by bringing the sensor closer to the object of interest. Table 1 (appendix 1) gives an overview of commercially available sensors relevant for marine archaeological surveys showing range, resolution and data type also with regards to different platforms. Fig. 2 illustrates the relationship between the sensor coverage and the ability to detect and record wrecks in different states of disintegration (size of shipwrecks and sedimentation are also important factors for the x-axis).

2.1 Payload sensors

The payload sensors are typical optical, acoustical and other mission specific sensors installed on a sensor carrying platform in order to gather data of any area and object of interests.

2.1.1 Optical sensors

Green Light Detection and Ranging (LiDAR) for bathymetric mapping is similar to airborne LiDAR for land mapping with one main difference: it uses a green laser for maximum range in the water column (green is the colour that is least attenuated in water), in combination with an infrared beam. The infrared beam measures the water surface, while the green beam measures the seabed (Song et al., 2015). Platforms could be fixed or rotary winged, and the speed above ground will affect the data resolution. Bathymetric LiDAR requires clear water, and the maximum mapping depth decreases with water turbidity.

Photo/Video cameras come in all sizes and can be put on any platform, but require external light sources as depth increases. Due to light scattering and attenuation in water, some distance between camera and lamp will yield better

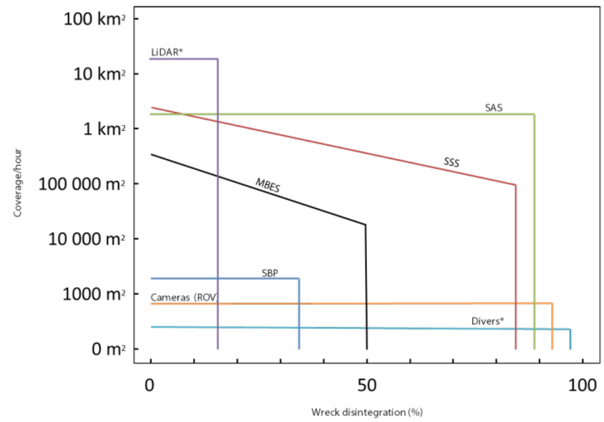

Fig. 2. Coverage and ability to detect wrecks. * LiDAR and Divers are constrained to max depth of approximately 30m.

image quality. Maximum range will depend on water visibility, but is typically below 10 meters. High definition video cameras are standard for ROVs used both for visual guidance by the pilot, and also for gathering data. Still cameras can be put in a stereo rig set to capture images synchronized (Nornes et al., 2015), or a single camera could be configured to capture images in intervals to ensure overlap between frames in sequence. Overlapping images can be processed using special software to create photomosaics and photogrammetric models.

Underwater Hyperspectral Imaging (UHI) is a novel technology with a considerable potential for archaeological applications. The basic principles are the same as for hyperspectral imaging used in satellite based remote sensing, but with some differences regarding environmental considerations (Johnsen, 2013). Hyperspectral imagery can be defined as images that contain the visible spectrum of reflected light with a spectral resolution of 1-5 nm per image pixel. Materials or compositions of materials will absorb, scatter and reflect light of different portions of the visible spectrum, giving them their own optical fingerprints that are unique, and can be used for classification and identification (Johnsen, 2013).

2.1.2 Acoustical sensors

Multi Beam Echo Sounder (MBES) also emits acoustic pulses in a fan shape using multiple transducers. By measuring the time and direction of the echoes one can produce point clouds with XYZ values for each point. This requires exact measurements of the position and pose of the sensor platform, traditionally a surface vessel. State-of-the-art MBES covers up to 3 times the sensor altitude at highest resolution. In addition to point clouds, most MBES can also produce backscatter imagery similar to SSS. Due to the grazing angle this imagery will show intensity of echoes, but to a lesser degree produce shadows. For an extensive discussion of MBES technology used in marine archaeology, the reader is referred to Bates et al. (2011).

Side Scan Sonar (SSS) backscatter imagery shows intensity and shadows on the seabed enabling visual interpretation of features that could possibly be wreck sites/UCH. The processing of standard SSS imagery is basically a function of time and speed of sound. The instrument repeatedly emits a