2019 IMEKO TC-19 International Workshop on
Metrology for the Sea
Genoa, Italy, October 3-5, 2019

A flexible autonomous bottom resident infrastructure for bentho-pelagic monitoring

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***Abstract* – This paper presents the ecology and policy basis as well as the technology solution for a Martera funded project (ARIM). The project develops platforms for bentho-pelagic monitoring using an arrangement of crawler and stationary platforms. A combination of visual and acoustic sensing along with standard oceanographic sensors supports advanced and continues spatial-temporal monitoring. Just as important is the automatic processing techniques under development that will allow habitat and species (or categories of species) to be automatically recognized and reported during the mission and thus support science and monitoring services without backing from expensive ship time. First version develops autonomy under controlled conditions with a tethered crawler exploring the neighbourhood of a cabled stationary instrumented garage. Our vision is that fuel cell technology will enable us to use the system for self-sustained long-term autonomous operations for science as well as for industry purposes.**

I. INTRODUCTION

Basic understanding of the dynamics and functioning of marine ecosystems are crucial for absolute assessment of human impacts. Presently, assessment and management suffer from the limitations of current techniques and available capacity to collect information in time and space adequate to understand and assess ecosystem processes at the time and space scales at which they occur [1]. Current approaches are not only restrained by technology limitations but also high costs. ARIM (Autonomous Robotic Sea-Floor Infrastructure for Bentho-Pelagic Monitoring) is a multi-national joint effort to establish novel sampling and processing technologies combined with a robust benthic based infrastructure that approach these sampling challenges. The product should fulfil the requirements from industry/government monitoring as well as basic research. In detail, we will:

- Create a docking interface between a cable node system for ROV free maintenance with an intelligent seafloor monitoring system (iCrawler) to provide independence from an infrastructure cable.
- Drastically increase the operational area and capability of the iCrawler by using an extended fibre-optic cable and provide the option to operate without umbilical.
- Provide crawler intervention and sampling capabilities through implementation of a manipulator arm.
- Construct a deep-sea fuel cell to provide energy for long-term self-sustained operations.
- Improve observation capacities using state of the art active acoustics and 3D camera technologies.
- Implement routines for automatic organism classification and individual tracking and integrate with the crawler sensors.
- Demonstrate performance and develop training facilities for new users and markets.
- Improve integration of hardware/software components to provide an efficient user interface.

II. THE ARIM APPROACH

We merge cable-based observatory technologies, mobile robotic seafloor technologies and image and acoustic processing and modelling methods into one operational autonomous product (Fig. 1).

The crawler enables detailed imaging of benthic marine life and their dynamics in space and time. The vertical acoustic sensor profiles the complete water column (~1000m range dependent of frequency) while the horizontal directed transducer is movable and covers a sector volume from bottom to surface with range ~1000m (dependent of frequency). One of the core ideas of our approach is to establish a real time data processing and interpretation system that enable categorization and, when possible, species identification in near real time both from the imaging and the acoustic sensors.

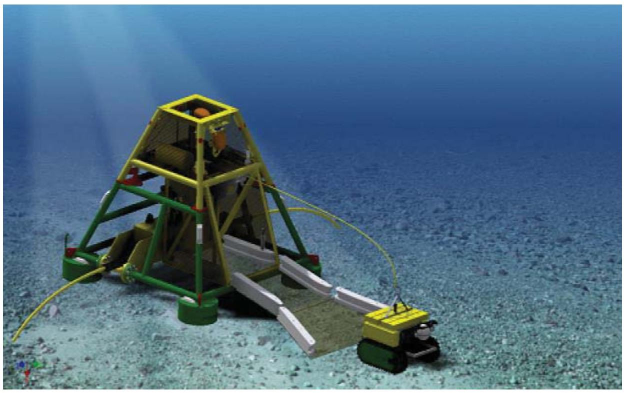

Fig. 1. The ARIM benthic platform with mobile crawler equipped with cameras and oceanographic sensors. The garage platform supports charging of batteries while the connecting cable enable communication between crawler and garage during training of crawler autonomous operations.

We are presently testing the system with focus on advanced imaging and acoustic sensing technologies along with standard oceanographic sensors. On longer term, we aim at establishing a flexible plug and play multi-purpose platform where users equip the platform and crawler with purpose specific sensors. Our approach will renew the way we sample the marine environment, but more important is that integration of the various technologies with simultaneous online processing allows operational feedback allowing adjustments to the sampling design based on real-time results. This offers new avenues to ecosystem understanding through an interactive feedback sampling design, for example to better understand interaction between the pelagic and the demersal habitats. However, the ARIM approach probably carry an even higher potential for renewing ecosystem monitoring in support of assessment of human impacts in the marine environment. Compared to today's ship-based systems, this new technology will drastically reduce monitoring costs associated to offshore and coastal industries.

Flexibility of our system is demonstrated through the possibility of using power/communication through established cabled observatories or alternatively stand-alone operation using new fuel cell technology to power the operations. Operational flexibility is also supported by the ROV free operation using a new launch and recovery tool (LRT) as illustrated in Fig. 2. This gives scientists the flexibility to move system to new locations without very expensive specialized ROV vessels.

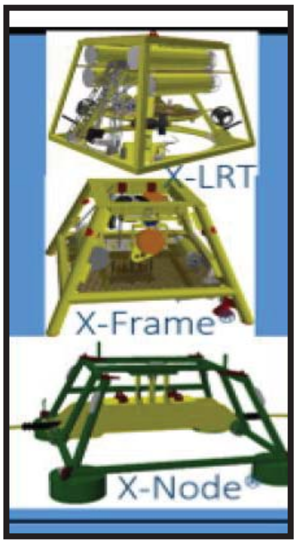

Fig. 2. The bottom unit in Fig.1 includes an X-node (docking stations) with permanent cable connection and an instrumented exchangeable top unit (X-Frame) that can be launched and recovered with the Launch-Recovery Tool (X-LRT) developed by partner (Metas AS). The ARIM X-frame includes the iCrawler garage (see Fig. 1). This allow user to operate and maintain the ARIM system without the assistance of expensive vessel time.

Autonomy is an important part of the development of ARIM. This includes both autonomous operation of the crawler and autonomous processing of images collected by the crawler. To avoid fatal operational accidents due to failures in the autonomous navigation software of the crawler, we will use a tethered version during our first stage testing to navigate safely back to base. This will ensure enough autonomous operation with the crawler under controlled conditions to minimize frequency of accidents when the next generation fully autonomous tether free vehicle is launched.

III TECHNOLOGY DEVELOPMENT

So far, we have experience with the various technologies separately. An early version of the crawler has been in operation in in the Neptune observatory off the Canada west coast [2] (https://www.youtube.com/watch?v=lSoqZXhXzqQ). The robustness and stability demonstrate that this unit is ready to be used in routine monitoring systems.

Based on the Neptune experience, an improved crawler with a functionality tailored to the ARIM project has been constructed. The crawler is belt driven, which makes a great variety of habitats accessible. When the crawler and its sensors are available through ethernet communication, remote vehicle navigation supported by online camera information is possible. This combination facilitates an important fundament for the autonomy development.

The crawler has a plug and play interface facilitating easy implementation of new sensors according to the function and usage of the system. In the first version of the ARIM the crawler will connect to the garage through an umbilical (Fig. 1). Navigation with the umbilical behind the vehicle without entangling in habitat obstacles is a critical element in the functionality. We discuss tow options. By installing a winch on the crawler we can pay out cable as the crawler moves. A cable heavier than water is left on bottom until the crawler start moving "home" along the exact same path. The winch will then start a tension-based retrieval of the cable. An alternative solution is a garage-based winch and a positive buoyant cable. Alternative 1 is safe but winch consumes power and reduces operation of the crawler. Alternative 2 with a floating cable increases risk for cable entanglement to the bottom habitat but extend operation in time and space.

The key sensor in our crawler is the imaging system collecting information about the surveyed benthic habitat. Repeated surveys will enable analysis of the development of the benthic marine life over time. Changes can be compared to changes in the marine environment like light, temperature, oxygen, current etc.

Fig. 3. The LoVe observatory with stationary acoustic and imaging sensors. The camera to the left images routinely a coral reef while the vertical and horizontal acoustic sensor mounted on the platform to the right monitor the full water column. Illustration Equinor ASA.

An early version of the benthic platform has been in operation in the Lofoten-Vesterålen observatory (LoVe; https://love.statoil.com; Fig. 3) since 2013 and has produced valuable data combing acoustic and imaging sensors [3]. The X-frame (Fig. 2) is the basic central unit collecting data either from sensors installed on the X-frame or from sensors at the satellite platform (Fig. 3). When a cabled connection is available, the X-frame connects to power and ethernet through the X-Node (Fig. 2). The adjustment implemented for this project is that the X-Node/X-frame is the design of the garage module that fits into the existing infrastructure (Fig. 1). The garage holds subsea mateable plugs for automated connection to the crawler for charging and data transfer (under autonomous operation without umbilical). Launch and recovery as well as coupling and decoupling is facilitated through the launch and recovery tool (LRT, see Fig. 2). Thrusters enable operator to move the LRT with X-frame on target and video monitoring helps remote coupling of X-frame and X-node (Fig. 2).

In the ARIM project, the key sensor of the benthic platform is the acoustic system using an EK-80 broadband scientific echosounder (Kongsberg ASA) with two multiplexed 70 kHz transducers. While the vertically pointing transducer is a reference for the vertical distribution of organisms, the horizontal moveable transducer enable a pelagic habitat search covering a sector from bottom to surface with range up to 1000 m. Back scattering from planktonic organisms to whales will be recorded at any time interval from seconds to season. Autonomous operation, including feedback from the acoustic backscatter to the operation software, will enable detection of behavioural related dynamics of organisms. This includes tracking of behaviour of individual organisms as well as the crawler.

In the ongoing LoVe observatory, we frequently imaged a coral reef habitat by a camera mounted on the satellite (Fig. 3). By keeping the camera position fixed, we follow the same animals over time and can thus uncover dynamics at all temporal scales (from hours to years). The images and the experience from this project is now used in development of the ARIM image analysis.

The detailed dynamics obtained through the coral reef images (Figure 4) has helped understanding temporal dynamics of the polyps while the acoustic data e.g. has given us better understanding of timing of ecosystem processes (Figure 5). Such experience is important for development of automatic image processing software for categorization and identification

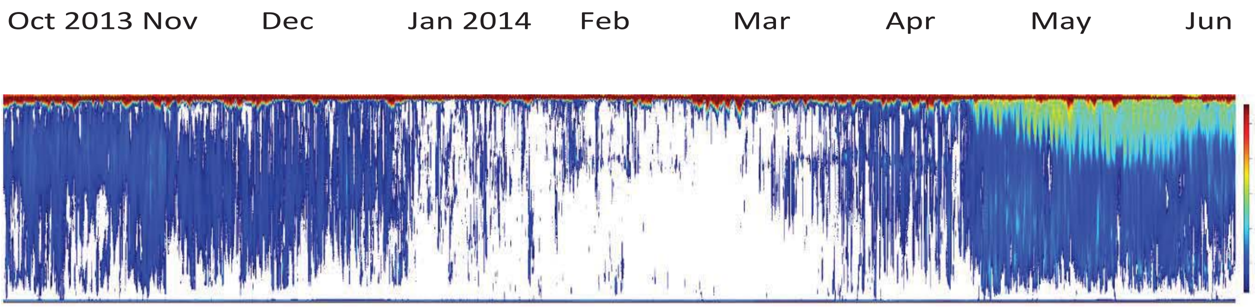

Fig. 5. Seasonal dynamics as observed in the acoustic records from October 2013 to June 2014. The acoustic system also observes with seconds' and cm resolution giving access to e.g. individual fish behavior information.

Fortunately, processing software for image interpretation improves continuously [4, 5], and we are now calibrating our analysis from images databases containing identified objects. A computationally demanding function of an underwater video monitoring system is the capability to automatically track and classify animals within different species as pre-established categories, based on patter recognition methods. Once pattern recognition has taken place, it is necessary to develop different methods of supervised classification based on training sets (Fig. 6A) to associate them with their corresponding species and validate the performances of the different routines according to the image quality (Fig. 6B).

Fig. 4. Coral reef with polyps visible. Their activity patterns inform about feeding dynamics. Further, activity patterns can also be associated with human impacts, e.g. from industrial activities. Photo Metas.

IV. EVALUATION

ARIM's performance is totally dependent on a cross disciplinary team of scientist and engineers working together towards a common goal. The team aims at continuing the development and utilizing the experienced by partners in ongoing projects at existing observatories (Neptun and LoVe). The project in particular take a holistic approach by combining sensor systems covering benthic as well as pelagic habitats. Combination of acoustics with oceanographic as done by Van Engeland et. al. 2019 [6] demonstrates the strength of coordinated sampling in time and space with various sensors. The unique contribution of ARIM is to establish technology and routines for combining imaging techniques of the benthic habitat and acoustic sampling of the pelagic habitat. This is a key factor for understanding marine ecosystem variability in time and space.

Although, the technique is promising we still see major challenges in establishing fully automatic systems that can operate unattended over extended periods. Energy will restrict sampling density, and hence, temporal gaps may obscure processes that otherwise would have been detected. Automatic processing and interpretation of both images and acoustics are still under development and will require substantial input in the years to come to produce reliable results.

The energy limitations are continuously improved through better batteries and more power efficient fuel cells and sensing systems. Reliable imaging techniques requires long term operation with cable collections through an online observatory to ensure that data are properly validated and that recognition algorithms are updated accordingly.

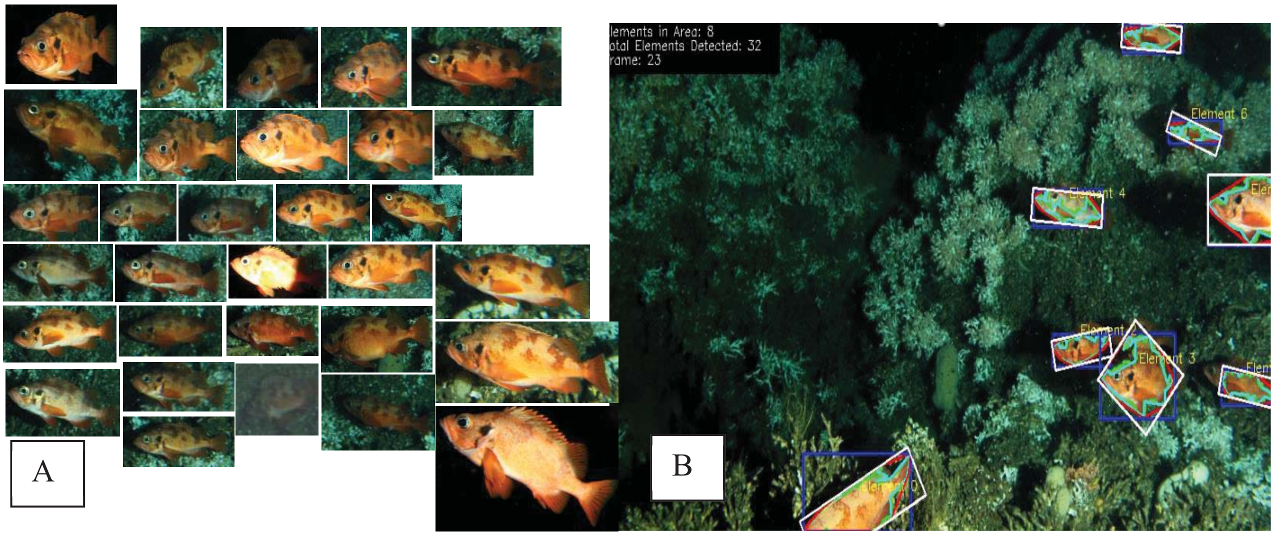

*Fig. 6. A-Set of images of a larger training library as an example of supervised tracking and classification of Rockfish (*Sebastes *sp.) within a constant field of view form archived videos at LoVe, B-Results of automated tracking as evidenced in a video by the recognition of individuals passing by.*

V. PLANS AND VISION

ARIM aims at launching a fully operating system in 2020 for testing. One element in our project is to test fuel cell technology as a power source. The aim is to enable long-term self-sustained operation of our system at any location. The simultaneous test of tethered free operation of the crawler will, if successful, make our system applicable to more users and for new scientific and commercial operations. Based on the experience from our upcoming field tests we will develop concrete plans for completion of full self-sustained autonomy of crawler operations including automatic data processing. Along with our ambitions of an efficient plug and play platform, for subsea sensors, we then consider the ARIM a multiple purpose system for the future marine research and monitoring. The challenges and obstacles for developing full autonomy should not be underestimated. Therefore, this project is define a stepwise development with continuous evaluation and adjustment.

VI. ACKNOLEDGEMENTS

ARIM is funded by the MarTERA partners, the Research Council of Norway (RCN), German Federal Ministry of Economic Affairs and Energy (BMWi) and Spanish Centre for the Development of Industrial Technology (CDTI) and co-funded by the European Union.

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