FOCUS TOPIC: SENSORS AND MONITORING

The topics of the first two calls have been defined by the 16 collaborating countries according to national priorities. They also contribute to the Strategic Research Agenda of JPI Oceans and WATERBORNE. These topics are reflected in five Priority Areas (PAs): Environmental friendly maritime technologies (PA1), novel materials development and structures (PA2), sensors, automation, monitoring and observations (PA3), advanced manufacturing/production (PA4) and safety and security (PA5).

The first issue of the MarTERA newsletter is dedicated to projects from the call 2017 that are addressing Priority Area 3: Sensors, automation, monitoring and observations. This PA encompasses the development of sensors for monitoring and observation including sensor fusion, technologies for the detection and measurement of emissions, miniaturisation of sensors, data transmission technologies and remote control systems and platforms. The second topic with PA3 covers monitoring and automation including underwater technologies for inspection, intervention, monitoring and control, intelligent predictive maintenance systems, underwater navigation and communication, control methodologies for ship and other marine vehicles (including cooperative behaviour, swarm technologies) as well as robust and reliable power supply for automated submarine technologies. Further topics include the development of improved models for marine vehicles and structures behaviour and environmental-friendly technology for exploitation, exploration and monitoring of deep sea resources.

On the following pages, the coordinators of seven PA3-projects from the MarTERA Call 2017 are presenting the scope and current status of their work, writing about goals, ambitions and the difficulties they have encountered.

We hope you enjoy reading the first issue of our newsletter!

Kind regards, the MarTERA consortium
Monitoring of contaminants in the marine environment still presents a number of challenges to overcome, e.g. large dilutions of pollutants which appear at very low, but biologically significant concentrations. The use of miniaturized biosensors can offer several advantages, such as high specificity, sensitivity, and ability to work on site. The outcome of the FLAshMoB project will be the development of small, portable, easy to use and robust biosensing platforms to monitor diverse relevant marine contaminants, focusing the attention on three classes of them: heavy metals, organic pollutants and algal toxins.

Among heavy metals, arsenic is a ubiquitous toxic metalloid present in the water. Water sources pollution by arsenic is a serious environmental problem all around the world, as it causes a lot of adverse health effects to humans at every level.

Polycyclic aromatic hydrocarbons derived from polyphenols are among the most important organic pollutants present in the environment. These compounds are thrown into the sea as wastes of several industrial processes for manufacturing of chemicals, or because they leak as fuel or oil from the ships. Other new emerging organic contaminants which will be monitored are the Endocrine Disrupting Chemicals (EDC).

Marine toxins, such as saxitoxin and domoic acid are associated with algae blooms and can bioaccumulate in shellfish which present both health and economic concerns. Ingestion of such toxins via contaminated shellfish, fish, or other potential vectors, can lead to intoxication syndromes with moderate to severe symptoms, including death in extreme cases. Environmental monitoring to detect the presence of these toxins is very important for prevention of intoxication.

In the development of biosensors, a key step is the biological interfacing of materials, i.e. immobilization of sensing proteins on the inorganic surfaces of electrodes. In this framework, the main innovation of the FLAshMoB project is the use of a fungal amyloid protein, able to self-assemble and adhere on surfaces. The sensing proteins is stably anchored onto a surface with a precise orientation by genetic fusion to this adhesive protein. Indeed, biosensors based on these fused proteins, named chimera, show an enhancement of efficiency and sensitivity with respect to other known systems.

Another important innovation of the FLAshMoB project is the use of nanomaterials to immobilize the fused proteins. Nanomaterials, such as the 2D material graphene, and the 3D materials carbon nanotubes, exhibit an ideal combination of (i) high active surface able to enhance the number of immobilized proteins per surface unit and (ii) intimate interactions with proteins in order to enhance the sensitivity of the device.

We have produced different fused proteins, endowed with both the adhesive properties of the self-assembling moiety and the recognition ability of specific proteins, suitable for monitoring the above-mentioned contaminants: (i) laccase, an oxidative enzyme useful for sensing aromatic pollutants -Polycyclic aromatic hydrocarbons and Endocrine Disrupting Chemicals; (ii) arsenate reductase, for specific arsenic detection; (iii) antibodies against marine toxins from algae, such as saxitoxin and domoic acid; (iv) GST, a multifunctional protein useful for the detection of the total heavy metals content. Project efforts are now focused on the immobilization of these chimera and on the development of the biosensing platforms.

The FLAshMoB consortium is developing lab-on-chip and portable devices, able to both deal with the harsh conditions often found in the marine environment and attain the sensitivity needed for many marine applications.

Paola Giardino is professor of biochemistry at the University of Naples Federico II, Italy and coordinator of the FLAshMoB consortium.
Currently, the aquaculture industry is facing production and environmental problems that challenge fish welfare and serve as key bottlenecks to further growth of the industry. The two greatest environmental risks are ectoparasite infestations and the escape of farmed fish. To tackle these problems, new farming technologies are being developed. Chief among the diverse approaches is developing new cage farming technologies that combat ectoparasites through manipulations of the cage structure. Recent innovations in cage design have involved placing a lice barrier in the upper section of salmon cages, either as a full skirt around cages or as an internal ‘snorkel’. These barriers are used to prohibit infection by parasites as they stop encounters between parasites and salmon in the upper depths (e.g. 0-10 m) of the water column. Skirts and snorkel technologies are more and more used in full-scale salmon farms by the industry with positive effects in reducing lice loads but there are still a lot of unknowns regarding the long/mid-term effects of these new farming technologies on the total structural integrity of the cage and farm itself.

The FLEXAQUA project investigates the strong needs to improve the understanding of the behaviour of such structures under various environmental conditions (currents, waves) and the effect of marine organism growth on the structural integrity, to develop new techniques to detect 3-dimensional structural damages, and to secure the operations with cost-efficient control systems.

The project delivers the necessary knowledge base and by developing necessary tools and methods for safe and reliable operations of these new type of cages. Developing a well-rounded and rigorous knowledge base is important for any emerging technology, however, it is particularly valued here given the increasingly competitive aquaculture arena. The consortium investigates and improves the use of flexible shielding skirts for prevention of ectoparasite infestation in relation to finfish farming, analyses the effect of marine organisms growth on these structures and suggests innovative, safe and efficient underwater monitoring procedures. Measurements on full scale commercial salmon cage with a snorkel are currently underway. Different sensors like load cells accelerometer and depth sensors have been deployed in order to gather information about deformation, load and vertical movement due to waves.

University College Dublin (UCD) has developed in-house real-time detection algorithms for Structural Health Monitoring. TCD has developed in-house algorithms implementing deep learning (Recurrent Convolutional Neural Networks) and other geometric transforms for the detection of features through a range of methods (e.g. Hough transform). A straightforward way to estimate biofouling and damage on the nets is to consider a section of the net as a flat 2D planar region and attempt to isolate the net (and attached biofouling) from the background. This is achieved by extracting a section of the net and applying geometric transformations (scaling, rotation, perspective transformations) as shown in the picture below (Photo: Trinity College Dublin TCD, Ireland).

Dr Pascal Klebert is Senior Research Scientist at SINTEF Ocean, Norway and coordinator of the FLEXAQUA consortium.
in the framework of Gita-
ro.JIM we seek an intelligent integration of multidisciplinary geophysical datasets.
Detailed knowledge of the marine subsurface is important in various fields, e.g. for planning the marine construction of cable and pipeline networks, for predicting hazards like marine landslides and associated tsunamis, and for accessing marine resources. Geophysical methods to explore the subsurface include experiments using sound waves (seismics), electromagnetic, static magnetic and gravity field measurements. Each geophysical dataset reveals specific information about the underlying earth, yet different physical properties contain different information about subsurface structure and resource potential. Ambiguities of the earth models derived by data inversion exist for each method owing to the physics of the method and to limited amounts of data acquired at discrete sites on the seafloor.

For example:
Ore deposits like massive sulphide deposits may be very conductive to electric currents, and dense and heavy, and easily propagate sound. Gas occurrences in marine sediments are resistive to electric currents, less dense and attenuate sound. Gas hydrate formations in the subsurface are ice-like structures known to hold large amounts of usable natural gas. They are electrically resistive, yet they propagate sound very well, in contrast to pure gas accumulations.

Thus, the combination of resistivity and sound measurements helps in these cases to distinguish the different target materials from the background setting.

In the laboratory, sediment samples from up to 150m deep drill holes in the old Danube Delta in the western Black Sea, are analysed for their composition and structures. The original as well as synthesized samples are investigated in pressure vessels at GFZ and University Southampton to determine the relationship of the gas hydrate saturation in the pore space (0 - 90%) and a) the velocity of selected acoustic waves, b) the change in attenuation of these waves and c) the electrical conductivity.

Both, theoretical and sediment specific experimental correlations are gradually integrated into the JIF. Since natural samples are not homogeneous but exhibit a layering, corresponding synthetic samples have been created from frozen sediments made for this purpose (see upper left picture).

First results of the project include the open-source release of emg3d, a multigrid solver for three-dimensional controlled-source electromagnetic diffusion with tri-axial electrical anisotropy. The advantage of multigrid solvers is its optimal scaling for both runtime and memory consumption. It is written completely in Python, where the most time- and memory-consuming parts are sped up through just-in-time compiled (jitted) functions. We also published an article alongside the code in the Journal of Open Source Software (see Werthmüller et al., 2019).

Dr Gerald Eisenberg-Klein is a geophysicist at TEEC GmbH, Germany and coordinator of the Gitaro.JIM consortium.
Phosphate and Nitrate sensors

There has been an increasing demand over the last decades for autonomous in situ measurement systems for the quantification of physical and chemical parameters in the marine environment. Of particular interest is here the in situ determination of dissolved nutrients such as phosphate and nitrate. These nutrients are essential for photosynthetic marine organisms and drive therefore oceanic primary production. Thus, the entire marine life depends ultimately on the distribution of dissolved nutrients. However, increasing anthropogenic pressure is compromising such sensitive ecosystems due to nutrient imbalance and enrichment. Due to the discharge of huge quantities of nutrients, e.g. through riverine run-off of agricultural affected waters into the oceans, an explosion of the population of phytoplankton (‘blooms’) can be stimulated. This means in turn a perfect feast for zooplankton. Bacteria feed on sinking zooplanktonic excretions as well as detritus while consuming all available dissolved oxygen. This leads ultimately to the formation of oxygen depleted zones, also referred as ‘dead zones’ as all oxygen requiring organisms will be either displaced or die. Prominent examples are here the Baltic Sea, coastal waters of the West Atlantic Ocean as well as the Gulf of Mexico. Thus, well resolved in situ time series (temporally as well as spatially) for dissolved nutrients are required in order to assess the status quo of our oceans under increasing anthropogenic pressure and to support decision making processes of governments and non-governmental organizations towards a sustainable management and conservation of important marine ecosystems.

Powerful tools for acquiring reliable and accurate in situ data for dissolved nutrients are optical approaches, such as absorption and fluorescence measurements. Nitrate can be detected directly in the water column as the ion itself features an absorbance band in the UV range. Several nitrate devices are already on the market, but suffer however from cross sensitivities of other compounds absorbing at the same wavelength range, such as bromide and organic matter. We have successfully developed an algorithm for compensating those interferences. We have further set up a system for the detection of phosphate, based on the wet chemical spectrophotometric ‘yellow method’ Sample or standard solutions will be aspirated and mixed with a phosphate sensitive reagent using a syringe pumping unit. A yellow colour will be generated when phosphate is present. After complete reaction and colour development the mixture is pumped towards a detection unit comprising a light source, an optical flow cell and a portable spectrophotometer. The measurement of standard solutions with known phosphate concentrations gave a linear calibration fit. Thus, the unknown phosphate concentration of real seawater samples can then be determined from the respective absorbance values using the linear fit. We found that phosphate concentration down to 0.07 µM (limit of detection; calculated as three times the standard deviation of the blank) could be detected with the current design which would be perfectly suitable for its application in coastal and open ocean waters. A high sample throughput of one sample per ca. 5 minutes can be achieved. However, further improvement will be achieved regarding the precision and the sampling frequency by adaption of the detection unit and minimization of the used sample and reagent volumes, respectively. We are planning to miniaturize the detection unit by using 3D printed detection cells including LEDs and photodiodes for light emission and detection, respectively. The miniaturization step is key for deploying the system autonomously in situ in a pressure compensating housing. In the near future shore based and shipboard underway test deployments will be undertaken in Kiel Bay (Germany). At a later stage autonomous deployments directly in the water column will be conducted. We will further set up a similar system for the in situ detection of ammonium based on a fluorescent approach.

Silicate electrochemical sensor deployments

In May 2019, electrochemical silicate sensors developed together by LEGOS and NKE Instrumentation were successfully deployed to measure silicate concentrations offshore Easter Island (Rapa Nui), as part of a joint campaign of the OCEANSensor project and the ESMOI program funded by Chile. The sensors sample and measure autonomously the in situ silicate concentration at 100 m depth during at least 2 months, which is a first for this type of sensor (silicate sensor). Several seawater samples were also collected at the same depth to analyse the silicate concentration by colorimetric measurements in order to inter-compare the results.

In collaboration with the Marine Station of Sète (part of the Observatory OREME), we deployed one silicate electrochemical sensor in the Thau pond (Mediterranean sea), measuring silicate concentration almost every hour, at 1 meter depth, during 19 days. Results are compared to water samples from the same site.

Professor Eric Achterberg is head of the Water Column Biogeochemistry working group at GEOMAR, Germany and coordinator of the OCEANSensor consortium.
POSEIDON aims to contribute with the provision of an efficient and innovative response for the alarming rise of marine pollution and its consequences. The POSEIDON solution is a compact multisensor system carried on small UAVs that integrates radar sensors jointly operating with EO/IR cameras to monitor marine areas and detect sea debris and oil spills. The main novelties of the proposed system are:

* Design of a compact, light and fully polarimetric radar with SAR imaging capabilities. The radar system is a 24/7, all weather surveillance sensor with enhanced capability of detecting floating debris and oil spills thanks to polarimetry and high spatial resolution.
* Use of EO/IR sensors for a better identification of the type of debris and the extension of the oil spill to help the coordination of a prompt response for the mitigation of the problem. To this end, recent advances in deep neural networks for object detection, segmentation, and classification will be explored.
* Application and development of ad-hoc fusion techniques for the two sensors to jointly operate in the same platform.

"POSEIDON focuses on the detection and identification of sea pollutant to help and enhance the effectiveness of mitigation actions."

By taking into consideration these aspects, POSEIDON focuses on the detection and identification of sea pollutant to help and enhance the effectiveness of mitigation actions. More in particular, the jointly use of two sensors provides the system with resilience and reliability, the use of a radar provides the system with 24/7 operability, finally the use of small drones makes the system easy deployable, reduces the deploying time, contributes to save money and time and also contributes to reduce risks for involved peoples.

The POSEIDON logical architecture is based on a micro service oriented architecture, that is, it is divided in modules that perform a reduced group of interrelated functionalities. This characteristics ensures a high degree of scalability to the overall system and make the addition of other sensors possible and easier. The different services are divided in two groups:

* **On board services:** the EO/IR sensor, the radar sensor, the avionic sensor, the data recorded, the on-board datalink

* **On ground services:** On ground datalink, data player, EO/IR image processing, radar image conformation and processing, sensor fusion, image database and GUI (GIS based graphical user interface).

The technical activities continued with the design of the POSEIDON subsystems. In particular, the drone and the EO/IR were chosen from the market while the radar system was customized. Due to SWaP constraints, the radar must be small, light and low power. Apart from some feasibility studies, there are no radar products with these features on the market. Therefore an ad hoc radar project was necessary.

The next period will be dedicated to the organization and implementation of the POSEIDON tests and the results analysis.

Dr Elisa Giusti is researcher at the Radar and Surveillance Systems (RaSS) National Laboratory of CNIT, Italy and coordinator of the POSEIDON consortium.
The goal of the RoboVaaS project is to revolutionise shipping and near-shore operations by offering on-demand robotic aided services via unmanned vessels (USVs) as well as remotely and autonomously operated underwater vessels (ROV and AUVs). The concept consists of a network of unmanned vessels, innovative sensor technologies, a comprehensive communication network and real-time web applications. The main project objective is to demonstrate the concept.

The project includes the following phases: 1) Design, 2) Specification, 3) Individual developments and Testing, 4) Implementation, 5) Demonstration, 6) Evaluation, and 7) Validation and Marketing.

Within phase 1, the consortium designed five use cases under consultation of experts and stakeholder to answer current needs in the maritime field:

UC1) Ship Hull Inspection

A USV with a tethered ROV that scans an area of a ship hull for fouling and abnormalities in real sea trials. The underwater ROV will inspect the ship hull with a scanning laser system while the USV manoeuvres in a way to optimise the inspection process. The use case will focus on demonstrating the inspection process by means of at large scale ROV.

UC2) Quay Wall Inspection

An ROV tethered to an USV inspect a quay wall for strength and other material properties. This use case will take place in a small-scale setup by using proprietary system but allowing demonstrating the entire RoboVaaS service chain from request via dispatch of vessels to service execution.

UC3) Data Collection via Data Mulling

An AUV/USV will collect environmental data from submerged sensor nodes via acoustic underwater communication. Demonstration will take place at small-scale level with overarching goal of further developing low-resource underwater communication inevitable for future RoboVaaS services.

UC4) Bathymetry Data Collection

A small-scale USV equipped with an echosounder will collect bathymetry data. This enables cost-efficient autonomous bathymetry survey of waterways.

UC5) Anti-Grounding

A USV equipped with a high-resolution sonar can inspect the ship hull and quay wall inspections. Fraunhofer CML adapted their USV in order to demonstrate UCG-4: A sonar, an ROV and an environmental sensory platform was integrated to the USV. They further started developing a dispatch system for the ROV, the RoboVaaS real-time web application and an anti-grounding application.

SmartPORT carried out fundamental research on the feasibility, efficiency, and resilience of underwater acoustic communication and developed novel algorithms. They prepared and performed initial tests for UC3. In order to allow for smooth integration and demonstration for the future phase 4 and 5 HPA, CRIS and CML started preparations and defined scenarios.

Johannes Oeffner is Research Scientist at Fraunhofer Center for Maritime Logistics and Services, Germany and coordinator of the RoboVaaS consortium.
The objective of the SEAMoBB project is to deliver a monitoring protocol for benthic marine biodiversity of rocky habitats. Describing community composition is central to biodiversity monitoring and thus biodiversity protection. Traditional methods (e.g., taxonomic experts, photo identification) can accomplish this task, however, due to the rich taxonomic diversity of hard bottom environments, additional methods need to be incorporated for monitoring. Metabarcoding provides a high-throughput, automatable and repeatable way of studying community composition, in contrast to taxonomic experts and photo identification that usually suffer from methodological bias.

We placed artificial structures at 28 hard-bottom habitats (distributed across 8 locations along the Mediterranean coast) and, upon deployment, performed scraping of benthos on natural substrate. Each year (2 or 3 successive years) samples of marine communities were taken from these artificial (after one year immersion, see picture below) or natural substrates. Among the achievements obtained so far, we established a robust molecular metabarcoding protocol for efficient and reliable analyses of eukaryotic species composition. In particular, we found that the DNA extraction method significantly influences the type of organisms recovered. While we observed similar results when comparing animal taxonomic diversity, one method (optimized for isolating genomic DNA from soil) was more efficient in recovering genomic DNA from algal taxa than the other method (i.e., we observed as many animal taxa, but more non-animal taxa: e.g., algae, diatoms, etc.). We thus selected this DNA extraction kit for subsequent analyses. Furthermore, we determined the optimal polymerase enzyme to maximize PCR yield (i.e., the amount of DNA sequences of appropriate size and quality recovered). Whatever the method employed for metabarcoding, a very important and encouraging result confirmed our expectations: the number of taxa recovered using metabarcoding methods are approximately ten-fold greater than taxonomic estimates revealed by photographic analyses. We are confident that the number of taxa recovered is not an overestimate, as we developed an extremely rigorous protocol associated with a stringent bioinformatic filtering pipeline.

Obviously, photo analyses cannot reliably identify small organisms and those hidden under ones on the surface, and cannot distinguish closely related species, which metabarcoding (using DNA sequences) can differentiate. Nevertheless, we are developing an interesting and innovative method for rapid and efficient photographic analyses by utilizing computer vision algorithms implemented through the NOAA web platform CORALNET UCSD. Developments of such automated methods are valuable because they can save time and provide very reliable results. For instance, the photographs from the first location took our taxonomic expert 3 weeks to analyse 200 photos. After training the CORALNET platform, however, it took him only 4 days for the third region, due to the help of artificial intelligence (deep learning) algorithms. It automatically proposed taxon identifications which the expert had to confirm or to correct manually. The more images analysed, the faster the identification, and the confidence of the taxonomic assignment. Thus, we expect that the speed and accuracy of photo analyses will further increase as the SEAMoBB project continues.

We are also trying to understand what factors control the spatial patterns of benthic biodiversity. One factor that could explain the similarity in community composition between distant regions, while others largely differ, is marine connectivity. Marine connectivity results from the heterogeneous dispersion and transport of larvae by ocean currents across the seascape. Depending on dispersal routes imposed by ocean circulation, some sites may be receiving similar larval supply, possibly explaining why their community composition may look analogous. Connectivity barriers would instead result in large differences of community compositions. Our ongoing analyses of the variability of benthic biodiversity among the 28 sites as measured by complementary state-of-the-art and standardized protocols, promise further exciting discoveries to be announced by the SEAMoBB consortium soon.

Dr Anne Chenuil is research director at the Mediterranean Institute of Marine and Terrestrial Biodiversity and Ecology of CNRS, France and coordinator of the SEAMoBB consortium.
Recently, the submission of full proposals for the step 2 procedure of the MarTERA Call 2019 has been concluded. 24 full proposals with a total requested funding of 30 M€ have been submitted. In the subsequent phase, the full proposals will be evaluated and ranked by an independent international evaluator panel. The results will be announced by the end of November 2019.

The MarTERA partners have agreed to launch a third call later this year. The participating countries, priority areas and committed funding for the MarTERA Call 2020 will be announced in December 2019. Please check the MarTERA websites and join our LinkedIn group to receive the latest updates.

<table>
<thead>
<tr>
<th>Call 2019</th>
<th>Call 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number</strong></td>
<td><strong>Total cost in M€</strong></td>
</tr>
<tr>
<td>Submitted and eligible pre-proposals for step 1</td>
<td>47</td>
</tr>
<tr>
<td>Selected pre-proposals in step 1</td>
<td>25</td>
</tr>
<tr>
<td>Submitted full proposals for step 2</td>
<td>24</td>
</tr>
</tbody>
</table>

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