TEC4SEA - A Modular Platform for Research, Test and Validation of Technologies Supporting a Sustainable Blue Economy

Paulo Mónica*, Alfredo Martins*+, Augustin Olivier*, Aníbal Matos*†, José Miguel Almeida*+, Nuno Cruz*†, José Carlos Alves*†, Henrique Salgado*†, Luís Pessoa*, Pedro Jorge*, Rui Campos*, Manuel Ricardo*†, Carlos Pinho*, António Silva #, Sérgio Jesus#, Eduardo Silva*+

*INESC TEC Institute for Systems and Computer Engineering of Porto
+ISEP - School of Engineering, Porto Polytechnic Institute, Porto, Portugal
†Department of Electrical and Computer Engineering, Faculty of Engineering, University of Porto, Porto, Portugal
#CINTAL - Centro de Investigação Tecnológica do Algarve
Email: {paulo.monica, aom, aolivier, nuno.cruz, jca, hsalgado, lpessoa, rcampos, mricardo, cpinho, eduardo.silva, jose.m.almeida, aom@inesctec.pt}

***Abstract*—This paper presents the TEC4SEA research infrastructure created in Portugal to support research, development, and validation of marine technologies. It is a multidisciplinary open platform, capable of supporting research, development, and test of marine robotics, telecommunications, and sensing technologies for monitoring and operating in the ocean environment. Due to the installed research facilities and its privileged geographic location, it allows fast access to deep sea, and can support multidisciplinary research, enabling full validation and evaluation of technological solutions designed for the ocean environment. It is a vertically integrated infrastructure, in the sense that it possesses a set of skills and resources which range from pure conceptual research to field deployment missions, with strong industrial and logistic capacities in the middle tier of prototype production. TEC4SEA is open to the entire scientific and enterprise community, with a free access policy for researchers affiliated with the research units that ensure its maintenance and sustainability. The paper describes the infrastructure in detail, and discusses associated research programs, providing a strategic vision for deep sea research initiatives, within the context of both the Portuguese National Ocean Strategy and European Strategy frameworks.**

Keywords*—*research infrastructure, deep sea, marine equipment development, open research platform.

I. Introduction

The Portuguese National Ocean Strategy (PNOS) [1] was revised in 2013, namely to encompass the new reality brought by the Continental Shelf Extension proposal, currently under appreciation by the United Nations's Commission on the Limits of the Continental Shelf (CLCS). With this extension, which defines the outer limits of the Portuguese continental shelf beyond 200 nautical miles, the Portuguese territory becomes approximately 4 million km^2 wide (roughly equivalent to 91% of the European Union's land area), with the vast majority of this North Atlantic area being constituted by deep and ultra-deep sea. These two combined characteristics, *dimension* and *depth*, create considerable technical difficulties to the national capability for both exploration and exploitation of these vast underwater domains.

Being fully aware of this fact, the PNOS adopted a very open and cooperative approach, anchored on the notion that an effective implementation of the strategy and its associated action plan will require the concerted efforts, skills and resources of all societal groups and stakeholders, to explore the immense potential resources promised by such a vast undersea territory. This idea became one of the three core principles of the PNOS, and constituted a loud call for participation of the civil society. Naturally, it led to the materialisation of a considerable set of dispositions, within the scope of the PNOS, designed to foster and support the appearance of national cooperative research infrastructures capable of participating in the prosecution of the defined objectives.

Three other context defining events took place in 2013, and also contributed to the appearance of TEC4SEA [2]. Firstly, the entry into force of the new European Union (EU) Framework Programme for Research and Innovation (Horizon 2020), which is the biggest EU Research and Innovation programme ever (approximately 80 billion of funding for the period 2014 to 2020), with 2478 million assigned to support and promote research infrastructures. Secondly, the fact that the Portuguese national funding agency for science, research and technology (FCT) initiated the process of producing a National Roadmap of strategic Research Infrastructures, thus opening a narrow time window for the recognition of new emerging entities. Thirdly, the Portuguese Regions have identified their strategic sectors for structural fund investment in the years 2014-2020, under the smart specialization paradigm. Within these smart specialization funding priorities, the Sea appears as a common strategic area for all Regions, and the development of new technologies and solutions a common need for many business sectors operating or living from the Sea.

Together, these events created the *need*, the *opportunity* and the *timing* for the creation of TEC4SEA. The set of existing skills, resources and competences of the founding entities created the *possibility* of its establishment. The TEC4SEA Research Infrastructure (RI) was therefore created, completely aligned with the previously mentioned smart specialization decisions, both at the national and regional levels. It is a distributed, multidisciplinary open platform, capable of supporting research, development, and test of marine robotics, telecommunications, and sensing technologies for monitoring and operating in the ocean environment. Additionally, the

RI will support advanced training programs for the deep sea technologies, enabling leading portuguese companies to increase their capacity to innovate in the sea economy arena. Due to the installed research facilities and its privileged geographic location, it allows fast access to deep sea, and can support multidisciplinary research, enabling full validation and evaluation of technological solutions designed for the ocean environment. This RI has been recognized by the FCT and included in the mentioned National Roadmap of strategic Research Infrastructures. The rest of this paper describes the platform in some detail, and presents some of the ongoing projects.

II. The TEC4SEA infrastructure

TEC4SEA is a vertically integrated infrastructure, in the sense that it possesses a set of skills and resources ranging from pure conceptual research to sea going missions, with strong industrial and logistic competences in the middle tier of prototype production. It can thus support researchers in all phases of technology development, from conception and theoretical analysis, to prototype development, field test deployments, and technology validation.

It is a geographically distributed infrastructure, with physical presence from the North to the South of Portugal. It is open to the entire scientific and enterprise/industrial community, with a free access policy for researchers affiliated with the research units that ensure its maintenance and sustainability. As a direct result of the nature of the founding partners and of the role envisaged for the infrastructure within PNOS, it is designed to serve not only the academic community, but also the industrial community, fostering and promoting R&D and technology transfer and, and helping the intended growth of a sustainable blue economy sector. The scientific objectives defined for the TEC4SEA platform are:

- To become a reference on experimentally-driven, multidisciplinary research on technology for the ocean, supporting research, development, and testing of new technologies along 4 major research lines:
  - Marine robotics, addressing the development of solutions for long term deployments, deep water operations, autonomous inspection and intervention, intelligent data harvesting, and safe operation of unmanned platforms;
  - Technologies and systems for underwater monitoring, namely fiber optic sensors and imaging systems for measuring physical, chemical and biological parameters and enabling smart infrastructures;
  - Broadband wireless communications systems for ocean environments, including radio systems for over water communications and acoustic, optical, and radio systems for underwater communications;
  - Acoustic systems for ocean monitoring and exploration,
- To support the specification and testing of draft standard technologies for the ocean environment;
- To support research in other scientific areas. Although devoted to support ocean technology, TEC4SEA is an asset capable of supporting research in other neighboring scientific areas;
- To integrate with international infrastructures. TEC4SEA aims at integrating with related and complementary RIs benefiting from the set up of new partnerships, and the attraction of new users;
- To support technical training of human resources as well as advanced education programmes. TEC4SEA is a unique environment that fosters the strict articulation, definition and dissemination of new technical training as well as education programmes.

A. Scientifc areas and resources

The dimension and depth of the Portuguese sea poses challenges in several scientific areas. Even though automation can, up to a point, mitigate the problem of dimension, as programs such as ARGOS [11] have successfully been demonstrating, operating autonomous (or remotely operated) vehicles in distant, deep waters poses problems in many distinct scientific/technological areas, from communications to energy harvesting and sensor development.

The same can be said when addressing the issue of deep sea observatories. These observatories are promising emerging tools to understand the ocean and the complex physical, biological, chemical, and geological processes taken place at the seafloor, and have been evolving rapidly over the last decades by means of programs and projects based on new instrumentation and permanent underwater networks. Current relevant on-going initiatives at global scale exist from: Canada (NEPTUNE [3] [4], North East Pacific Time-series Underwater Networked Experiments), USA (OOI [5] - Ocean Observatories Initiative), Japan (DONET [6] [7] - Dense Oceanfloor Network system for Earthquakes and Tsunamis), Taiwan (MACHO [8] - Marine Cable HostedObservatory) and Europe (through ESONET [10]-NoE- European Seas Observatory NETwork-Network of Excellence and recently with the infrastructure project EMSO - European Multidisciplinary Seafloor Observatory). These initiatives are typically based on sets of fixed nodes with a multitude of sensors that can be interconnected and also have cabled links to shore for real time data transmission. Although some of these initiatives are already starting to integrate emerging technologies such as mobile nodes, the concept of Autonomous Oceanographic Sampling Networks [9] is still in the early stages of implementation. In fact, although there are currently hundreds of mobile nodes in operation throughout the oceans (drifting buoys, underwater gliders, underwater autonomous vehicles), the persistent use of these assets and their seamless integration with long term observatories is still a topic of research and development.

Having been designed with these problems in mind, the TEC4SEA platform is highly multidisciplinary in nature. It brings together a set of laboratories, testbeds, equipment, and support facilities for experiments in controlled and real environments, with a special focus in four scientific areas, considered to be paramount for the problem at hand: i) Robotic systems, including autonomous and remotely operated vehicles, sensors and navigation/positioning systems, actuators and manipulation systems; ii) Communication systems, including overwater radio as well as underwater acoustic, optical and/or radio comms; iii) sensor development (mostly fiber optic based); iv) Acoustic systems for ocean monitoring and exploration. The most relevant existing facilities are:

- Laboratories of (a) robotics with test tanks, (b) optical/radio communications with access to an anechoic camera, (c) acoustic submarine signal processing and instrumentation development for submarine exploration, and (d) optical and image sensors, with access to infrastructure for fabrication of fiber optic based devices,

microfabrication (clean room), and optoelectronics instrumentation.
- ≻ Maritime wireless networks testbed with fixed stations and sea nodes deployed in fishing ships.
- ≻ Support facilities at Leixões sea port
- ≻ Robotic platforms capable of supporting different payloads, including buoys and aerial, surface, and underwater vehicles.

B. Provided services

As results from the broadness of its defined scientific objectives, the services provided by the TEC4SEA platform encompass a large spectrum of functions, which far exceed the primary mission of of supporting research, development, and test of technologies for marine operations. A strong focus (and a high percentage of its budget) is also put on technical and advanced training (including MSc, PhD, and Post-Docs), and on providing services to the industry, namely by providing technical staff and equipment. The main offered services are:

- ≻ **Access to the Optical and Electronic Technologies laboratory**. Supervised access to equipment that enables:
  - S parameter characterization of optoelectronic devices up to 20 GHz and electronic devices up to 50 GHz;
  - Bit error rate testing up to 13 Gbps;
  - Modulation / demodulation of RF signals using digital/analog modulations;
  - Modulation and detection of optical signals;
  - Antenna design and characterization;
  - Access to numerical simulation software Matlab;
  - Access to electromagnetic simulation software COMSOL Multiphysics;
  - Laboratory monitoring and support
- ≻ **Access to the Photonics Centre laboratory for sensing technologies**. Supervised access to equipment that enables fabrication, test and characterization of optical fibre sensors for detecting physical, chemical and biological parameters:
  - Fabrication: Fiber Bragg / Long Period Gratings, Interferometers;
  - Characterization: Spectroscopy, Interferometry, sensor test and calibration;
  - Types of optical sensors: Physical (strain, temperature, vibration, salinity, electric current); chemical (O2, Methane, CO2, pH, heavy metal); Biological (toxin, bacteria).
- ≻ **Access to the Photonics Centre laboratory for imaging technologies**. Supervised access to equipment for advanced imaging systems for structural and spectral analysis (functional and analytical characterization):
  - Optical Coherence Tomography systems
  - Hyperspectral systems based on compressive sensing technologies
  - LIDAR and imaging LIDAR systems
- ≻ **Access to the robotics laboratories for scientific and technological testing, acquisition of data sets, experimental runs and evaluation**. Supervised access to a test tank (Length, Width, Depth in metres: tank 1, 10L x 6W x 5.2D; tank 2, 4L x 4W x 2D) with vision ground truth equipment for:
  - Evaluation of underwater electronic equipment;
  - Evaluation of underwater navigation systems;
  - Evaluation of control strategies;
  - Underwater sensor integration and evaluation;
  - Underwater communications;
  - Developments in advanced perception systems for localization and mapping;
  - Teleoperation training.
- ≻ **Access to the field robotics mobile laboratory in open sea for scientific and technological testing, acquisition of data sets, experimental runs and evaluation**. Supervised access to sea area, equipped with acoustic ground truth system for non GPS positioning, underwater communication system, surface Wi-Fi infrastructure, physical and chemical sensors for probe calibration and support vessels for evaluation of:
  - Electronic equipment;
  - Navigation systems;
  - Control strategies;
  - Sensor response;
  - Communications;
  - Advanced perception systems for localization and mapping;
  - Behavioral modeling and evaluation of marine systems.
- ≻ **Mission support services**.
  - Mooring/recovering planning and execution;
  - Assembly of demonstrators in controlled and/or real environments to conduct custom experiments and tests, requiring customized set up and configuration;
  - Logistics support;
  - Possibility of conducting experiments related to: underwater acoustics tomography; communications and sediment characterisation; AUV Control Strategies; Environment perception methodologies; ROV operational evaluation; SLAM experiments; bathymetric operational methodologies.
- ≻ **Sub-contracted services**. Possibility to request R&D contracts in the areas covered by the research infrastructure to achieve specific results or to perform certain tasks. This might include the support and experimental testing of:
  - Underwater positioning and navigation
  - Wireless control of ROVs
  - Autonomous inspection/intervention;
  - Smart data sampling;
  - Long term deployments;
  - Electronic and optical devices and antennas;
  - Smart structures (instrumented with sensors);
  - Imaging systems for analytical monitoring.

C. Strategic alignment

As discussed in Section I, a great deal of effort was put into guaranteeing that the TEC4SEA RI was aligned with the PNOS, so that it might become an useful asset for the promotion of national blue growth. The PNOS was not, however, the only national strategy which was considered. In 2013, a revised version of the Portuguese National Strategic Defense Concept (PNSDC), the top level strategic document concerning the National Defense, was produced. A considerable part of this document naturally concerns the issue of military defense and of military forces and equipment. Considering that most of the ocean related technology can be used for security related missions, be it area/border control for illegal activity detection or full military surveillance and control, the alignment with the PNSDC was also pursued; in fact, the TEC4SEA is fully aligned with 6 of the 11 non-permanent national objectives

defined in this document. A cooperation protocol with the Ministry of Defense was signed, in order to enhance and facilitate collaboration for oceans multidisciplinary research and development, and empower the national business development of Dual Use technologies with application in the maritime economy and exploration potential in the global market.

At the european level, the alignment did not require any special efforts. Since the new PNSO was already fully aligned with the european relevant documents, namely the European Comission's Maritime Strategy for the Atlantic Ocean Area, and the latest version of its Integrated Maritime Policy, the strategic alignment at the national level mostly implied the alignment at the european level.

To ensure that this strategic alignment is kept over time, a Strategic Advisory Board was created within the management structure of TEC4SEA. It is constituted by all the relevant national policy makers, and, as such, will guarantee that the TEC4SEA infrastructure remains a strategic national asset, synergistically aligned with the surrounding environment, and the national efforts/objectives.

III. Projects

Even though many of the administrative details involved in the TEC4SEA setup are still being negotiated with the appropriate entities (and, notably, the financial negotiations with the national funding agency for science, research and technology), many activities are already under way, using both european and own funds. The selection and approval of projects is, naturally, subject to a competitive process, but it is safe to say that projects will be well positioned in this process if they contribute to at least one of the three TEC4SEA mantras, which stem directly from the need to respond to the previously discussed characteristics of the Portuguese sea: "*Automate*", "*Go deep*", and "*Do it safely*". As examples of on-going activities, we will present three typical projects, each one of them conceived to directly address one of these mantras.

- **Automate**
  An on-going project typical of the "automate tasks, as a mean to mitigate the dimension problem" is the european project *Sunny - Smart UNmanned aerial vehicle sensor Network for detection of border crossing*, whose aim is to contribute to EUROSUR (an information-exchange system designed to improve management of the EU external borders) by defining a new tool for collecting real-time information in operational scenarios, capable of improving the effectiveness of the EU border monitoring. It employs a two-tier, fully integrated, intelligent heterogeneous UAV sensor network, in order to provide both large field and focused automatic surveillance capabilities (see Figure 1). The TEC4SEA involvement in this project is mainly in the areas of architecture definition, network sensing, onboard processing, data fusion, situational awareness, and UAV to UAV Communications. This project is expected to contribute greatly to the platform competences and capabilities in these areas. It is a recent project (started in 2014), and no results are, therefore, yet available.
- **Go deep**
  The "go-deep, because our sea is even deeper" operational principle is well exemplified by project *TURTLE - Autonomous Support System for SubSea Operations*. As has been previously discussed, deep sea observation laboratories are still evolving, and much work remains

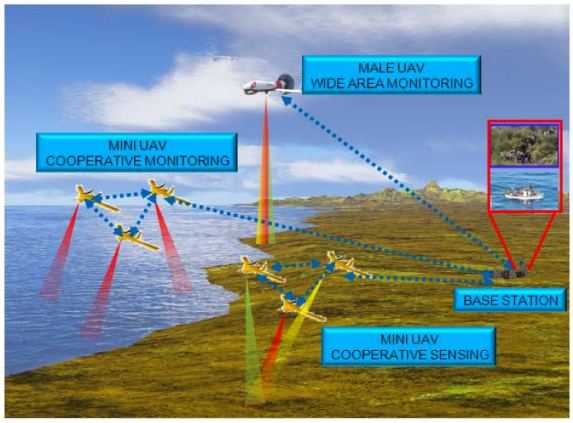

Fig. 1. SUNNY two-tier concept

to be done in this area. Hence, TEC4SEA aims at providing technology developers with a set of tools for speeding up the field testing of new concepts concerning persistent ocean observation systems. Unlike state-of-art fixed structures, we propose to so in a lightweight, relocatable manner, through a mobile heterogeneous inspection/monitoring network that supports developments of deep sea technology (see Figure 2. The TURTLE project

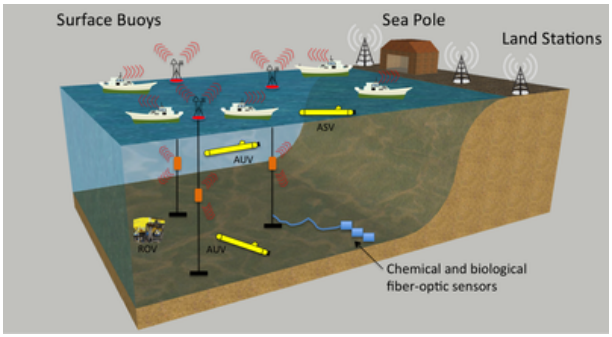

Fig. 2. TEC4SEA concept

is a first step towards this goal. The technology aims to produce new robotic ascend and descent energy efficient technologies, to be incorporated in robotic vehicles used by dual-use (civil and military) stakeholders for underwater operations, allowing underwater unmanned marine systems and robotics to operate at lower cost and added capabilities. The demonstration prototype is a large rigid structure, fit for use both as as general underwater observatory or as a docking station for UUV, and capable of very efficient robotic deep sea ascend and descent, allowing for easy redeployment. It therefore aims at developing key enabling technologies for a sustainable and long term presence in the ocean. This is a purely national project, involving the national industry, and is being funded by own resources. The dual-use potential of this project has been recognized by the European Defence Agency (EDA), which chose it as one (the first, in fact) of the research initiatives it supports to access European Structural Funds (ESF) [12].

- **Do it safely**
  The third operational principle is well represented by project *ICARUS - Integrated Components for Assisted Rescue and Unmanned Search operations*, an European project whose objective is to develop unmanned SAR technologies for detecting, locating and rescuing humans in catastrophe scenarios (see Figure 3). The TEC4SEA platform is responsible for the maritime component of

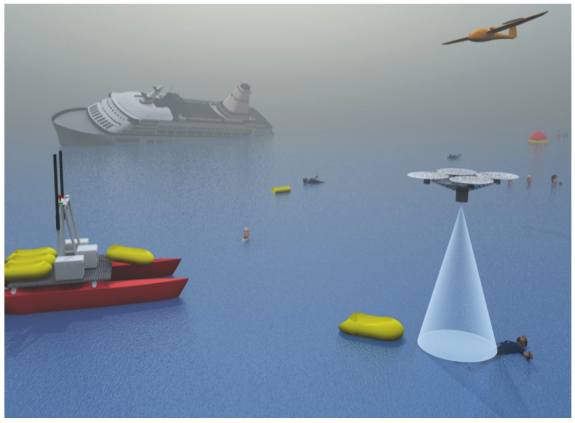

Fig. 3. ICARUS concept

this project, where a smart rescue capsule capable of autonomous detecting and approaching survivors at the sea surface was to be developed. The main contributions of the TEC4SEA platform were in the areas of capsule development, situational awareness, operator certification and training, and robotic platform coordination. This project is almost completed, with final demonstration and validation tests scheduled to happen within the next few months.

A fourth project which should be mentioned here is the *MARBED - MARitime wireless networks testBED* project, because it represents a different category of project, and one which is an integral and defining part of the supporting platform that TEC4SEA intends to constitute. In fact, the core of the MARBED project is not to develop any specific new type of technology or device, but instead, it aims at producing a testbed which adds to the support capabilities that TEC4SEA provides to the academic and industrial communities. It is thus, in essence, an enabler project, which will increase the ability of TEC4SEA to fulfill its mission, in this particular case, by providing adequate support to the existing challenges in the field of maritime communications. It is a maritime wireless networks testbed composed of two land stations and eight sea nodes deployed in fishing ships sailing within the coast line of the Porto Metropolitan area up to 10 nautical miles from shore (see Figure 4). The testbed has been up and running since April 2013 and in the short to medium-term will evolve to four land stations and thirty ships. In the long-term, the aim is to extend it further along the Atlantic coast of Portugal. For that purpose, protocols have already been established with industry and the Portuguese Ministry of Defence. Using MARBED some pioneer results on Wi-Fi maritime communications have already been obtained, which have shown the feasibility of Wi-Fi long-range maritime communications, but also the myriad of problems and challenges that still need to be faced in this new environment towards the Future Internet.

As a final note, the participation of TEC4SEA in the ERDEM commitment [13] should be referred. ERDEM advocates the pro-active engagement of scientists, industry, policy makers and organizations involved in deep-sea (and extreme environments) exploration, governance and management, to collaboratively develop a Sustainable Underwater Mining Framework. This is to be achieved through integrated management practices, technological breaker equipment and methodologies for exploration, exploitation and impact assessment activities, standards, conventions, guidelines and recommendations for the legal instruments required to achieve economically viable, environmentally sound and socially acceptable exploration and extraction of EU deep sea (and extreme environments) and sub-sea floor resources. The initiative is fully integrated in the European maritime and environment related policies and strategies, involving the appropriate stakeholders to demonstrate proposed advances, contributing to satisfy the European needs in highly critical mineral raw materials.

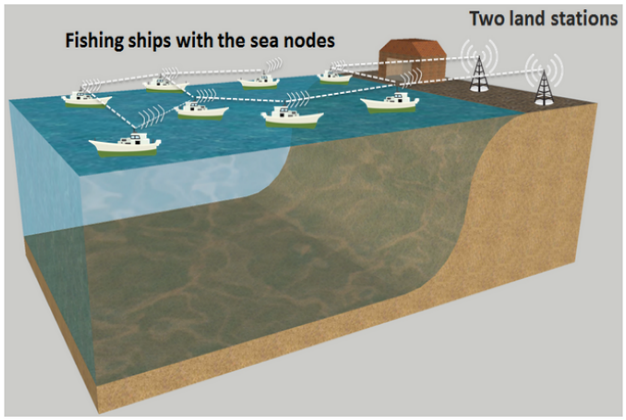

Fig. 4. MARBED present setup

A. Conclusions

A new research infrastructure (TEC4SEA) was created in Portugal, whose aim is to support research, development, and test of marine robotics. Being an open platform, accessible to the entire scientific and enterprise community, and due to i) its multidisciplinary nature; ii) its vertically integrated model, and iii) its privileged geographic location (with fast and easy access to deep sea), this research infrastructure is an interesting and useful asset, where researchers can find support for all stages of the process of developing marine robotics, telecommunications, and sensing technologies for monitoring and operating in the ocean environment. It is operational, and ready to fulfill its mission of supporting marine science and technology.

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