TURTLE – A robotic autonomous deep sea lander

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Abstract—**This paper presents a new concept for a deep sea lander system combining both sea bottom permanence characteristics with autonomous repositioning functionalities and efficient ascent/descent motion in the water column.**

The TURTLE hybrid lander is a particular type of autonomous underwater vehicle designed to act as sea bottom fixed observation node or in operations of transport equipment to the deep sea.

The paper discusses the general concept of operation and applications and also presents the developed prototype. This system was developed under a dual use EDA (European Defense Agency) project and with national and European funds. Considered as one of the dual use (civil and military) success stories, the demonstrator was equipped to sensors allowing both seismographic data gathering and acoustic monitoring applications.

Keywords— deep sea, landers, AUV, ocean observatories

I. Introduction

Robotics can provide effective tools to improve sustained presence in the sea. Deep sea exploration and exploitation rely in robotic systems for a large number of tasks.

In this work an innovative robotic system combining characteristics of standard sea landers with autonomous underwater vehicles is presented.

Autonomous presence can be achieved with cabled observatories [1] [2] or with multiple mobile and fixed systems such as AUVs and sensors [3]. In the long term monitoring and observation tasks, seabed landers [4] provide a relevant tool for deployable and reconfigurable observer nodes. These systems comprise in general a sensor payload connected to a local datalogger, a disposable weight and an acoustic release allowing for retrieval of the lander. For redeployment a support vessel is required, increasing the operational costs of multiple location observations. In addition, the there is little control on the landing spot both in terms of final position accuracy and in the characteristics of the local seabed. In alternative, apart from fixed cabled nodes, when local precise information gathering is required ROV systems (or AUVs for particular cases) are used. However the ROV operation is not compatible with long term observation and for deep waters the operational requirements are very high.

A possibility of combining reposition on the sea bottom with reduced operation costs comparing with ROVs is the use of autonomous robotic crawlers [4]. These can provide mobility in the seabed. However still have limitations in terms of autonomy (due to the locomotion process) and high requirements for launch and recovery.

Other type of activity in the deep sea is the support to undersea operations and in particular the deployment and transport of equipment to and from the sea bottom to the surface. AUV based approaches [5] have been used in order to reduce the operational requirements of the use of traditional work class ROVs. A relevant application need for robotic means is thus the transport and precise positioning of cargo in the deep ocean bottom.

The TURTLE robotic deep sea lander combines both the locomotion and autonomy capabilities of an AUV with long term permanence at the bottom functionalities from traditional landers.

One of the key aspects of the TURTLE robot is the capability of perform efficient dives. This is achieved by the use of a variable buoyancy system. Variable buoyancy systems are used in highly energy efficient AUVs such as underwater gliders [7] or for buoyancy trimming in large ROVs [8]. Typically the glider VBS systems use oil based solutions with very small buoyancy changes. The system developed for TURTLE is water based allowing for large volumes of displacement, in order to allow for the vehicle to gain sufficient weight to remain stationed at sea bottom.

The TURTLE system design goals were dual use (civil and military) applications in the deep sea, both in equipment positioning or in station keeping observation at the sea bed. Security examples of these missions are acoustic monitoring for harbor protection, marine observatories or seismic studies.

TURTLE was one of the EDA (European Defense Agency) dual-use approved flagship projects and was partially funded by Portuguese funds. It was led by a portuguese company A. Silva Matos in close cooperation with INESC TEC as scientific and technological robotics partner, the Portuguese Navy and the mechanical engineering company Ply Engenharia. The project and system correspond also the results of a technology transfer process, that takes into consideration the necessities and requirements of the economy of the sea and in particular of the characteristics of the Portuguese sea (large and with high depths).

II. Vehicle operation

The system can be either deployed from a traditional support vessel or, when the distance is adequate to be towed with a small support boat to the diving place. When at the surface, the vehicle is buoyant allowing for easy maintenance tasks and wireless communications to the onboard computers. For diving the vehicle uses its variable buoyancy system to gain weight and thus avoid the use of thrusters.

Once near the sea bottom the vehicle can adjust its positioning using a set of thrusters. Once deployed the onboard computer has the possibility to select the systems to be powered and the vehicle can remain stationed on the bottom gathering data (either continuously, at a programmed rate or depending on events). When it is needed to relocate the vehicle in the area, the onboard thrusters can be used to reposition itself without a surface operation.

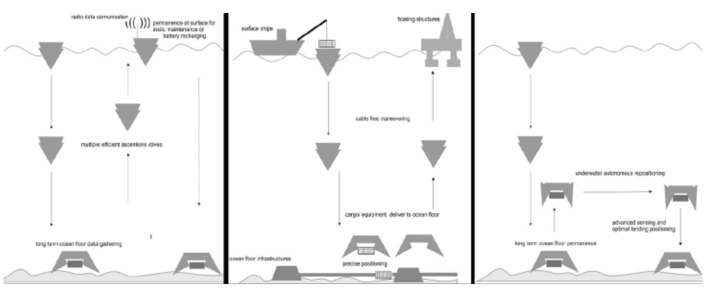

Fig. 1. Concept of operation

For ascent the vehicle changes its buoyancy. This process allows for efficient dive and for the possibility of performing maintenance and data download at high rates in the surface without the need of a special vessel equipped with a crane to take the vehicle of the water. The designed hotel payload allows also to use the system in diving operations that combine the descent/ascent characteristics with the thruster based fine positioning at the sea bottom to deploy cargo at depths.

The TURTLE system was designed taking in mind three main application missions: efficient transport of equipment to and from the sea bottom, long term permanence at the bottom (for example acting as a re-locatable observatory) and support of operations in deep sea.

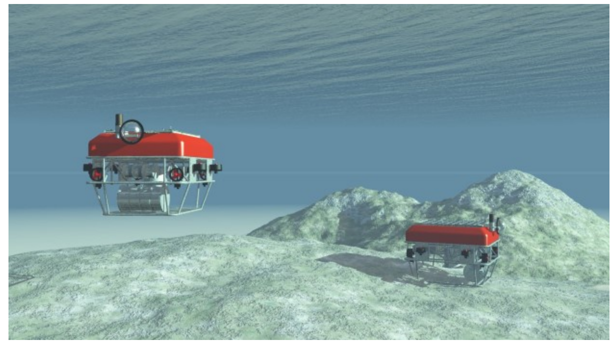

Fig. 2. Transport to/from sea bottom and long term permanence

Equipment transport in the water column and precise deployment at the sea bottom (Figure 2), can be achieved with energy efficiency due to the VBS operation and the autonomous navigation and locomotion capabilities.

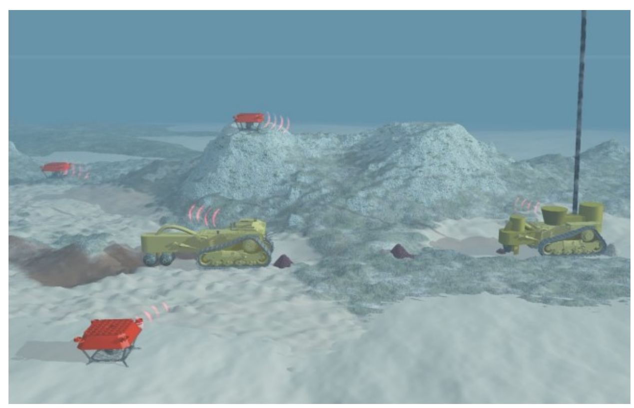

Fig. 3. Support of operations at sea bottom (exmaple of mining operation)

The use of multiple TURTLE systems deployed in an area of operations can also provide a navigation support acoustic network for intervention at the sea bottom (as depicted in Figure 3 for mining operations). Since the vehicles are capable of relocating themselves the support network can rearrange itself according to the area of intervention and to the best topology for positioning of the relevant assets.

This autonomous locomotion capability allows for continuous adaptation to the area of operation without the need to redeploy localization means, such as when using a bottom fixed set of beacons in LBL based localization.

In addition, the autonomous deploy provides also operational advantages in terms of required support ships at the surface.

III. TURTLE PROTOTYPE

A. Mechanical design

The vehicle was designed (Figure 4) in order to have a payload area at the bottom allowing modular interchange of hotel payloads according with the mission objectives.

It has 8 electric thrusters (providing full actuation) with 4 of them in the vertical allowing for smooth landing control and repositioning of the vehicle with the VBS (Variable Buoyancy System) system with negative buoyancy.

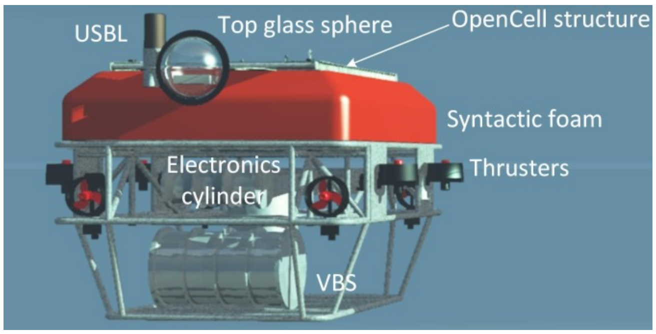

Fig. 4. TURTLE mechanical design

The main mechanical structure is based on two *OpenCell^{TM}* [9] plates and additional steel structures.

OpenCell^{TM} structures are used in the aeronautics industry allowing for high structural integrity and mechanical support with reduced weigh.

Syntatic foam is used to provide buoyancy for the vehicle net weigh and hotel payload.

Energy is provided by a set of LiFe-Po batteries providing 8KWh of energy in its base configuration. These batteries are pressure tolerant thus reducing the need of pressure canisters with relevant weight gain.

The Variable Buoyancy System is constituted by a high pressure water pump allowing for operations at 6000m depth and a water/air tank providing up to 50 kg of variable buoyancy.

Two glass spheres are used to house wireless communication equipment when at surface and optional payload on the bottom such as cameras for bottom observation.

The prototype has 1400kg of weight in its neutral configuration with 200kg of payload.

Initial prototype (see figure 7) was designed for 1000m depth rating (although most of the system components are already developed for higher depths). This design is also a result of the phased plan in development and validation of the technology transfer with the final objective of 4000m of depth rating.

B. System architecture

The TURTLE system is composed by the robotic lander itself and a support system at surface (Figure 5).

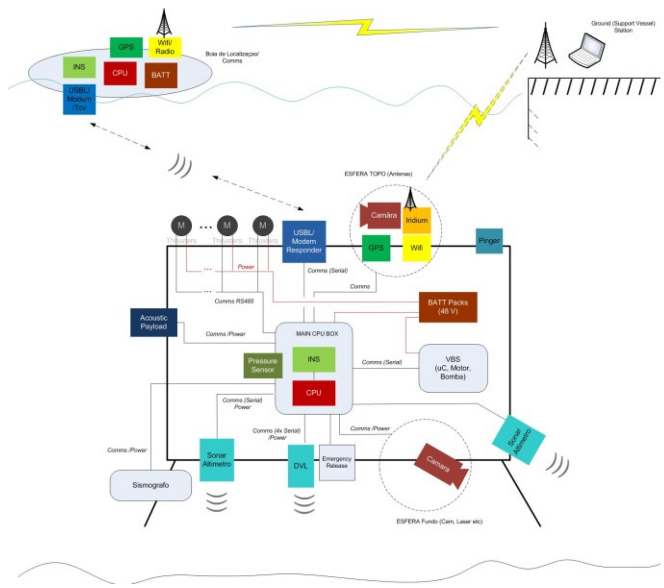

Fig. 5. System architecture

The support system at surface is used when the vehicle is within range either of radio communications when at surface or of acoustic communications when the vehicle is underwater. It has an USBL transceiver for positioning and tracking and an acoustic modem. The vehicle can also operate without this surface system, completely autonomous.

The vehicle has an embedded computer providing mission control, navigation and guidance in the main electronics cylinder.

When submerged the navigation is provided by a pressure sensor, a FOG INS system and a Doppler Navigation Log sonar. These sensors provide information for the navigation filter with the external USBL system providing position fixes (transmitted from the surface by an acoustic link) when available.

The vehicle has also a multibeam sonar for close terrain navigation and aiding in the landing process.

The VBS system embedded controller communicates to the main CPU providing status information and receiving trimming commands.

In addition to the thrusters and the VBS a safety weight release mechanism is also present to provide vehicle emersion in an emergency. This safety mechanism can be activated either by a dedicated controller or passively with the predefined timed corrosion mechanical latch.

Both acoustic payloads (for sound recording and event detection when in station at sea bottom) a seismometer are used in example applications such as security missions of civil seismic studies.

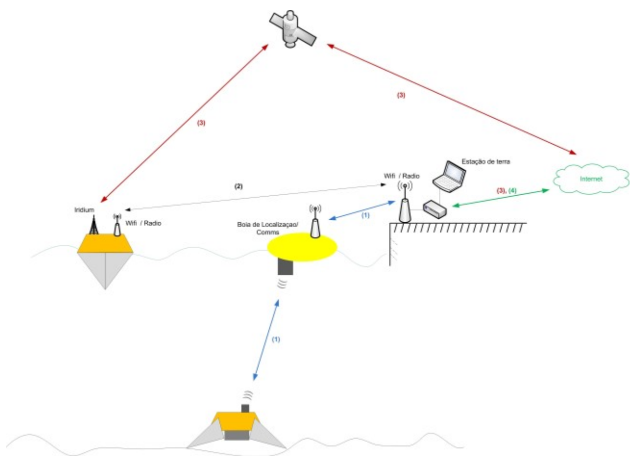

Fig. 6. System communications

A top glass sphere houses a GPS receiver for position fixes when at surface and 3 wireless communication subsystems: a WiFi card for close range communications, a long range RF modem and an Iridium satellite modem for communications when out of support areas at the surface.

When submerged the vehicle uses an acoustic modem (Figure 6) for communications with the surface, if the support system is within range (8km).

IV. Preliminary Field trials

The vehicle prototype upon preliminary tests at the INESC TEC robotics lab test tank, was first tested at Leixões harbor in the north of Portugal (Figure 7)

Fig. 7. Vehicle prototype in sea trials at Leixões harbour

A set of missions with deployment, autonomous dive and ascent were performed near Sesimbra, Portugal (Figures 8 and 9).

Fig. 8. TURTLE at surface in Sesimbra

Vehicle positioning with the USBL system was tested at low depth (up to 20m) in addition with autonomous control and navigation.

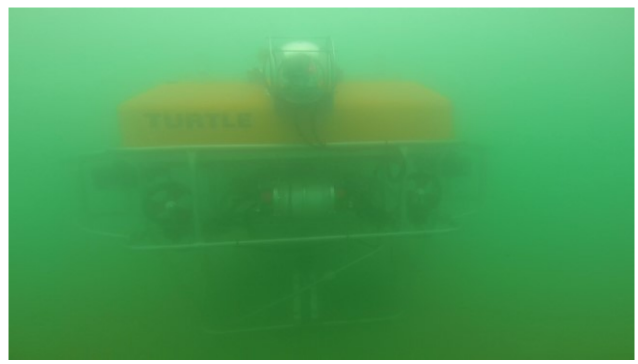

Fig. 9. TURTLE deployed in sea bottom (low depth in Sesimbra area)

It was also verified the deployment for short ranges with the vehicle being towed at surface with a small rib boat, upon deployment to the water from the pier. In addition the Portuguese Navy NRP Zarco provided local operations support).

System validation for deep sea missions is planned to occur at Setubal canyon in the south of Portugal.

V. Conclusions

An innovative robotic hybrid lander for deep sea operations was developed and a system prototype was also tested at sea.

This system allows for efficient ascent and dive in the water column using a variable buoyancy system designed for the purpose.

In addition to the cargo transport and positioning to the sea bottom, the system is capable of having long term permanence at the bottom acting as an observatory node and also of being able of repositioning itself upon command or in a pre-programmed way.

It also allows for navigation support of operations in deep sea by allowing the implementation of a network of movable acoustic beacons.

The TURTLE robot prototype was built by a consortium led by A. Silva Matos, a Portuguese metalworking company in partnership with INESC TEC, the Portuguese Navy and Ply Engineering, being an example of success high technology transfer and economic value creation.

This initial prototype is part of phased plan to develop similar systems up to 4000m of depth rating corresponding to a vast majority of the Portuguese sea area depths. In this context, both the development and validation of a 4000m depth capable system is in the next steps along with the immediate plan of validate a network of TURTLE systems working at 1000m depth.

Acknowledgment

The authors acknowledge the financial support from National Funds through the FCT - Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) as part of project UID/EEA/50014/2013 and from Project "Coral - Sustainable Ocean Exploitation: Tools and Sensors/NORTE-01-0145-FEDER-000036" is financed by the North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, and through the European Regional Development Fund (ERDF).

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