P2-ROV a Portable/Polar ROV

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***Abstract*—P2-ROV is a portable polar ROV. Designed to be transported via-helicopter and easily handled by a small team of scientists it is specially addressed to work under the shelf ice of Antarctica by exploiting the holes drilled in the ice by means of a special 350 mm auger; the shape of the vehicle reminds that of a torpedo contained in a 340 mm diameter.**
Highly automated, P2-ROV is designed to work in hovering in order to monitor the peculiar Platelet Ice and to collect biological samples. For this purpose it will be equipped with a mechanical arm with an embedded suction pump which permits to collect larvae and fish eggs of the species that live and breed in the Platelet Ice. During these operations P2-ROV is remotely controlled, with a tether that transmits mutual information and electrical power, by operators safely standing on the Pack Ice.
P2-ROV, light and manageable, is highly modular thanks to the open-frame chassis that allows for quick installation and shifting of tools, equipment and sensors. Even thrusters are interchangeable and displaceable modules. In this way the vehicle can be reconfigured at every mission according to the specific needs.

I. Keywords

Marine Robotics design, modularity, modular, ROV, AUV, Portable, Polar Science, Silverfish, Antarctica

II. Introduction

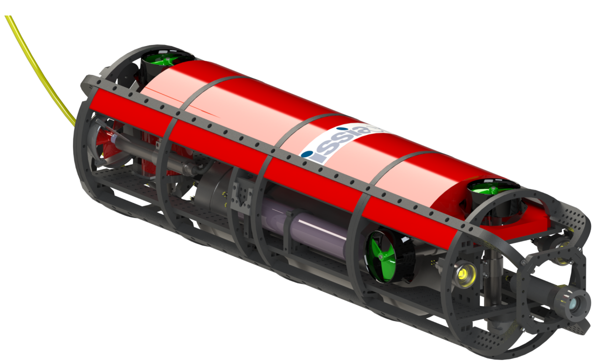

Fig. 1. P2-ROV design

P2-ROV, Portable-Polar Remotely Operated Vehicle, arises from the project POLE, funded by the PNRA (Italian National Program of Antarctic Research) which is a pioneer implementation of the ecorobotics paradigm. POLE integrates ecological approaches and robotics to develop technological tools for persistent monitoring and targeted sampling of biological structures in the polar marine environment. POLE (Fig.2) involves marine robotics and automation technology for the persistent monitoring and the targeted sampling of biological structures into the Antarctic Ocean with the aim of studying the processes of formation of the peculiar Platelet Ice and the spawning of the Antarctic Silverfish (Pleuragramma Antarctica).

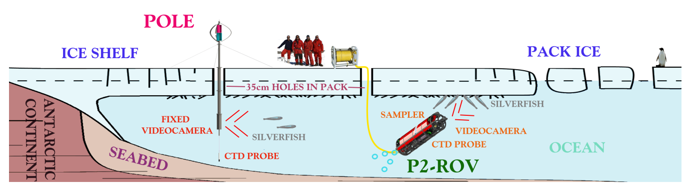

Fig. 2. POLE Project schematic explanation. Two systems are used: an automated pole for the persistent observation of the bottom surface of the pack and the collection of basic environmental parameters during Antarctic winter and an ROV for the targeted sampling of biological structures.

POLE project is based on the assumption that marine robotics has proved its effectiveness in exploring, sampling and monitoring the polar sea environment, e.g. ice profile, benthic habitat and sea-air interface in different campaigns. Examples are given by the under-ice operations carried out by Gavia AUV [1] and MIT Odyssey AUV [2], by the ALTEX Arctic Cruise [3] carried out with MBARI Dorado AUV and the exploration of floating extensions of Antarctic ice sheet by NOC Autosub3 [4]. The adoption of hybrid vehicles as Nereid-UI [5] shows how robotic research is increasing its operativity. The most recent example of marine robotics application in polar science is SCINI ROV [6], a vehicle with characteristics similar to P2-ROV and originating from the same kind of requirements as shown in [7].
Robotics is especially necessary where human limits are reached and the safety is just ensured by the presence of a good equipment. As hinted by a recent survey of underwater robotic vehicle design for under-ice operations [8] that showed the potential for robotic under-ice scientific surveys, new and improved approaches to the design (and navigation) of underwater vehicles is required. In particular the vehicle design has to be targeted on the type

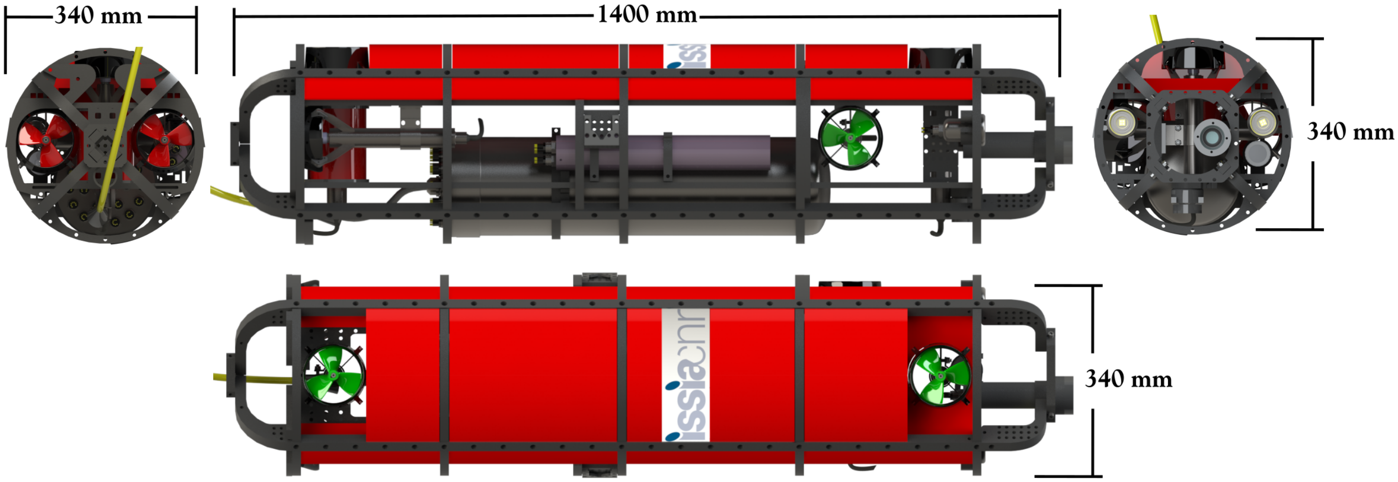

Fig. 3. P2-ROV design and dimensions

of survey to carry on and should undergo to adequate suggestions coming from experience.

P2-ROV is developed by CNR-ISSIA which polar marine robotics research has mainly focused on the development and exploitation of the Romeo ROV [9] and of Charlie USV [10]. Romeo was used during under ice-cap benthic exploration and survey [11] (also through remote tele-operation [12]) and in the ROV-operated deployment and recovery of a benthic chamber [13]) while Charlie was used for sampling of sea surface micro-layer [14].

In 2013-2015 the use of CNR-ISSIA customised commercial mini-ROV for sampling of Antarctic Silverfish eggs and larvae [15] (PNRA project RAISE), and of the Shark USV for data collection in the proximity of Arctic glaciers for the study of air-water-ice interface [16] (Project ARCA) proved the effectiveness of portable UMVs for polar applications where light logistics is a key requirement suggesting the need of developing suitable equipments like P2-ROV.

P2-ROV is designed with a special eye on functionality and usability in harsh and remote areas on the basis of these experiences. In the more risky environmental areas where it allows for a safe operative behaviour the vehicle can be remotely controlled by a small team of operators which, safely standing on the Pack Ice of Antarctica on land or on a boat, can communicate with the vehicle with a high bandwidth fibre-optic tether that transmits mutual information and electrical power.

The aim is to give the scientists a fundamental tool that could be used to easily perform different type of analysis/sampling/survey in marine research in the Polar Regions.

III. VEHICLE DESIGN

As mentioned before CNR-ISSIA experienced in different Polar campaigns acquiring more informations regarding the requirements in the design of polar robotics.

P2-ROV is a Portable/Polar unmanned underwater vehicle expressly designed for polar explorations where marine tools have to be portable, easily deployable, repairable and reconfigurable for the different missions.

P2-ROV belongs to the newest class of hybrid underwater vehicles capable of working both in the remotely controlled configuration with a tether cable (ROV) and autonomously without a tether cable (AUV).

P2-ROV design is shown in Fig.3, it is characterised by a torpedo shape and an open-frame structure. The vehicle is 1400 mm long 340 mm wide and 340 mm high with a weight of about 40 kg.

In operations that require a reduced logistics and a high degree of modularity the idea was to realize a vehicle that could be easily transported by hand by two operators but also via-helicopter or on a snowmobile with little effort.

In particular P2-ROV dimensions are studied to access under the thick layers of the ice sheet of Antarctica by exploiting the holes drilled in the ice by means of a special hand-auger which diameter is 350 mm.For this reason a the torpedo-shape is chosen for its perfect matching with this operational requirement.

Since a classical torpedo peripheral cylinder is usually a closed structure it is hard to think that a structure like this can become ”flexible and easy to use”. For this reason we decided to use an open-frame structure similar to the one adopted by the classical ROVs.

Adopting an open-frame structure P2-ROV became modular and highly reconfigurable. It's easy to add or remove tools from the vehicle and to change the position of sensors, camera, lights and what else is present on the vehicle.

This concept follows the road of new class of reconfigurable vehicles based on the concept of flexible and shockproof chassis outlined by the recently-born vehicle of CNR-ISSIA named e-URoPe.

Highly automated and controllable in the six DOF by means of five thrusters, P2-ROV is designed to work in hovering in order to monitor the required polar parameters as the formation of the Platelet Ice in Antarctica or the ice melting in the Arctic glaciers and to collect biological samples.

For this purpose it will be equipped with a mechanical arm with an embedded suction pump which permits to collect larvae and fish eggs of the species that live and breed in the Platelet Ice.

P2-ROV, which characteristics are shown in Table I is supported by a plastic main frame, composed by assembled elements, able to receive and carry the main parts constituting the vehicle: electronics, motors, buoyant foam, lights, sensors etc. The core of the vehicle is a stainless steel cylindrical canister containing the electronics of control, communication and AHRS. As shown in 3 P2-ROV is equipped with five propulsion modules, two thrusters for propulsion in the horizontal plane, two vertical thrusters for heave and for pitch control and one bow thruster for manoeuvring. The thrusters allow the vehicle to move at 0.7 m/s with 200 m of underwater tether.

The vehicle maximum depth is limited to 250 m, a good compromise between the operational needs and the logistics requirements.

These dimensions allow the vehicle to be operated from small vessels or from remote camps by a dedicated crew of 2/3 people.

The buoyant foam, situated in the upper part of the vehicle, is composed of modular elements of PVC foam adapt for re-calibration/balance of weights. Thanks to this solution the vehicle is always passively stable in pitch and roll.

TABLE I. P2-ROV CHARACTERISTICS

Main Characteristics		
Type	Open Frame Hydrid AUV/ROV	
		Vehicle
Length L	$[mm]$	1400
Breadth B	$[mm]$	340
Height H	$[mm]$	340
Weight	$[kg]$	40
Maximum Depth	$[m]$	250
Rated Speed	$[m/s]$ $at200[m]$	0.7
Single Propeller Thrust	$[N]$	38
Vertical Thruster	nr	2
Main Thrusters	nr	2
Transversal Thrusters	nr	1
Power and Electronics		
ROV Communication	2GBit - Fiber Optic Ethernet	
AUV Communication	Acoustic Modems	
Maximum Power	$[W]$	600
AUV Autonomy	$[h]$	2
Native Payload		
CTD Probe	nr	1
Echo Sounder	nr	2
LED Lights	nr	4
Video Camera	nr	2
IMU		1
Additional payolad capacity	[kg]	10

IV. MODULAR DESIGN

P2-ROV main design requirements were to fit through a 350 mm hole in the ice, and to be easily deployed and serviceable in polar harsh environment conditions. The size limitation was set by the diameter of PNRA available auger and by the need of transportability on a helicopter. Therefore we opted for a torpedo shape associated with a modular design which allows for reconfiguration in operations different from the ones providing the access in the holes and requiring bulkier vehicles.

The buoyant element of the vehicle is positioned at the top of the frame allowing a good reconfiguration of the lowest part together with a good intrinsic stability.

The frame is made of HDPE, a light and shock-proof material resistant to low temperatures and suitable for damping of the standard stresses and vibrations caused by daily transportation with snowmobile or helicopter that could cause damage to the internal equipments. The frame,

Fig. 4. Essential P2-ROV frame

designed through a 3D CAD software and scantled through a FEM linear and non linear analysis (due to its plastic nature), is composed by flat elements obtained from HDPE sheets by using a CNC milling machine (fig.5). As shown in 4, the essential frame in constituted by four longitudinal elements positioned on a circumference at 90° connected by six (or more or less) transversal circular sections and one bow and one stern transversal elements closing the structure. The internal elements that can be added to this structure are flat plates or circular supports used to connect the various elements. The choice of a modular

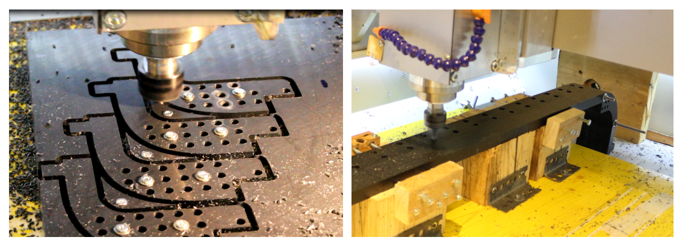

Fig. 5. CNC-milling of HDPE for P2-ROV frame

frame is the daughter of the experience of CNR-ISSIA with the ROV/AUV e-URoPe. Every element is widely predrilled with a pitch of 25 mm with a standardized 6 mm hole dimension and all the pieces are assembled together by means of standard M6 bolts as shown in Figure 6. In this way it is elided every ambiguity on future designs of payload or additional frame elements. With this solution the logistic is minimized to some small portable tools that can be easily transported during polar missions.

This modular chassis allows to insert additional elements to adapt the vehicle to the different needs coming from the manifold type of mission and the actual indications arising from the environment: it is possible to easily modify the position of sensors and cameras, to add more payload, modify the frame and even move the propulsion units.

V. PROPULSION SYSTEM AND STANDARD LAYOUT

The propulsion system is constituted by five thruster modules. Two modules, one per side, are positioned astern and provide for the forward thrust. Two vertical modules, one fore ad one aft, are used to control the vertical motion and for the pitch control during surveys under the

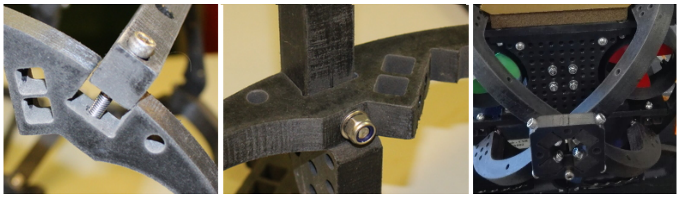

Fig. 6. P2-ROV bolted connections

pack-ice. One horizontal bow thruster is used for a better manoeuvring in the horizontal plane.
The thrusters are interchangeable and displaceable modules especially designed by CNR-ISSA. These can be moved in different configurations thus allowing for different positioning of the propulsion units in function of the requirements.
Each thruster consists of a 4-pole DC brushless motor (120 W at 36 V) with the corresponding encoder and planetary gearbox and is coupled with a three-blade propeller.
The propulsion unit is constituted by an external titanium jacket containing bearings, shaft, a flexible coupling and an aluminium internal cylinder supporting the motor. The solution permits to achieve lightness and thinness (fig. 7) and the external pressure is compensated by a strong structure. The rated maximum operating depth of these propulsion units is 500m.
The water tightness is ensured by a mechanical seal on the shaft side and a pouring of resin on the cables side.

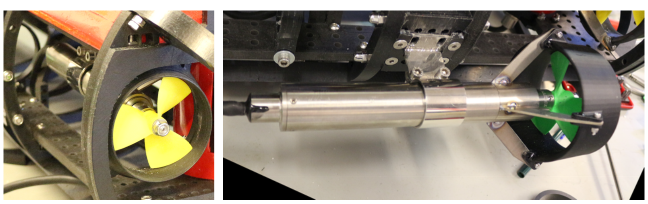

Fig. 7. P2-ROV Propulsion units

The thrusters are designed to allow the vehicle to reach a speed of 0.7 m/s with 200m of cable. To achieve this result we performed a drag prediction on the basis of [17]. When working in AUV configuration or in shallow water the maximum rate of drag comes from the vehicle's itself friction. At higher depth the tether drag becomes more important and thus it was necessary to assess the operative limits in function of the tether length as show in Fig. 8. To guarantee the required performances we studied

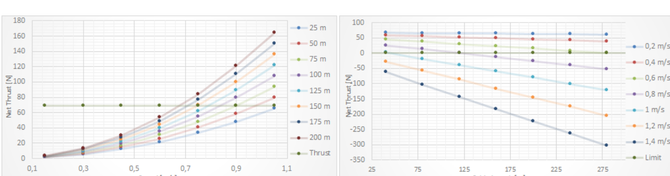

Fig. 8. Net thrust in function of tether length at different current speed

propellers of the Wageningen Ka series ([18]) for their good behaviour at low speeds. Due to the small speeds of the vehicle and the functioning in the four quadrants it was necessary to adopt the C_t and C_q to study the propeller.
The chosen thrust propellers are Ka 3-0.65 with P/D=0.94 and a 19A kort nozzle while manoeuvre thrusters have a 37 kort nozzle.
The propellers and the kort nozzles were built in ABS using a CNR-ISSIA 3D printer. During the design the propeller blades were reinforced at the root to obtain a stronger element.
The propellers were tested in laboratory to check if the performances were preserved after re-design and in presence of uncertainties coming from a 3D printed model. The resulting thrust obtained in the tests was acceptable even if lower than expected one. This maybe due to the uncertainties resulting from the 3D printing. Further analysis on these aspects will be carried on.

VI. ELECTRONIC CONTROL SYSTEM, POWER AND COMMUNICATIONS

P2-ROV is a Remotely Operated Vehicle (ROV), with an open-frame structure, connected by means of an umbilical cable to the operator station. The tether, that can be deployed and retrieved through a portable and electrically actuated winch, transfers both power supply and data and video signal. Despite its ROV nature it is foreseen the possibility of transforming P2-ROV into an un-tethered Autonomous Underwater Vehicle (AUV). Exploiting its modular nature it is possible to add a battery pack to the vehicle removing the tether. The on-board computing system (Fig. 9) of P2-ROV is

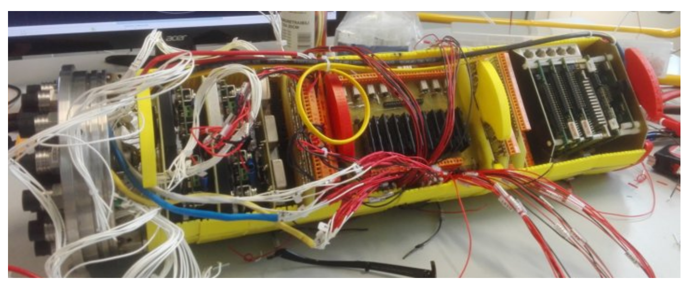

Fig. 9. The electronic core of P2-ROV

installed in a movable stainless steel canister based on a SBC (Single Board Computer) and three PC/104 modules providing digital input/output, analog input, analog output and serial input/output respectively. The canister contains DC-DC converters, motor servo-controllers and optic-fibre transceivers. The I/O channels allow the SBC to communicate and interact with the manifold sensors and actuators installed on the vehicle. Underwater connectors are present for: optical-fibre, motor control, power supply, network, CTD probe, echo-sounders, LED lights, cameras, IMU, VGA, USB and possible payload.
The total power supply is demanded to a system of highly advanced small and efficient EMI Class B AC-DC converter contained in an aluminium anodised canister that can be moved on the vehicle to better balance the

intrinsic stability.

The dry control unit (Fig.10) is contained inside an IP67 special luggage and is primarily composed by the power supply board used for all devices. The luggage contains the multiplexers (analog and ethernet fibre) connected to the two optical fibres of the tether and to a 1 Gbit ethernet switch used to distribute the robot net. A VCR is used for the three analog cameras signals which are displayed on a high brightness industrial lcd monitor used to control the vehicle when operating underwater or under the pack-ice.

Fig. 10. The control unit

VII. PAYLOAD AND DEVICES

A basic sensors and tools set is contained in the chassis of P2-ROV. Four necessary led lights are positioned on the bow of the vehicle to well operate under the ice sheet or at higher depths. Two pilot camera are used to control the vehicle and an observation camera is used to detect or track biological structures like silverfish larvae or eggs. Two echo sounders are used as depth-meter. One is used for measuring the distance from the bottom and one is used to measure the distance from the above standing ice surface of Antarctica.
The standard payload is completed by a multi-parametric probe with Conductivity, Temperature and Density sensors.
The modular structure allows for the adaptation of different sensors and tools. Modules of frame elements can be added to the main chassis. For example a module for a robotic arm with an embedded suction pump which permits to collect larvae and fish eggs of the species that live and breed in the Platelet Ice can be jointed to the frame.
The vehicle can also act as a semi-submersible vehicle able to tow Multi-Parametric probe and samplers.

VIII. NAVIGATION, GUIDANCE AND CONTROL

The navigation, guidance and control system is composed by a set of modules that can be flexibly interconnected in such a way to on-line select the desired or most proper configuration for the specific mission. The overall control architecture relies on an embedded real-time platform , based on GNU/Linux and PC compatible hardware, already successfully employed for previous CNR-ISSIA's robotic prototypes.
The modules are based on a kinematic and dynamic modelling of the robotic platform. The vehicle is characterized by full actuation on each of the 6 DOF but only surge, sway, heave, pitch and yaw motions are controlled, leaving and roll motion free of control given its intrinsic stability.

IX. CONCLUSION AND FUTURE DEVELOPMENT

Fig. 11. P2-ROV in sea trials

P2-ROV originates from the necessity of creating new robotic tools to support the research in Antarctica. Polar science is hugely important to help us to understand how the Earth works and how its inhabitant behave and evolve. Scientists are focused on key issues such as weather and climate and the impact on human societies on the earth. Usually the methods used by the scientists for survey and sampling that prove to be portable and functional are not effective or efficient and usually the research in remote areas becomes a cost and not a result. The use of robotic tools allows to increase the effectiveness of the survey and sampling and the usability of the data collected. In this optic portable tools like P2-ROV that becomes usable by a small team of scientists may be the best compromise for the scientists. The sought solution kept an eye on portability and usability in harsh environment but also on operational requirements in terms of logistics, reconfigurability and maintainability. The latter requirements come from the experience of CNR-ISSIA in different campaigns in harsh environment (e.g [12]: Romeo in Antarctica, Charlie in Antarctica and Shark at Svalbard). [11] Charlie in Antarctica [19], Shark at Svalbard [16]).
The adoption of the latest technologies like plastic materials, 3D printers and CNC milling machines has allowed to adopt new solutions that permitted to increase the production speed and to investigate various set-ups with a low effort.
Starting from the experience of the ROV/AUV e-URoPe, CNR-ISSIA has designed P2-ROV, a vehicle which is light, shockproof, highly controllable, highly modular and reconfigurable.
The concepts resulting from the design of P2-ROV showed how an open-frame torpedo-shaped ROV can become the base for the development a new class of portable vehicles

which are modular and studied for harsh environment. With its modular and highly reconfigurable structure P2-ROV suggested to extent the concept to more than just the under-ice world.
The design of P2-ROV originated the concept of a family of modular, reconfigurable and manageable robots, that CNR-ISSIA is nowadays developing. This can be reconfigured to become a robot with a different nature. Starting from an ROV(Remotely Operated Vehicle) we can transform the vehicle to have an AUV (Autonomous Underwater Vehicle) or a USSV (Unmanned semi-submersible Vehicle) or and USV (Unmanned Surface Vehicle).

X. Acknowledgements

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