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Planetary Stations and Abyssal Benthic Laboratories: an Overview of Parallel Approaches for Long-Term Investigation in Extreme Environments

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ABSTRACT

In spite of the apparent great differences between deep ocean and space environment, significant similarities can be recognized when considering the possible solutions and technologies enabling the development of remote automatic stations supporting the execution of scientific activities.

In this sense it is believed that mutual benefits shall derive from the exchange of experiences and results between people and organizations involved in research and engineering activities for hostile environments, such as space, deep sea and polar areas.

A significant example of possible technology transfer and common systemistic approach is given in this paper, which describes in some details how the solutions and the enabling technologies identified for an Abyssal Benthic Laboratory can be applied for the case of a lunar or planetary station.

INTRODUCTION

As recently highlighted by the European Space Agency (ESA) Lunar Study Steering Group, the utilization of the Moon offers a wide range of possibilities, for a better understanding of the Moon itself, of the Earth-Moon system, of the history of the solar system, as well as an improved potential return for astronomy and later on for life science activities and research into artificial ecosystems. On this regard three possible categories of scientific activities for future lunar missions can be envisaged:

- Science of the Moon, covering determination of physical, chemical, and geological characteristics of lunar surface and internal structure;
- Science on the Moon, dealing with questions relating human activities in space and development of artificial ecosystems;
- Science from the Moon, including specific areas in astronomy that can be better studied from the Moon than from satellites or Earth.

These activities call for the availability of dedicated stations, capable of operating autonomously for long periods and carrying out a wide number of scientific tasks. A similar approach is being studied for the study of underwater abyssal environment.

THE CASE OF THE ABYSSAL BENTHIC LABORATORY

As for the lunar environment, knowledge of deep sea bottom and related processes (physical, chemical, biological and geological) is still quite limited, but at the same time the demand for the execution of research activities at depths below 4000 to 6000 meters is growing and wider ranges of scientific needs are being identified. What is lacking nowadays is the possibility to go deeper in the ocean and conduct long term and large scale multidisciplinary activities, not limited to sensing and observation, but extended to sampling and, above all, ensuring real "experimenting" capabilities.

On behalf of European Union (Directorate General XII), Tecnomare assessed the feasibility of a configuration for a benthic underwater system, called ABEL (Abyssal BEnthic Laboratory), capable of operating both under controlled and autonomous modes for a period of several months to over one year at abyssal depths up to 6000 m.

A network of co-operating stations, open to different configuration arrangement, has been identified in order to satisfy the widest range of scientific expectations, and at the same time to address the technological challenge to increase the feasibility of scientific investigations, even when request is not yet well clarified. The overall system (shown in Figure 1) consists of three main elements:

- a **Main Fixed Station** devoted to the execution of the most complex scientific activities, characterized by a high level of interaction between internal functions, like sampling, observation and sensing, and performance of experiments asking for actuations and manipulation as well as tele-operated activities.
- one or more **Satellite Stations**, acting as nodes of a measuring network (e.g. for seismic, geodynamic, hydrographycal measurements), or as remote stations, placed in proximity of a site or phenomenon worth a continuous monitoring activity.
- a **Mobile Station** extending ABEL capabilities with the possibility to carry out surveys over the investigation area and interventions on the fixed stations such as visual inspection, instruments positioning and maintenance, data/sample transfer, reprogramming of activities.

Communication between stations is based on hydroacoustic links (shown as dashed arrows in Figure 1).

ABEL architecture also includes a dedicated Deployment and Recovery Module, as well as sea-surface and land-based facilities. Such an installation constitutes the sea-floor equivalent of a meteorological or geophysical laboratory.

Three different operating modes have been envisaged, each referring to a different level of interaction among ABEL system components and surface facilities:

- **autonomous mode**, characterised by the absence of any interaction with surface facilities after system installation. Mission autonomy is not completely determined a priori; the capability of modifying mission profiles according to observations and events has to be included.
- **interactive mode**, in which the ABEL system interacts with surface facilities, such as a vessel or a moored buoy, by means of a low capacity, time delayed link, based on hydroacoustic transmission; in this way a limited capability of data transfer and further instruction transmission is ensured.
- **controlled mode**, characterised by a direct and real-time remote interfacing of scientific personnel with the ABEL system. A high capacity, fiber optic link, communication is provided by the Deployment and Recovery Module. This mode make it possible to perform the most complex tasks requiring direct operator control and data/image transmission.

APPLICATION OF KEY ROBOTIC TECHNOLOGIES TO UNDERSEA AND SPACE EXPLORATION

Among the various analogies existing between a deep ocean benthic laboratory and a planetary base, the need to tele-operate a scientific laboratory from a remote control station is the aspect involving the use of very similar robotic technologies such as supervisory control, tele-operation, man-machine interface (MMI) and telepresence, computer vision, etc.

This paragraph deals with a short description of these key technologies, the approaches and the results achieved in the marine sector and highlights possible technology transfers to space.

The basic control approach which has been adopted in the more advanced telemanipulation systems installed on free swimming Remotely Operated Vehicles (ROV's) to carry out underwater complex tasks in substitution of divers, is *Supervisory Control.*

As known, Supervisory control (Figure 2) represents a methodology aimed at properly combining human and computer actions for the efficient control of complex systems. According to this methodology, the different interactions between operator and computer are suitably combined in such a way to substantially facilitate the human Operator in carrying out the system control: in this sense the system is conceived to assist, not to substitute for the operator. More specifically, in the supervisory control scheme, the Operator is requested to carry out high level tasks such as planning, system instruction, monitoring during system operation and intervention when necessary (e.g. on account of unexpected situations or for varying pre-defined task parameters). The supervisory computer(s), instead, takes care of the interpretation and decoding of the Operator high level commands in elementary tasks and of their execution by using the sensors and actuators of the controlled system. The supervisory control paradigm is particularly suited for the control of advanced telerobotic systems. In particular it easily allows to increase more and more the system autonomy in dependence, for example, of the development of Artificial Intelligence (AI) technology and of the experience gained in actually carrying out tasks.

Key technologies and capabilities constituting the prerequisites of the supervisory control approach are:

1) Motion-force primitives, i.e. elementary tasks that the system is able to carry out both in fully automatic way or in tele-operation. An example could be the motion from point A to point B while avoiding obstacles. In a bottom-up approach for automation they represent the elementary building bricks of a large spread of tasks. The approach of motion-force primitives may be considered of general application; for this reason the developments carried out for underwater environment can be easily modified and finalised for space robots such as rovers.

2) Advanced MMI and telepresence. These technologies are fundamental in remote-controlled operations. In fact even if supervisory control greatly simplifies the Operator's tasks, he remains a fundamental element in the control chain. The human factors include any telepresence techniques, associated with methods for computer representation of the working scenario. As known, the ultimate target of telepresence is to make the operator feeling to be within the working scene as he was looking and manipulating with his own senses (eyes, hands etc.). This may be approached in different ways: one is to proceed by testing step by step new techniques. For example, considering the extremely poor scene perception obtained from underwater TV cameras, an idea is to complement TV images with 3D graphic representation of the working scenario (made possible after scene reconstruction). This solution enhances considerably the effectiveness of operator interface especially when TV images are mixed with graphics in such a way to artificially increase the TV cameras field of view. Particular synergies exist between space and underwater areas, to make the advanced MMI technologies developed for one sector almost directly applicable to the other.

3) Computer vision systems. This technology deals with vision methods for measuring the geometry of the working environment. Computer vision is one of the key elements in measuring the size and shape of the working environment with a view to computer workspace modelling. To this purpose Tecnomare developed the TV-Trackmeter (Fig. 3) a stereo computer vision system capable to measure points of the scene taken by stereo cameras, while tracking them in case of relative motion between the vehicle and the scene. Typical measurement accuracy is 4 mm at 2 m range; repetition rate is around 12 Hz. To reconstruct the scene geometry, a very high number of points are measured; then the measurements are "fitted" to the geometrical shape of the scene, assumed known, by using optimal algorithms. In this way key geometrical parameters (e.g. radius and axis for a cylindrical shape) are estimated with considerable accuracy. Computer stereo vision is a typical robotic technology having a large spread of different applications and it is almost directly applicable in different sectors such as underwater and space.

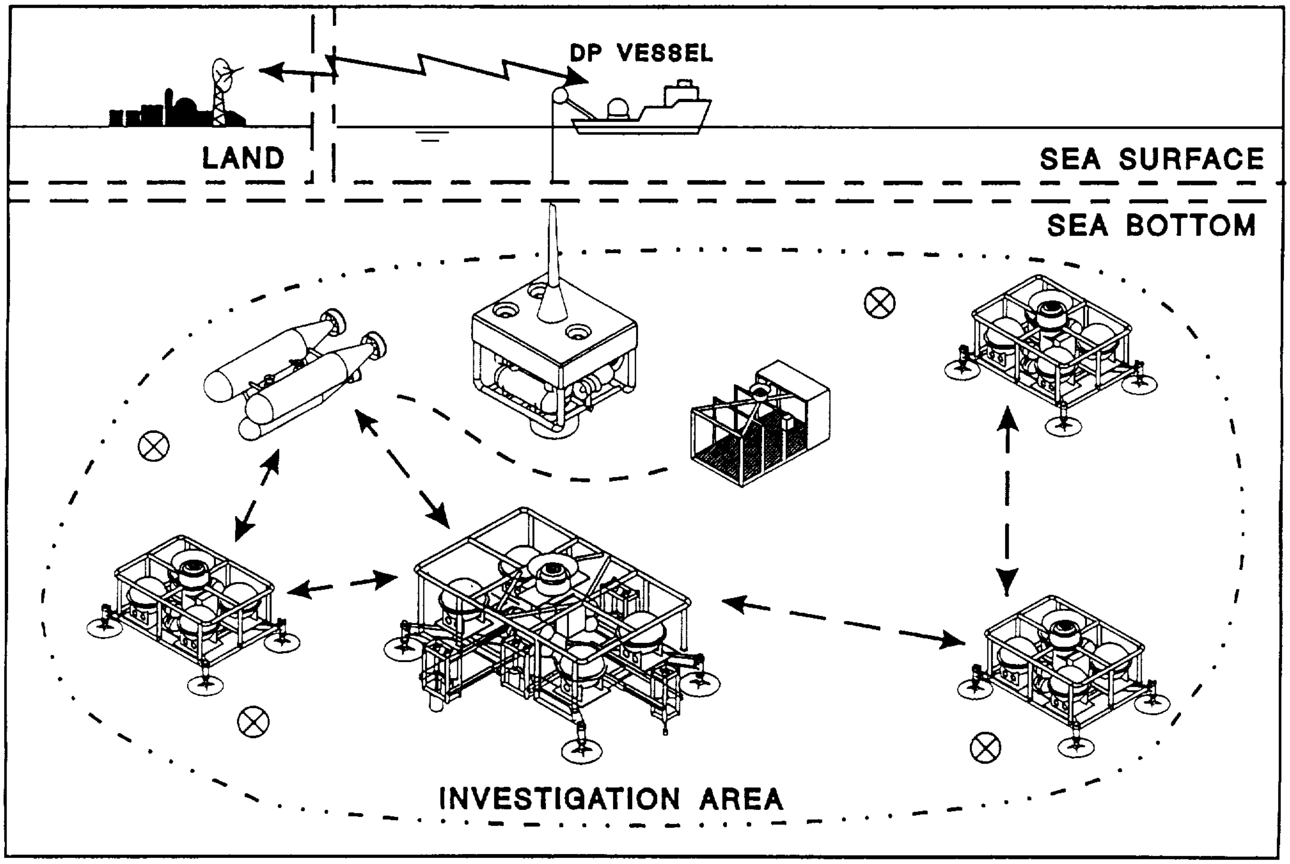

Figure 1. Abyssal Benthic Laboratory

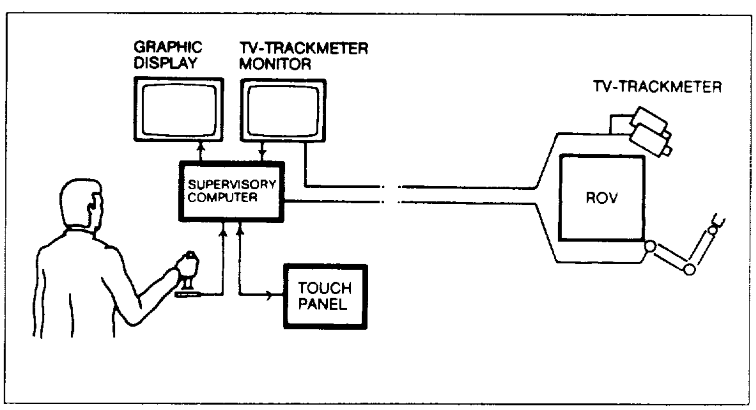

Figure 2. Supervisory Controlled Telemanipulation

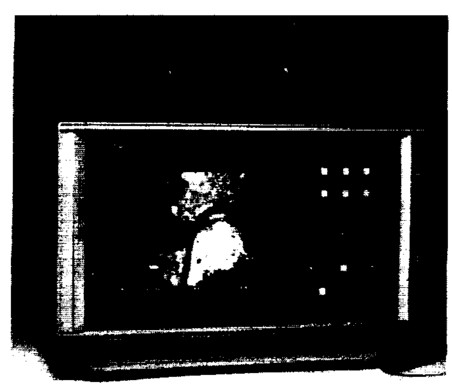

Figure 3. TV-Trackmeter