Research in Marine Sciences
Volume 10-Issue 1-2025
Pages 722-731

Autonomous underwater vehicle for oceanographic work in coastal waters

Rosario Garza Ruiz*, and Sara Rivera Cruz

Faculty of Naval and Oceanic Engineering, Polytechnic University of Cartagena, Spain

Received: 2025-01-11 *Accepted: 2025-02-27*

Abstract

The Autonomous Underwater Vehicle (AUV) in Murcia, Spain, is part of a growing interest in marine technology and underwater exploration. This paper tries to review the deployment of underwater robots that has become increasingly prevalent in marine research, environmental monitoring, and exploration. Autonomous Underwater Vehicles (AUVs) have seen significant advancements and applications in various marine research initiatives around the world, including in the region of Murcia, Spain. In recent decade, several experiments and projects involving AUVs were conducted in this area, focusing on marine exploration, environmental monitoring, and underwater archaeology. This work consists of the description of the work carried out by the research teams of the submarine laboratory of the UPCT, of the autonomous submarine Aegir, of the experience carried out in November 2013, in a scientific mission of oceanographic exploration in the Murcia. The elements of the submarine and the challenges for the future are described.

Keywords: Oceanographic explorations; Navigating; Autonomous underwater vehicles (AUV).

1. Introduction

Underwater robots, including remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs), serve essential roles in marine research and industry. Understanding the environmental factors that affect their operation is crucial for improving their efficiency and reliability. AUVs are part of a large group of underwater systems

* Corresponding Author's Email: rgruiz@puc.es

known as Unmanned Underwater Vehicles (UUV), a classification that includes ROVs, which are underwater vehicles that are operated remotely from a station on the surface of the sea. UUVs have been developed to carry out underwater missions such as facilitating the monitoring of coastal areas, deactivating underwater mines, oceanographic studies, and underwater archaeology (Antonelli *et al*., 2001; Pérez Ruzafa *et al*., 2005).

The Submarine Vehicle Laboratory of the UPCT – Isaac Peral – is a multidisciplinary research group with experience in Biological Oceanography, Naval Architecture, Ocean Engineering, Robotics, Artificial Neural Networks, Electronics, and Telecommunications (Lorentz and Yuh, 1996; Yoerger and Slotine, 1985). Currently, the laboratory is located in the Center for Development and Technological Innovation of the UPCT located in the Technological Park of Fuente Álamo and in the Higher Technical School of Naval and Ocean Engineering of Cartagena. The objective of this team is the development of equipment and techniques useful for ocean exploration (Carreras *et al*., 2005; Garcia-Cordova *et al*., 2007).

AUVs can operate independently for extended periods, following pre-programmed routes or adapting to real-time conditions. This autonomy allows them to explore areas that may be difficult or dangerous for human divers. AUVs are typically equipped with a range of sensors, including sonar systems for mapping the seafloor, cameras for visual inspections, and chemical sensors for monitoring water quality. These tools enable comprehensive data collection on marine ecosystems. They can be used in various applications such as oceanographic research, underwater archaeology, environmental assessments, and search-and-rescue operations. Their versatility makes them valuable assets in both scientific and commercial fields. Many modern AUVs utilize advanced battery technologies or energy-efficient designs that allow them to operate for long durations without needing frequent recharging or maintenance. Some AUVs have onboard processing capabilities that allow them to analyze data in real-time during missions. This feature can enhance decision-making processes during underwater operations.

1.2. Key AUV Experiments in Murcia

1.2.1 Marine Biodiversity Assessment

AUVs were deployed to assess marine biodiversity along the Mediterranean coast of Murcia. These vehicles equipped with advanced sensors collected data on fish populations, benthic habitats, and water quality parameters. The data helped researchers understand the ecological health of marine ecosystems and identify areas needing conservation efforts.

1.2.2 Underwater Archaeology

The use of AUVs in underwater archaeology became prominent during this period. Projects aimed at mapping submerged archaeological sites off the coast of Murcia utilized AUVs equipped with high-resolution sonar systems. These experiments provided detailed maps of ancient shipwrecks and other historical artifacts, enhancing our understanding of maritime history.

1.2.3 Pollution Monitoring

AUVs were also employed to monitor pollution levels in coastal waters. Equipped with chemical sensors, these vehicles conducted surveys to detect contaminants such as heavy metals and microplastics. The data collected contributed to regional efforts aimed at improving water quality and addressing pollution sources.

1.2.4 Hydrographic Surveys

Hydrographic surveys using AUVs became more sophisticated during this period. Researchers utilized these vehicles for mapping seabed topography and sediment characteristics, which are crucial for understanding coastal dynamics and planning sustainable development projects.

2. The autonomous submarine Aegir

The underwater vehicle of the company Gaymarine S.R.L, belonging to the Spanish Navy, was requested for transfer due to disuse and inoperability, as it is over 30 years old. This transfer has a duration of about four years, extendable, of which one has already been completed. The vehicle was in a fairly deteriorated state, damaged, and out of use; most of its instrumentation and components were not functioning. Since the vehicle was transferred, it has undergone numerous changes, the most important of which can be seen in the following photos (Figure 1), highlighting the red color with a yellow stripe in the middle imitating the colors of the Spanish flag. Also, the modifications it has undergone at the head, where a hole has been made to install a pivot with 4 sockets for passing cables, above the new sonar installed and a new winch socket for passing the umbilical cable that connects the submarine with the outside.

Figure 1. Difference Aegir underwater vehicle

The interior of the submarine is what has undergone the greatest change, due to repairs and the installation of new devices. The interior of the submarine is shown separately and generalized. As can be seen in Figure 2 and Figure 3, the submarine has five motors, ten lead-acid batteries, the first six are the power batteries intended to supply the motors, the last two are the control batteries responsible for powering all the electronics, and the two that are formed from the sides are arranged as support at the moment they are determined, for example, to switch the motors from 24V to 48V. A connection box for the motors and the cRIO (Compact RIO) has been arranged along with the controller card for the signals and some electrical supplies; in the area of the batteries, to the left of them, are the signal connections coming from the head and the power supply cables coming from the batteries.

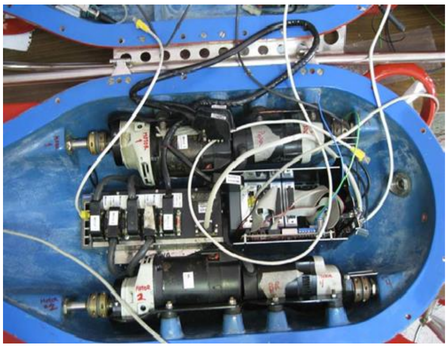

Figure 2. Image of the interior of the Submarine, area of engines 1, 2, 3 and 4 and cRIO 9022

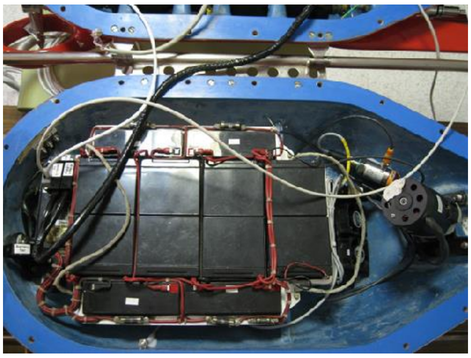

Figure 3. Photo of the interior of the Submarine, battery area and engine 5

In Figure 4, the interior of the head can be seen, where we can appreciate some of the added components such as the GPS, the camera, IOLAN DS1, the switch, etc. The small button that can be visualized is the test button for the flooding sensor; when pressed, it creates a short to test that this sensor works perfectly.

The cRIO is the processing unit for all the signals processed in the program, except for those treated at a high level or at the CPU level, such as the network camera, the GPS, or the sonar. The controller is model 9022, its chassis is 9113 with four ports, of which two are used. Module 1 is the 9477 of digital outputs, so at the programming level, only Boolean signals arrive; if other data is needed, they would be analog inputs, as is the case with module 2, the 9205 of analog inputs, where data arrives at the CPU in the form of double precision numerical data.

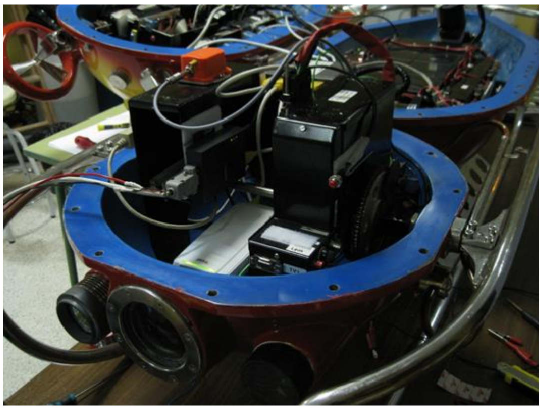

Figure 4. Image of the interior of the Submarine head, camera area, GPS, IOLAN, etc.

Module 1 collects the activation signals of all the motors and the change of direction of the motors, in addition to the activation signal for lights, mode 24V48V, movement of the head, direction of the head, activation of body fans, and other signals such as indicators, micromotor1, micromotor2, or DCDC which are not described in this work. Module 2 collects temperature, humidity, battery level, power and control, flooding, depth, and position of the head. It should be clarified that these data arrive through two distinct inputs, that is, depth: it has the depth signal (+) positive and the depth signal (-) negative, which must be treated as differential data so that these two are combined into one and thus obtain the desired real data (Figure 5).

Figure 5. Image of the Micron DST sonar mounted on the head of the Aegir Submarine

The sonar is connected via a serial port to the IOLAN DS1 converter (Figure 6). This serial cable is special as both of its pins are used to power the sonar, which during tests has used a power supply, and during water tests, the power is provided by a battery located in the head of the submarine vehicle.

Figure 6. IP camera inside the head of the Aegir Submarine

In Figure 6, the network camera which is mounted on a support at the bottom of the head, so that it is centered in one of the openings intended for vision devices. The camera is wired with Ethernet to the switch in the head, from there to the body switch, and from this to the router.

The converter allows transforming the signal from the serial port to Ethernet (RJ-45). During land tests, a crossed RJ-45 cable has been used to make a direct connection with the converter. During water tests, it is connected to a common switch for several devices.

The sonar is positioned so that it is always oriented towards the front, although it can make 360° rounds; normally, it would make them at specific moments and keep it almost always in tracking mode of 90° or 180°. The cable runs inside tubes seen in Figure 7, it has two entries for thin cables and the other two for thicker cables.

The GPS antenna, not shown here, has a 1.5-meter cable and is installed in the interior and upper part of the head's hull. The submarine, being made of thick resin, allows the transmission and reception of GPS, mobile, WiFi signals, and etc.

The Ethernet serial converters are both located in one of the metal structures in the head; one is for the submarine's sonar and the other for the inertial unit. Each has different configurations, as the sonar one is designed to be used on the Tablet and the inertial system on the laptop.

In Figure 8 two photos of the switches are seen, one is installed in the head to unify the network signals from the camera, the sonar and the inertial unit and the other is to connect to the body switch. The body switch receives the Ethernet signal from the head, from the cRIO and the one that links to the external router through the umbilical cable.

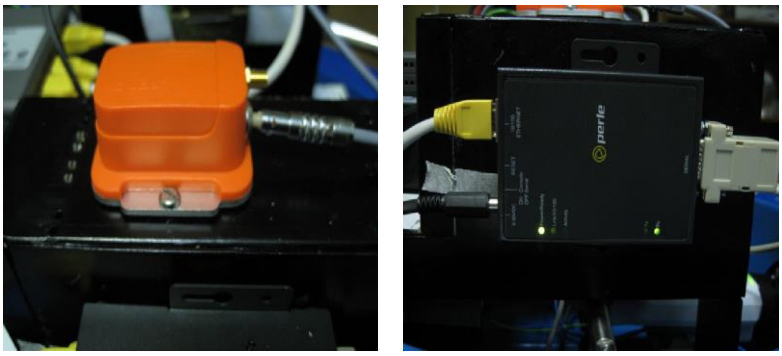

Figure 7. Converter and inertial unit inside the head of the Aegir submarine

Figure 8. The switches inside the head and body of the Aegir Submarine

The temperature sensor, although it has a digital screen to show the temperature, this screen is not useful, since the submarine will be closed, the signal is transmitted to the analog input module 2 of the cRIO. To detect the temperature, the sensor has a pointed sensor located on one side of the body batteries, Figure 9.

Like the temperature sensor, the humidity sensor also uses module 2 of analog inputs to transmit the signal to the monitoring program. It is mounted on a small board because the sensor operates at 5V and it is necessary to use a 5V voltage regulator.

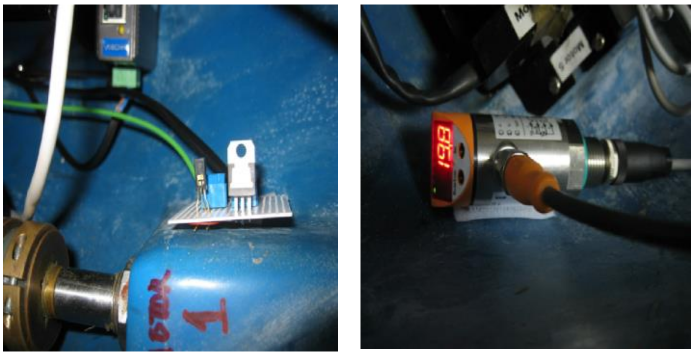

Figure 9. Temperature and humidity sensor inside the body of the Aegir Submarine

The inertial system requires one of the two IOLAN DS1 converters used in the submarine, to convert the signals from the serial port cables into packets that can be sent and processed via Ethernet, thus unifying the necessary elements within the extensive Ethernet network has been installed to simplify the transport of data and cables leaving the submarine.

2.1. Trawled surface vessel

One of the main risks of developing an AUV is the possibility of losing the vehicle in tests or missions in open sea. The worst condition that can arise is in operations without connection to the surface, without GPS positioning or the trajectory under the sea established. The implementation of autonomous algorithms in AUV involves a great risk of losing the vehicle, for this reason, the solution adopted to reduce these risks in tests in open sea is the design, manufacture, and connection of a towed vehicle on the surface to the AUV.

2.2. Description of submarine-surface connection

Connection of the underwater environment with the surface is by a submarine cable with Kevlar protection, 1000Kg towing capacity, composed of six power cables and one Ethernet communication cable. Data communication between the towed vehicle on the surface and the support boat or the station in port is by a power generator from the surface (Table 1) to increase the autonomy and operation time of the underwater vehicle. The surface vehicle has a GPS system, trajectory calculation, positioning, and direction of the towed vehicle. Combining the data from the underwater platform and the depth generates the operational position; on the other hand, in case of loss of the vehicle, the search area is limited.

Table 1. Characteristics of the power generator

Model	Lanzarote
Alternator	Multipolar
Stability system	Inverted
Distortion	Modulation
Maximum power	3%
Nominal power	2.2kva
Volume	2.0kva
Oil capacity	125cc
Gasoline capacity	0.45 L 10W40
Autonomy 50%	7l
Sound level (7 meters empty)	6.5 hours
Starting system	65dB
Dimensions	Manual/Electric
Reference	54×29×51 cm

3. Different experiments in the Murcia

In the context of Murcia's coastal waters and marine environments, AUVs can play a crucial role in studying biodiversity in the Mediterranean Sea and assessing the health of marine ecosystems, tracking pollution levels and assessing the impact of human activities on marine habitats, investigating submerged archaeological sites along the coast of Murcia, and collecting data on fish populations and habitats to support sustainable fishing practices.

In November 2011, an international experiment in oceanographic underwater robotics was held in the coastal lagoon of the Murcia, the main objective was to measure the salinity of the seawater between the Mar Menor and the Mediterranean Sea in the Estacio channel, which is the largest seawater exchange flow between both seas (Nakamura and Savant, 1992).

This international experiment called “Underwater Experiment Mar Menor Coastal Lagoon 2011” had the participation of MBARI, CETMAR, University of Girona, Polytechnic University of Catalonia, University of Porto, Carlos III University and the Polytechnic University of Cartagena in charge of the reception of the different institutions. The UPCT LVS (Underwater Vehicle Laboratory)-Isaac Peral, participated in this experiment with the AUV/ROV Aegir attached to the surface towed. The mission was to record data of the seawater flow between the Mediterranean Sea and the Mar Menor lagoon in a selected region marked by GPS, to achieve this mission the UUV Aegir was equipped with a multi-parameter probe conductivity directly related to salinity, temperature and depth directly related to ambient underwater pressure (Porto and Fogel, 1990). In the bad weather conditions, the inexperience of the support ship for the team, and the failure to test the deployment and recovery system of the support ship for the AUV caused the UPCT vehicle to be seriously damaged on the first day of the experiment. Despite this, the UPCT team worked hard to restore the system that connects the equipment and repair the damages. The provisional repair was carried out on the starboard immersion propeller, which had been seriously damaged during deployment at sea. All this work was successfully completed to make the UUV Aegir operational to finish the task of measuring salinity.

Once the system was reactivated, the UPCT team returned to the experiment site, this time with a recovery ship operated by a trained team from the Maritime Search and Rescue System of the Spanish Merchant Marine Directorate. This time, with remote control and automatic procedure modes that allowed the UUV Aegir to cover the area designated by GPS and measure the salinity associated with the explored area and depth.

4. Improvements in recent decade

Overall, the use of AUV technology in Murcia reflects a commitment to advancing marine science and conservation efforts while promoting innovation in underwater exploration techniques.

4.1. Technological Advancements

Over these years, significant improvements were made in AUV technology, including enhanced battery life for longer missions, improved navigation systems using GPS and inertial measurement units (IMUs), and better sensor integration for multi-disciplinary applications.

4.2. Data Processing Capabilities

Advances in data processing algorithms allowed for real-time analysis of the information collected by AUVs. This capability enabled quicker decision-making processes regarding environmental management and conservation strategies.

4.3. Collaboration with Research Institutions

Increased collaboration between universities, research institutions, and governmental bodies led to more comprehensive studies utilizing AUV technology. Joint projects facilitated knowledge sharing and resource pooling that enhanced experimental outcomes.

4.4. Public Awareness and Education

Efforts to raise public awareness about marine conservation issues through educational programs involving AUV demonstrations helped foster community engagement in scientific research initiatives.

4.5. Regulatory Framework Development

As the use of AUVs expanded, regulatory frameworks began to evolve to ensure safe operations within marine environments while balancing technological innovation with environmental protection.

Conclusions

The recent decade marked a transformative era for AUV experiments in Murcia, characterized by technological advancements that improved operational efficiency and broadened their application scope across various fields such as ecology, archaeology, pollution monitoring, and hydrography. These developments not only contributed valuable insights into the region's marine environment but also laid a foundation for future research endeavors aimed at sustainable ocean management.

The UUV Aegir was proposed as a test platform to develop control techniques, underwater trajectory generation, automatic navigation, and testing of various multidisciplinary equipment. The UUV Aegir is an underwater vehicle easily adaptable to different missions and tasks in the underwater environment, such as environmental monitoring, oceanographic research, scientific sampling, mapping search and rescue operations, underwater archaeology, and security and surveillance operations. This underwater equipment has open software, and its hardware architecture allows for the incorporation of new equipment and software

References

Antonelli, G, Chiaverini, S, Sarkar, N, and West, M. 2001. Adaptive control of an autonomous underwater vehicle: experimental results on ODIN," Proceedings 1999 IEEE International Symposium on Computational Intelligence in Robotics and Automation. CIRA'99 (Cat. No.99EX375), Monterey, CA, USA, 1999: 64-69, doi: 10.1109/CIRA.1999.809948.

Carreras, M., Yuh, J., Batlle, J., and Ridao, P. 2005. A behavior-based scheme using reinforcement learning for autonomous underwater vehicles. IEEE Journal of Oceanic Engineering. 30(2005): 416-427.

Garcia-Cordova, F., Guerrero-Gonzalez, A., and Marin-Garcia, F. 2007. Design and implementation of an adaptive neuro-controller for trajectory tracking of nonholonomic wheeled mobile robots. In Mira, J., Alvarez, J.R., eds.: Nature Inspired Problem-Solving Methods in Knowledge Engineering, Lectures Notes in Computer Science. Volume 4528. Springer-Verlag Berlin Heidelberg, LNCS4528, Part II, ISBN: 978-3-540-73054-5.

Lorentz, J., and Yuh, J. 1996. A survey and experimental study of neural network AUV control. In Proceedings of Symposium on Autonomous Underwater Vehicle Technology (pp. 109-116). IEEE.

Nakamura, Y., and Savant, S. 1992. Nonlinear tracking control of autonomous underwater vehicles. In: Proceeding IEEE international conference on robotics and automation, Nice, France.

Pérez Ruzafa, Á., Marcos, Diego, C., and Gilabert Cervera, F.J.L. 2005. The ecology of the Mar Menor coastal lagoon: a fast changing ecosystem under human pressure.

Porto, V.W., and Fogel, D.B. 1990. Neural network techniques for navigation of AUVs. In Symposium on Autonomous Underwater Vehicle Technology (pp. 137-141). IEEE.

Yoerger, D., and Slotine, J. 1985. Robust trajectory control of underwater vehicles. IEEE journal of Oceanic Engineering, 10(4): 462-470.