Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

Unmanned Marine Vehicles at CNR-ISSIA *

**Massimo Caccia * Marco Bibuli * Riccardo Bono *
Gabriele Bruzzone * Giorgio Bruzzone * Edoardo Spirandelli ***

* *CNR-ISSIA, Genova, Italy (Tel: +39-01064756{12,15,57}; e-mail: {max,marco,riccardo.bono,gabry,gio,ed}@ge.issia.cnr.it).*

Abstract: This paper discusses the requirements, design and operational aspects of the Unmanned Marine Vehicles (UMVs), namely the Romeo Remotely Operated Vehicle (ROV) and the Charlie Unmanned Surface Vehicle (USV), developed at CNR-ISSIA, Genova, Italy for robotics research and scientific applications, pointing out the synergies between the development of underwater and surface unmanned vehicles.

1. INTRODUCTION

In the last years a large number of unmanned marine vehicles (UMVs) have been developed for different scientific, archaeological, industrial and military applications. According to their working field and connections with the operating/supervision station, UMVs can be classified in three basic categories:

- Remotely Operated Vehicles (ROVs), i.e. underwater vehicles, usually open-frame, connected through a tether, supporting both vehicle power supply and data and video transmission, to the operator station. Currently, ROVs are a standard tool for underwater operations with more than 400 ROV models, 130 ROV builders and 180 ROV operators. Recently, electrically powered systems with fibre-optic links are increasing their diffusion. The main fields of application are off-shore operations, scientific and archaeological surveys and sampling, and, generally speaking, all the activities requiring strict interactions with the seabed or underwater structures. The reader can refer to (ROVs of the World) for an exhaustive overview of the existing vehicles.
- Autonomous Underwater Vehicles (AUVs), i.e. untethered underwater vehicles with on-board power supply, propulsion, navigation and control systems, usually connected to the supervisory station by an acoustic link. After a phase of research prototypes development, in the new century a number of commercial AUVs have been put on the market and are currently operational to carry out geological surveys, collecting oceanographic data, and in mine countermeasure applications. See, for instance, (Allen et al. (1997)), (Hagen et al. (1999)), (Henriksen et al. (1995)) for a description of the Remus, Hugin and Martin AUVs.
- Unmanned Surface Vehicles (USVs), i.e. autonomous or remotely controlled/supervised vessels connected to the operating station through a wireless communication link. They are used for bathymetric surveys (Manley et al. (2000)), pollution detection and tracing (Xu et al. (2006)), study of the sea-air interface, mine countermeasure operations (Cornfield and Young (2006)), and as communication relay with a companion AUV (Pascoal and et al. (2000)).

In the following attention focuses on the ROV and USV prototypes developed at CNR-ISSIA Genoa, Italy (former CNR-IAN).

2. ROMEO ROV

2.1 Romeo requirements and design

The Romeo ROV was designed and developed for robotics research and marine science applications in the mid Nineties, when the debate in the underwater robotics research community focused on the design of fully modular vehicles both from the mechanical, communication and control architectures (Wang and Coste-Manière (1994)). The result was the development of a *generation* of scientific ROVs, such as the deep water vehicles Victor by IFREMER (Nokin (1996)) and Tiburon by the Monterey Bay Aquarium Research Institute (Kirkwood (1998)), characterised by a networked architecture, an interchangeable toolsled for scientific payloads, and an intelligent control architecture, supported by the availability onboard of high computing power.

In order to allow the collection of images and samples in the proximity of the seabed without interacting with the operating environment, the Romeo ROV required high manoeuvring capabilities both in the vertical and horizontal plane (i.e. auto-altitude and hovering control).

Logistics requirements, basically related to the possibility of operating the vehicle from small support vessels, i.e. about 16 meters boats such as the one available in the Italian Antarctic station of Terra Nova Bay, and by a reduced crew, i.e. two-three people, induced constraints on the ROV weight in air (500 Kg), size (about 1 m^3) and maximum operating depth (500 m).

The result was an open-frame ROV fully controllable in the six degrees of freedom, with the vertical propellers

---

* This work was supported in part by the Italian National Program of Research in Antarctica, by the European Union under the contract MAS3CT970083 ARAMIS (Advanced ROV package for automatic mobile investigation of sediments), and by PRAI-FESR Regione Liguria prot.5 "Coastal and harbour underwater anti-intrusion system".

978-1-1234-7890-2/08/$20.00 © 2008 IFAC 10.3182/20080706-5-KR-1001.0164

positioned on the top in order to minimize the interactions with the seabed and the horizontal thrusters symmetrically positioned in the corners in order to guarantee a high manoeuvrability. The redundancy of the actuation system (four vertical and four horizontal thrusters) allowed the vehicle to handle faults in the propulsion system without sensibly altering its motion control performances (Caccia et al. (2002)).

The mechanical design was characterised by an interchangeable toolsled mounted below the basic frame, allowing the connection of a generic payload through a couple of connectors, i.e. power supply and communications. The core vehicle was composed of a stainless steel frame (130 x 90 x 66 cm (lwh)), equipped with a number of titanium cylindrical canisters for electronics (100 x 32 cm ld), batteries (80 x 15 cm ld), DC/DC converters (80 x 15 cm ld), and compass, gyro, and inclinometers (60 x 15 cm ld). The standard toolsled, which measures 130 x 90 x 30 cm (lwh), brings additional batteries and the payloads for marine science applications and robotics research.

The system control and telemetry architecture is fully networked and can be connected to the world-wide web for remote control and data access. In particular, an on-board Ethernet LAN connects the control system computer, which executes the basic navigation, guidance and control (NGC) tasks and manages the vehicles plant, to on-board scientific/multidisciplinary payloads, while a surface Ethernet LAN basically supports the human interactions with the machine, scientific data and ROV telemetry broadcasting, and control system Internet access. The two LANs are connected through a 600 m long fiber electro-optics tether, which makes available an Ethernet connection at 10Mbps, plus a number of serial and video channels.

As far as the computing power is concerned, the ROV was equipped onboard with a VME rack with a couple of Motorola MVME162 boards at 32 MHz, running the execution and execution control levels of an intelligent control architecture (Caccia et al. (2005b)). A Motorola MVME162 board in the surface station manages the system Human Computer Interface, constituted by three stations for the pilot, supervisor and scientific end-user, and the surface navigation package, constituted by the acoustic positioning system and ship instruments, e.g. GPS and gyro-compass.

For a detailed description of the Romeo system the reader can refer to (Caccia et al. (2000a)) and (Caccia et al. (2002)).

2.2 Romeo exploitation

In virtue of its modularity and network connectivity, the technological and scientific exploitation of the Romeo ROV, carried out in polar and Mediterranean regions, focused on different classes of applications presented in the following.

Benthic survey and exploration Romeo ROV standard toolsled configuration is suitable for generic benthic survey and exploration recording video images and photographs of the seabed. This activity was carried out during a number of Antarctic missions for characterising the Antarctic Specially Protected Area nearby the Italian station of Terra Nova Bay, Ross Sea (Bono et al. (1998))(Bono et al. (2006)). In particular, during the 2004-'05 campaign, in the framework of the project ECHOFISH in cooperation with ICRAM, the Tethys Bay seafloor habitat and the reproductive behaviour of fishes has been surveyed.

Pelagic data collection and sampling During this class of missions the vehicle was used for collecting data, e.g. multiparametric profiles, and samples along three dimensional paths in the water column (Caccia et al. (1999)). Specific missions, involving the integration with special devices, were performed:

- zooplancton sampling under the Antarctic ice-pack (Italian Expedition to Antarctica 1997-'98), when the toolsled was equipped with a microness as shown in Figure 1, where the ROV mechanical modularity is pointed out;

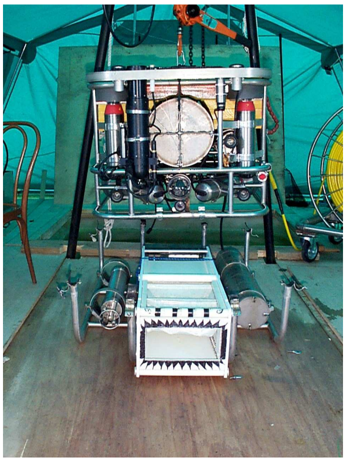

Fig. 1. Romeo ROV toolsled equipped with zooplancton sampling microness; a CTD is visible in the left.

- the test of a LIDAR fluorosensor mounted in the ROV toolsled in cooperation with ENEA Frascati during the Italian Expedition to Antarctica 2001-'02;
- the water sampling with a rotating drum mounting a number of bottles during the final demo of the EC ARAMIS project in the Greek island of Milo in 2000 (Caccia et al. (2002)).

Seabed probing and coring In the framework of the EC ARAMIS project the Romeo toolsled was equipped with a sediment sensor system, consisting of probes, i.e. four sensors for temperature, pH, sulfide and oxygen, to be inserted in the sediment to take physical/chemical profiles, and of a small sediment sampler able to collect small cores of the seabed. It is worth noting that Romeo had to smoothly landing over the seabed and support direct interactions with the environment during sediment probing and coring. In particular, the vehicle agility in manoeuvring, together with a detailed view of the operations provided by a dedicated camera, allowed the human operator to position the sediment probes right over thermal vents. A view of coring operations from the human interface is shown in Figure 2.

Benthic chamber deployment and recovery In the framework of the PNRA project Antarctic Benthic Shuttle (Bono et al. (2006)), Italian Antarctic Expedition 2003-'04, the Romeo ROV was employed for deploying and recovering, after 24 hours, a benthic chamber over the seabed

Fig. 2. Romeo ROV interface: pilot and coring monitoring camera images are shown in the monitors.

under the ice-pack. The dedicated toolsled consisted of a benthic chamber, i.e. a glass box of 30x30x20 cm (lwh), equipped with a CTD with oxygen sensor, two camcorders, which monitored the space inside and the seafloor nearby the chamber, and three bottles for suspended particle sampling. These devices were managed by a data acquisition and control system located in a dedicated cylinder onboard the toolsled. Every half an hour, an external programmable timer switched the system on, that collected data and video for five minutes before turning itself off. The skid releasing system was made by a couple of centring units and a couple of hooking units, while the benthic module localisation was simply performed by tracking the ROV position with a SSBL acoustic positioning system, whose transducer was mounted in a fixed location, i.e. a hole in the ice canopy, in the ice field. It is worth noting that the SSBL precision was of the order of few meters, allowing the visual localisation of the benthic chamber without particular difficulties. A view of the benthic chamber over the seabed is shown in Figure 3.

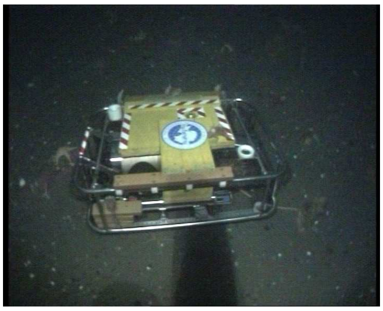

Fig. 3. Benthic chamber over the Antarctic seabed (view from the Romeo camera).

Internet-based tele-operation The Romeo networked architecture allowed the execution of a number of experiments of Internet based tele-operation demonstrating the possibility of integrating modules of an intelligent control architecture developed by different research teams for different vehicles, on one side, and the feasibility of remote tele-operation in harsh environments for edutainment and scientific purposes, on the other side.

In 1999 the Romeo ROV executed a simple mission in a Genova Pool under the supervision of the CORAL mission controller, developed by the IST-ISR for the MARIUS AUV (Oliveira et al. (1998)), running in Lisbon and connected through an Internet connection (Bruzzone et al. (1999)).

The possibility of remotely controlling an ROV in a polar region through Internet was demonstrated in the framework of the projects E-Robot1 and E-Robot2 in the period 2001-02, respectively in Antarctica and in the Arctic Sea. For details on system architecture and communication channels, the reader can refer to (Bruzzone et al. (2003)). Antarctic experiments, carried out with a ground station on the pack-ice, demonstrated the possibility for every user, provided with a standard Internet connection, of easily tele-operating an ROV in an unstructured environment. Arctic trials, carried out with the ground station onboard the support vessel, verified the effectiveness of the remote control of the robot used in extreme environment for telescience applications.

3. CHARLIE USV

3.1 Charlie requirements and design

The Charlie USV was originally designed for sampling the sea surface microlayer and immediate subsurface layer for studying the sea-air interface in Antarctica (Caccia et al. (2005a)). This application required a vehicle able to both move at a relatively high cruising speed to go to and come back from the sampling area, in order to avoid its pollution by the support vessel, and to maneuver at an advance speed of a few centimeters per second with respect to the water while collecting samples. Indeed, sea surface microlayer sampling was performed by a Harvey-like rotating drum (i.e., a rotating hydrophilic cylinder collecting the adsorbed film) (Harvey (1966)). The need of integrating the above-mentioned sampling device, as well as considerations about stability with respect to roll, capability of payload transport with respect to the hydrodynamic drag, and redundancy in hull buoyancy, motivated the design of a catamaran shaped vessel, whose size was constrained by the space available on the stern deck of the Antarctic support vessel and by the need to maximize the space for the scientific payload between the hulls. Thus, a catamaran was built with a length of 2.40 m, a width of 1.80 m, a hull height of about 0.60 m, and a space between the two hulls of 0.90 m. The vehicle was electrically powered, and equipped with a basic navigation package consisting of GPS and compass. In order to guarantee high performance during low speed maneuvers, a propulsion system consisting of two propellers actuated by two electrical thrusters was designed. Steering was based on differential propeller revolution rates. Since commercially available electrical thrusters for small boats do not usually guarantee a fine velocity tuning at low speed, the choice was to use the Romeo ROV actuators, specially designed for operating near bollard condition (that is, when the propeller is rotating with no speed of advance). Power supply was given by a set of four lead batteries, 12 V at 42 Ah, integrated with a set of solar panels to supply power peaks and to increase system autonomy.

On-board computing power was guaranteed by a single board computer (SBC) supporting an Intel Pentium CPU, serial ports and Ethernet, plus three PC 104 modules supporting digital input/output, analog input, and analog output respectively.

A radio wireless LAN at 1.9 Mbps allowed communications, i.e. data telemetry and commands, with the operator station, consisting of a laptop running the user graphics interface and the communication module. The operator station is fully autonomous from the power supply point of view thanks to a suitable combination of batteries and solar panels.

In 2005, the vehicle was upgraded with a rudder base steering system consisting of two rigidly connected rudders, positioned behind the propellers, and controlled by a step motor. The resulting vehicle is shown in Figure 4. The software architecture was modified too, substituting the original combined MS-DOS/RTKernel operating system with an embedded real-time system based on standard Linux (Bruzzone and Caccia (2005)).

Fig. 4. Charlie USV in its current configuration.

3.2 Charlie exploitation

Sampling of sea surface microlayer At first, the Charlie USV was exploited in the framework of the SEa Surface Autonomous Modular unit (SESAMO) project (Caccia et al. (2005a)), funded by the Italian National Program of Research in Antarctica (PNRA), and carried out in cooperation with the CNR Institute for the Dynamics of Environmental Systems, Venice. The scientific goal of the project was the study of sea-air interactions in the Ross Sea, Antarctica. The water samples collected by a Harvey-like drum (diameter 0.33 m, length 0.50 m, rotation rate between 4 and 10 rpm), actuated by an electrical brushless thruster, and the sub-surface seawater intake were distributed in suitable stocking buckets for organic and inorganic samples by a system of teflon-membrane pumps and three-way valves. During the XIX Italian Expedition to Antarctica in January-February 2004, the Charlie USV, deployed and recovered by the Malippo, a 16m support vessel hosting the human operator station, executed six missions (two for communications, navigation, guidance and control tests and four for water sampling) working for more than 20 hours and collecting about 95 l both of microlayer and immediate sub-surface water samples. A view of the USV in sea surface microlayer sampling configuration is shown in Figure 5.

Robotics research Due to the light logistics required for its operations, as well as its hardware and software modularity, the Charlie USV is also an easy-to-use testbed for robotics research in the field of marine robotics. This research, which presents strict synergies with the one in the ROV field (see section 4), has been supported by projects such as:

- *Coastal and harbor underwater anti-intrusion system* funded by PRAI-FESR Regione Liguria in the period 2005-2007, supporting research on modeling and identification; navigation, guidance and control; and mission control, in order to evaluate the possibility of using USVs for harbor bottom-mapping in the presence of usual traffic;

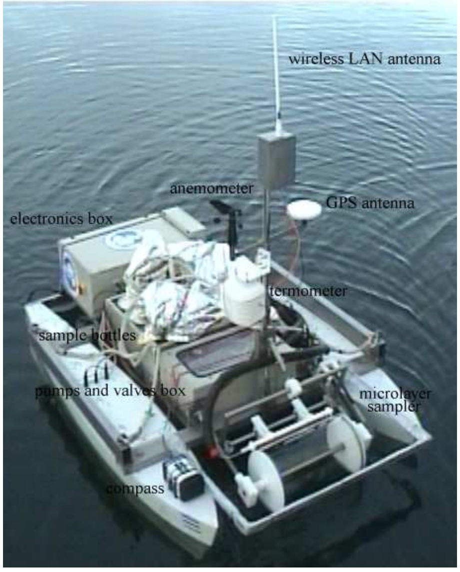

Fig. 5. Charlie USV in SESAMO project configuration.

- *Sensor-based guidance and control of autonomous marine vehicles: path-following and obstacle avoidance*, in cooperation with the Laboratoire dInformatique, de Robotique et de Microélectronique de Montpellier, focusing on the development of a sensor-based guidance system for path-following and obstacle avoidance able to be integrated both on the Charlie USV and Taipan AUVs (Paim et al., 2005); in particular, nonlinear path-following techniques based on the concept of following the rabbit, i.e. controlling also the motion of a target vehicle on the path, using it as an extra degree of freedom for the guidance algorithm (Lapierre et al., 2003), have been integrated in the Charlie control system and tested at sea in the Genova Prà harbor in December 2006 (Bibuli et al. (2007)).

Support to other USV development In 2007-2008 the Charlie USV is going to support the development, testing of sub-systems, and performance evaluation through comparative trials, of a multi-purpose prototype USV that CNR-ISSIA is going to design, develop and test in the framework of a feasibility study funded by the Parco Scientifico Tecnologico della Liguria. The new prototype USV will be characterized, according to the specifications of the customer, by an aluminum hull and the capability of deploying and recovering simple instruments for underwater data collection.

4. ROV AND USV SINERGIES

As already discussed in (Manley et al. (2001)) for the families of AUVs and USVs developed at MIT Sea Grant Program, the development of USVs, in virtue of their lower logistics and operability costs, can strongly support the one of unmanned underwater vehicles, taking advantage, on the other hand, of previous results in already developed underwater systems. Synergies between the development of the Romeo ROV and Charlie USV are discussed in the following.

4.1 Modelling and identification methodology

The common problem of determining a suitable methodology for the definition and identification of a *practical* model for a small unmanned marine vehicle has been faced, where *practical* basically stands for consistent, from the point of view of the degree of accuracy, with the quality in terms of noise and sampling rate of the measurements provided by the sensors commonly available on-board a small and relatively low-cost vehicle. The result has been the development of a methodology based on:

- the design of suitable steady-state manoeuvres for the identification of drag coefficients for single degrees of freedom, as well as interactions with the hull and control planes;
- the determination of the physical parameters to be included in the steady-state model according to the standard deviation of their estimate, i.e. the possibility of observing them with the available measurements;
- definition of suitable manoeuvres for the identification of the system inertia, considering the uncertainty in the exerted control action and in the available measurements, which typically are low sampling rate position measurements.

This methodology has been originally developed for the Romeo ROV, see (Caccia et al. (2000b)), and then extended to the Charlie USV (Caccia et al. (2006)).

4.2 Software and hardware architecture

Recent developments in computing power of PC boards and in the real-time capabilities of free, originally non real-time, operating systems have led to the development of research-oriented ROVs characterised by the use of free software, i.e. standard GNU/Linux OS, and commercial-off-the-shelf hardware for real-time applications, and the contextual location of the control system boards on the ROV surface station, as in the case of Jason II (Whitcomb et al. (2003)). On the basis of experience gained in applications of industrial automation, a GNU/Linux based embedded real-time system has been developed for the Charlie USV (Bruzzone and Caccia (2006)). It runs on Single Board Computer and PC 104 boards, and supports the control architecture discussed in the following section. Moreover, this platform is being ported to the Romeo ROV, whose architecture is being modified in order to use the on-board Motorola MVME162 boards only for plant, actuators and sensor management, transferring all the vehicle intelligence on the surface.
The use of the Romeo ROV propulsion system for the Charlie USV has already been discussed in section 3.1.

4.3 Control architecture and navigation, guidance and control algorithms

The overall control architecture has been developed within the framework of intelligent control following a bottom-up approach, i.e. developing first the actuator and sensor drivers and the execution level and then supervision, coordination and mission control modules. In particular, on the basis of the experience gained with the Romeo ROV operations, an *execution control level*, solving conflicts and dependencies on task resources, typically variables, and thus guaranteeing the system consistency, has been introduced (Caccia et al. (2005b)). The resulting architecture has been adopted for the upgraded version of the Charlie USV in 2005 leading to a common infrastructure for both the vehicles able to support navigation, guidance and control algorithms (Caccia and Bruzzone (2007)).
In particular, the same navigation, guidance and control structure based on model-based extended Kalman filtering for motion estimation, and a dual nested loop architecture for guidance, handling system kinematics, i.e. position control, and control, managing system dynamics, i.e. velocity control, works satisfactorily on both the UMVs. Details for the Romeo ROV, for which the system was originally designed, and the Charlie USV can be found in (Caccia and Veruggio (2000)) and (Caccia et al. (2007)) respectively. Here, it is worth noting that the same algorithms for extended Kalman filtering of yaw motion, PI gain-scheduling velocity control, and PI-type position control generating speed references, are adopted for both the vehicles.

5. CONCLUSION

The requirements, design and exploitation of the UMVs developed at CNR-ISSIA have been discussed in this paper, pointing out the synergies between the development of vehicles of different classes. Here, it is worth noting that these synergies get stronger and stronger while developing components at high levels of the control architecture, such as path planners and mission controllers, as well as at the level of hardware and software platforms, as shown, for instance, by the current activity of introducing video processing capabilities on both the ROV and the USV.

ACKNOWLEDGEMENTS

The authors wish to thank Gianmarco Veruggio for his enthusiastic contribution in building and developing the marine robotic research group at CNR-IAN.

REFERENCES

B. Allen, R. Stokey, T. Austin, N. Forrester, R. Goldsborough, M. Purcell, and C. vonAlt. REMUS: a small, low cost AUV; system description, field trials and performance results. In *Proc. of OCEANS '97*, volume 2, pages 994–1000, 1997.

M. Bibuli, M. Caccia, and L. Lapierre. Path-following algorithms and experiments for an autonomous surface vehicle. In *Proc. of IFAC Conference on Control Applications in Marine Systems*, 2007.

R. Bono, Ga. Bruzzone, Gi. Bruzzone, M. Caccia, E. Spirandelli, and G. Veruggio. Romeo goes to Antarctica. In *Proc. of OCEANS '98*, volume 3, pages 1568–1572, 1998.

R. Bono, Ga. Bruzzone, Gi. Bruzzone, M. Caccia, E. Spirandelli, and G. Veruggio. Romeo ROV Antarctic exploitation for benthic research. In *Proc. of 7th IFAC Conference on Manoeuvring and Control of Marine Craft*, 2006.

G. Bruzzone and M. Caccia. Notes on standard GNU/Linux for embedded real-time robotics and manufacturing control systems. Technical Report SRAC-TR06/01, CNR-ISSIA Genova, 2006.

Ga. Bruzzone and M. Caccia. GNU/Linux-based architecture for embedded real-time marine robotics control systems. In *Proc. of IARP Int. Workshop on Underwater Robotics*, pages 137–144, Genoa, Italy, 2005.

Ga. Bruzzone, R. Bono, M. Caccia, G. Veruggio, C. Ferreira, C. Silvestre, P. Oliveira, and A. Pascoal. Internet mission control of the Romeo unmanned underwater vehicle using the CORAL mission controller. In *Proc. of MTS/IEEE Oceans'99*, volume 3, pages 1081–1087, Seattle, USA, 1999.

Ga. Bruzzone, R. Bono, Gi. Bruzzone, M. Caccia, P. Coletta, E. Spirandelli, and G. Veruggio. Internet-based tele-operation of underwater vehicles. In *Proc. of 1st IFAC Workshop on Guidance and Control of Underwater Vehicles*, Newport, UK, 2003.

M. Caccia and G. Bruzzone. Execution control of ROV navigation, guidance and control tasks. *International Journal of Control*, accepted for publication, 2007.

M. Caccia and G. Veruggio. Guidance and control of a reconfigurable unmanned underwater vehicle. *Control Engineering Practice*, 8(1):21–37, 2000.

M. Caccia, R. Bono, G. Bruzzone, and G. Veruggio. Variable configuration UUVs for marine science applications. *IEEE Robotics and Automation Magazine*, 6(2): 22–32, 1999.

M. Caccia, R. Bono, G. Bruzzone, and G. Veruggio. Unmanned underwater vehicles for scientific applications and robotics research: the ROMEO project. *Marine Technology Society Journal*, 24(2):3–17, 2000a.

M. Caccia, G. Indiveri, and G. Veruggio. Modelling and identification of open-frame variable configuration unmanned underwater vehicles. *IEEE Journal of Oceanic Engineering*, 25(2):227–240, 2000b.

M. Caccia, R. Bono, Ga. Bruzzone, Gi. Bruzzone, E. Spirandelli, and G. Veruggio. Romeo-ARAMIS integration and sea trials. *Marine Technology Society Journal*, 2: 3–12, 2002.

M. Caccia, R. Bono, Ga. Bruzzone, Gi. Bruzzone, E. Spirandelli, G. Veruggio, A.M. Stortini, and G. Capodaglio. Sampling sea surface with SESAMO. *IEEE Robotics and Automation Magazine*, 12(3):95–105, 2005a.

M. Caccia, P. Coletta, G. Bruzzone, and G. Veruggio. Execution control of robotic tasks: a Petri net-based approach. *Control Engineering Practice*, 13(8):959–971, 2005b.

M. Caccia, G. Bruzzone, and R. Bono. Modelling and identification of the Charlie2005 ASC. In *Proc. of IEEE 14th Mediterranean Conference on Control and Automation*, 2006.

M. Caccia, M. Bibuli, R. Bono, and G. Bruzzone. Basic navigation, guidance and control of the Charlie2005 ASC. In *Proc. of European Control Conference*, 2007.

S.J. Cornfield and J.M. Young. *Advances in unmanned marine vehicles*, chapter Unmanned surface vehicles - game changing technology for naval operations, pages 311–328. IEE Control Series, 2006.

P.E. Hagen, N.J. Storkersen, and K. Vestgard. Hugin - Use of UUV technology in marine applications. In *Proc. of Oceans '99*, volume 2, pages 967–972, Seattle, USA, 1999.

G.W. Harvey. Microlayer collection from the sea surface. a new method and initial results. *Limnol Oceanogr.*, 11: 608–613, 1966.

L. Henriksen, A. Bjerrum, and A. Ishoy. Sea trials of MARTIN a european survey AUV. In *Proc. of Oceans '95*, volume 3, pages 1439–1445, 1995.

W.J. Kirkwood. Tiburon: science and technical results form MBARI's new ROV integrated to a SWATH platform. In *Proc. of Oceans'98*, volume 3, pages 1578–1583, Nice, France, 1998.

J.E. Manley, A. Marsh, W. Cornforth, and C. Wiseman. Evolution of the autonomous surface craft AutoCat. In *Proc. of Oceans'00*, volume 1, pages 403–408, 2000.

J.E. Manley, J. Curran, B. Lockyer, J. Morash, and C. Chryssostomidis. Applying AUV lessons and technologies to autonomous surface craft development. In *Proc. of Oceans'01*, volume 1, pages 545–549, 2001.

M. Nokin. ROV 6000 - a deep teleoperated system for scientific use. In *Proc. of 6th IARP Workshop on underwater robotics*, Toulon, France, 1996.

P. Oliveira, A. Pascoal, V. Silva, and C. Silvestre. The mission control system of MARIUS AUV: System design, implementation, and tests at sea. *Int. J. on Sys. Science - Special Issue on Underwater Robotics*, 29(10): 1065–1080, 1998.

A. Pascoal and et al. Robotic ocean vehicles for marine science applications: the european asimov project. In *Proc. of Oceans 2000*, 2000.

ROVs of the World. *ROVs of the World.* Oilfield Publications Limited.

H.H. Wang and E. Coste-Manière. A look at the vocabulary of various underwater robotic control architectures. In *Proc. of 2nd IARP Workshop on mobile robots for subsea environments*, Monterey, USA, 1994.

L. Whitcomb, J.C. Howland, D.A. Smallwood, D. Yoerger, and T.E. Thiel. A new control system for the next generation of US and UK deep submergence oceanographic ROVs. In *Proc. of the 1st IFAC Workshop Guidance and Control of Underwater Vehicles*, pages 137–142, Newport, UK, 2003.

T. Xu, J. Chudley, and R. Sutton. Soft computing design of a multi-sensor data fusion system for an unmanned surface vehicle navigation. In *Proc. of 7th IFAC Conference on Manoeuvring and Control of Marine Craft*, 2006.