Future Trends in Marine Robotics [TC Spotlight]

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The IEEE Robotics and Automation Society (RAS) Marine Robotics Technical Committee (MRTC) was first established in 2008 following the dismissal of the Underwater Robotics Technical Committee in spring 2008. The goal of the MRTC is to foster research on robots and intelligent systems that extend the human capabilities in marine environments and to promote maritime robotic applications important to science, industry, and defense. The TC organizes conferences, workshops, and special issues that bring marine robotics research to the forefront of the broader robotics community. The TC also introduces its members to the latest development of marine robotics through Web sites and online social media.

Marine robotics has been an important branch of robotics since its beginning in the early 1970s. It is a difficult field since many special challenges exist in marine environments that are not present in ground and aerial robotics. These challenges often block the transfer of success from other domains to the marine environments. Marine robotics is also a highly interdisciplinary field that spans engineering, computer science, environmental science, and oceanography. Successful research programs in marine robotics tend to be achieved by collaborations among experts with diversified skills and specialties. Therefore, there is no lack of large-scale, high-impact projects in marine robotics. Over the years, the community has seen great advancements and developments in both theory and applications that have been reviewed in several recent survey articles [1]–[3]. Like all other fields of robotics, modern marine robotics has developed faster than ever due to the numerous innovations in supporting technologies in energy, perception, navigation, communication, control, and autonomy. In this article, we intend to bring the readers' attention to some of the future trends from three perspectives: 1) platform technologies, 2) information technologies, and 3) future applications.

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Platform Technology

The harshness of the maritime environment poses great challenges to marine robots, and they must be reliable, robust, and highly autonomous. The hardware platform, often called a marine vehicle, must have high quality comparable to that of a spaceship. Indeed, marine vehicles and spaceships have similar trajectories of historical developments, and a number of successful commercial vehicles have emerged recently. The robotics community is encouraged by the fact that the platform technology has become mature enough to invite new innovations.

Energy-Efficient Platforms

One of the most perceivable trends in platform technology is the development of energy-efficient, long-endurance, and long-range marine robots that are able to harvest energy from ocean environments. Sea gliders, first prototyped in the 1990s as a result of an Office of Naval Research program, represent the debut of the long-endurance robotic platforms in maritime applications [4]. This innovation in platform technology has since inspired great advancements in marine robotics, and there have been hundreds of sea gliders sold worldwide. In addition, several new prototypes have been developed by the European Union (EU), Japan, and China [5]. The innovation of the sea gliders lies in a buoyancy-driven propulsion mechanism that consumes minimal power and a feedback control mechanism to adjust the direction of motion. Using primary batteries, the sea gliders are able to perform missions that last several months on a single charge. Originally, scientists envisioned that sea gliders should be equipped with energy-harvesting mechanisms, such as a thermo engine, so that they can sample the ocean without charging [6]. This has now become a reality, and the mission length is only limited by the reliability of the parts. The waveglider developed by Liquid Robotics is an autonomous surface vessel that leverages wave energy to move forward while harvesting solar energy for electronic devices [7]. Wavegliders have successfully accomplished a mission to cross the Pacific Ocean and are performing day-to-day missions across the world.

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One of the limitations of the sea gliders and the wavegliders is the relatively low speed of the vehicles, which makes them vulnerable to strong ocean currents. Some hybrid types are developed to combine propellers with a buoyancy-driven mechanism to achieve higher speeds when needed. The products are either a hybrid glider like the hybrid Slocum or a hybrid long-endurance autonomous underwater vehicle (AUV) like the Folaga [8] or the Tethys [9] (Figure 1).

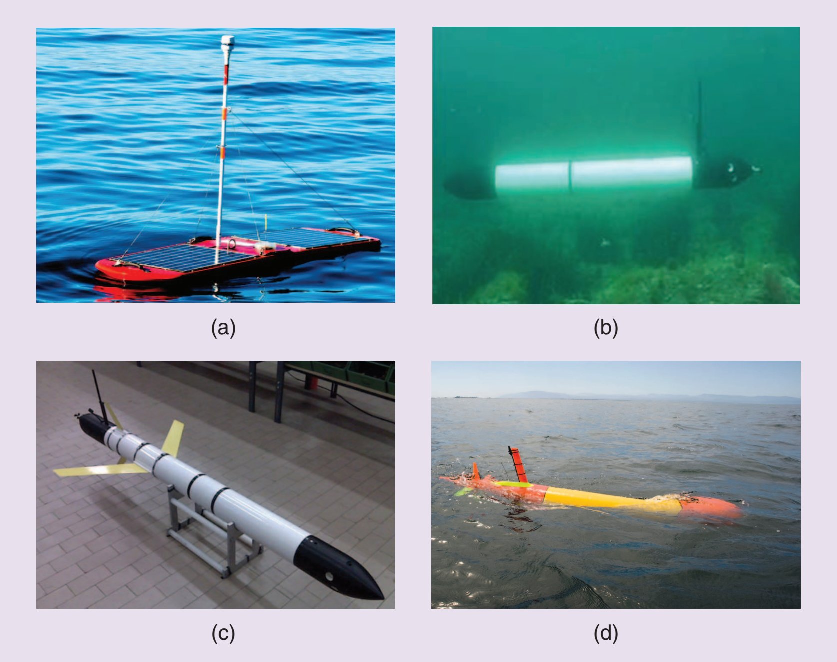

Figure 1. (a) The Waveglider, (b) the Slocum, (c) the Folaga, and (d) the Tethys. [Photos courtesy of (a) Liquid Robotics, (b) Teledyne Webb Research, (c) Graal Tech, and (d) MBARI.]

Underwater Manipulation

One of the greatest demands for marine vehicles comes from the offshore oil and drilling industry for underwater construction and operation. Remotely operated vehicles (ROVs) have been developed for such needs. Work-class ROVs represent a relatively mature and steadily growing industrial sector for marine robotics. However, the recent Deepwater Horizon incident has brought both the successes and limitations of current ROV technology to public attention [10]. ROVs need to be more powerful, more flexible, and more user friendly. Recent research for underwater manipulation aims to improve the human robot interface to allow operators to have better control of the underwater manipulator, to improve the onboard autonomy of the vehicle to allow the operator to achieve more complicated tasks, and to allow multiple ROVs to coordinate on a single task.

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In addition to ROVs, innovation has occurred in manned submersibles, hybrid ROVs, and autonomous underwater manipulation. The Chinese Jiaolong manned submersible has explored seafloors up to 7,000 m, and the hybrid ROV Nereus developed by Woods Hole Oceanographic Institution was the first vehicle to explore the Mariana Trench since 1998. While AUV development has been mostly directed toward survey-oriented vehicles, there are a few examples of AUVs used for underwater intervention. These examples include the OTTER I-AUV by the Stanford Aerospace Robotics Laboratory. OTTER, developed in 1996, is a hover-capable underwater vehicle, which operates in a test tank at the Monterey Bay Aquarium Research Institute (MBARI). Another Intervention AUV, ALIVE, was developed in 2003 by Cybernetix. The aim of the EU-funded ALIVE project was to develop an Intervention-AUV capable of docking to a subsea structure, which was not specifically modified for AUV use. One of the most recent research efforts in underwater autonomous manipulation is the EU-funded TRIDENT project. This project proposes a new methodology to provide multipurpose dexterous manipulation capabilities for intervention operations in unknown, unstructured underwater environments. The SAUVIM AUV [11] was jointly developed by the Autonomous Systems Laboratory of the University of Hawaii, Marine Autonomous Systems Engineering, Inc. in Hawaii, and the Naval Undersea Warfare Center Division located in Newport, Rhode Island. SAUVIM is one of the most advanced underwater robots in the world because of its unique capabilities of performing autonomous underwater intervention.

Unmanned Surface Vehicles

Unmanned surface vehicles (USVs) represent an important branch of marine robotics. Staying on the surface of the water, the USVs usually have better access to localization and communication via electromagnetic links to satellites or to land-based cellular networks. A number of underwater robots also regularly spend time at the surface

vehicles providing charging, deployment recovery, and communication relaying services.

Figure 2. The artificial Jellyfish made by Festo. (Photo © Festo AG & Co. KG.)

to localize and communicate. Global positioning system (GPS) and the Iridium satellite communication services have proven to be essential for real-life operations. The cost of Iridium communication, however, has been one of the limiting factors for long-duration operations. Small, low-cost USVs have shown great potential to operate in inland rivers and lakes to help monitor water quality [12]. USVs such as the waveglider mentioned earlier may serve as important supporting or service platforms for both underwater and aerial

Futuristic Platforms

Due to the advancements in smart materials, a range of artificial muscles or soft actuators are now available for generating animal-like motion underwater (Figure 2). These technologies have fueled a new research trend to develop bioinspired underwater platforms [2], [13]–[15] that mimic marine animals. The bioinspired platforms have to go through a number of improvements to find their way into real-life applications in challenging marine environments. One of the major challenges is to improve the power density and power efficiency for propulsion so that the smart actuators can compete with traditional propellers. Hence, most of these new platforms are still prototypes that have only been tested in labs and mild natural environments. Nevertheless,

these new developments may soon enter into practice. In addition, these animal-like robots serve as great educational and outreach tools to attract future generations of marine robotic researchers.

Information Technology

As marine platforms are becoming more mature and reliable, information technology plays a more important role. The classical perception-plan-action cycle has been adopted by most platforms to achieve various levels of autonomy. Recent developments enhance this cycle by incorporating the latest sensing, computing, and actuation technologies. Furthermore, networked marine robotics becomes a reality supported by the state-of-the-art communication systems. Networked robotics is especially preferred in environmental sensing and ocean observation applications [16].

Perception, Control, and Planning

Many sensors used by ground and aerial robots see severe performance degradation in maritime environments. Cameras are blurred by the turbidity of the water and limited in application due to the significant absorption of light by the water. There is no equivalence of an odometer, and, hence, underwater robots use a technique called dead reckoning, based on inertial measurement units, to self-localize. This localization is significantly less accurate than for terrestrial or aerial mobile robots. Therefore, an external localization service, such as an acoustic-based system, is needed for accurate localization. Underwater perception has to deal with significant environmental disturbances, such as turbidity, low lighting conditions, and unstructured terrains. Progress in this domain may benefit fundamental research in other domains as well.

The limited performance in the perception algorithms calls for improvements over existing control and path planning algorithms. Many of the novel control ideas may not be applicable for marine robots due to the limited computing resources and the limited information flow available onboard a vehicle. Path planning often requires a significant amount of computation, and suboptimal solutions that are easier to compute are often pursued. It is perceivable that more investments will be made to increase computing power and sensor capabilities on marine vehicles. These improvements will potentially open interesting new research directions.

Networked and Distributed Marine Robots

Underwater networking and communication is such a difficult problem that it is traditionally treated as an independent research field. However, as reliable commercial acoustic modems have become more accessible and easier to use, a confluence between marine robotics and underwater networking has emerged as mobile maritime networks. Even though mobile communication underwater is still unreliable, new applications and ideas have been formulated, such as using a swarm of robots to map underwater acoustic fields [17], or using robots to collect data from underwater sensor networks [18]. This marriage between two previously separate areas is mutually beneficial. Marine robots can leverage underwater networking to enhance their intelligence and to achieve higher mission goals, while underwater networks can leverage marine robotics to survey a deployment site or ferry data.

Maritime mobile sensor networks are potentially useful in environmental monitoring applications [19]. Networked gliders have been used to cooperatively map ocean environments during the AOSN and ASAP experiments [20]. A key challenge in mobile ocean sensing is coordinating the motion of vehicles to achieve better map-making results. Since networks often operate over a larger area than a single vehicle, ocean circulation models may provide very useful information about the strength and direction of the current that affects the motion control and path planning of the platforms [21], [22]. New research directions are emerging here as well.

Conquering the Extremes

Either individually or collectively, future marine robots will be tasked to conquer the extremes in all bodies of water on earth [23]. Extreme environments include but are not limited to extremely shallow environments, such as marsh areas and shallow rivers; extremely deep environments, such as the bottom of the Mariana Trench; regions with extremely fast currents or large waves, such as the sea surface during hurricanes or typhoons; polar regions with ice cover and poor GPS signals; and environments with hazards, such as coastal water during the Fukushima nuclear leakage. New advancements in marine robotics have been spurred by the need to operate autonomous systems in these environments.

The major activities of the MRTC are reflected through sponsorship and participation in multiple workshops and symposia at internationally recognized conferences, e.g., ICRA and IROS. The TC plays a major role in the IFAC Workshop on Navigation, Control and Guidance of Underwater Vehicles and all ISOPE conferences. We maintain a mailing list with more than 125 researchers and connect with more than 150 people via Facebook and other social media. You can keep up with the activities of the IEEE RAS MRTC at http://www.ieee-ras.org/marine-robotics. Please visit https://groups.google.com/forum/#!forum/members-marineroboticstc to become a member of the MRTC.

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from the University of Illinois at Urbana-Champaign. These students kept the IROS Facebook and Twitter sites busy with photos and posts, helping to broaden the reach of conference activities. Photos of several of them can be seen in Figures 2 and 3, and many more can be seen on the IROS2014 Facebook page.

In addition to reporting at conferences, the SAC is also developing ways to showcase student news and events happening worldwide. We have initiated a restructuring of the RAS Web page to feature student-focused news and calendar feeds, which will also be adopted by other member communities. We hope this format will allow us to gather news and event information from international RAS student branches and individual members and to easily publicize that information electronically and through social media. We are looking for student reporters to actively encourage submission of stories, so please get in touch if you are interested in helping out with this effort.

The SAC is actively working on getting more students involved in the Society.

Logo Design and Video Competitions

This fall also concluded a design contest to find a logo to use in student-related RAS e-news and announcements on the SAC Web site and on promotional material at events. Over the course of a few months, we received about 30 designs from students all over the world. The student community voted on the winning design, which can be seen in Figure 4. Santiago Morante, a Ph.D. student at the Universidad Carlos III de Madrid, created the winning logo. We received many fantastic designs and would like to thank everyone for submitting. We had a lot of fun looking through all the fantastic submissions.

Figure 4. The winning design from the SAC Logo Design Contest created by Santiago Morante.

Looking forward, we are currently accepting submissions for a student video contest and will feature the winner at ICRA 2015. The details can be found on the SAC Web site.

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