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EXPANDING ROLE OF MARINE ROBOTICS IN OCEAN ENGINEERING

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ABSTRACT
As the ocean attracts great attention on environmental issues and resources as well as scientific and military tasks, the need for and use of underwater robotic systems has become more apparent. Underwater robotics represents a fast growing research area and promising industry as advanced technologies in various subsystems develop and potential application areas are explored. Great efforts have been made in developing autonomous underwater vehicles (AUVs) to overcome challenging scientific and engineering problems caused by the unstructured and hazardous ocean environment. With the development of new materials, advanced computing and sensory technology, as well as theoretical advancements, R & D activities in the AUV community have increased.

INTRODUCTION
The world's oceans cover 2/3 of the Earth's surface and have been critical to human welfare throughout history. As in ancient times, they enable the transport of goods between nations. Presently, the seas represent critical sources of food and other resources such as oil and gas. In the near term, we may soon see the emergence of offshore mining for metals as well as the exploitation of gas hydrates. Conversely, the ocean can also threaten human safety and damage infrastructure through natural phenomena such as hurricanes and tsunamis. Our scientific understanding of the deep sea is expanding rapidly through the use of a variety of technologies. The first scientific explorations were conducted primarily through the use of diving and human-occupied submersibles, complemented by a variety of other technologies such as towed or lowered instruments, trawls, dredges, autonomous seafloor instruments, and deep-sea drilling.
More recently remotely operated and autonomous vehicles have begun to revolutionize seafloor exploration, often returning superior data at reduced costs. In the near future, seafloor observatories linked by fiber-optic cables and satellites will return massive amounts of data from coastal and deep sea sites. These observations will complement those from conventional expeditionary investigations, and will require tele-operated or robotic intervention during installation and for service. An example of a remotely operated vehicle developed for the scientific study of the seafloor is the Jason 2 vehicle developed at the Woods Hole Oceanographic Institution, and a list of remotely operated vehicles for scientific exploration appears below.

Vehicle	Depth	Institution	Manufacturer(m)
Hyperdolphin	3000	JAMSTECa	ISE
Dolphin 3K	3000	JAMSTEC	JAMSTEC

Quest	4000	MARUMb	Shilling
Tiburon	4000	MBARIc	MBARI
ROPOS	5000	CSSFd	ISE
Victor	6000	IFREMERe	IFREMER
Jason	6500	WHOIf	WHOI
ISIS	6500	NOCg	WHOI
UROV 7K	7000	JAMSTEC	JAMSTEC

Offshore oil and gas installations are presently serviced almost exclusively by remotely operated vehicles (ROVs) physically connected via a tether to receive power and data, with human divers used only for the shallowest installations. Subsea systems require extensive work capability during installation, and need frequent inspection and intervention to support drilling operations, actuate valves, repair or replace subsea components, and to accomplish a variety of tasks required to maintain production rates and product quality. The trend toward robotic and tele-operated subsea intervention is certain to continue as offshore oil and gas production moves into deeper waters, and economic considerations push key production steps from surface platforms to the seafloor. Remotely operated manipulators enable these systems to perform complex tasks such as debris removal, cleaning using abrasive tools, and to operate a variety of nondestructive testing tools.

The effectiveness of using ROVs decreases with depth mainly due to the cost increase and the difficulties of handling the long tether. Autonomous underwater vehicles (AUVs) are free swimming unoccupied underwater vehicles that can overcome the limitations imposed by ROV tethers for some tasks. Such vehicles carry their own energy supplies (presently batteries, perhaps fuel cells in the future) and communicate only through acoustics and perhaps optical links in the near future. Limited communications require these vehicles to operate independently of continuous human control, in many cases the vehicles operate completely autonomously. AUVs are currently used for scientific survey tasks, oceanographic sampling, underwater archeology and under-ice survey. Military applications, such as mine detection and landing site survey, are presently operational, and more ambitious applications such as long-term undersea surveillance are in engineering development. Presently, AUVs are incapable of sampling or manipulations tasks like those done routinely by ROVs, as typical work environments tend to be complex and challenging even to skilled human pilots. Today, approximately 200 AUVs are operational, many of them experimental.

However, they are maturing rapidly. Recently several companies now offer commercial services with AUVs. As an example, for the oil and gas industry the cost reduction of a survey performed with an AUVs instead of a towed vehicle is up to 30% and the data quality is generally higher. Likewise, commercial manufacturers in several countries now offer turnkey AUV systems for specific, well-defined tasks. Currently, remotely operated manipulators are standard equipment for most ROVs, while on the contrary autonomous manipulation is still a research challenge; the two projects SAUVIM and ALIVE were devoted to studying this control problem. Boats have been used by humans since the start of recorded history, but vehicles able to go under water are more recent. Perhaps the first recorded idea of an underwater machine came from Aristotle; according to legend he built the: skaphe andros (boat-man) that allowed Alexander the Great (Alexander III of Macedonia, 356–323 BC) to stay submerged for at least half a day during the war of Tiro in 325 BC. This is probably unrealistic; if true it would precede Archimedes' law, which was first articulated in approximately 250 BC. Leonardo Da Vinci may have been the first to design an underwater vehicle.

His efforts were recorded in the Codice Atlantico (Codex Atlanticus), written between 1480 and 1518. Legends say that Leonardo worked on the idea of an underwater military machine but he destroyed the results as he judged them to be too dangerous. The first use of feedback theory for marine control was probably the North seeking device, patented in 1908, that used gyroscopic principals to develop the first autopilot. From that point on, the use of feedback theory in marine control grew continuously; it is interesting to notice that the proportional–integral–derivative (PID) control commonly used today in numerous industrial applications was first formally analyzed in 1929 by Minorsky. The first remotely operated underwater vehicle, POODLE, was built in 1953, and the ROV evolved through the 1960s and 1970s, mostly for military purposes. In the 1980s ROVs became established for use in the commercial offshore industry and began to emerge for scientific applications. The first tetherless, autonomous vehicles were built for experimental purposes in the 1970s. Currently, AUVs are becoming increasingly commonplace for scientific, military, and commercial applications. Turnkey AUV systems for a range of tasks are available from commercial vendors, and AUV services can be acquired from a number of companies.

SENSOR SYSTEMS

Underwater vehicles are equipped with a sensor system devoted to enabling motion control as well as accomplishing the specific mission it has been commanded to complete. In the latter case, sensors developed for chemical/biological measurements or mapping may be installed, which is beyond the scope of this chapter. AUVs need to operate underwater most of the time; one of the major problems with underwater robotics is in the localization task due to the absence of a single, proprioceptive sensor to measure the vehicle position. The global position system (GPS) cannot be used underwater. Redundant multi sensor systems are commonly combined using state estimation or sensor fusion techniques to provide fault detection and tolerance capability to the vehicle. The sensors that can be found on an underwater vehicle are:

1. Compass. A gyrocompass can provide an estimate of geodetic north accurate to a fraction of a degree. Magnetic compasses can provide estimates of magnetic north with an accuracy of less than 1° if carefully calibrated to compensate for magnetic disturbances from the vehicle itself. Tables or models can be used to convert from magnetic north to geodetic north.
2. Inertial measurement unit (IMU). An IMU provides information about the vehicle's linear acceleration and angular velocity. These measurements are combined to form estimates of the vehicle's attitude including an estimate of geodetic (true) north from the most complex units. In most cases, for slow-moving underwater vehicles, an independent measurement of the vehicle's velocity is also required to produce accurate estimates of the translational velocity or relative displacement.
3. Depth sensor. Measuring the water pressure gives the vehicle's depth. At depths beyond a few hundred meters, the equation of state of seawater must be invoked to produce an accurate depth estimate based on the ambient pressure.With a high-quality sensor, these estimates are reliable and accurate, giving a small error of order 0.01%.
4. Altitude and forward-looking sonar. These are used to detect the presence of obstacles and distance from the seafloor.

5. Doppler velocity log (DVL). By processing reflected acoustic energy from the seafloor and the water column from three or more beams, estimates of vehicle velocity relative to the seafloor and relative water motion can be obtained. Bottom-tracking velocity estimates can be accurate to ≈ 1mm/s.
6. Global positioning system (GPS). This is used to localize the vehicle while on the surface to initialize or reduce drift of estimates from an IMU/DVL combination. GPS only works at the surface.
7. Acoustic positioning. A variety of schemes exist for determining vehicle position using acoustics. Long baseline navigation can determine the position of the vehicle relative to a set of acoustic beacons anchored to the seafloor or on the surface through range estimates obtained from acoustic travel times. Ultrashort-baseline navigation uses phase information to determine direction from a cluster of hydrophones; this is most often used to determine the direction of the vehicle (in two dimensions) from a surface support vessel, which is then combined with an acoustic travel-time measurement to produce an estimate of relative vehicle position in spherical coordinates.
8. Vision systems. Cameras can be used to obtain estimates of relative, and in some cases absolute, motion using a type of simultaneous localization and mapping (SLAM) algorithm and used to perform tasks such as visual tracking of pipelines, station keeping, visual servoing or image mosaicking.

ACTUATING SYSTEMS

Marine vehicle are generally propelled by means of thrusters or hydrojets. In the case of ROVs with structural pitch–roll stability, there are usually four thrusters that provide holonomic mobility to the four remained DOFs, in particular, the depth is often decoupled and the vehicle is controlled on a plane in the surge, sway, and yaw DOFs. Those vehicles, being under actuated, cannot easily be used for interactive control by means of a manipulator due to the impossibility of counteracting the generalized forces exchanged with the manipulator’s base; in such case, six or more thrusters are required. AUVs generally have a torpedo-like shape and are used for mapping/exploration. They are propelled using one or two thrusters parallel to the fore–aft direction and a fin and a rudder; this kind of propulsion is obviously non-holonomic and experiences a loss of mobility at low velocities. Hydrojets, also known as pump jets or water jets, are systems that create a jet of water for propulsion; they have certain advantages over thrusters such as a higher power density and usability in shallow water, but can provide thrust in one direction only.

MISSION CONTROL SYSTEM

The mission control system (MCS) can be considered as the highest-level process running during an AUV’s mission; it is responsible for achieving several control objectives. At the highest level it works as an interface between the operator, accepting his instructions in a higher-level language and decomposing those instructions into mission tasks according to the implemented software architecture. The mission tasks are generally concurrent and their handling depends on the vehicle state and environmental conditions; it is therefore the MCS that handles the tasks, eventually suppressing, sequencing, modifying, and prioritizing them. An MCS is also usually equipped with a graphical user interface (GUI) to report the mission state to the operator. As for most advanced robotics applications, an efficient MCS should allow the use of complex robotic systems by users that do not necessarily know all of their technical details. An overview relevant to underwater mission control is given in, which includes an interesting classification of the MSCsin use in several laboratories according to which four major AUV control architectures were identified: the hierarchical, heterarchical, subsumption, and hybrid.

From a mathematical point of view, the MCS generally needs to be designed in order to be able to address hybrid dynamical systems, i. e., handling both eventdriven and time-driven processes. e.g., the MSC developed at the Portuguese Instituto Superior Técnico (IST), named CORAL, is implemented by resorting to a Petri-net-based architecture that properly handles all the necessary tasks in order to manage navigation, guidance and control, sensing, communications, etc. The motion-oriented operating system (MOOS), designed at the Massachusetts Institute of Technology, is a software tool capable of executing and coordinating amplitude of subsea operations. The MSC developed at the Naval Postgraduate School is in the framework of the behavioral control organized in three layers.

LOCALIZATION

Localization in the underwater environment can be a complex task, mainly due to the absence of a single external sensor that gives the vehicle position such as, e.g., the GPS for outdoor ground vehicles; moreover, the environment is often poorly structured. One of the most reliable methods is based on the use of acoustic systems such as the baseline systems: the long-baseline system (LBL), the short baseline system (SBL), and the ultrashort-baseline system (USBL). These systems are based on the presence of a transceiver mounted on the vehicle and a variable number of transponders located in known positions. The transceiver's distance from each transponder can be measured via the measurement of an echo delay; from this information the position of the vehicle can be calculated by basic triangulation operations.

The USBL can be used with a single transponder, which is usually mounted on a surface ship whose position is measured by GPS. Another localization system is called terrain-aided navigation and is based on the use of terrain elevation maps; bathymetric maps are available, especially in the case of well-known locations such as harbors where they usually have a resolution of ≈ 1m. In this case, the vehicle position is obtained by filtering the information coming from a downward-looking sonar. In, a particle filter approach was used to localize an AUV in Sydney harbor.

CONCLUSION

The underwater environment is extremely hostile for human engineering activities. In addition to high pressures and hydrodynamic forces that are both nonlinear and unpredictable, water is not an appropriate media for electromagnetic communication except at short ranges. This pushes underwater technology to rely on acoustic communication and positioning systems that are characterized y low bandwidth. On the other hand, the ocean is extremely important for numerous human activities from the commercial, cultural, and environmental points of view. Research on underwater robotic applications is active both from the technological and methodological aspects. The power endurance of commercially AUVs is currently up to 50 h; this will increase as energy storage devices improve. Improved energy and power capability will enable longer missions, higher speeds, or better/additional sensors such as, e.g., more powerful lighting for underwater video/photography. The current trend for the price of AUVs prices is downward, with more and smaller research institutions building or buying AUVs to enrich their research results; moreover the setup of multiple-AUV systems is becoming cost effective. The goal is to develop fully autonomous, reliable, robust, decision-making AUVs.

REFERENCES

[1] P. Marty: ALIVE: An autonomous light intervention vehicle, Advances in Technology for Underwater Vehicles Conference, Oceanology Int. (2004)
[2] T.I. Fossen: Marine Control Systems, Guidance, Navigation and Control of Ships, Rigs and Underwater Vehicles (Marine Cybernetics AS, Trondheim 2002)
[3] S. Bennett: A brief history of automatic control, IEEE Contr. Syst. Mag. **16**(3), 17–25 (1996)
[4] J. Yuh, M. West: Underwater robotics, J. Adv. Robot. **15**(5), 609–639 (2001)
[5] SNAME: Marine engineers: nomenclature for treating the motion of a submerged body through a fluid, Techn. Res. Bull. **1-5**, (1950)
[6] T.I. Fossen: Guidance and Control of Ocean Vehicles (Wiley, New York 1994)
[7] O.M. Faltinsen: Sea Loads on Ships and Offshore Structures (Cambridge Univ Press, Cambridge 1990)
[8] J. Yuh: Modeling and control of underwater robotic vehicles, IEEE Trans. Syst. Man Cybern. **20**, 1475– 1483 (1990)
[9] T.I. Fossen, A. Ross: Guidance and control of unmanned marine vehicles, IEEE Contr. Eng. Series (Peregrinus, Stevengce 2006) pp. 23–42
[10] W.E. Cummins: The impulse response function and ship motions, Techn. Rep. **1661**, David Taylor Model Basin, Hydromechanics Laboratory (DTIC, Washington 1962)
[11] T.F. Ogilvie: Recent progress towards the understanding and prediction of ship motions, 5th Symposium Naval Hydrodynamics (1964) pp. 3–79
[12] T. Perez, T.I. Fossen: Time-domain models of marine surface vessels for simulation and control design based on seakeeping computations, 7th IFAC Conf. Manoeuvring Contr. Marine Craft (IFAC, Lisbon, 2006)
[13] T.I. Fossen: A nonlinear unified state-space model for ship maneuvering and control in a seaway, J. Bifurc. Chaos **15**(9), 2717–2746 (2005)
[14] M. Nahon: Determination of undersea vehicle hydrodynamic derivatives usingthe USAF Datcom, Proc. Oceans Conf. (Victoria 1993) pp. 283–288
[15] J.N. Newman: Marine Hydrodynamics (MIT Press, Cambridge 1977)
[16] A.J. Healey, D. Lienard: Multivariable sliding mode control for autonomous diving and steering of unmanned underwater vehicles, IEEE J. Oceanic Eng.**18**, 327–339 (1993)
[17] B. Stevens, F. Lewis: Aircraft Control and Simulations (Wiley, New York 1992)
[18] I. Schjølberg, T.I. Fossen: Modelling and control of underwater vehicle-manipulator systems, 3rd IFAC Conf. Manoeuvring Contr. Marine Craft (IFAC, Southampton 1994) pp. 45–57
[19] E.A. de Barros, A. Pascoal, E. de Sea: Progress towards a method for predicting AUV derivatives, 7th IFAC Conf. Manoeuvring Contr. Marine Craft (IFAC, Lisbon 2006)