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PREGLEDNI RAD
(*Review*)

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State and Perspectives of Underwater Robotics - Role of Laboratory for Underwater Systems and Technologies

Abstract

The state and perspectives of underwater robotics is presented. The role and achievements of Laboratory for underwater systems and technologies (LABUST) in this domain is described. Two LABUST projects are shortly described.

Keywords: Unmanned underwater vehicles, remotely operated vehicles, autonomous underwater vehicles, underwater systems.

1. Introduction

Unmanned Underwater Vehicles (UUVs) are:

- Remotely Operated Vehicles (ROVs) that can free fly or crawl on the bottom
- Autonomous Underwater Vehicles (AUVs) that can be with active (AUV) or passive (Gliders) propulsion

UUVs face a unique challenge that other unmanned vehicles (on land or air) do not:

- the ocean - a corrosive environment in which high pressure often presents a challenge for mechanical design
- the ocean depths – where the communication is difficult where the range of acoustic communication depends on the available power/battery capacity and the bandwith is small compared with the aerial communication by electro-magnetic waves

- large and mainly unknown underwater space that should be explored

Designers of the unmanned underwater vehicles are today split among two different architectures:

- pressurized vehicles - a pressurized vehicle is entirely airtight and pressurized like a submarine
- free-flood - this architectures enable the vehicle to fill with water while keeping some components in pressurized compartments

In the field operation, cycling cable connections and repeatedly opening pressure assemblies is a great way to introduce failures. Modular, plug-and-play UUV is ideal that is still not achieved.

Unmanned underwater vehicles (UUVs) are today used in a variety of applications, from oil and gas exploration to underwater archaeology missions or autonomous ship hull inspections.

The commercial use of UUVs centers mainly on the gas and oil industry. With development of technology, UUVs are expanding into the mainstream with the ability to complete a wider variety of missions than their research-specific predecessors. Intervention tasks (turning valves, cleaning etc.) as well as persistent autonomy and cooperation among vehicles is in focus of research today. Cognitive robotics that is the hot topic in land and aerial robotics is slowly entering the marine robotics domain.

In commercial use, high resolution seabed mapping and imaging for commercial mapping and oil/gas pipeline surveying in shallow and deep waters are major tasks done for the oil and gas industry. Inspection, maintenance and repair (IRM) are done in depths over 300m almost exclusively with remotely operated vehicles (ROVs) which are main type of vehicles for IRM tasks.

Military use of UUVs focuses on surveillance, minesweeping and mine countermeasure work. Maritime security of ports and sailing routes are today in high priority. Autonomous underwater vehicles and remotely operated vehicles are equally in use here.

The scientific community continues to make advancements in UUVs usage. Use of autonomous underwater vehicles (AUVs) and Remotely Operated Vehicles (ROVs) for high-resolution mapping of the deep ocean floor, as well as mapping salinity, temperature, oxygen, fluorescence, backscatter and pH over a full annual cycle is very common. AUVs and ROVs are used under the ice in the Arctic for the purpose of monitoring the influences on climate change. Quantitative survey of hydrothermal plumes and other near-bottom surveys in rugged seafloor terrain is going on today on a yearly basis. The usage and capabilities of AUVs and ROVs will continue to grow.

2. Present state of technology – unmanned underwater vehicles

Unmanned underwater vehicles are characterized with the lack of pilot (man/women) onboard the vehicle.

2.1. Remotely Operated Vehicles

2.2. Historical remarks

Dimitri Rebikoff (born 1921 in Paris, died 1997 in Florida, USA) developed the first underwater electronic flash, stereophoto and film cameras, the world´s first underwater scooter, the Torpille, the Pegasus and the first remotely operated vehicle (ROV) Poodle (1953). He holded ~ 60 patents and worked for several years with Jacques-Ives Cousteau.

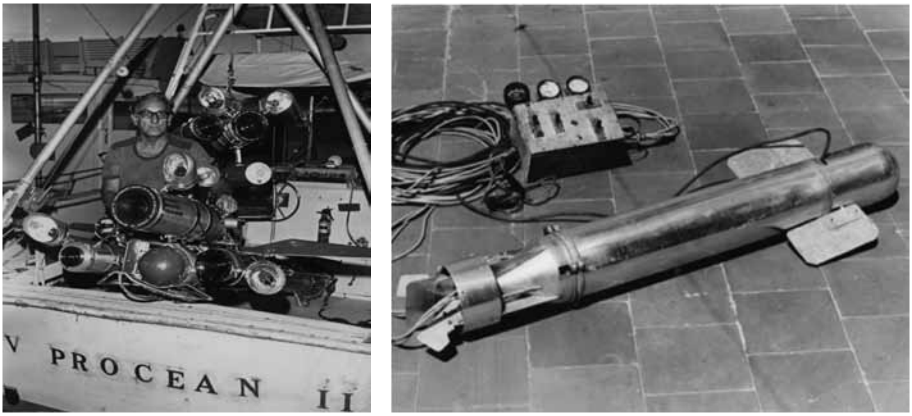


Figure 1. First ROV POODLE by Dimitri Rebikoff, built in 1953.

2.3. Types of Remotely Operated Vehicles

ROVs has been used for the last 60 years all over the world to get access to under-water locations not easily accessible by divers or by other means. ROVs are under-water vehicles that are tele-operated. An umbilical, or tether, carries power and command and control signals to the vehicle and the status and sensory data back to the operator’s console.

Figure 2. Sonsub Innovator workclass (yelow) and Seabotix miniclass ROV (red)

ROVs can vary in size from small vehicles fitted with one TV camera (used for simple observation), up to complex work systems that can have several dexterous manipulators, video cameras, mechanical tools and other equipment. They are generally free flying, but some are bottom-founded on tracks. Towed bodies, such as those used to deploy side scan sonar, are not considered ROVs.

ROVs for scientific use have lower power (to keep umbilical size small). Typical missions include: instrument placement, retrieval and support; *in situ* experimentation; ecological studies and observations (mid-water and benthic); sampling and light coring; surveys of environmental parameters.

Deep water ROVs have some well known problems which are related with the higher cost of operation, because the DP vessel is needed, and those ships are in big demand and because of this, not always on disposal. Also, long thether management becomes a major problem. Despite all these, ultra-deep ROVs primarily for scientific use has been developed.

2.4. ROV – status and perspectives

ROVs are mature technology suitable to meet all needs of the oil & gas industry (up to 3000 m depth) as well as scientific and military community. New developments in deep water ROVs include: all electric deepwater WorkClass ROVs, reduction of inefficiencies (30% and more), smaller and lighter units, more reliability (less parts), smaller umbilicals (optical becomes very popular), more sophisticated tooling and advancement in launch and recovery systems. Lately, more automation in ROVs, that are relieving operators from strain work is in trend. New type of ROVs especially for deep sea has been developed. These hybrid ROVs (HROVs) have batteries, so through the optical cables only information is transferred. The trend is that field work with them is possible using ships without DP capabilities which greatly reduce cost of the operation.

2.5. Autonomous Underwater Vehicles (AUVs)

AUVs are free-swimming, unmanned submersible vehicles, independent of outside facilities or operators. They are capable to fulfill the mission without the help of operators. Present applications include: sub-sea survey; sub-sea inspection; pipeline inspection; cable inspection; oceanographic sampling; environmental monitoring; iceberg profiling; under-ice surveys; mine detection and countermeasures; diver delivery / supply vehicles; downed airplane / shipwreck searches; underwater photography.

2.6. Historical remarks

In 1864 Robert Whitehead (left) (born 1823 in Bolton, UK and died 1905 in Shrivenham, UK) made a contract with the retired officer of the Austro-Hungarian

Navy Ivan (Lupis) Vukić (right) (born 1813 in Rijeka, died 1875 near Como, Italy) in order to perfect Vukić's invention of the first prototypes of a self-propelled torpedo in 1866. Vukić tried to realize his long-time idea of the "coast saviour", a new naval weapon. The weapon was a low-profile surface boat, propelled by compressed air, and controlled by ropes from the land. Whitehead improved it and designed the control system for the underwater weapon later known as torpedo. Torpedo has all the characteristics of the autonomous underwater vehicles and can be considered as first AUV. However, almost 100 years have to pass until AUVs in modern sense was re-invented.

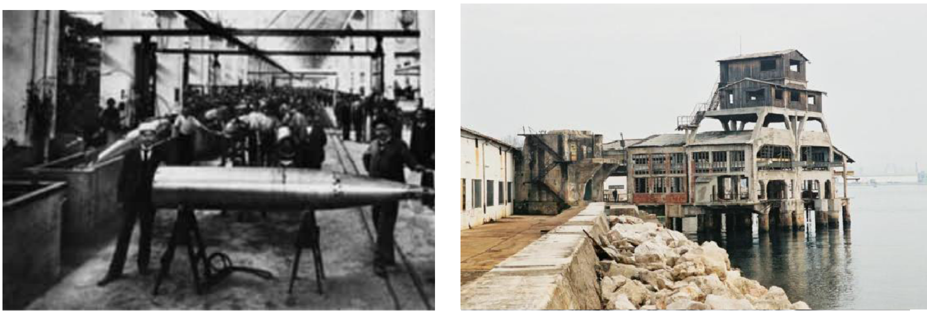


Figure 3. Torpedo factory and test site in Rijeka.

New development began in the early 60's with vehicles such as Rebikoff's SEA SPOOK in 1960, followed by the SPURV 1 in 1963. In 1950 Applied Physics Laboratory, University of Washington's begins work on the Self-Propelled Underwater Research Vehicle (SPURV 1). The vehicle was ready and launched in 1963. SPURV 1 AUV had depth rate of 3000m, speed of 4-5 knots and autonomy of 4 hours. Development was funded by the Office of Naval Research (ONR). A total of five SPURV vehicles served in the U.S. Navy operating until 1979.

Figure 4. SPURV II in launch.

An improved SPURV II in 1973 had a longer endurance and depth rating. They were soon followed by others such as:

- SKAT at the Shirshov Institute of Oceanology (USSR), 1970
- OSR-V (Japan);
- EAVE West, RUMIC, UFSS (U.S. Navy);
- EAVE EAST (University of New Hampshire, U.S.); 1970 and
- EPAULARD (France), 1970.

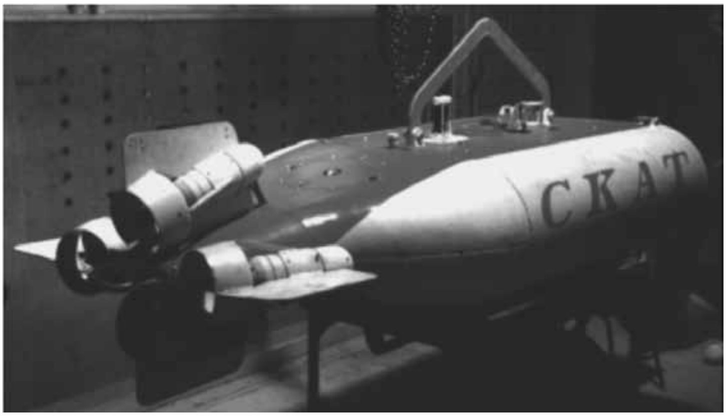


Figure 5. SKAT AUV.

2.7. Types of autonomous underwater vehicles

AUV industry has begun to emerge from the R&D and prototype phase to production runs. Scientific community and military were the early adopters. For the oil & gas industry AUVs are becoming efficient tool for seafloor survey and mapping, especially in deepwater (up to 3000m). Types of AUVs are given in Figure 6. Lately AUVs with hovering (DP) capabilities are emerging primarily in R&D domain, but for future use of AUVs for IRM tasks this capability will be a necessity. Cost reduction of up to 30% with better data quality with respect to traditional tools (towfish) should be expected from AUVs. Commercial AUVs services are now offered. However, the costs of AUV operations are still significant.

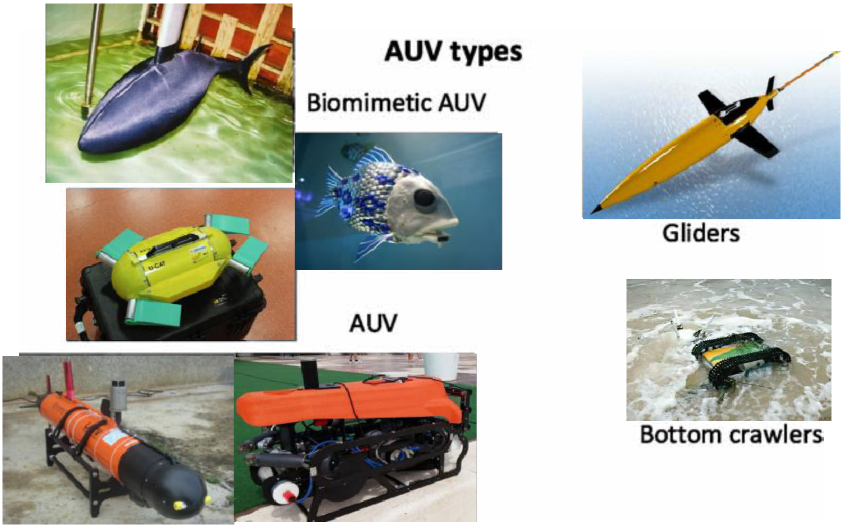


Figure 6. AUV types.

2.8. Future of AUVs

Typical endurance of commercially operated AUVs is up to 70 hours; it will continue to increase as energy storage technology improves. This will allow also for higher speeds, additional sensors and better lighting for underwater video/photography. AUV costs will trend downward. However, low cost AUVs (like low cost ROVs) will have commensurate limitations in their capabilities. Use of multiple AUVs simultaneously will become practical where projects are significant enough in size to justify the increased investment. Research and development will focus in the future toward:

- Real-time data at the surface. Present acoustic modems allow for subsampling of data batches. The ideal would be real-time acoustic command and control.
- Power. To stay longer underwater and operate tools.
- Ability to hover. This is especially important for inspection and intervention tasks.
- Physical interaction with the working environment
- Tool design (electrical tools, minimize power, size and complexity)
- Launch and recovery. Most existing systems are satisfactory but there is still work to be done at the sea/air interface.
- Size of systems. If an AUV system is to be retrofitted on an offshore facility it would need to be no larger than the existing ROV package
- Layout and design of subsea facilities
- Cooperation and coordination of many AUVs

2.9. Market forecast

Main market drivers of underwater robotics are in commercial sector (Offshore oil & gas industry), security sector (Defense & Security) and in research sector with its need for measured data from oceans. Technological developments in other fields such as in robotics, communications, and other sectors also are very important. In [4] it was stated that:

- The global expenditure on ROVs and AUVs in the energy sector in 2012 was in total ~$1.52bn.
- Global sales of ROVs in 2010 reached $850 mil. 50% were purchased by oil and gas industry, defense & security purchased 25% and research 25%. Global ROV market is estimated to be $1,2 bn in 2014
- AUV market in 2014: 70% military sector and 26% R&D sector with only 4% commercial sector
- AUV market forecast for 2018: 72% military sector 19% R&D sector and 9% commercial sector
- The global AUV market is estimated to be $457 million in 2014 (from ~ 200 mil. USD in 2010)
- World AUV market is expected to grow and is forecasted to rise by 2016 to 930 units, from 390 units in 2009 and 560 units in 2012.
- By 2019 UUV market (AUVs and ROVs) is forecasted to $4.84 bn.

This estimated values show that this sector have quite good potential for growth and that in this sector new developments is expected with great interest.

2.10. AUV – key technological requirements for sub-sea intervention

For subsea intervention tasks by AUVs we will need key technological achievements such as real-time data at the surface - ideally real-time acoustic command and control; more power to operate tools; ability to hover with capability of physical interaction with the working environment. Simpler launch and recovery and smaller size of systems i.e. AUVs should not be larger than the existing ROV package. New layout and design of sub-sea facilities will also be needed. Present AUV concept (survey-class) cannot have a role in Inspection, Repair and Maintenance (IRM) tasks in commercial sector. To make AUV suitable to carry out intervention tasks on sub-sea facilities it is necessary to combine ROV and AUV capabilities and develop a completely new configuration of AUV, different from the survey-class, i.e. AUV that can hover and be capable to intervene (intervention/or work class AUVs).

3. LABUST ROLE AND ACHIEVEMENTS

Laboratory for underwater systems and technologies (http://www.fer.unizg.hr/zari/labust) has been involved in various types of missions for end-users from 2003. We can mention here:

- ✓ inspection of hydro-power plant dams in Croatia, Slovenia and Bosnia & Herzegovina (from 2003 on);
- ✓ inspection for unexploded ordnance in port of Gruž-Dubrovnik in 2005
- ✓ search and rescue missions of plane crash near Dugi otok in 2008 and a suicide in river Sava in Zagreb in 2014
- ✓ missions for marine biology/ecology: Telaščica 2006, Lastovo 2007, National Park Kornati 2010-2011, ...
- ✓ missions for underwater archaeology Senj 2007, Rogoznica 2008, Cavtat 2009, Pula 2010, Gnalić 2011-2013, Caesarea (Israel) 2014 – 2015, Valgjärv (Estonia) 2015,...

LABUST is a top laboratory at UNIZG-FER for performing international projects ! We have ongoing projects funded by EU, NATO and the US Navy Office of Naval Research Global.

Projects supported by EU are:

- FP7 project „New operational steps towards an alliance of European research fleets - EUROFLEETS2 (2013-2017) http://www.eurofleets.eu/np4/home.html
- ECHO project „Underwater Robotics Ready for Oil Spills - URready4OS“ (2014-2016) http://www.upct.es/urready4os/?lang=en
- FP7 project „Cognitive Autonomous Diving Buddy – CADDY“ (2014-2017) http://www.caddy-fp7.eu/
- H2020 project „Submarine Cultures Perform Long-term Robotic Exploration of Unconventional Environemntal Niches - SubCULTron (2015 – 2019) http://www.subcultron.eu/
- H2020 project „Excelling LABUST in marine robotics – EXCELLABUST“ (2016 – 2019)

Projects supported by the US Navy Office of Naval Research Global (ONRG) are:

- „Breaking the surface“ - BtS (2012 - 2015)
- “Diver navigation using range-only measurements from an autonomous surface vehicle” - DINARO (2015 – 2017)
- „Spatial Auditory Human-Machine Interface for UxV Teleoperation” - SPATEL (2015 – 2017)
- “Bio-inspired Synchronous Jumping Marine Sensor Networks” - SeaJumper (2015 – 2017)

NATO SfP project is „Unmanned system for maritime security and environmental monitoring” - MORUS (2015 - 2018).

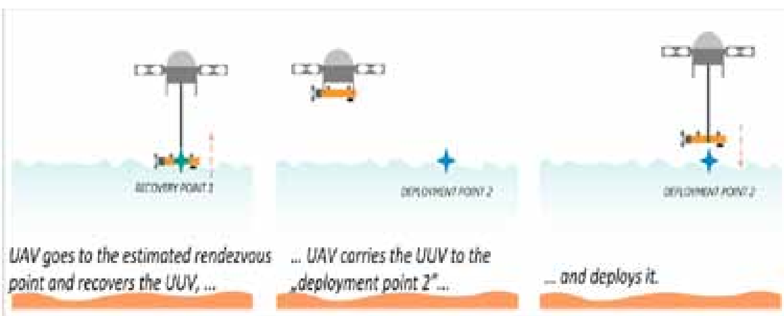
MORUS goals are in:

- Design and development of a fully operational complex robotic system prototype comprised of an UAV and an AUV capable to autonomously and cooperatively execute missions related to
  - environmental,
  - border and
  - port security.
- Design and develop autonomous aerial and marine robotic systems, capable of collective engagement in missions taking place in dynamic and nondeterministic environments.
- The design will focus mainly on payload enhancement and UAV autonomy which is mandatory for AUV transport. Besides that, a docking system and cooperative control algorithms will be developed enabling autonomous deployment, re-deployment and data exchange at the open sea.
- Operating environment of the proposed prototype is an unknown, uncertain and remote, i.e. far from a human operator. Therefore, a whole set of novel cooperative control algorithms, combined with augmented human machine interface, will be designed and implemented in order to ensure safety and recoverability of the described system.

Two scenarios will be tested.

Scenario 1

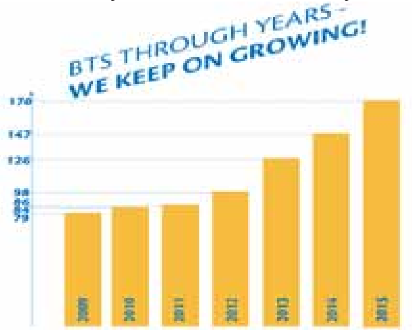
Scenario 2



“Breaking the surface” (http://bts.fer.hr) is a week long field training that was supported between 2009 and 2011 by the FP7 project “Developing Croatian Underwater Robotics Research Potential – CURE”, and from 2012 till 2015 by the ONRG. This is a week long field training with four+ main disciplines:

- marine robotics (MAROB),
- marine biology/ecology (MARBIO),
- underwater archaeology (MARCH),
- maritime security (MARSEC)
- .....

At BtS we have ~20 plenary lectures, 3 ~ 5 tutorials, demonstrations of projects and company products. During the BtS, echange of new ideas, initiatives for project proposals and cooperations were agreed. „Breaking the surface“ became a brand that is very popular which is shown by attendance over the years.



4. Conclusions

Underwater systems and technologies have bright prospects in the future. Many possible applications can be identified. Submarine areas are still mainly unexplored areas. Only 5% of World Oceans are explored. Technology trends should be expected in:

- increased intelligence and on-board decision making as well as use of different unmanned marine vehicle types (Autonomous underwater (AUV) or surface (USV) vehicles, ROVs, and Unmanned aerial vehicles (UAVs or drones)) to provide a complete remote solution for inspection and intervention tasks.
- Improvements in sensor technology and better quality of data due to sensor fusion
- Development of reliable autonomous launch and recovery (docking) systems
- Penetration-free recharging of batteries
- Improvements in communication capabilities

Research and developments topics will be in the persistent autonomy, intervention repair and monitoring (IRM) tasks preformed by autonomous vehicles (AUVs, USVs, UAVs), autonomous launch and recovery in all weather conditions, extended battery capacities, autonomous work over longer period of times in various weather conditions, UAVs capable of taking off and landing in the water or on USV, autonomous, multi-vehicle operations moving towards cooperating, heterogeneous vehicles, standardization (communication, tools, subsea assets, ...).

Laboratory for underwater systems and technologies is heavily involved in the R&D and our specific expertise, especially in navigation, guidance and control of unmanned marine vehicles, enable us to perform challenging projects with our partners from the EU. Exploration of Oceans in 21st century will boost research, development and innovation in marine robotics.

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Zoran Vukić, Nikola Mišković

Stanje i perspektive podvodne robotike - uloga laboratorija za podvodne sustave i tehnologije

Sažetak

Stanje i perspektive podvodne robotike su predstavljene u ovom radu. Uloga i postignuća Laboratorija ua podvodne sustave i tehnologije (LABUST) u ovom području su opisane. Osim toga, dva projekta LABUST laboratorija su sažeto opisana.

Ključne riječi: Bespilotne ronilice, daljinski upravljana vozila, autonomne ronilice, podvodni sustavi.