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Autonomous unmanned underwater vehicles development tendencies

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Abstract

This article gives a brief overview of the AUV development history from the beginning to the present day. We have considered different types of AUV from remote operated vehicles (ROV) to biomimetic AUV. Our goal is to define the vector of AUV development at an early date on the basis of the AUV history.

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Keywords: Autonomous underwater vehicle; underwater glider; bionic underwater vehicles; underwater research; development of AUV

1. Introduction

AUV have made a real revolution in the field of ocean research [1, 2]. During the last two decades AUV were transformed from heavy and expensive equipment for ocean academic research into a tool for solving a wide range of issues in many theoretical and practical fields including commercial and military fields. As a result the load capability requirements, necessities for computational capabilities, autonomous and acoustic requirements have grown for such devices. Herewith low cost and versatility are very important.

Therefore, knowledge of trends in the development of AUV is the key not only to our competitiveness in this area and to enable current research of the ocean, but also the defense of our country, at sea and in the coastal zone. To identify these trends, we need to first turn to the history of the AUV, find out how they have evolved and changed since its inception.

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2. Screw driven AUV

The first device, which can be classified as AUV, was developed in 1957 in the USA, Applied Physics Laboratory, University of Washington and named SPURV (Special Purpose Underwater Research Vehicle), designed to research in the Arctic waters [3].

SPURV hull was made of aluminum and had a torpedo like shape. SPURV had classical hydrodynamic shape and it was driven by a screw. Control of this AUV was carried out by means of acoustic communications. SPURV had been successfully used in oceanographic research until 1979, and declare itself as a reliable and practical tool to explore the ocean [4].

After successful SPURV testing scientists from the University of Washington developed the SPURV modification - SPURV II. Unlike its predecessor, SPURV II had better ride performance and operating time under water, a large number of sensors and recording devices. In addition, SPURV II had the ability to be controlled by computer mounted on an oceanographic ship. SPURV II as well as SPURV I were successfully used till the 80s, [5].

A group of scientists from the Institute of Automation and Control Processes, Far Eastern Scientific Center of the Academy of Sciences was created AUV "Scat" in 1974. Based on the knowledge and experience gained from Scat development and exploitation processes L-1 and L-2 had been created. L-1 was used for testing and developing new technologies for the AUV, L-2 - for oceanographic research. These AUV also had module construct and unified AUV and its systems design [7].

Further development of technology has expanded the AUV possibilities. The company ISE Ltd. with the assistance of the Canadian Hydrographic Service and the Department of Defense developed the ARCS in 1983. Its first dive took place in 1987. Feature of the device was using a 32-bit processor Motorola, which allowed users to monitor and control AUV in real time as well as to stay under water from 10 to 35 hours, depending on the modification. ARCS had been successfully used as a test platform for new technologies in the field of AUV, such as the new navigation system, algorithms missions and new types of batteries [6].

In the late 90s, scientists from the Russian Institute of Marine Technology Problems interested in the possibility of installing solar panels on the AUV. This project was named SAUV (solar autonomous underwater vehicle). It was created in cooperation with AUSI (Autonomous Undersea System Institute). In 1998 SAUV was created. Subsequently, based on the developing experience of such vehicles, researchers from AUSI created their own solar AUV - SAUV II. Solar panels installed on it, allowed the vehicle to carry out its mission during a few weeks or months by means of regularly recharging the batteries. SAUV was able to move without recharging the battery for 8 hours, navigate using GPS and had high load capability [8].

Further developing of screw driven AUV led to REMUS (Remote Environmental Monitoring Units) developing in 2001. It was designed for reconnaissance, inspection and mine works at the shallow depth of the ocean. REMUS had a large number of sensors and measuring devices, the information from them was transmitted using acoustic communications to a controller. Controller could be used for AUV programming and plotting a course. Singularity of REMUS-100 is compactness: the device has small size and low weight - 30 kilograms.

REMUS-600 was the next modification of REMUS-100. Weight, size, diving depth as well as load capability were increased. REMUS-600 singularity is also modularity and universality: quick having changed the equipment, it is possible to prepare AUV for the new task. Additionally extra batteries can be installed in REMUS-600 allowing voyage up to 280 miles. This AUV had three bow and fodder rudders that had given high yaw direction stability

Comparative characteristics of the several AUVs are given in Table 1.

3. Underwater gliders

Cruising range of most classical type of AUV was insufficient. Scientists and the military needed vehicle capable to stay under water for a number of weeks or months. Herewith silent AUV was needed for military. As a result scientists had diverged of traditional AUV design with the classical hydrodynamic shapes and screw propellers. Therefore a new type of AUV – autonomous buoyancy-driven underwater gliders have appeared. The trajectory of the glider is like a saw-tooth profile [10]. Wings are needed to stabilize the glider movement and smooth dive.

The idea of the gliders was formed Henry Stommel and Doug Webb in 1955 [9]. And today these ideas are embodied in a variety of models of underwater gliders.

iRobot company represented the Seaglider in 1999. It had an aluminum hydrodynamic hull form with 1 meter foil span. Buoyancy was controlled by small pumps. Batteries were electric power supply. Seaglider is very energy effective and as a result has very high cruising range – 4600 miles [10].

Subsequently Seaglider was modify and got the composite hull from carbon fiber, which had given the opportunity to dive to a depth of 6000 m. This modification was called ‘Deepglider. Its first dive was in 2006 [11].

One of the most ambitious projects of underwater gliders is SLOCUM gliders. Besides the AUV, this project included not only AUV developing but the infrastructure needed to gliders launch, tracking its course and data analysis.

There are two main modifications of SLOCUM Glider - SLOCUM Electrical and SLOCUM Thermal. SLOCUM Electrical operation principle is similar to the Seaglider: it controls its buoyancy by means of a hydraulic system powered by batteries. This glider was designed special for operation in shallow waters. SLOCUM Electrical singularity is antenna for communication and navigation which located at vertical stabilizing tail [10].

SLOCUM Thermal is the glider with fundamentally new buoyancy control technique. It uses the thermocline effect for buoyancy changing. This effect is used for ethylene glycol temperature changing and as a result vehicle buoyancy. This idea reduces energy consumption by 3-4 times [10]. SLOCUM Thermal has been designed for depth greater than the SLOCUM Electrical has had. Singularity of this underwater vehicle is high autonomy according to calculated data. SLOCUM Thermal is capable to float under water 40 000 kilometers.

Gliders have also attracted the attention of the military. Silent, able to move under water for thousands hours, they can be an effective tool for reconnaissance and detection submarines or other objects. One of the projects putting into practice this idea is the Liberdade XRAY glider. It was constructed based on the "flying wing" scheme, which is the most advanced for further AUV developing. Liberdade XRAY also has large payload and can contain a lot of measuring equipment. This glider is the largest among the existing vehicles of this class. It has a 6.1 m foil span. Tests have shown that Liberdade XRAY is able to stay under water for six months, using hydrophones for controlling large areas and detecting submarines and tracking their movement, carried out acoustic reconnaissance [10, 12].

Comparative characteristics of several underwater gliders are shown in Table 1.

Table 1. Comparative characteristics of AUV.

AUV model	Weight (kg)	The length and diameter (m)	Depth (m)	Cruising range	Speed (m/sec)	Thrusters	Foil span (m)	Communication systems
SPURV (1957)	484	3,1 and 0,5	3650	4..5,5 h 7..9 km	1,95	Screw propeller	-	Hydroacoustics
SPURV II (1973)	598	4,57 and 0,508	1500	5,5..7 h	1,7..3,4	Screw propeller	-	Hydroacoustics
L-1/L-2 (1979/80)	1140/1180	4,3 and 1,2	2000/6000	6 h	1	Screw propeller	-	Hydroacoustics
ARCS (1987)	1360	6,4 and 0,68	305	10..35 h	2,05..2,85	Screw propeller	-	Hydroacoustics
SAUV II (2003)	200	Length 2,3 Width 1,1 Height 0,5	500	8 h prior to discharge the battery	0,5..1	Screw propeller with adjustable vector	-	Hydroacoustics and radio communications, GPS-navigation
REMUS-600 (2003)	240	3,25 and 0,32	600..3000	about 24 h	2,05	Screw propeller	-	SSSA and radio communications, GPS-navigation, Wi-Fi and

								connect to the satellite "Iridium"
Seaglider (1999)	52	1,8 and 0,3	1000	3800..4600 km	0,25	The automatic buoyancy control	1	Communication with the satellite "Iridium"
SLOCUM Electrical (2001)	52	1,5 and 0,21	200..1000	1500 km	0,3..0,4	The automatic buoyancy control	1,2	Radio, ARGOS, satellite contact "Iridium"
SLOCUM Thermal (2001)	60	1,5 and 0,21	2000	to 40 000 km	0,4	The automatic buoyancy control	1,2	Radio, ARGOS, satellite contact "Iridium"
Deepglider (2006)	62	1,8 and 0,3	6000	8500 km	0,25	The automatic buoyancy control	1	Communication with the satellite "Iridium"

4. Bionic AUV

Further electronic components size reduction had given scientists the opportunity to develop compact AUV. There are two categories of such vehicles - mini-AUV (mass from 20 till 100 kilograms) and micro-AUV (mass up to 20 kilograms). The most part of existent AUV can be attributed to mini-AUV. Micro-AUVs are one of the high developing AUV types. They generated up to 20-25% from all known AUVs as for 2009. It is worthy of note that 50-60% from them were bionic AUVs [13]. Such vehicles may find application in a wide range of military and civilian tasks.

Bionic AUVs have excellent maneuverability. This is their main advantage. So-called Gray paradox is studied with help of bionic AUV. Gray paradox consists in that fish are available to accelerate without significant muscle effort.

MIT students were one of the first who created in 1994 the underwater robot imitating tuna (Tune project). Further they also designed the RoboPike which had flexible body and ride characteristics comparable to traditional AUV.

Besides swimming bionic AUVs, crawling bionic AUV have been creating: Ariel II, RoboLobster and others. They are available to move using "clutches" resembling lobsters and crabs. Bionic AUV with fin are also developed (AQUA2 project and others). AQUA2 is a robot for working on shallow, environmental monitoring of sea ground and coral reefs. It has four fins manufactured from durable polymers, allowing the robot to move not only under water, but also on the sand or snow. Four fins have given very high mobility to AQUA2 in comparison with conventional AUV [14].

Fish robot MT1 was designed and built in the UK. It has a small mass and size (3.55 kg, length-width-height: 48-21.5 - 15 centimeters). MT1 is able to move under water at depths up to 10 meters using two pectoral fins and one tail, driven by an electric motor. But the main MT1 singularity is an opportunity of self-orientation in water space, and using neural networks and artificial intelligence techniques for motion algorithms [15].

Red dots indicate scientific institutions creating AUV:

1. Australian National Facility for Ocean Gliders, Australia, Perth
2. Autonomous Undersea Systems Institute, USA, New Hampshire
3. ETH Zurich Autonomous Systems Laboratory, Switzerland, Zurich
4. Florida Atlantic University, Florida, USA
5. Institute of Marine Technology, Russia, Vladivostok
6. Institut français de recherche pour l'exploitation de la mer, France
7. Japan Agency for Marine-Earth Science and Technology, Japan, Yokosuka
8. Korea Institute of Ocean Science & Technology, South Korea
9. Laboratory for Underwater Systems and Technologies, Zagreb, Croatia
10. MIT AUV Laboratory, USA, Massachusetts
11. National Institute for Oceanography, India
12. Rutgers University Institute of Marine and Coastal Sciences, USA, New Jersey
13. Sheyang Insitute of Automation Chinese Academy of Sciences, China, Shenyang
14. University of Washington Applied Physics Laboratory, USA, Seattle
15. Woods Hole Oceanographic Institute, USA, Massachusetts

Blue dots indicate the commercial organization established AUV

1. Fugro Seafloor Surveys, United States, Seattle
2. Teledyne Gavia, Iceland
3. Teledyne BlueView, United States, Seattle
4. Teledyne Webb Research, USA, Massachusetts
5. Saab Seaeye, United Kingdom
6. iRobot Maritime Systems, USA, Massachusetts
7. Bluefin Robotics, USA, Massachusetts
8. SeeByte, United Kingdom, Edinburgh
9. Kongsberg Maritime, Norway

Fig. 1. The major scientific and commercial organizations developing AUV

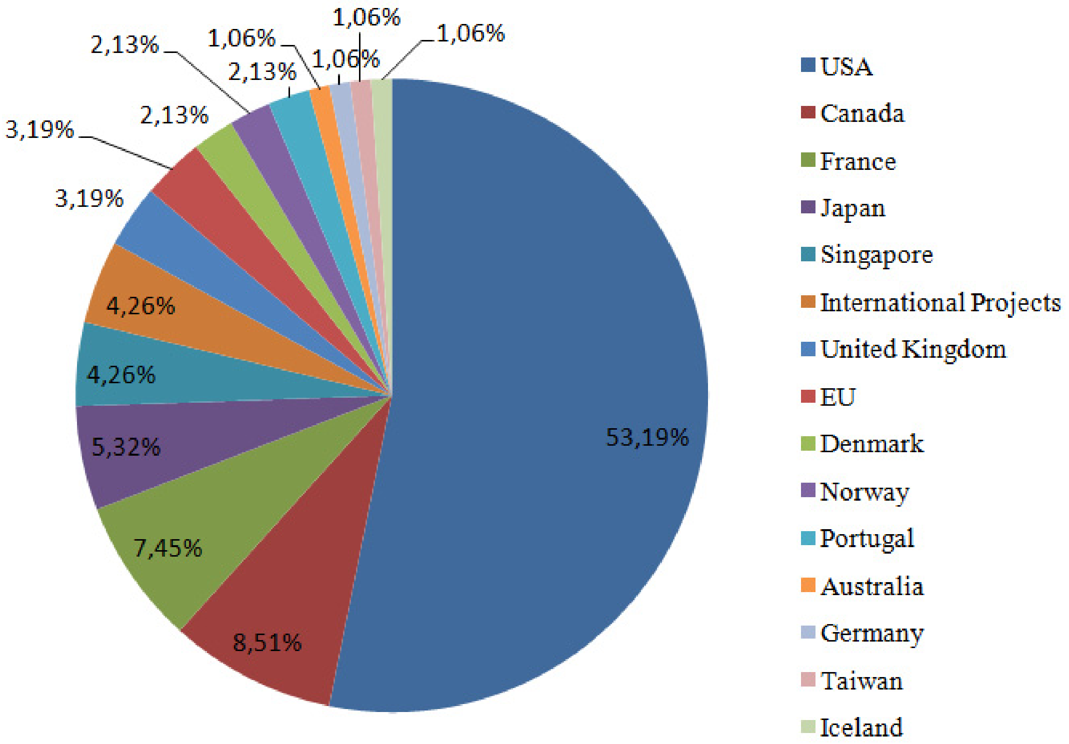

Fig. 2: Countries developing AUVs (data for the year 2009) [13]

5. Tendencies of development AUV

Having brief reviewed the history of AUVs and noted their changing over time, we are able to determine how the AUV will develop in the near future, what challenges will appear.

5.1. Materials

List of new materials used in autonomous underwater robots will continuously expand. Besides aluminum, a variety of composites and carbon fiber will be utilized. These materials will allow the AUV to be both lightweight and strong, and to withstand heavy loads. An example of AUV with similar materials is Deepglider capable to submerge up to 6 km.

New strong and flexible materials are required for bionic AUV. "Smart materials" converted electrical signals into mechanical vibrations will find application in this AUV type. Smart materials can be applied to produce AUV fins for simulation undulatory motions [16].

5.2. Engines

New types of propulsors differing from traditional propelling DC screw will be developed. If the experiments with bionic AUV are successful we will see how they replace devices with classical hydrodynamic shapes and propelling screw, exceeded traditional AUV in maneuverability and cruising range. We should also note even now underwater gliders are predominantly used in large-scale sea research when long stay under water is needed.

Alternative energy sources such as solar cells or piezoelectric elements will be increasingly frequently implemented in AUV. Effective accumulators with greater power capacity and smaller size will be implemented for increasing AUV mobility, velocity and autonomy [17].

5.3. Cheaper and smaller

Further AUV miniaturization as well as electronic components and new materials availability will reduce AUV size, cost and simultaneously increase their working characteristics. Vehicles will be cheap, small, mobile, simple to operate, with a sufficient load capability and module construct they will be perfect for the group action. Several such AUV can replace one large, expensive and complex to operate apparatus, with an equal or even greater efficiency of work [18]. MicroHunter series are the example of such vehicles. They were developed in period from 1999 to 2002 and have a length from 5 to 20 centimeters, were powered by AA batteries and were designed for operation in groups [15]. In the future, the AUV application in groups will be more actual. Therefore the study of AUV cooperation with each other will be very important.

5.4. Intelligent

One of the main causes of AUV development is further computational capability increasing and electronic components miniaturization. The first allows us to use more accurate equipment to operate more efficiently and implement new algorithms. Miniaturization is especially important for mircoAUV and mini-AUV designed for use in large groups [20]. There is an opportunity for powerful control system creating in the future. This control system based on environmental measurement will make AUV more autonomous and give them the opportunity to choose the further purpose of following and build a route around obstacles [3]. It can be adaptive control systems or control systems based on artificial neural network. MT1 is an example of the bionic underwater vehicle using some elements of artificial intelligence and neural networks.

5.5. AUV as a basis for future reconnaissance of the Navy

AUV military applications will expand. Modern army and navy, more and more widely use these autonomous devices that provide new opportunities and allow us to solve some problems without people involving and consequently without a serious risk for them. AUV can become for navies the same as UAV have becomes. As far back as 90s the USA have been developing AUV for following tasks [19]:

1. Hydro acoustic and electronic reconnaissance.
2. Detection of submarines, naval mines and other objects and destroying them using torpedoes or missiles carried by the AUV.
3. Setting naval mines, sensors and communications.
4. Provide communication between devices for detecting submarines and command centers on ships or on shore.

6. Conclusions

Review of the AUV history gives understanding how AUV have developed from the very beginning to the present day. The main AUV developing trends in near future are:

1. Using new materials and new AUV design concepts.
2. Application radically new propulsion systems and batteries with high capacitance.
3.Increasing AUV application in military.
4. AUV miniaturization and increase their computational capability

5. Reducing AUV cost.
6. Using neural networks and artificial intelligence.
7. Increasing AUV application for working in groups.

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