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TRENDS IN THE DEVELOPMENT OF UNMANNED MARINE TECHNOLOGY

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ABSTRACT

The article constitutes an attempt to identify current tendencies regarding the development of unmanned marine technologies such as unmanned surface and underwater vehicles. The analyses were performed on the basis of available literature, databases on research projects and internet sources. The material has been divided with regard to the location the research was conducted, the following groups being identified: the European Union, the United States of America and Poland. On the basis of the review of objectives and final effects of projects, tendencies in the development of the discussed marine technology have been identified. An interesting result of the review consists in an observation that Polish R&D works in this area are placed within the main identified developmental trends. Unfortunately, their effects are incomparable due to the minuteness of national funds allocated to R&D as opposed to other countries.
Key words: underwater work technology, marine engineering.

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INTRODUCTION

An article published in Polish Hyperbaric Research No. 1 (2016) presents an analysis of development of underwater techniques and technologies enabling the conquest of depths and working under water with regard to the maximum depth reached [1].

The said material demonstrates that in the years of development of this domain, numerous difficulties had been overcome, thus resulting in preparation and construction of a number of solutions, thanks to which humans were able to descend to the maximum depth of the ocean registered on Earth. Still, attention was drawn to the fact that it was only possible due to insulating solutions. On this basis a conclusion was made that the presence and work of man at large depths will only be possible virtually.

One of the currently available methods of technical implementation of such a presence in the depths consists in the use of remotely operated vehicles (the so-called ROVs) or widely understood unmanned marine vehicles. These devices have been developing cumulatively for a long time, over four distinguishable periods of development, which had been previously described in detail in earlier publications of the author [2,3]. Today, this is one of the most dynamically developing branches of underwater works technologies.

The presented material constitutes an attempt to identify the current development trends on the basis of the available information on underwater and surface unmanned technologies. The analysis was based on the data taken from full-text databases on the content of scientific magazines and databases on the implemented projects, e.g. CORDIS – Community Research and Development Information Service – or the information available on websites of research centres. The material has been divided with regard to the territories where the research was conducted into the areas of the European Union, the United States and Poland. This division is an effect of the previously conducted analyses, whose results indicated a greater dynamics of activities in the discussed scope in the territory of the EU and the USA. Poland was considered for the obvious reasons.

RESEARCH AND DEVELOPMENT WORKS IMPLEMENTED IN THE EUROPEAN UNION

Starting from 4FP, approximately 110 different R&D projects connected with the technology of unmanned vehicles have been implemented in the EU. The objective of one of them was to design a remotely operated robot to perform cleaning activities on the hulls of watercraft ("HISMAR").

The project aim was to design a remotely operated device, pursuant to the applicable EU regulations, that would perform hull cleansing activities, removing lichen from the underside of vessels in an economically viable manner, without needed to dry dock the ship . Poland participated in this undertaking as one of the implementers (PRS S.A.).

Another programme implemented in the EU is "ASIMOV" – body of water reconnaissance with the use of an underwater semi-autonomous abyssal vessel; controlled with a hydro-acoustic beam by an unmanned autonomous surface vessel, these vehicles are capable of transmitting information to various users. Also we have the "Swimmer" programme, whose objective was to design a hybrid autonomous vehicle to transfer an ROV to an underwater station, for instance, in an oil field, where it is docked via hydro-acoustic steering to the previously prepared underwater garage connected via an umbilical with a surface ROV control station.

Upon the completion of the docking procedure, the ROV establishes a connection with the control station, leaves the carrier and performs remotely controlled tasks (Fig. 1.1). The SAAB Company from Sweden, on the other hand, implemented a programme, whose aim consists in the construction of a modular vehicle using a periscope to facilitate observations both underwater and on the surface. Using a Saab Ventures platform, in cooperation with a Danish company C-Leanship APS, the company realises a project concerned with ROVs used for cleaning underwater parts of watercraft. A similar subject matter is covered by such projects as the Norwegian CleanHull or transcontinental DNV-Oceaneering (American-Norwegian).

An interesting solution integrating the European research environments was a project implemented within the 6FP with the acronym FREESUBNET – European network for key technologies for intervention autonomous underwater vehicles. The programme enabled construction of virtual communication tools between scientific environments concentrating more than fifteen European scientific centres scattered around Europe.

In its course, over 170 scientific dissertations were published with the use of this tool, several of which ended with the granting of a doctoral degree, and a few dozen master's degrees. The access to information contained in the network for young scientists constituted a unique opportunity for cooperation with leading academic employees and research centres dealing with underwater vehicles.

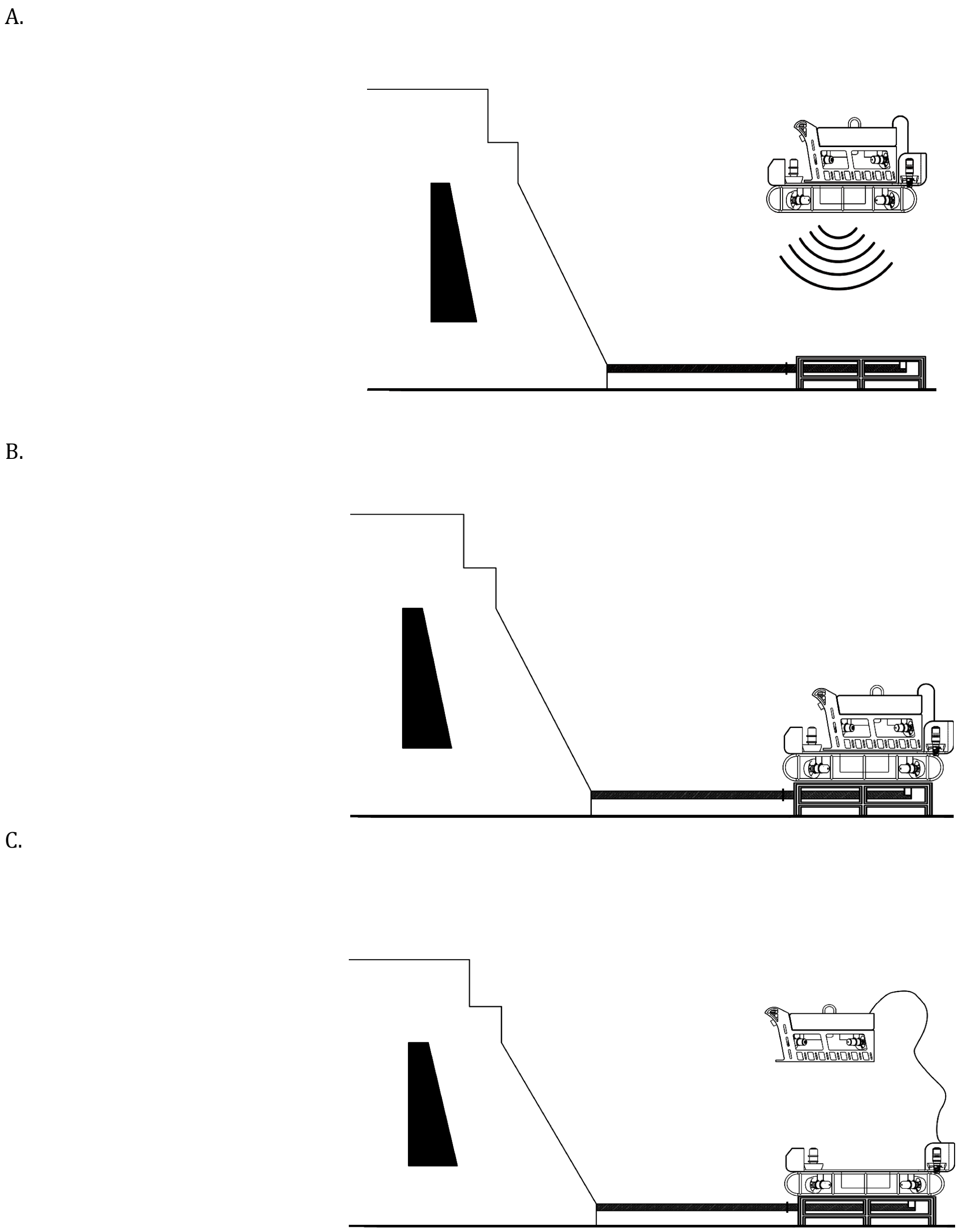


Fig. 1.1 Modular construction of an underwater system – an autonomous vehicle transports a remotely controlled vehicle to a docking station (A), after the docking in the station is completed, connection with the controlling cable is established (B), a remotely controlled vehicle leaves the station for the purpose of task performance (C).

More than a dozen research programmes in the area of unmanned underwater techniques were implemented within the 7FP for a total of over 30 million Euros including an own contribution of beneficiaries [4,30a]. The most interesting of them included projects with the following acronyms: CURE, ARROWS, MORPH, PANDORA, COCORO, NOPTILUS, SURF3DSLAM, TRIDENT and POLMOSAIC.

The objective of the CURE project[1] implemented between 2009 – 2012 was the strengthening of Croatian potential in underwater robotics. The activities focused on the support and activation of human and material resources, partnership development with leading scientific and research centres in Europe, as well as improvement of the research infrastructure.

The project coordinator was Sveuciliste at Zagrebu Fakultet Elektrotehnike i Racunarstva. In the case of the ARROWS project[2] (2012 – 2015), the objective consisted in the development of cost effective constructions of underwater vehicles for the purpose of obtaining a significant reduction in the cost of implementing archaeological underwater research. The project was jointly implemented by scientific centres from Italy, Estonia, Spain and Great Britain. The coordinator was the Universita Degli Studi Di Firenze (Italy).

The project entitled *Marine robotic system of self-organizing, logically linked physical nodes* – MORPH – was implemented (2012 – 2015) with the aim of designing separate cooperating mobile underwater robots capable of conducting penetration activities in bodies of water and adjusting their multi-modal configuration to the situation in the field, combined into an intelligent network with the use of underwater communication networks. Such a capability enables an efficient and highly accurate method of mapping of an underwater environment.

The project was implemented by scientific institutions from Germany, Portugal, France, Spain and Italy – the coordinator was a German company – Atlas Elektronik Gmbh. In the case of the PANDORA project[3] realised in the years 2012 – 2014, the goal was to develop new methods of automatic identification of damage and failures in underwater vehicles as well as ways of reacting to them.

The project was implemented in cooperation between research institutions from Great Britain, Greece and Spain, and the coordinator was the Heriot-Watt University (Great Britain). Interesting solutions were proposed in the implementation of the COCORO project[4] (2011 – 2014), whose objective consisted in the development of swarm technologies for underwater robots ensuring their cooperation and joint task performance by establishing interactions between underwater vehicles being a part of the swarm.

The project was implemented by 5 scientific institutes from Austria, Italy, Great Britain and Belgium, and the project coordinator was Universitaet Graz (Austria). The NOPTILUS project[5] (2011 – 2015) allowed preparation of an innovative autonomous method of controlling underwater vehicles. The project was implemented by 8 scientific units from Greece, Portugal, Switzerland, the Netherlands and Great Britain, and coordinated by the Hellas Centre for Research and Technology (Greece). The SURF3DSLAM project [6] (2011 – 2013) was to develop an accurate positioning system for underwater vehicles without the use of an external infrastructure. It was independently implemented by Universitat De Girona from Spain.

The TRIDENT project[7] (2010 – 2013) defined assumptions for a heterogeneous robot system comprising abyssal and underwater watercraft. The project was implemented by 8 scientific establishments from Spain, Great Britain, Italy and Portugal, and the coordinator was Universitat Jaume I De Castellon (Spain). The last of the aforementioned projects had an acronym POLMOSAIC[8] (2010 – 2012). Its objective was to develop a technology enabling the obtainment of high definition image of the seabed for the purpose of creating a photomosaic with the use of polarimetry methods. The project was implemented independently by Universitat De Girona in Spain.

In the area of Europe special attention should be devoted to the research and development activities of a Swedish company SAAB AB. Svenska Areoplan AktieBolaget AB is a company established in 1937 as a Swedish aviation concern. After the Second World War it was divided into a car manufacturing part – Saab Automobile AB (liquidated in January 2012) and Saab AB producing defence technologies, mainly for aviation and marine needs.

Practically since 1990 both entities, operating under nearly identical names, had constituted separate enterprises. At present, SAAB AB operated in five business areas encompassing aviation, electronic security systems, maritime, aviation technologies and technical services. The company annually allocates approximately 2.5 billion PLN to research and development (data as of the end of 2011) [5].

It is currently the European leader in the underwater vehicles segment offering 10 different ROV types. The activity within underwater vehicles production is conducted by a subsidiary named Saab Underwater Systems AB. One of the forms of financing innovative solutions in Saab is the Saab Ventures platform through which the company invests in small and fast developing spin-out companies, thus assuming corporate oversight over the company and its technologies.

This mechanism was utilised in the acquisition of a British company Seaeye Marine Ltd. founded by Ian and Janet Blamire in 1986 thus establishing SAAB Seaeye Marine Ltd. Recently the company has increased its production capacity by 50% due to the opening of a new production plant in Portsmouth. The plant encompasses technical workshops, containers for vehicle testing, construction and conference-project facilities. Saab Seaeye Marine Ltd. has become a leader in the ROV market due to the application of innovative technologies in brushless motors, polypropylene frames and an innovative approach to the systems of power supply, steering and control. Currently, one of the similar projects implemented with the use of the Saab Ventures platform involves cooperation with a Danish company C-Leanship APS within ROVs used for cleaning of the underwater parts of watercraft hulls.

Among the projects co-financed by the European Union it is worth mentioning the research project coordinated by a Polish scientific establishment with the acronym CHEMSEA[9](2011 – 2014) [6]. Although its main objective consisted in performing an assessment of chemical munition dump sites remaining in the Baltic Sea since the Second World War, the project also involved research tasks concerned with the construction of abyssal vehicles.

It consisted in an adaptation of an ROV construction to conducting research in potentially contaminated sites with the possibility of taking samples of seabed material and water from the layer over the seabed. The project was implemented by 11 scientific establishments from Poland, Sweden, Finland, Germany and Lithuania. The coordinator was the Institute of Oceanology of the Polish Academy of Sciences in Sopot[10].

AMERICAN RESEARCH

Ocean researcher worldwide aims towards the possibility of collecting data concerned with bodies of water, enabling the obtainment of comprehensive information from various areas and with the use of various technical solutions. Traditionally, this is done with the use of oceanographic ships equipped with diverse apparatuses. An interesting initiative in this respect is a research institute founded in 2009 by Eric Schmidt under the name of Schmidt Ocean Institute with the seat in Palo Alto (California, USA).

The Institute's mission consists in acquiring oceanographic knowledge through the collection of data with the use of a fleet of underwater robotised devices, their analysis and open exchange with various environments [30b]. At the same time, it is important to note the fact that according to Schmidt, the potential problem rests in data processing not collection.

For this reason, he believes that this should be handled by properly constructed analytical machinery capable of managing the enormous amounts of collected bezzałogowe. Obecnie instytut realizuje projekt głębokowodnego pojazdu badawczego o hybrydowej konstrukcji zdolnego do pracy na głębokościach 4500m (Rys. 2.1). information. The primary research tool of the institute is the R/V Falkor ship equipped with a number of environment analysis tools, including unmanned vehicles. At present the institute is implementing a project of a deep water hybrid research vehicle capable of working at a depth of 4500 m (Fig. 2.1).

The project provides for the construction of an entire flotilla of such vehicles, the first of which is to become operational in 2016, and the others in the years to come. In prospect, the plan envisages reaching operational capacities with the use of these devices at depths of 11000m.

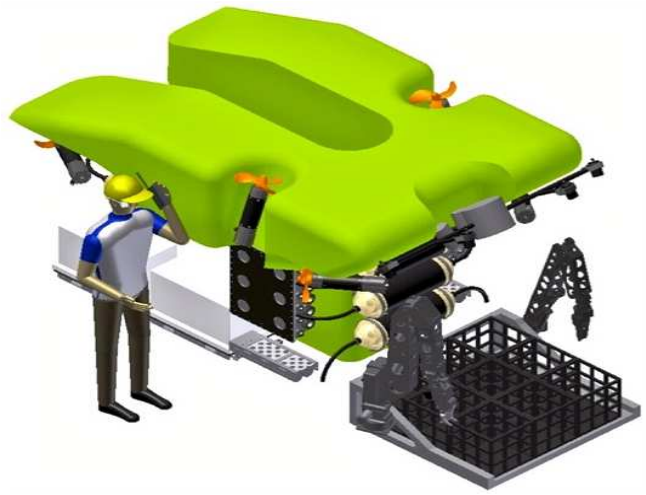


Fig. 2.1. The concept of a deep water hybrid vehicle developed at the Schmidt Ocean Institute [30b].

On the other hand, wherever there is a need solely regarding data collection on the aquatic environment, there are attempts to withdraw from the use of remotely operated devices and aim towards designing highly autonomous vehicles in terms of energy consumption and independent in task realisation. This is feasible, since in such a case there is no need for performance of any kind of technological operations or those connected with sampling the seabed material, and the basic on-board equipment consists of sensors of environmental parameters.

The data collected with their use can be transmitted in any way that is known to modern technology, for instance to a smartphone belonging to a research project manager. In such cases the systems used in ocean research comprise underwater and surface gliders like that designed and developed by Liquid Robotic Wave Glider (Sunnyvale California, USA) – Fig. 2.2.

This surface glider moves at speeds of up to 4 km per hour and, since it utilises wave movement, does not require any power source. Six meters below the surface hull there are wings that propel the vehicle. Wave movement is transferred to horizontal planes resembling the horizontal caudal fin of a whale. Power is supplied to all on-board devices, including satellite communications, with the use of solar cells installed in the upper part of the vehicle.

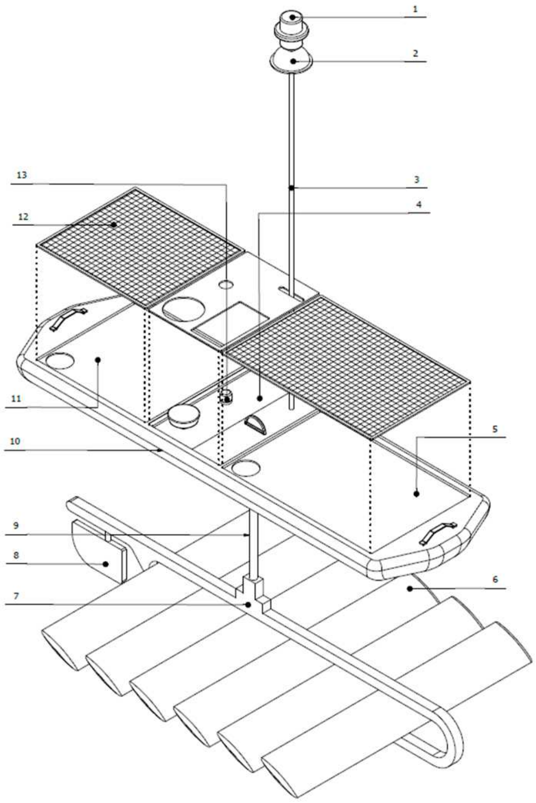
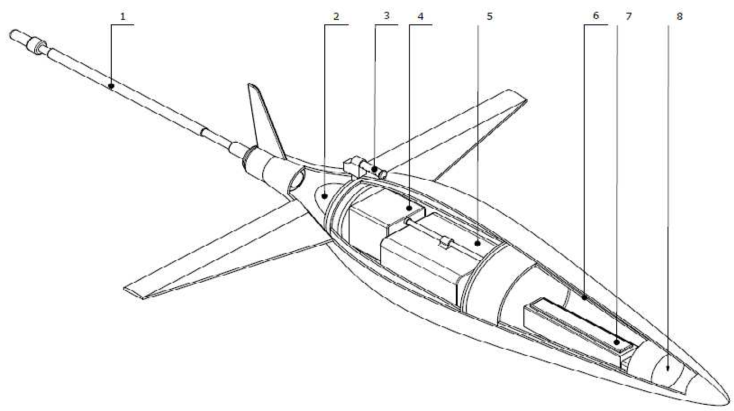


Fig. 2.2. Wave Glider vehicle developed by Liquid Robotics.
1 – weather forecast station, 2 – running lights, 3 – mast, 4 – chamber with electronic equipment, 5 – nose battery, 6 – propelling wings, 7 – wing frame, 8 – rudder, 9 – pole connecting surface and underwater parts, 10 – lifting fuselage, 11 – stern battery, 12 – solar panel (stern), 13 – automatic ship identification antenna (ASI) [30c].

However, Wave Glider cannot immerse and explore ocean depths. Such a purpose is served by a different kind of a marine unmanned glider. For instance, the one designed by the University of Washington in Seattle (USA), the Seaglider vehicle – Fig. 2.3. The vehicle is submerged by moving the ballast between the nose and the tail and generating carrying capacity in horizontal depth rudders.

The effect is intensified by pumping oil by a small pump, which changes the position of the vehicle's nose. The vehicle moves in midwater with a sinusoidal movement, covering a horizontal distance of several kilometres in a single immersion, and descending as much as one kilometre in depth. By moving this way at speeds of approximately 1 km/h (0.5 kn) it can work even for several months, as the battery powering the small pump motor does not require too frequent a replacement. As can be seen, a real challenge for these devices is their powering with electrical energy.

An interesting and innovative concept in this respect was presented in a science fiction article published in Oceanography magazine in 1989 by Henry Stommel [7]. Its implementation, on the other hand, was the work of engineers from Teledyne Webb Research commissioned by Woods Hole Oceanographic Institution in 1991 [8]. It is an underwater glider (called Slocum Glider) powered with a displacement engine supplied with a heat exchanger.



2.3. SeaGlider vehicle developed at the University of Washington [30d].
1 – GPS antenna, 2 – pneumatic balloon, 3 – measurement sensors, 4 – hydraulic system with oil, 5 – batteries, 6 – pressure shield, 7 – electronic module, 8 – hydroacoustic transponder.

The propulsion uses temperature differences between surface and deep waters. The basis is material changing its volume under the effect of temperature changes, which powers up a small hydraulic pump feeding the current generator. As studies showed, such a solution allows the glider to descent to a depth of approximately 1800 metres and travel a distance of almost 4 km (Fig. 2.4) [30e].

The most recent solutions by Teledyne Webb Research includes a vehicle which weighs up to 60 kg, has an operational depth of up to 1200 metres, with energy autonomy of up to 5 years and the possibility of covering distances of approximately 40000 km. The Slocum G2 Glider moves with the use of a displacement engine at the speed of 0.35 m/s [30e].

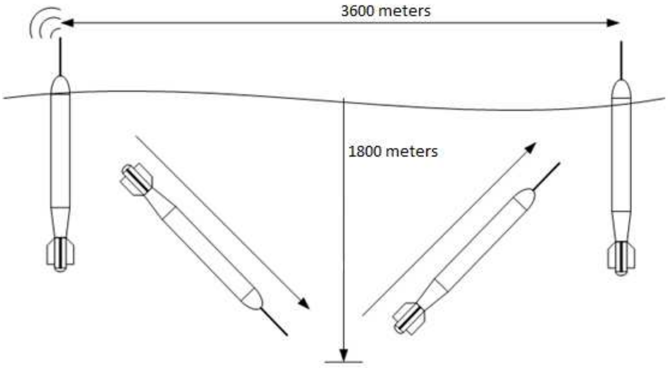


Fig. 2.4. Slocum Glider mission profile [8].

A significant breakthrough within the scope of constructional solutions concerning the technical methods of the remote control of vehicles has occurred quite recently. In 2013 an American vehicle, Nereus, working at the depth of over 700 meters was controlled with the use of a hydroacoustic channel with simultaneous visual data transmission at the speed and in a quality enabling real time control of the vehicle's manipulator (Fig. 2.5).

Of course, this solution used a hydro modem immersible to a significant depth with the use of an fibre optic cable, and for this reason such a configuration is called a hydroacoustic-optic channel [9].

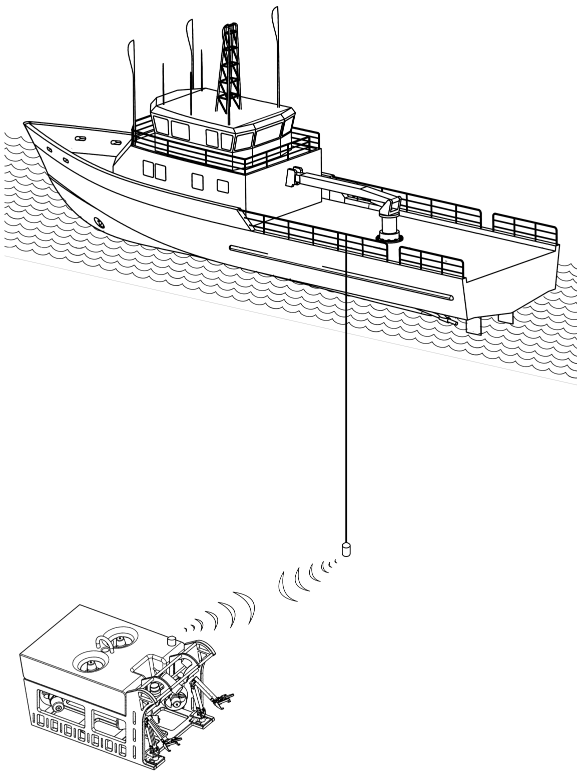


Fig. 2.5. The use of a hydroacoustic-optic channel to control a vehicle at large depths.

A number of interesting development projects in the area of marine unmanned platforms is implemented by the Naval Research Laboratory (NRL), and in particular the Laboratory for Autonomous Systems Research.

One of such projects concerns the development of a concept of an unmanned flying-diving vehicle – Flimmer UAV/UUV – its objective consists in providing a solution combining unmanned flying vehicles and underwater vehicles, which is to significantly improve the tactical availability of underwater vehicles operating within a short time horizon, at small distances and in places they would find difficult to reach independently, for instance, due to strong currents (Fig. 2.6).

Another research unit of NRL implements a similar project involving a UAV/USV vehicle – i.e. a flying-swimming vehicle (Sail-a-Plane), which is to be used for reconnaissance purposes. A different NRL project within underwater unmanned technologies involves an underwater vehicle with the so-called "fluttering fins", which is to be used in reconnaissance of very shallow coastal bodies of water [10] – Fig. 2.7.

Moreover, the Naval Research Laboratory implements a project entitled Adaptive Testing of Autonomous Systems, aimed at the development technologies used for the testing and evaluation of control software for intelligent autonomous systems.

Another NRL project consists in conducting research towards the improvement of operational manipulator capacities within the scope of artificial sensory impression aimed at increasing the perceptive capabilities of manipulators encompassing a sense of touch.

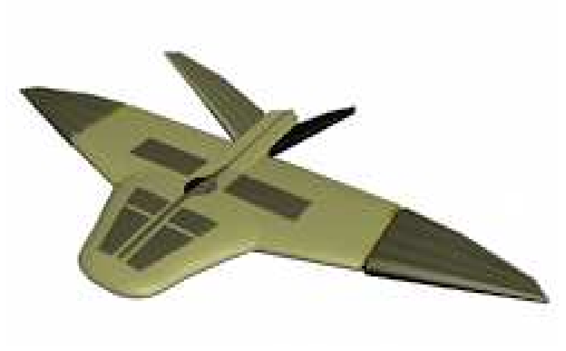


Fig. 2.6. The concept of UAV/UUV Flimmer vehicle [30f].

Fig. 2.7. UUV with propulsion using the so-called "fluttering fins" [10].

POLISH RESEARCH AND DEVELOPMENT WORKS

In the second half of the 20th century research works connected with the technology of unmanned underwater vehicles conducted in Poland were the domain of institutes located on the coast, such as the Szczecin University of Technology, the Gdańsk University of Technology and Naval Academy.

The pioneering works in this field were implemented by a team supervised by Prof. A. Piegata from the Szczecin University of Technology (today's West-Pomeranian University of Technology), and the pinnacle was the defence of Piegata's doctoral dissertation concerned with the control of the propulsion system of underwater vehicles in 1988 at the Wilhelm Pick University in Rostock, as Poland did not have a committee that could evaluate his scientific achievements.

For the purpose of implementation of this research, at the beginning of the 1980s the first construction of this type was prepared in Poland – the AITS vehicle (Fig. 3.1). It applied quite simple and then available construction solutions, even using waste materials [12].

Despite its modest construction (when compared with more recent times), these solutions allowed the thorough research which in turn verified the mathematical movement models and regulator selection. A similar research area is currently being examined at the Department of Information Technology of the West-Pomeranian University of Technology by Prof. A. Tariova and S. Kruszko, M.A. [11].

The Department of Maritime Technology and Transport on the other hand, for many years, has been carrying out comprehensive and multifaceted studies at the Faculty of Construction, Mechanics and Ship Technologies under the supervision of Tadeusz Graczyk, Ph.D., Eng. The documented effects of their implementation are technology demonstrators and prototypes of such underwater vehicles as NUR – a carrier of underwater works devices, MUNA, KRAB, and "Magis" – presented in Fig. 3.2 [13].

Other achievements of this academic environment include an underwater observation apparatus PAO-100, diving abyssal vehicles NPG-600 and NPG-300 (Fig. 3.3) and a transporter of monitoring devices TUM-600 [14]. Current works of the team encompass topics connected with the problematique of automatic control of submersible devices and their power supply systems [14,15,16].

Fig. 3.1. Underwater vehicle AITS during testing in Drawskie Lake in 1982 [12].

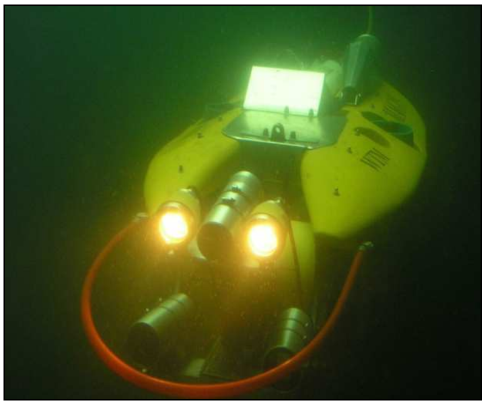


Fig. 3.2. Underwater vehicle "Magis" during testing in an experimental pool of the Department of Maritime Technology and Transport of the West-Pomeranian University of Technology in Szczecin [12].

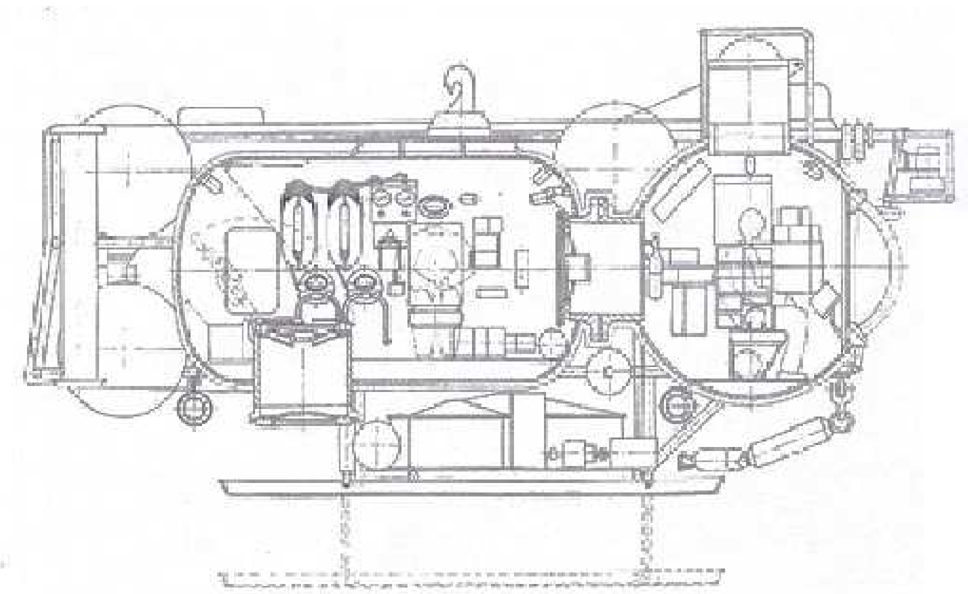


Fig. 3.3. Section in the symmetry plane through the diving and command division of the Diving Abyssal Vehicle (DAV) designed at the West-Pomeranian University of Technology in Szczecin [16].

At the Gdańsk University of Technology works connected with submersible devices are performed mainly at the Department of Ocean Engineering and Shipbuilding, and specifically at the Faculty of Ship Design and Underwater Robotics, with the Institute of Abyssal Technology operating under its aegis. They are conducted by alumni of Prof. Jerzy Doerffer, who began their adventure with abyssal techniques as early as in the 1970s. At present, the faculty is run by Lech Rowiński, Ph.D., Eng., who in 1993 defended his habilitation dissertation devoted to designing submersible devices with the use of computer techniques [17].

The achievements of this research centre are significant and characterised by a high implementation rate. The main documented results of this team's works in the period between 1974-2000 are presented in Table 1.1 below. One of the most interesting constructions developed by the team was a manned vehicle LTS-7 "Grześ" constructed in 1975 on commission of the Maritime Fishing Institute intended for the observation of fishing tools at work [18,19,20] – Fig. 3.4. Further accomplishments of the team included, first of all, an ROV used as a mine countermeasure under the name of "Ukwiał" [21,23,19] and a new generation of disposable vehicles called "Głuptak" – Fig. 3.5 [19,23].

Apart from the problems associated with the construction of underwater vehicles the team seeks solutions concerning hydroacoustics, use and operation of vehicles, for instance, to excavate polymetallic nodules from the seabed [20,24,30g,30h,30i,30j,30l], [30m]. Another achievement of the team consists in conducting training in the instruction of controlling an unmanned underwater vehicle [22]. One of the last accomplishments involved the concept and project of an underwater hotel and a multi-task underwater vehicle called "Morświn" (Fig. 3.6).

Tab. 1.1

Submersible devices and vehicles designed and constructed by a team from the Gdańsk University of Technology in the years 1974-2000 on the basis of [30k].

Year	Vehicle name	Operational depth	Dimensions LxBxH	Weight
		[m]	[m]	[Mg]
1974	Czapla	60	2.5x1.2x0.8	0.03
1976	LTS-7	200	3.5x1.8x1.8	3000
1984	Burzyk	200	3.0x0.8x0.8	1200
1986	Kapsuła	50	4.0x4.0x7.0	20000
1990	Koral	400	0.6x0.6x0.6	0.150
	Konkrecja I	6000	4.0x1.0x2.0	3.0
	Konkrecja II	6000	20.0x20.0x5.0	1500000
	Holonur 1	50	0.7x0.4x0.3	0.035
1995	Koral AT	400	0.9x0.7x0.7	0.070
	Holonur 2	50	0.8x0.4x0.3	0.035
	AUV	no data	3.0x10.0x5.0	0.700
1997	Holonur 3	50	no data	0.035
2000	Ukwiał	200	1.5x0.7x0.75	0.200

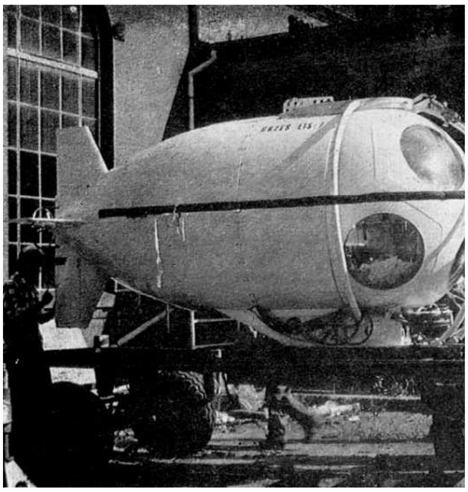


Fig. 3.4. Vehicle LTS-7 "Grześ" [17].

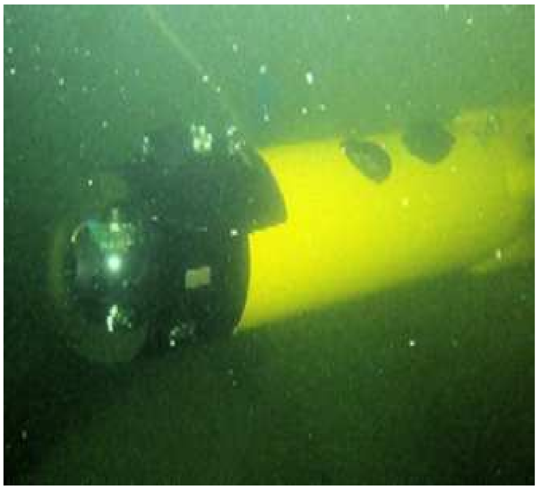


Fig. 3.5. Vehicle LTS-7 "Głuptak" [23].

Fig. 3.6. Multi-purpose underwater vehicle "Morświn" designed at the Gdańsk University of Technology.

Fig. 3.7. Unmanned surface vehicle "Edredon".

In 1970s a team of employees of the Polish Naval Academy (AMW) under the supervision of Prof. Władysław Wojnowski worked out a long-term development plan of underwater techniques in Poland for the years 1980-1995. The plan comprised construction of a wide range or submersible devices in the country – an underwater habitat, a wet and dry underwater vehicle, a submarine aimed at performing subsea scientific research and other devices.

In the implementation of this plan the team of Prof. Wojnowski developed well advanced technical projects of all of the planned solutions, however, for various reasons, it was never fully realised. At present, works on the unmanned vehicles technology are implemented by different interdisciplinary teams mainly concentrated at the Institute of Electrotechnology and Marine Automatics, as well as at the Institute of Underwater Works Technology.

The teams solve a broad problematique, starting with unmanned surface and underwater vehicles to those that are rem otely controlled and autonom ous. For example, the team guided by Prof. Z. Kitowski, Ph.D., Eng., within the fram ework of a project im plem entedby a scientific-industrial consortium, has designed and constructed the first Polish unmanned surface vehicle for monitoring ports and coastal zones – "Edredon"[11]– Fig. 3.7.

Within another project, combined teams from the Department of Navigation and Naval Armament and the Mechanical-Electrical Department, for the purpose of verification of project assumptions for an anti-collision module of an unmanned surface vehicle, have developed and constructed a miniature unmanned surface boat called USV Gambir[12] (Fig. 3.8, Fig. 3.9). The same interdisciplinary project team is currently implementing two projects connected with the construction of biomimetic vehicles, i.e. mimicking an animals' behaviour and appearance. In one case it is a project connected with developing solutions concerning a wave drive of vehicles reminiscent of fish and seals[13].

In the other, implemented within the European Defence Agency in cooperation with the Budenswehra Technical Centre 71, their use in underwater reconnaissance as a shoal of abyssal vehicles[14] (Fig. 3.10, Fig. 3.11).

Apart from collective works, team members implement individual research projects, for instance, concerned with control systems, using in their activity the fuzzy logic method, artificial neuron networks and evolutional methods in tuning up the structure and parameters of the above mentioned control systems of abyssal vehicles and their groups.

Another area for individual activity consists in the evaluation of the technical condition of surfaces of underwater objects and their identification with the use of visual systems installed on unmanned vehicles with computer analysis of underwater photograms.

Fig. 3.8. USV Gambir concept.

Fig. 3.9. USV Gambir hull during the first tests carried out in real conditions.

Fig. 3.10. One of the concepts of an underwater biomimetic vehicles developed within the 'Śledzik' project.

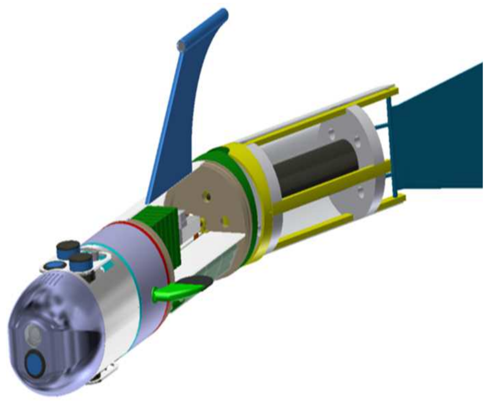


Fig. 3.11. The concept of a biomimetic vehicle with wave drive.

Moreover, the Institute of Ship Electrotechnology and Automatics implements works on the electrical power supply system in autonomous abyssal vehicles based on fuel cells as well as visual systems for controlling the vehicle-manipulator system. The Institute of Underwater Works Technologies, on the other hand, besides the works on new constructions of micro and mini ROV vehicles, implements works connected with the technology of utilisation of such devices in the implementation of underwater works, environmental research and providing support during diving activities.

The first and second decades of the 21st century is a period when the problematique of the underwater unmanned technique has spread across other research centres in the country. For instance, currently the research is realised at the Cracow University of Technology, where the bases of the wave drive have been developed along with the construction of the first prototype of a CyberFish, which was then further developed in cooperation with the Naval Academy within the Śledzik project.

Another centre where the works on this subject matter are carried out is the Poznań University of Technology (Institute of Information Technology and Engineering), where the construction of the "Isfar" vehicle was designed and developed (Fig. 3.12). It is a miniROV (weight up to 50 kg) with the dimensions of 0.6x0.9x0.4 m and maximum operational depth of15 metres.

It was constructed mainly with the purpose of verification of application algorithms assumptions to control the vehicle. Moreover, the team deals with issues connected with underwater optics [26]. The Faculty of Applied Mechanics and Robotics at the Rzeszów University of Technology, on the other hand, solves problems connected with the modelling of mobile robots, including underwater ones.

In the work published in 2012, for instance, the team introduced simulation research results for a dynamics model of an underwater caterpillar robot [25]. Also at the Institute of Automatics, the Department of Automatics, Electrotechnology and Information Technology of the Silesian University of Technology research works concerned with underwater unmanned technologies have been initiated.

Fig. 3.12. Underwater vehicle "Isfar" developed at the Poznań University of Technology [26].

The said works encompass general principles of design of underwater vehicles with the focus on control systems, for instance, with regard to heading stabilisation and maintenance [27,28].

Recent years have brought a new phenomenon in Poland consisting in the development of our own constructions of underwater vehicles by economic entities, thus discovering an opportunity to increase their competitiveness in the market. One of such examples is a Research-Production Enterprise "Forkos" Ltd. operating within the Pomeranian Scientific and Technological Park, which in cooperation with the Department of Underwater Works Technology of the Naval Academy has developed and constructed the KH-100 ROV shown in the Figure 3.13.

The company has established extensive cooperation with the Naval Academy, thanks to which two cooperating mini and micro ROVs as a modular system used in aquatic environment exploration were developed as a part of a project co-financed with the EU funds within the IE OP (Fig. 3.14, Fig. 3.15). Furthermore, Forkos actively participates in other projects implemented in this field as a member of a scientific-industrial consortium or as a subcontracting party manufacturing technology demonstrators.

The second example is the GRALmarine company from Wrocław, which has developed and built an ROV called "Humbak" (Fig. 3.16). In Gdynia there is also a company named Deep Ocean Technology Ltd., which since 2012, in collaboration with the Gdańsk University of Technology, has been involved in the implementation of a project within the Applied Research Programme entitled: *Research of critical technologies for a high-power underwater mobile robot with multi-sensor reconnaissance kit.* The result of the project is to be a vehicle performing inspection activities at depths of approximately 1000 metres, working in strong current conditions.

Another examples in the enterprise sector is the Delta Prototypes company operating within the Academic Business Incubator of the Cracow University of Technology. The result of the activity of this entity is an unmanned technology demonstrator "Kalmar", which was used in the verification of the concept of a wave drive, as well as a design of a manned underwater vehicle "SR 1200 Stingray" using hydraulically controlled propulsors with variable geometry.

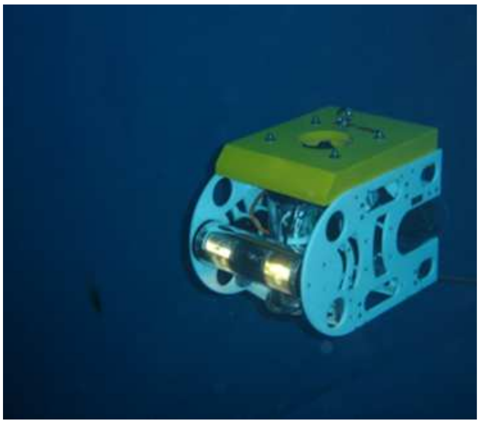


Fig. 3.13 MiniROV KH-100 developed by PBP Forkos Ltd. from Gdynia.

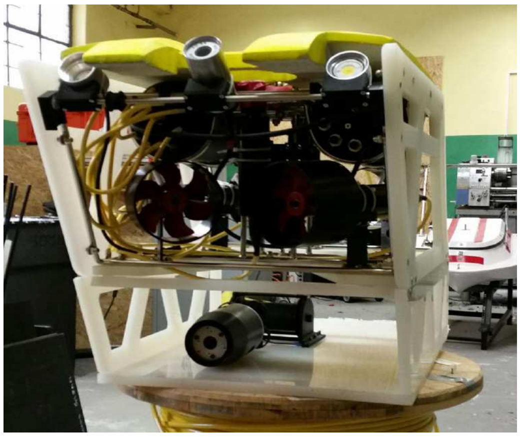


Fig. 3.14 Modular system for the exploration of aquatic environments and underwater objects built by Forkos Ltd. within the IE OP project no. 01.04.00-22-069/13 (the system comprises two cooperating underwater vehicles: miniROV KH-200 and microROV Frog).

Fig. 3.15 MicroROV Frog developed by Forkos Ltd. within the IE OP project no. 01.04.00-22-069/13 with an automatic cable winch and a special TV system for dimensioning underwater objects.

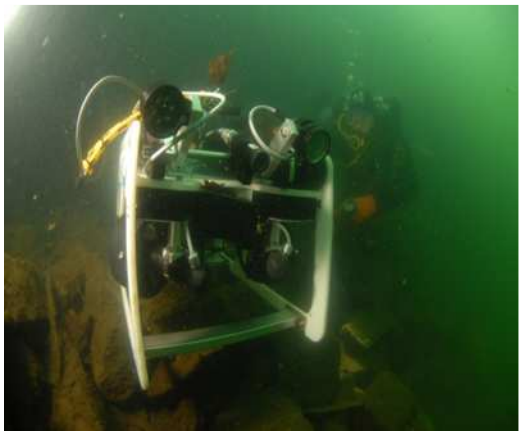


Fig. 3.16 MiniROV "Humbak" developed by GRALmarine company from Wrocław (material rendered available as a courtesy of GRALmarine company).

SUMMARY

As it was demonstrated, the efforts towards the development of unmanned technologies at sea pursue different directions. Generally speaking it can be concluded that as far as manufacturers are concerned, targets are mainly aimed at lowering production costs, increasing operational capacities (new manipulator solutions), developing new energy storage possibilities, increasing the effectiveness of works and maintaining competitive advantage in the market, all of which are important, as after a certain time the above become a binding standard.

Scientific centres, on the other hand, concentrate first of all on providing new construction solutions, new ways of utilisation and application of vehicles, as well as new environmental data collection methods and cooperation with diversified (heterogeneous) vehicle constructions during task implementation.

With the consideration of the projects and research activities presented in the material, it is possible to identify primary directions of development in maritime unmanned technology.

In the case of autonomous vehicles, understood as devices that are largely independent in performing tasks, this will mainly include aiming towards developing methods of long-standing environmental data collection over large marine areas. This is directly linked to attempts at reaching maximum possible autonomy in terms of energy. Moreover, efforts are being made towards enabling exploration at significant depths. Of course, such research has been implemented before, however they used to be more incidental in nature.

Nowadays, the target is sought in establishing continuous monitoring at significant oceanic depths. Such research directions are also imposed by works connected with obtaining the greatest attainable independence in the activity of surface and underwater devices. Contrary to what one might expect, there is still a lot to be done in this area, and apart from these problems new ones keep emerging, perhaps not connected to the technical solutions, yet equally important. For instance, with regard to the safety of swimming – it concerns the responsibility of the user of an unmanned surface boat moving among other vessels.

In the case of remotely operated vehicles, the basic trend of development is modularity of their constructions. This is what manifests a shift in the attitude to the character of an abyssal mission performed by such a device.

In this case modularity should be interpreted as a hybrid construction enabling partial task performance as an autonomous or semi-autonomous vehicle and implementation of the core part of a mission as a remotely operated vehicle. Colloquially speaking, the aim is that a submersible device should be able to independently reach the place of work, yet perform the work itself under strict supervision of the operator. For these reasons, solutions allowing for the transmission of control and image signals in the aquatic environment with the use of a sound wave are being developed.

In this way it is sought to eliminate hundreds of metres of cable lines dragged behind the vehicle during its work, which has an immediate impact on the size and construction of the propulsion system. Moreover, modularity enables diversification of the devices' functionality. Easy replacement of functional modules containing peripheral devices (sensors, manipulators, etc.) enables quick modification of the target functions in a device.

Moreover, this is conducive to the limitation of operating costs. For example, in a modular construction there is no need to transport the entire device to be serviced at the manufacturer's premises but only the damaged module. The diversification of functionalities, on the other hand, allows for the purchase of a single multi-task device.

Another trend of development encompasses vehicles, which imitate marine animals with their appearance and behaviour, i.e. the so-called biomimetic constructions [29]. Here, the driving force consists in the need for performing covert actions and reducing the noise connected with the work of screw propulsors in midwater.

A very interesting result of the above review consists in the observation that Polish research related to unmanned marine technologies is presently in amongst all the main currents of development. This may confirm the expertise potential of the personnel dealing with this subject matter in the country.

Of course, the scale of these activities is much smaller as compared with other countries. Perhaps, this is due to the fact that Poland is a country that spends the least funds on research and development per capita among the countries in our region. According to the data obtained from the Central Statistical Office, comparable expenditure on R&D is noted only in Slovakia, a country with the population seven times smaller than Poland (Fig. 4. 1) [30n].

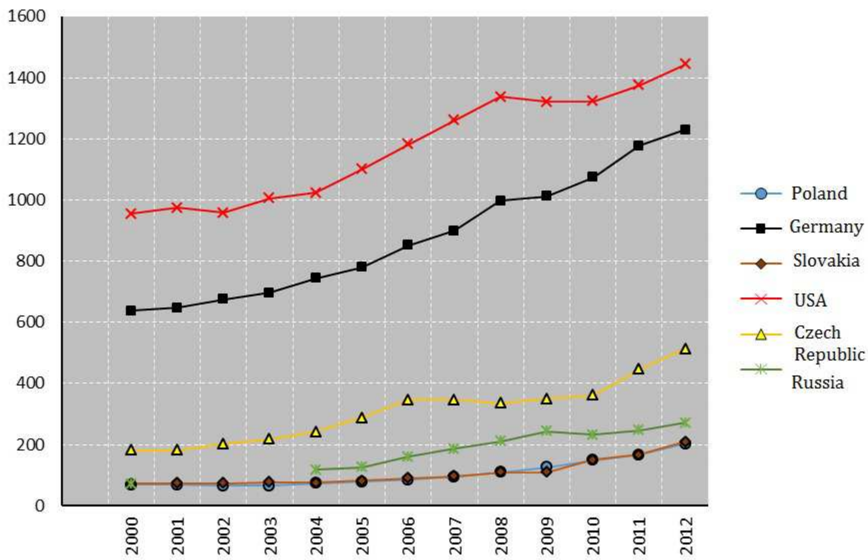


Fig. 4.1 Per capita expenditure on R&D activities in selected countries in the years 2000 – 2012 (on the basis of the data from the Central Statistical Office [30n]). There are no data concerning Russia in the period between 2001 – 2003. The expenditure in Poland is barely visible, as it is similar to the spendings of Slovakia. Only in 2009 did we spend slightly more than our neighbour.

As it stems from data presented in Fig. 4.1, for 12 years Poland spent on research and development the total of 1350 USD per capita (i.e. 5373), i.e. nearly the same amount as Slovakia, less than Russia, almost three times less than the Czech Republic, over eight times less than Germany and eleven times less than the United States of America.

The growth in the national expenditure per capita after the year 2007 from the level of 95 USD to 109 USD in the year 2008, which further grew to the amount exceeding 200 USD in 2012 is probably due to EU subsidies. Nonetheless, Poland is still the country that spends the least on the activity in this area. In the case that such a situation is maintained, it will be very difficult for Poland to reach competitive results to solutions developed elsewhere. We will become a country of little innovation, forced to import advanced technologies.

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[3] Project title: Persistent Autonomy through Learning, Adaptation, Observation and Re-planning,
[4] Project title: Collective Cognitive Robots,
[5] Project title: Autonomous, Self-Learning, Optimal And Complete Underwater Systems,
[6] Project title: Probabilistic 3D Surface Matching For Bathymetry Based Simultaneous Localization And Mapping Of Underwater Vehicles,
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[8] Project title: Advanced Underwater Image Mosaicing through Imaging Polarimetry,
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