PWr Diving Crew Technical Design Report (July 2019)

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I. Abstract

PWr Diving Crew is a project, which has been established by Students' Scientific Club of Control Engineering and Robotics "ROBOCIK", functioning at the Mechanical Faculty of Wroclaw University of Technology. Current model is a third generation of "ROV" submarine family, built by our team. The very first prototype gave us valuable knowledge and essential experience in constructing these type of vehicles. We divided process of design into three different, yet related sections which consist of – mechanics, electronics and software. Mechanics section is focused on making the ROV 4.0 body and it's componentry as light and durable as possible, therefore we chose polypropylene for framework's structure in which aluminium-made pipe is located. The pipe provides cover for electronic parts. The vehicle is powered by eight brushless DC motors, whose power supply consists of two 14,4V batteries with capacity of 23Ah each. ROV's 3-DOF manipulator arm, powered by two DC motors and equipped with single servomechanism, allows to achieve total lifting capacity up to 0.5 kg and operation range up to 600 mm. Control system is based on three devices: microcomputers Nvidia AGX Xavier, Raspberry Pi, and a STM32 microcontroller. Xavier receives signals from several sensors and cameras deployed around the submarine and control steering thrusters through Raspberry Pi. There have been implemented a number of sensors in our AUV. The most essential one is AHRS module, which is a position sensor integrated with an accelerometer, gyroscope and magnetometer. Software of robot is really efficient, demanding and consists of many algorithms responsible for autonomous movement of the vehicle as well as realization of the rest of functions. The main challenge for us was the software itself. The Software includes two components: movements algorithms and module for image recognition, which uses convolutional neural nets and "traditional" machine vision. The virtual environment is our main tool for testing and dataset collection.

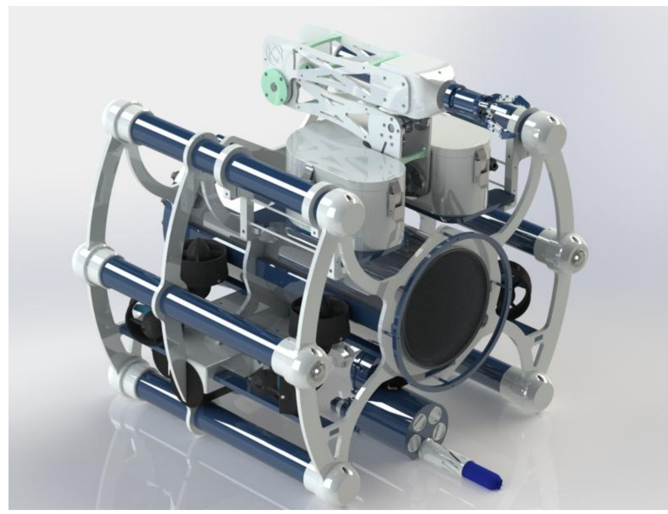

Figure 1 Model of our robot

II. Competition strategy

Our main goal in the construction of an underwater autonomous vehicle was an ability to execute our algorithms for competition's tasks. When we were designing the vehicle, we decided that the modularity of AUV is a priority. This approach enabled us to simply attach additional components in response to this year's tasks. Consequently, time needed to prepare the sub for the competition after the tasks were published, was reduced to the minimum.

We managed to find solutions for the majority of tasks in this year's competition, except for the cross gripping. We are not sure if we will be able to move cover for garlic drop, which highly depends on the resistance of the lever. There is also a possibility, that accuracy of a trained neural networks model will not reach our expectations.

We ensure maximum reliability of our algorithms. For every task, we have multiple solutions, based on a different approach to the problem. We choose these ones, which perform best on tests. Therefore there is an ability to change solution by the simple interface.

Last year it turned out that quick access to the heart of vehicle is critical. This model of AUV is equipped with two simple latches which block entrance to the interior, in opposite to last year model's 23 screws.

Our main tool for testing and dataset collection is the simulation. We have limited access to a pool, so the virtual environment is much helpful. Also, preparation of actual models of tasks is time-consuming, so virtual environment enables us to have an overview of the model of underwater elements and gives us the ability to test algorithms.

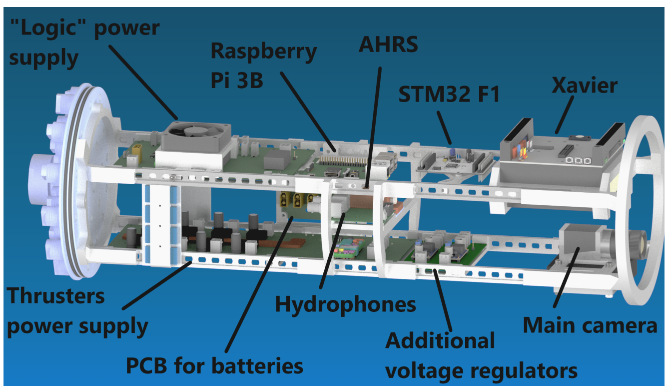

Figure 2 Interior of our robot.

III. Design creativity

In order to fulfill the assumptions listed in the previous point, the team had to rely on the experience gained during the last year's construction to analyze the available options, then select and apply the best ones and use experience to prepare a better construction. Thus, the following applies:

A. *Mechanics*

To ensure enough space for all componentry and sensors, we decided to built bigger vehicle than last year. The framework is made of polypropylene (PP) which due to its properties has replaced much heavier materials. In addition it has a high resistance to aquatic environment conditions and provides natural buoyancy. In order to improve rigidity, the whole structure was reinforced with fibreglass PVC pipes. Due to its shape, pipes are capable of carrying additional load. Therefore it allows us to control the centre of gravity, depending on the equipment that is currently in use. Furthermore, the framework acts as the basis for eight 350W BLDC thrusters. By the use of experience, we decided to design electronic casing in cylinder shape. It is highly resistant to hydrostatic pressure. The centre of ROV's body is a pipe made of aluminium alloy of the variant 6082. In order to provide maximum recording ability for cameras mounted inside, the front cover is made of plexiglass, whereas back cover is made of aluminium alloy, to which sealed cable glands and Ethernet socket are affixed. Below the pipe, a torpedo tube (which reloading system is based on Geneva drive) and three Li-Ion batteries are situated. The ROV's “ears”, which consists of sonar and hydrophones, are placed in the front. In contrast, double claw and effector are set in the back. Finally, on the upper pipes, there are main switch and the router. They are covered by a specially designed container, which is protected by a layer of resin.

B. *Electronics*

The most important circuit is power supply. We are using two large batteries for the demanding motors and other “power” devices, and have a smaller battery for separated “logic” circuit consisting of voltage sensitive electronic devices, such as Xavier. Man operated vehicle reed switch, allows batteries connection to power supply boards. Additionally Raspberry Pi 3B controls whether power is connected to the thrusters.

Brain of our robot is Nvidia AGX Xavier computing platform. It has a superior control over all other modules and systems. All classifiers and elements of artificial intelligence algorithms have been implemented on it. The auxiliary unit is the Raspberry Pi 3B microcomputer and a STM32 microcontroller. Their task is to execute commands from Xavier, and communicate with the rest of electronics.

Our robot is propelled by eight thrusters. We use BLDC motors, dedicated for underwater use – 350W power each. Four of them are mounted in vertical direction to maintain depth. Remaining four are mounted horizontally. Each of them is rotated 45 degrees in regard to main hull axis. Such setting allows to achieve every possible motion. In order to reduce voltage spikes on those thrusters we are using LC filters.

Regarding torpedos task, a servomechanism pulls trip wire, contactron determines when it should stop. AI positions robot, basing on readings from vision systems and sonar. When vehicle is ready Xavier transceivers signal to release energy from capacitors to electromagnets, which shoots the torpedos.

Our robot has been equipped with a system of few basic sensors.:

- AHRS - an integrated accelerometer, gyroscope and magnetometer. It provides knowledge about the position and orientation of the robot with great accuracy,
- a pressure sensor with a range of 10 meters, and a depth resolution of 0.16mm, to determine vehicle's depth,
- Sonar with a range up to 30 meters, which is used to measure distance to obstacles in front of the robot, especially in the torpedos task,
- hydrophones system, used to locate tasks' locations based on ultrasound signal from pingers

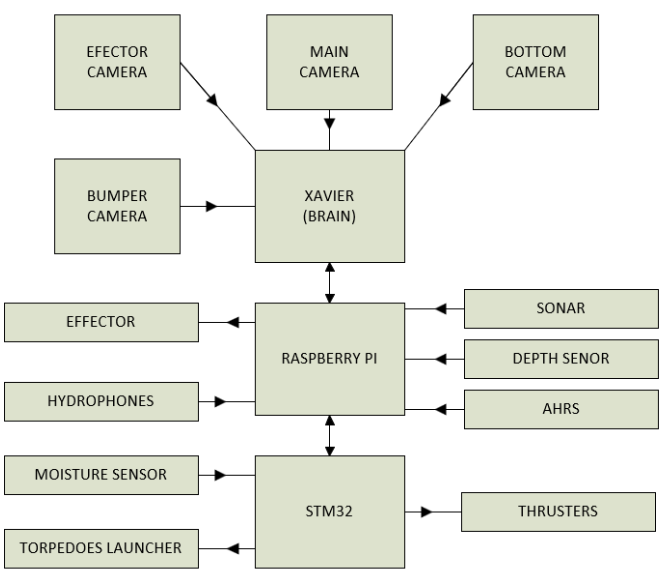

Figure 3 Communication oflements scheme

C. *Software*

Software is the most advanced part of our project because it basis on the mechanics and electronics. Therefore, its reliability depends on the reliability of the hardware components.

For stabilization, we used the PID regulator, based on data of the AHRS sensor.

In programming data transmission system, we mainly used Python scripts. It's easy to use language which allows writing code quickly. The efficiency of that code wasn't a problem for us because in more critical applications we used faster languages such as C. For example, code for API cameras (produced by Basler) has been written in C++ (camera's manufacturer's libraries). We made, therefore, bindings for Python.

Our main tool for real-time object detection is YOLO network. It was chosen among several other candidates (namely SSD, and multiple variants of R-CNN), mostly because it produces the best compromise between speed and accuracy and - equally important - it is fast to train. YOLO is incredibly convenient to use and turned out to perform great during tests. Its main task is to both locate and classify important objects on images acquired from onboard cameras. Because we need a large, labelled and diversified dataset of images as fast as possible we used an artificial environment created in Unity 3D Engine. The simulation has also the ability to change water transparency and lighting conditions of the simulated environment. Such an approach allows us to create large and perfectly labelled data in matters of hours. Later on, we expanded datasets with images taken on real objects, which we constructed based on competition datasheets. To have an alternative in case of failure, we also prepared some more classical solutions using Hough transform and Haar Cascade. They are considerably slower and less reliable but can be tuned to different lighting and other environmental conditions much faster than neural networks.

We also used reinforcement learning for training of neural net which is in full control over AUV. For training, we use a feature of simulation. We achieve success and high reliability of this solution, but it turned out to but hard to write proper fit function, so time for preparation model for a particular task was very time-consuming.

Simulation is also able to emulate vehicle and environment physics, so we can examine algorithms without using real pool and AUV.

Every task had multiple solutions, for example, the gate can be detected by a trained neural network or algorithm, which implements Haar Cascade.

IV. EXPERIMENTAL RESULTS

Design of current autonomous operated vehicle developed by our team is based mainly on the experience gathered during previous season and construction of prototype submarine. This allowed us to draw following conclusions:

- Algorithms based on colour filtering are highly depended on lighting condition and water transparency, so there is a need to calibrate the filter variables when conditions severely change;

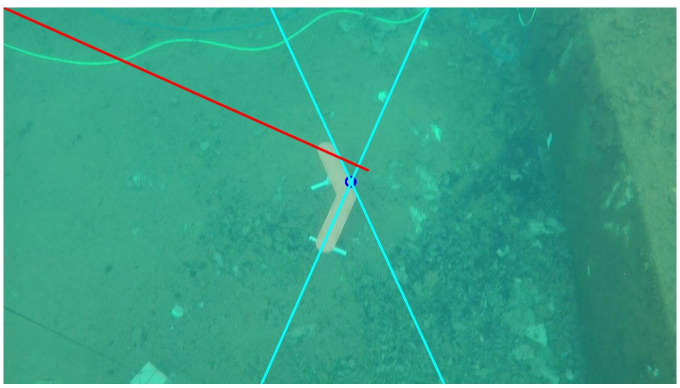

Figure 4 Path axis detection on Robosub 2018 video

- the frame should be made of POM or aluminium to ensure more stiffness;
- the proper trained neural network is resistant to various environment conditions;
- the additional distance sensor (sonar) directed to the bottom should be added as additional collision protection;
- a vent valve facilitates main the container closing.

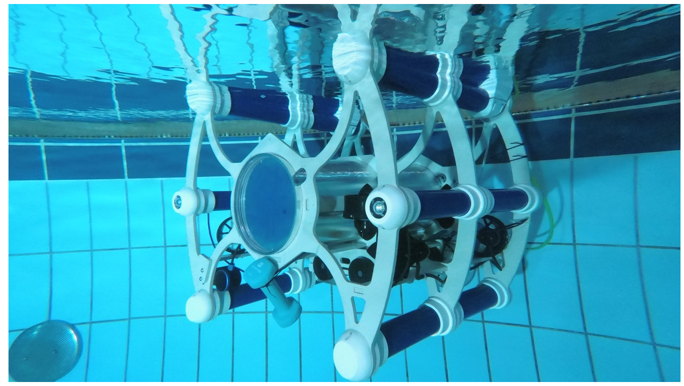

Figure 5 Submarine during tests

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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Appendix A:

Subjective Measures			
	Maximum Points	Expected Points	Points Scored
Utility of team website	50	50	
Technical Merit (from journal paper)	150	150	
Written Style (from journal paper)	50	40	
Capability for Autonomous Behavior (static judging)	100	100	
Creativity in System Design (static judging)	100	100	
Team Uniform (static judging)	10	10	
Team Video	50	50	
Pre-Qualifying Video	100	100	
Discretionary points (static judging)	40	0	
Total	650	600	
Performance Measures			
	Maximum Points		
Weight	See Table 1 / Vehicle		
Marker/Torpedo over weight or size by <10%	minus 500 / marker	0	
Gate: Pass through	100	100	
Gate: Maintain fixed heading	150	150	
Gate: Coin Flip	300	300	
Gate: Pass through 60% section	200	200	
Gate: Pass through 40% section	400	400	
Gate: Style	+100 (8x max)	100	
Collect Pickup: Crucifix, Garlic	400 / object	400	
Follow the “Path” (2 total)	100 / segment	200	
Slay Vampires: Any, Called	300, 600	600	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	700	
Drop Garlic: Move Arm	400	0	
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	1200	
Stake through Heart: Move lever	400	400	
Stake through Heart: Bonus - Cover Oval, Sm Heart	500	500	
Expose to Sunlight: Surface in Area	1000	0	
Expose to Sunlight: Surface with object	400 / object	400	
Expose to Sunlight: Open coffin	400	400	
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)	0	
Random Pinger first task	500	500	
Random Pinger second task	1500	1500	
Inter-vehicle Communication	1000	0	
Finish the mission with T minutes (whole + factional)	Tx100	0	

Appendix B:

Component	Vendor	Model/Type	Specs	Cost	Cost(PLN)
Buoyancy Control	-	-	-	-	-
Frame	Zaopatrzenie24, Wimarol	5 mm	POM	$82	310,00 zł
Waterproof Housing	Adamet-Niemet, Euromill	550 - long 200 - diameter	Aluminum	$526	2000 zł
Cable gland	-	Own Design	stainless steel, anodized surface	$263	1000 zł
Thrusters	Bluerobotics	T200	350 Watts, Waterproof, BLDC	$1445	5500zł
Motor Control	Bluerobotics	Basic 30A ESC	max current 30A voltage 14.4V	$226	860 zł
High Level Control	-	-	-	-	-
Actuators	-	-	-	-	-
Propellers	Bluerobotics	with thrusters	-	-	-
Battery	Gralmarine	6,8 Ah	14,4v, 98 Wh, Li-ION	$2100	8000 zł
Converter	-	-	-	-	-
Regulator	-	-	-	-	-
CPU	Botland	Raspberry Pi 3B	1GB RAM 1,2GHz	$79,10	299,00 zł
Internal comm Network	-	-	Ethernet, SPI	-	-
External comm Interface	-	-	TCP/IP Ethernet	-	-
Programming Language 1	-	-	Python	-	-
Programming Language 2	-	-	C, C++, C#	-	-
Compass	included in AHRS	-	-	-	-
Inertial Measurment Unit (AHRS)	X-sense	MTI-30	AHRS sensor	$1 461,64	5 525,00 zł
Doppler Velocity Log (DVL)	-	-	-	-	-
Camera(s)	Basler	daA2500-14uc	CMOS, 14fps, 5MP, Color	$793,65	3 000,00 zł
Hydrophones TC4013	-	-	-	$23125,85	1 000,00 zł
Manipulator	BIBUS MENOS	Own Design	PA2200	$1 058,20	4 000,00 zł
Algorithms: Vision	-	-	Haar cascade, convolutional neural nets, edge and colour detection, Hough transform	-	-
Algorithms: acoustics	-	-	phase difference	-	-
Algorithms: localization and mapping	-	-	-	-	-
Algorithms: Autonomy	-	-	-	-	-
Open source software	-	-	YOLO	-	-
Team Size	-	-	50	-	-
HW/SW expertise ratio	-	-	1,57	-	-
Testing time: simulation	-	-	100h	-	-
Testing time: in-water	-	-	35h	-	-

Appendix C:

This year, the Scientific Club of Robotics "Robocik" actively participated in the education of the local community. In the name of idea: spreading knowledge and science, we took part in many projects, both free and those in which we obtained funds. The main ones are:

- Underwater-robot project realized as part of "Zawodowy Dolny Śląsk" program. As part of it, we conducted a total of 36 hours of training closely related to the subject of submarine technologies, with particular emphasis on software development. Technician students who were beneficiaries of the classes learned the ins and outs of programming in C ++ on a practical example of programming electronic circuits in AUV.
- Project of the Industrial Robot realized as part of "Zawodowy Dolny Śląsk" program. For more than 62 hours of joint classes, it was possible to present the problems of programming manipulators with 6 degrees of freedom. Both training on programming in C++ and basic information on simple and inverse kinematics were conducted.
- Classes conducted as part of the "Zawodowy Dolny Śląsk" program. Classes mainly concerned two topics related to submarines. The first of them concerned electric motors, while the second of them were microcontrollers. As a part of this project, a total of 400 people were trained in 240 hours.
- Scientific Picnic of Polish Radio and The Copernicus Science Center. During the event which took place at the National Stadium in Warsaw, many young potential inventors were inspired by the subject of submarines.
- “Technikalia”. Teaching aimed to acquaint students who aren’t actively involved in student activities with additive manufacturing. The event took place in Wroclaw University of Science and Technology. As a result of the course, 20 people were trained

- “Czas na zawodowców”. Organised by Lower Silesian Marshal Office and aimed to improve skills of vocational schools students in order to help them with their start on labor market. The event consisted of series of weekly trips to Bożków, where daily classes were held by members of “Robocik” team - 40 hours during a week. Participants had an opportunity to learn about 3D printing and 3D modelling. More than 200 people benefited from this project.

- “Rajd po Wałbrzyskiej Strefie Ekonomicznej” - we have visited and have been presenting our latest development at conference organised by Walbrzych Special Economic Zone, which interested many investors - about 220 companies are currently in the WSEZ.

- POTENCJOmetr - a contest which aims to award the best students’ scientific project. By taking part, students of “Robocik” were able to exchange knowledge with groups of the best students in Poland. We also compete or act as special guests in various robotic tournaments: Robotic Arena, Robodrift, Robomaticon, because of the idea of popularizing our inventions and ideas.

Figure 1 Members at POTENCJOmetr

- IFA in Berlin and CeBIT in Hanover. “Robocik” participates in leading trade shows for industry, especially electronics, information technologies, robotics. This way, we are able to popularise underwater engineering as a benefit for industry.
- TEDx Politechnika Wrocławska - we took part in TEDx conference organised at Wroclaw University of Science and Technology. The main topic was “run the world” and we wanted to show, that our developments may be beneficial for the world in fact.

Figure 2 Team lead at TEDx

Figure 3 Presenting new ROV 4.0 submarine to national media