PWr Diving Crew
Technical Design Report (July 2018)

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I. Abstract

PWr Diving Crew is scientific project, which has been established in Science Club of Robotics "ROBOCIK" - students organization functioning at Mechanical Faculty in Wroclaw University of Technology. Current robot is second construction of this type built by our team after manufacturing of prototype model, which let us to gain some precious experience and learn about characteristics and properties of this type vehicles. Design of an autonomous robot can be divided into three sections – mechanics, electronics and programming. First of it consists of aluminum frame made of special, acid-resistant alloy dedicated for boat-building applications. It is supported by body fabricated of laminate, which creates space box for electronics. Vehicle is powered by seven Brushless DC motors. Two manipulators with six degrees of freedom, which fulfill executive function, are manufactured in SLS 3D printing technology. Four batteries with capacity of 1600 mAh serve as power supply module. The main basis of electronics is Jetson TX2 unit and microcomputer Raspberry Pi. They are transceivers of signals from several cameras deployed around the submarine and emitters of signals steering motors and other mechanisms. There have been implemented a number of sensors in our autonomous operated vehicle. The most essential one is IMU module, which is a position sensor integrated with an accelerometer, gyroscope and magnetometer. In addition, we incorporated into electronics system crucial circuit boards responsible for voltage conversion, H bridges and communication protocols. 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, because of remote control steering realized by pad in the previous construction. However, to be precise in listing differences between prototype and this year project, we have to admit, that mechanical part as well as electronics were quite similar in concept but the this is a kind of naturally reached evolution and development.

Figure 1 Model of our robot

II. Competition strategy

Our main goals in the construction of an underwater robot was modularity, versatility and multitasking. That is why a basis of the project is an underwater drone, capable of autonomous swimming, with places to attach other elements, such as manipulators, torpedo tubes, additional cameras and thrusters. These components can be freely attached to the AUV, to extend its functionality. We focus on reliability of the construction. We ensured a trouble-free first task (passing through the casino gate), then we worked on extending the functionality to each subsequent task. This year's competition is a first big event, where we are participating, so we are aware that providing full functionality is very serious task. We are still working on the improving of our robot to make it able to perform all the tasks on the competition. It should also be noted that our main objective is expanding our knowledge. So far, we had small experience with autonomous control of the robot. We have only build one prototype robot before we decided to take a part in the RoboSub. That is why we hope to learn good competition strategies and methods of building solid constructions from other teams during competition.

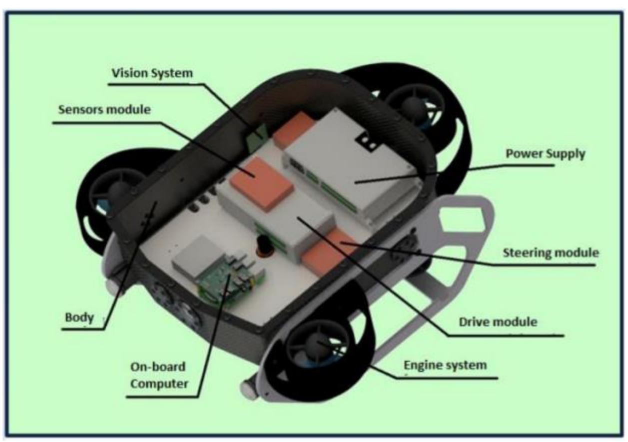

Figure 2 Interior of our robot.

III. Design creativity

In order to fulfill the assumptions contained in the previous point, the team had to rely on the experience gained during the prototype creation to analyze the available options, then select and apply the best ones. Thus, the following applies:

A. Mechanics

To fulfill the assumptions of the simplest and lightest basic construction, a frame made of durable and light material was needed. That is why the team decided on aluminum just like in the prototype version. However, it was also necessary to provide protection against aggressive water environment, also against salt water. That is why a special 5083 boat-molding alloy of aluminum – a sheet with thickness of six millimeters was selected.

Our goal during design of container for electronics was to provide as much space as possible for all components. As distinct from the prototype version of the robot, the team decided to use one large box instead of two smaller ones, due to problems related with the transmission of data between them. It was also decided to use an innovative material – a carbon/glass laminate, because of its high strength, low weight and aesthetic qualities, which increased submersion of the boat. This operation also made a robot much more controllable and improved its buoyancy. Therefore, we were able to increase the number of additional components that can be mounted on it.

Thrusters are also an important, mechanical element. In this case we decided to use trusted BLDC T200 motors from the BlueRobotics company –with 350W power each. To ensure full freedom of movement, we have installed seven thrusters with propellers.

Two manipulators with six degrees of freedom were used as executive elements of the boat. To ensure the smallest mass, we have decided to make their housings in 3D printing. However, the basic FDM technology would not provide sufficient tightness and pressure resistance, which is why the SLS technology was selected. The manipulators have been designed to lift a weight of 2 kilograms. Their range is 600 mm. Each kinematic pair is controlled by a servo drive.

To ensure the image delivery to electronic systems, several inspection holes have been drilled in the body, then they were sealed with a transparent polycarbonate material. In these places there are cameras, including the one with high resolution, which is a main part of image acquisition in the vision system. There are also three additional wide-angle cameras that will perform auxiliary functions. This was implemented due to the conclusions drawn by the team during the construction of the prototype, in which only one camera was used – that solution significantly reduced the capabilities of the drone. In addition, appropriate lighting conditions for the above-mentioned cameras had to be provided. That is why two Blue Robotics' LED lamps have been used with a total light intensity of 1500 lumens.

B. Electronics

The heart of the electronics is the Nvidia Jetson TX2 computing platform, which has a superior control role over all other modules and systems. All classifiers and elements of artificial intelligence algorithms have been implemented on it. The auxiliary unit is the RaspberryPI microcomputer, which receives signals from auxiliary cameras and several smaller sensors. In the prototype version of the robot only Raspberry Pi and several STM-microcontroller boards were used, because of it was not designed for autonomous work, and therefore did not need such a large computing power.

All modules are connected to each other and communicated using the CAN bus protocol. The previous robot used communication via the I2C protocol, but it was not enough efficient. In the current version, it is used only as an auxiliary and in emergency situations.

The boat has been equipped with a system of diffrent sensors to provide as much information as possible for the control system. In addition to the mentioned vision system, the following sensors are used:

- IMU position sensor, which is an integrated accelerometer, gyroscope and magnetometer. It will provide a knowledge about the position of the robot will with an accuracy of a few millimeters,
- a pressure sensor with a range of 100 meters with an accuracy of 5 cm, to determine the draught of the boat,
- ultrasonic distance sensor with a range of 4 meters, directed towards the bottom to prevent the boat from colliding with the bottom of the tank,
- temperature sensor designed to protect the interior of the boat (and therefore all electronics) from overheating,
- several moisture sensors that are designed to quickly detect a leak and prevent flooding of the boat's electronic systems.

In comparison to the prototype version, the team focused on the high level of sensorisation, due to the adaptation of the boat to autonomous movement and receiving stimuli.

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 PID regulator, based on data of IMU sensor. We also trayed to implement neural network for stabilization based on the view from camera, but this solution turned out to be less efficient than PID and it also used valuable computational resources.

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

For simulate and testing algorithms we used Unity game engine. It's easy to use environment. A few of us had some experience in using this tool. It's easy to use, so we could quickly finish simulating pool and physics and start testing algorithms. For implementation of machine learning solutions in game engine we used Unity ML (machine learning for Unity).

Our main tool for real time object detection is YOLO network. We thought about other object recognition approach, like R-CNN, but it turned out to be more complicated and less efficient. YOLO is very convenient and turned out to be very good in tests. We trained neuron networks for recognize object using pictures generated in the Unity. We also prepared some solutions using Hough transform and Haar Cascade.

For machine learning we tried Keras as an interface and TensorFlow.

We also used OpenCV. Mainly for camera view preprocessing (scaling, color changing, maximize contrast).

Every task had multiple solutions, for example gate can be detected by trained neuron 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:

- one huge container dedicated for electronics is superior to several compacts, because of difficulties in connecting significant components;
- there is a need to reduce a mass of the project by minimizing frame size and implementation of other materials, for example laminates from carbon fiber reinforced polymer materials;
- due to enhanced maneuverability and velocity of movement in the water we should add one more thruster and change distribution of motors located in vertical position;
- we decided to increase modularity of construction and maximize a number of sensors which gather data from external environment;
- additional executive elements such as manipulators should be implemented.
- originally, we have made certain efforts to implement a dozen of Raspberry Pi microcomputers in a way that each would be responsible for realization of just one task. However, on account of boosted computational power, we've decided to implement just one huge calculation platform - Jetson TX2.

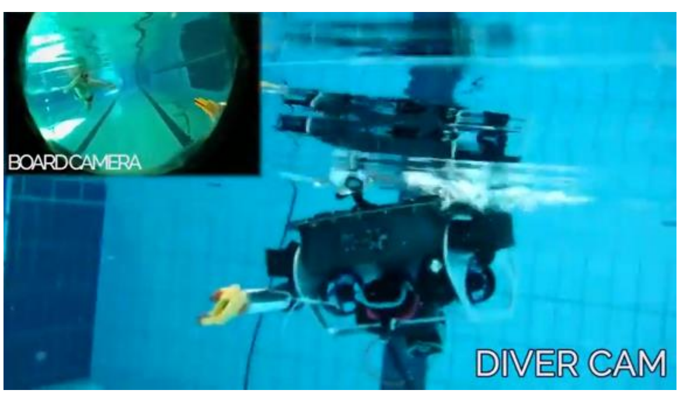

Figure 3 Submarine during tests

V. Acknowledgements

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Figure 4 Our team

VI. References

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Appendix A:

Component	**Vendor**	**Model/Type**	**Specs**	**Cost**	**Cost(PLN)**
Buoyancy Control	-	-	-	-	-
Frame	Sebros, Wimarol	6 mm	5083 aluminum alloy	$396,83	1 500,00 zł
Waterproof Housing	R-Composite	Own design	carbon/glass fiber 5mm	$925,93	3 500,00 zł
Waterproof Connectors	LappKabel	-	stainless steel, in IP68 standard. max pressure 10 bar	$1 119,58	4 232,00 zł
Thrusters	Bluerobotics	T200	350 Watts, Waterproof	$1 183,00	
Motor Control	Bluerobotics	Basic 30A ESC	max current 30A voltage 12A	$175,00	
High Level Control	-	-	-	-	-
Actuators	-	-	-	-	-
Propellers	Bluerobotics	with thrusters	-	-	-
Battery	Gralmarine	6,8 Ah	14,4v, 98 Wh, Li-ION	$687,83	2 600,00 zł
Converter	-	-	-	-	-
Regulator	-	-	-	-	-
CPU	Botland	Raspberry Pi 3 B	1GB RAM 1,2GHz	$79,10	299,00 zł
Internal comm Network	-	-	CAN, I2C	-	-
External comm Interface	-	-	TCP/IP Ethernet	-	-
Programming Language 1	-	-	Python	-	-
Programming Language 2	-	-	C, C++, C#	-	-
Compass	in IMU	-	-	-	-
Inertial Measurment Unit (IMU)	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	-	-	-	-	-
Manipulator	BIBUS MENOS	Own Design	PA2200	$1 058,20	4 000,00 zł
Algorithms: Vision	-	-	Haar cascade, Hough transform	-	-
Algorithms: acoustics	-	-	-	-	-
Algorithms: localization and mapping	-	-	-	-	-
Algorithms: Autonomy	-	-	-	-	-
Open source software	-	-	YOLO	-	-
Team Size	-	-	21	-	-
HW/SW expertise ratio	-	-	1,57	-	-
Testing time: simulation	-	-	-	-	-

Testing time: in-water	-	-	20h	-	-

Appendix B:

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 was 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.