PWr Diving Crew Technical Design Report (July 2020)

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I. Abstract

This paper discusses the design and construction of PWr Diving Crew's AUV. Vehicle was prepared for Robosub 2020 competitions. This is the third edition in which the team takes part. The experience in previous editions was used to prepare an optimal vehicle, paying special attention to construction, software, and electronics.

Construction was designed to ensure maximum agility and allow usage of torpedo launcher and grabber. AUV uses a dedicated algorithm for every task execution and convolutional neural networks for object recognition. Part of the machine is a set of sensors and cameras, which enable the vehicle to gather real-time information of the environment. Important fragment of software is a simulation, which enables dataset generation and algorithm testing in a virtual environment.

The project was a good way to engage students in the organization, as well as a method to connect them with the RoboSub community and local companies collaborating with this project.

II. Competition strategy

The main goal in the construction of the underwater autonomous vehicle was an ability to execute algorithms prepared for execution competition's tasks. As every year's tasks are similar some elements of construction and software could be prepared before the official information. Grabber and torpedo launcher were prepared earlier, as well as centring algorithms. The idea requires only new model training to adapt to new tasks.

Figure 1 Model of the robot

Easy access to every element of the vehicle is necessary to ensure the fast replacement of parts. PCBs were designed to ensure dependable connections.

To ensure flexibility of the code, adjustments of every algorithm are stored in a separate file. This approach, with fast wi-fi connection when the vehicle is on the surface before the start, enables quick adjustments between runs.

There are two sources of datasets for training object recognition models: pictures generated by simulation and data gathered during real-life tests.

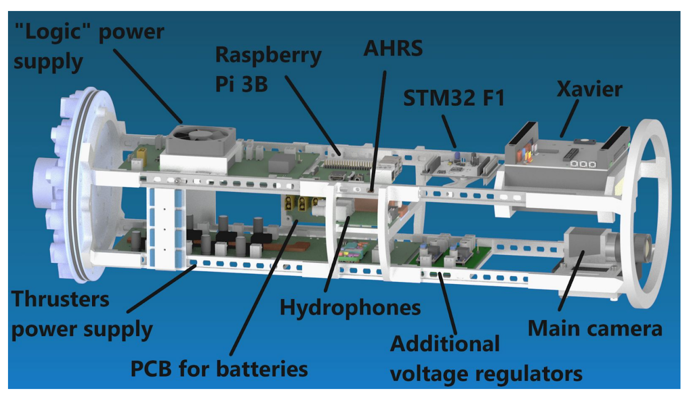

Figure 2 Interior of our robot.

III. Design creativity

In order to fulfil 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 the experience to prepare a better solution. Thus, the following applies:

A. Mechanics

To ensure low mass, construction of the current AUV generation was redesigned. The framework has been made of polyacetal (POM), due to its high resistance to the aquatic environment and neutral buoyancy. In order to improve rigidity, the whole structure has been reinforced with aluminum pipes. The pipes have also other role – their interior serves for a really simple and reliable balancing mechanism. There is a movable lead burden inside the pipe, which controls the AUV's submerging level and the centre of gravity.

Furthermore, the framework acts as a chassis for eight thrusters, each of them containing 350W BLDC motor dedicated to underwater usage. Aluminum electronic casing design is formed in a cylindrical shape, which is way more resistant to hydrostatic pressure than the cuboid shape of 2018's design. In order to provide maximum recording capability for camera mounted inside the casing, the front cover has been made of plexiglass, whereas back cover serves as a sealed connection between electronic components and BLDC thrusters. Below the casing, a torpedo launcher and three Li-Ion batteries are situated. Torpedoes itself are CO2 cartridges built into the plastic casing. They are activated by a firing pin and then reloaded by a system based on Geneva drive.

Figure 3 Torpedo launcher.

Our AUV is also equipped with sonar and hydrophones, which allow underwater navigation. In addition, the vehicle is able to carry triple-claw gripper capable of performing various tasks underwater.

Finally, the main switch and router are placed in a specially designed container, which is protected by a layer of resin.

B. Electronics

This year, a further step regarding electronics in our vehicle has been taken. Many major improvements resulted in work optimization and aesthetics. Eliminating unnecessary PCBs, introducing designing standards, taking advantage of version control systems and developing low-level programs are just a few of those upgrades. Our team focused on carrying out research and testing new actuator technologies.

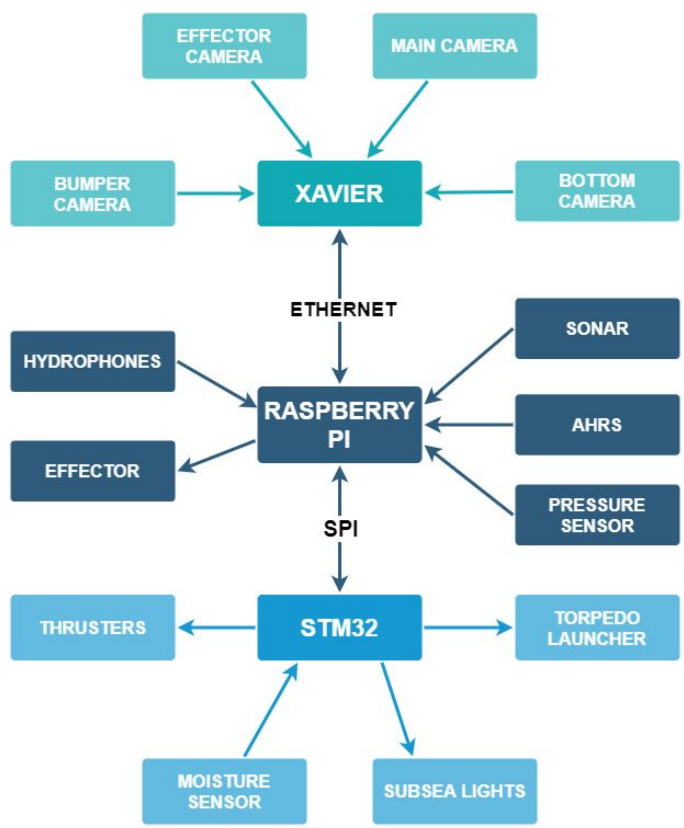

Diagram 1 Communication elements scheme

Power supply

Like every human need a heart to live, every machine needs a power supply to function properly.

AUV has been provided with three Li-ion batteries whose capacity of 54.4 Ah allows the vehicle to operate for 2 hours without recharging. The battery bank is supported by BMS module which ensures increased safety. The system maintains high stability by the digital and actuators' circuits separation. This solution grants constant voltage levels across sensitive electronics regardless of the motors' angular speed fluctuation.

Sensors

AUV has been equipped with several devices collecting data about the robot's environment and its spatial location:

· **AHRS**, which is an integrated accelerometer, gyroscope and magnetometer, provides details about the machine's translocation and orientation with high accuracy,

· **Depth sensor** with 10-meter range and 2 cm depth resolution determines a vehicle's submersion, based on pressure information,

· **Ultrasonic sonar** measures distance to obstacles placed up to 30 meters in front of the robot, which is particularly used in the torpedoes tasks,

· **Hydrophones system**, detecting sound frequencies from 1 Hz to 170 kHz, allows locating tags by receiving and processing ultrasonic signals sent by pingers.

Furthermore, a unique safety system has been developed based on previous experience to prevent electronics from working in humid conditions. If any amount of water is detected, information from the system is sent to the main processing unit and the robot immediately starts the process of resurfacing.

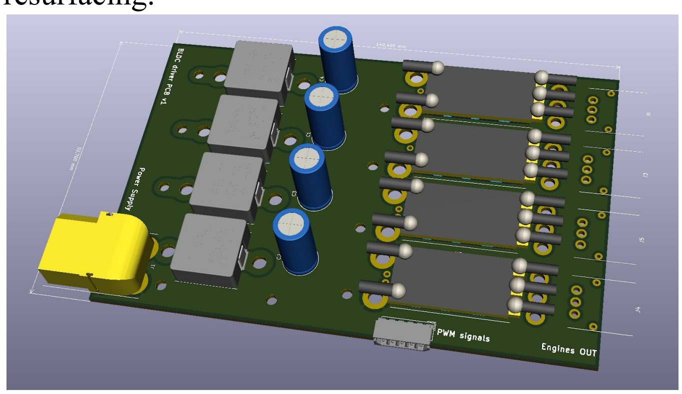

Figure 4 Render of PCB with power regulators and thrusters' controllers

Control system

Three main control units have been applied to supervise AUV's internal processes and give corresponding instructions. Nvidia AGX Xavier is a computing platform equivalent to robot's brain, with all classifiers and elements of artificial intelligence algorithms implemented on it. Based on the data collected from cameras and two other control units it takes further actions to realize the main goal coded in the software. Xavier is connected to Raspberry Pi 3B+ which gathers information from the sonar, AHRS, depth sensor and hydrophones. This microcomputer executes commands that consider effector's functioning as well as uploads sensor measurements to the brain. Python 3.7 has been chosen to implement these services because of its simplicity and variety of easily available libraries. STM32 from F1 series is responsible for moisture sensor, thrusters, subsea lights and torpedo launcher. Its source code has been written in C language using HAL and LL libraries. Connections mentioned above are presented in *Diagram 1*.

Actuators

Thrusters' BLDC motors are controlled by PWM signal sent from STM32 to ESCs which drive the motors accordingly. In order to reduce voltage spikes, LC filters have been added to the power supply distribution board whose 3D model is shown in Figure 4.

C. Software

Raspberry Pi and Nvidia Xavier run dedicated versions of Linux distributions (Raspbian and specific compilation of Ubuntu). Each program works in a separate thread to ensure responsiveness on external incentives.

Each of the 3 control units described in the previous chapter has a dedicated role. Main control program runs on Xavier, sensors and effectors handlers run on STM and Raspberry Pi. In addition, RPI hosts a program dedicated to holding depth and orientation. It uses the PID controller with the input of depth, magnetic field, and acceleration data. There are two main parts of the control program: object recognition (OR) and decision-making (DM).

Every task of the competition has a dedicated algorithm to fulfil the assigned job. The program access results of the OR and sensor data provided by Raspberry Pi. After data processing, the program sends commands to movement control unit.

The main goal of the object recognition part is to determine the position of an object recorded by the camera and to determine the relative size of the target. The 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. Also, it doesn't require large dataset to train a reliable model. Its main task is to both locate and classify important objects on images acquired from onboard cameras.

As was shown in the previous competition, a key ingredient of successful usage of test runs on the TRANSDEC pools is data collection. A recorded video from every camera is saved for further analysis. Also, comprehensive logs of every aspect of the code are collected to ensure efficient localization of eventual failure and allow adjustment of decision parameters.

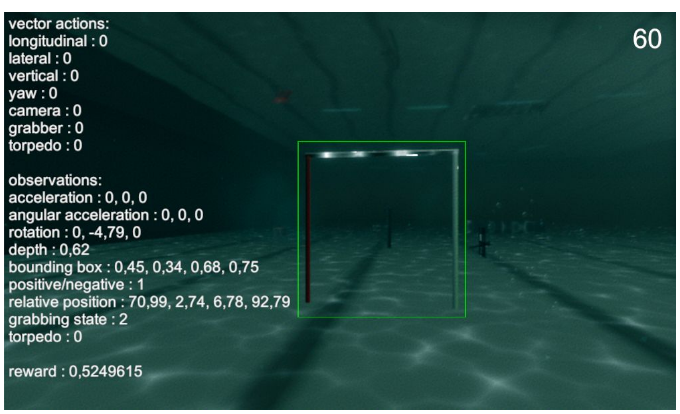

Figure 5 Debug view of the simulation showing exchanged data

In order to speed up the process of developing the software, an artificial underwater environment was created using Unity 3D. It can be connected to the controller program through ML-Agents toolkit. The simulation outputs camera view, vehicle's acceleration, rotation and position relative to the target. In exchange, it receives the actions chosen by the controller program. This allows us to test software without the need to transport the AUV to the actual pool. The simulator uses NVIDIA PhysX to introduce collisions, water current and various water particles that could potentially disrupt object detection.

The simulation can also work in dataset collection mode, which gathers labelled image data for YOLO neural network training. At each frame, it assembles a new scene from pre-modelled parts, chooses lighting and water conditions and then places the AUV and the target. After that, it creates a screenshot and a file containing the expected output from the object detector. This allows creating a very diverse dataset without the need to label the data by hand or modify the images to introduce more variation.

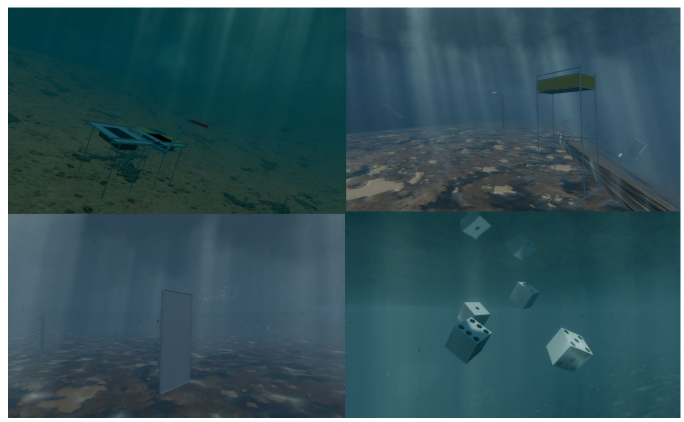

Figure 6 Samples from the computer-generated dataset

To have an alternative in case of a failure of correct detection, some more traditional solutions were prepared. These use colour and edge detections and are considerably slower and less reliable but can be tuned to different lighting and other environmental conditions much faster than neural networks.

Some experiments with the usage of reinforcement learning were conducted to train a neural net to fully control AUV. The simulation is used for training. High reliability of this solution was achieved, but it turned out to be hard to write proper fit function, so preparing a model for a particular task was a very time-consuming process.

IV. EXPERIMENTAL RESULTS

Design of current AUV developed by our team is based mainly on the experience gathered during two previous seasons. The last vehicle's generation turned out to be a vastly reliable solution, so this year's construction was similar to previous shape and software solutions.

In previous years the main problem with data gathered via simulation was its artificiality compared to real-life data gathered by the camera. Models trained using such dataset were less reliable than the ones trained with real photos. This year's version finally enables us a creation of photorealistic simulation images. The key to realism is light propagation in the aquatic environment. The best results are obtained when both real-life photos and artificial simulation images are used to train a model.

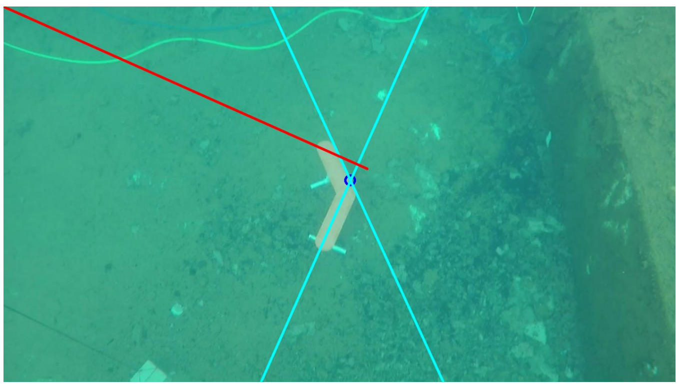

Figure 7 Path axis detection on Robosub 2018 video

Since March 2020 the access to swimming pools was restricted, so simulation was necessary for algorithms testing. Everyone could test their solution independently by running their own instance of the simulation. Also, algorithms could be checked using automated unit tests working on extracted data.

Figure 8 Photo of the current version of AUV

V. ACKNOWLEDGEMENTS

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Appendix A:

Component	Vendor	Model/Type	Specs	Cost	Cost(PLN)
Buoyancy Control	-	-	-	-	-
Frame	Zaopatrzenie24, Wimarol	8 mm	POM	$164	620,00 zł
Waterproof Housing	Adamet-Niemet, Euromill	550 - long 200 - diameter	Aluminum	$526	2000 zł
Cable gland	-	Own Design	Aluminum, anodized surface	$263	1000 zł
Thrusters	Bluerobotics	T200	350 Watts, Waterproof, BLDC	$1445	5500 zł
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	784Wh	14,4v, 784 Wh, Li-ION	$3000	12000 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 Measurement 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
Gripper	-	Own Design	PA2200	$1 058,20	4 000,00 zł
Algorithms: Vision	-	-	convolutional neural nets, edge and colour detection, Hough transform	-	-
Algorithms: acoustics	-	-	phase difference	-	-
Algorithms: localization and mapping	-	-	-	-	-
Algorithms: Autonomy	-	-	-	-	-
Open-source software	-	-	YOLO (Darknet Framework)	-	-
Team Size	-	-	50	-	-
HW/SW expertise ratio	-	-	1,57	-	-
Testing time: simulation	-	-	300h	-	-
Testing time: in-water	-	-	20h	-	-

Appendix B:

The structure of the organization is based on functional division. It consists of two parts - the technical department and the marketing and management department. The technical department is divided into three teams as well. There are construction, electronics and software teams, each of which is supervised by a team lead. The Chief Technical Officer and project manager are responsible for the work of the technical department. In turn, the marketing and management team consist of two parts. The first one is responsible for creating marketing content and is supervised by the Chief Marketing Officer. The main objective of the second part is contact with partners, and caring about purchases. The Chief Financial Officer is the person who coordinates this department. The Chief Executive Officer coordinates the work of all leads and represents the organization.

Throughout the years the cascade method of planning and realization of projects was the main tool for coordination of the whole project. Now some elements of Agile, specifically the Scrum framework, are being implemented into the planning and work process. The organization is developing all the time, not only in technical ways, but management techniques are changing as well. The main goals are flexibility and at the same time maximum efficiency. The basic organizational structure is represented by the following scheme.

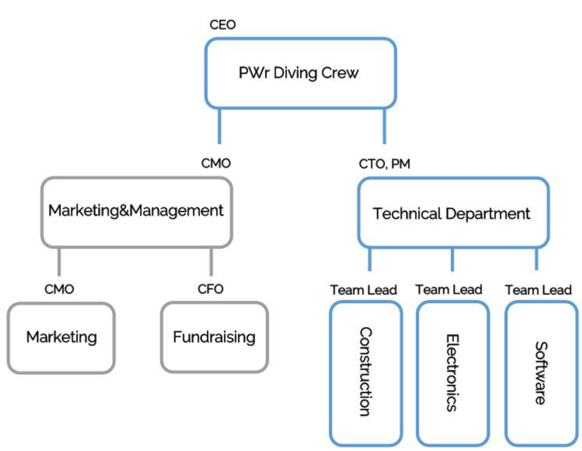

Figure 9 Organizational structure

However, thanks to the quarantine the organization had an opportunity to develop online work skills. Leads managed to provide the spring recruitment process completely online, including recruitment tasks and interviews. The technical department tried to work as much as possible using platforms like Zoom, Discord, workspace Podio (which includes project backlog, task boards, etc.). In turn, marketing started two huge projects online, one of them was connected with branding and recreating the website. The second one was based on providing some internal and external courses and webinars online covering different topics like SolidWorks, Python, Excel, CV, negotiations in business, Russian language, etc.

Last season the team took part in a large number of different competitions, projects and technology events. Here are the main ones:

Competition of innovative student's projects "3Mind" organized by The Main Technical Organization of Wrocław in conjunction with 3M Company. "Robocik" competed with the best projects from major Technical universities from all over the country and took first place.

Figure 10 Competition "3Mind" by 3M

Student’s competition of innovative and environmentally-friendly projects in Kraków, Poland “EkoInnowatorzy”. There, Robocik took first place in two categories: “Audience Award” and “Environment”. It was a great step for the organization in the way of developing eco-friendly projects.

Figure 11 Presentation on the student’s competition “EkoInnowatorzy”

International Robotics Tournament in Wrocław, Poland “Robotic Arena XII” where the team presented their project for the third time in the category “Freestyle”, and for the third time took third place.

Figure 12 Robotics Tournament “Robotic Arena XII”

The very important title, which the team was able to get in 2020, is the title of the main strategy science club of Wrocław University of Science and Technology, which means the organization is able to represent the University in the international area in the most responsible way.