THE CENTER FOR ROBOTICS DEVELOPMENT

RC-AUV team Autonomous underwater vehicles for RoboSub 2021

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Abstract – Our team consists of three students and we started preparing for the competition only in May 2021. We had the 2019 AUV, but all the team members were new and we were given only 2 thousand dollars. Taking these obstacles, our previous experience, and the experience of other teams into account, we have developed a strategy that could help us win. We decided to buy premade AUVs and focus our efforts on the development of the payload. We have manufactured a marker dropper, a torpedo launcher, a manipulator, a Bluetooth receiver/transmitter, and also integrated a hydroacoustic system. To avoid downtime, we took a simulator, which we actively used to practice the entire mission and test the navigation algorithms, computer vision, and the hydroacoustic system for both vehicles. Whenever possible, we looked for ways to save money and worked on our negotiating skills. Most importantly, we did not stop working on the project even for a day.

Fig. 1. RC-AUV team

I. COMPETITION STRATEGY

Before deciding to participate in this year's competition, we had to evaluate all the initial resources that we could use. We tried to express them as precisely as possible because the success of our strategy depended on this. Here's what we had at the beginning of May 2021:

1. Our team has participated in RoboSub 2019. We took second place in the semifinals and tenth place in the finals. However, none of the original members of that team are in the current team

2. There are only 3 people in our team: 2 programmers and 1 design engineer. Still all the participants have already made other underwater robots before, for example, two out of three received second place at MATE 2019.

3. We have an excellent AUV from 2019 that could perform almost all tasks: recognize objects, drop markers, perform tasks with a manipulator, shoot torpedoes, find a pinger. However, the members of the current team have never worked with him.

4. We started preparing for RoboSub 2021 too late, only in May 2021.

5. Our budget for this year was only $ 2,000.

6. We were and still are determined to win and want to score the maximum amount of points.

With these conditions, it was extremely difficult to develop a winning strategy and that is why it was vital to have one.

First, we analyzed the experience of 2019. Our main strategy that year was to build as many systems as possible from scratch to gain experience. We had almost 10 people on the team and 10 months of preparation. At the competition, we relied on completing as many tasks as possible, not on completing the tasks that we were confident about. Still, despite the fact that we could potentially perform all the tasks and tried to do it, we got the last place in the finals.

So, this year we decided to use our strengths and focus only on the things we do well: computer vision, designing simple and reliable payload devices, creating websites, and shooting videos. In 2019, we won the Most Entertaining Video nomination.

Then the requirements for this year's AUV were formulated:
- low cost;
- high reliability;
- small size and weight;
- the possibility for add additional devices to be added.

After we wrote down all the requirements, we realized that we would not be able to make such a robot on our own in the remaining time. And it will not be possible to "revive" the 2019 AUV without the members of that team. Therefore, we decided to buy a pre-made AUV. After analyzing the market for affordable AUVs, we came to the conclusion that now there is only one option, and that is MiddleAUV [1]. This educational AUV is not very well known outside of Russia, but in our country, it is the most popular educational AUV. It is used in several national competitions and we were lucky that one of our team members, Alexey Zauzolkov, works for MUR Company, which makes MiddleAUV.

Next, the team's budget was planned. Our organization gave us $ 2,000 and provided us with equipment, the old AUV, some inexpensive components, and mentors. We needed to make good use of the available resources. While analyzing the capabilities of MiddleAUV, we realized that one robot is not enough to complete all tasks but just the robot alone was 2000$ which was our whole budget. We asked MUR Company management for a 10% discount, and they also let us borrow another vehicle for free.

Fig. 2. MiddleAUVs

Our main strategy in planning a budget is to spend money only on the essentials and ask discount or invite friends for all the other things. Therefore, we spent the rest of the money on a good camera operator to shoot our videos, hosting with a domain, and some additional parts. We agreed with the Maritime State University about the use of their pool (though only at night) and asked a translator we knew to check the use of English in our report.

Last, we made a preparation plan, including tasks associated with making the additional

equipment and programming of the AUV, the website, the video, the report, and the tests in the pool. We kept in mind that we had only 3 people in the team and the was happening pandemic. Here we made sure that everyone should become a good specialist through practice. It was a part of our strategy. For example, Platon engaged in writing a script for the video and its entire production process, Vitaliy was writing the technical report, and Alexey developed the website. The second part of the strategy was that we should work every day. Since every day doing nothing does not bring us closer to victory, but slowly takes it away from us.

So, after evaluating our original data, last years' experience, formulating the requirements for the AUV, and considering the budget we created a strategy that could lead us to victory. It consisted of six items:

1. Remembering our strengths and weaknesses.
2. Make the most out of the cards we were dealt.
3. Focus on the tasks we perform successfully.
4. Improve the stability of things that work well.
5. Spend money carefully and learn to negotiate.
6. Work on the project every day.

II. DESIGN CREATIVITY

A. Mechanical

Since we bought the AUV, we had no problems with the design. The hull, the thrusters, and the electronics were ready. All we had to do was to upgrade the vehicle to perform tasks, which meant we had to design and install payload devices:

- Marker dropper;
- Torpedoes and a device for their launch;
- Manipulator;
- Hydroacoustic system.

Still, there was a big obstacle in our way. All the payload devices had to be made to fit the small size and weight of our AUV.

Marker dropper. We decided to use the smallest solenoid we had in order to make the device as small as possible

Fig. 3. Marker dropper

Torpedo launcher. In 2019, we used a large sealed servo for the torpedo launcher trigger. This was not an option this year, since such servos are very expensive and heavy. We decided to use small brushed motors. After testing these motors, we found that they can work in water for almost a month. This means that for this year's competition, we only needed four brushed motors and their cost is more than 50 times less than that of a sealed servo.

Fig. 4. Torpedo launcher

Manipulator. We also redesigned the old manipulator using a brushed motor. It has become 4 times lighter than the 2019 manipulator.
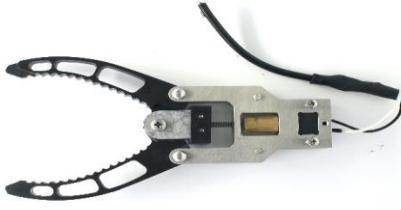
Fig. 5. Manipulator

Hydroacoustic system. We modernized the old hydroacoustic system to integrate it into the vehicle. We wrote about this in more detail below.

The main advantage of the MiddleAUV educational vehicle is the availability of free sealed lead-in cable glands for connecting additional devices. Nevertheless, they became a problem for us since there are only 2 of them, and we had 4 devices. It was at this point in the design that we realized that we would need a second sub.

But then another problem arose. We were not sure how to distribute the payload between the two vehicles. Here is our thought process. To complete the task "Survive the Shootout", the sub needs a hydroacoustic system, since there is no other way to get to this task. That is how we figured out the best combination

MiddleAUV 1 will carry a torpedo launcher and hydroacoustic system and MiddleAUV 2 will carry a marker dropper and manipulator.

B. Software and Navigation

The use of purchased vehicles relieved us of the burden of developing the onboard software. However, we had to create topside software, for two subs, even though we only had two programmers.

We needed to divide the work in a way that could help avoid duplicate work and still exploit the strengths of each programmer. Therefore, we

have divided the software into 3 parts. The first part was responsible for the basic functionality of the AUV: the operation of motors, actuators, movement, handling emergencies. The second part was computer vision and the third part were navigation which was responsible for planning the mission and orientation in water space.

The advantage of this separation is that the first and second parts are practically identical for both subs and can be developed independently by two programmers. Alexey took up the basic functionality since he knows the features of the MiddleAUV better, and Vitaliy began to work on computer vision since he has extensive experience in this area.

The third part is significantly different for the two vehicles, so it was developed separately for each robot. Alexey wrote the code for MiddleAUV 1, since he had already worked with the Hydroacoustic system earlier, and Vitaliy got MiddleAUV 2.

To debug the code and select coefficients for the rate and depth controllers, we used the simulator built into the MUR IDE [2, 3].
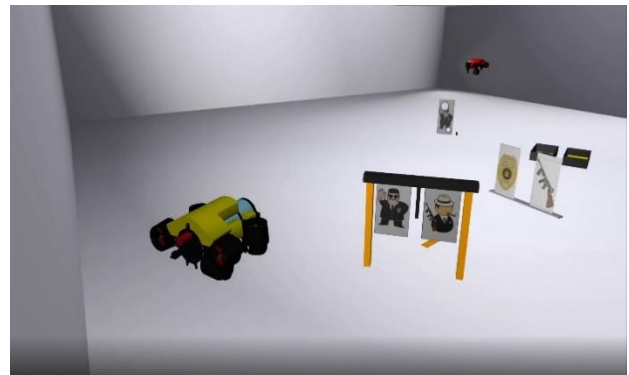

Fig. 6. MUR IDE Simulator

This simulator is a very convenient tool for testing, as it allows one to create the necessary scene, shoot torpedoes, drop markers, work with the hydroacoustic system, and also use the manipulator. This allowed us to effectively manage our time: all basic functionality and navigation could be tested in the simulator, and

computer vision could be debugged at the initial stage.

C. Computer Vision

For object recognition, we used the functions of the OpenCV library [4]. We did not consider other options, since we already had experience with this library, and we did not have time to study new ones.

Having studied the regulations, we realized that in most cases, simple recognition by color is enough. At the moment, we have implemented this using binarization: we selected the desired color in the picture, applied the mask and converted the entire image to black and white format. This method can be implemented rather quickly, which is also important for the competition. When we tested the performance of our algorithms in the simulator, everything worked perfectly.

However, we also plan to use a neural network, since in conditions of color change depending on lighting, binarization will not work well. We have already installed Google Coral on the devices and established their communication with the head Raspberry Pi 4 [5, 6]. Furthermore, we have experience in developing neural networks. Thus, we will separate the tasks performed by computer vision. We will perform easier tasks, for example, stripe recognition, using OpenCV, and more complex objects using a neural network on Google Coral.

D. Intersub Communication

As soon as we decided to use two AUVs we asked ourselves whether they need to communicate with each other. In case it was necessary how should

To answer the first question, we thought out in detail the mission to two vehicles. Tactics set maximum number of points turned out as follows:

- Both subs float through the Gate. One sails with style. Find a Path pointing to Buoy.
- The vehicles relate to two Buoys at once. Find a Path indicating on the Dins.
- MiddleAUV 2 opens the Bin and drops the marker.
- MiddelAUV 1 defines the course on Octagon and transmits it to MiddleAUV 2.
- MiddelAUV 1 goes to the task with Torpedoes and performs it. Then goes to the Octagon.
- MiddleAUV 2 comes to the Octagon, performs a task with a manipulator. Both AUVs float in the Octagon.

With such a tactics, it turns out that communication of the subs is reduced to the transmission of one number, the course of the Octagon.

We looked at all possible ways to transfer data under water: from the ABC Morse with LEDs to hydroacoustic modems. And stopped at the most simple and cheaper way. We decided to use Bluetooth. According to the experience of participation in MATE [7], we know that the transfer of data under water at a distance of 20 cm is quite stable, and the components are affordable and cheap. Since additional germinations do not remain in the vehicles, we installed Bluetooth modules inside the electronic units.
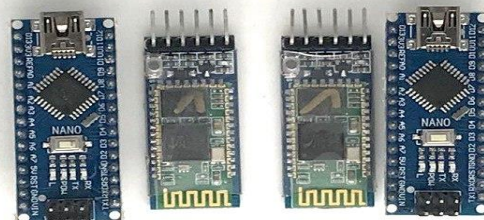

Fig. 7. Bluetooth modules and Arduino Nano`s

E. Electrical

There is no electronics engineer in our team, so we needed to make decisions that could help us handle the AUVs ourselves and not break anything. Therefore, our intervention in the AUV was limited to the wiring of the payload. It was enough for us to know that the robot allows one to connect an additional two devices via PWM [8], two UART and two I2C. We connected the brushed motors and the solenoid via PWM, and the hydroacoustic system via UART.

Manufacturing the Bluetooth receiver and transmitter was a bit difficult as well. But we found pre-made electrical diagrams on the Internet [9] and used them. We took a standard Bluetooth module, connected it to the Arduino Nano which we connected via UART to the Raspberry Pi.

F. Hydroacoustic system

Finding the pinger is one of the most important tasks. It's good that we still have hydrophones from the 2019 AUV. Therefore, the main task for us was to integrate the hydroacoustic system [10] into one of the MiddleAUVs. At the time of this writing, we have not had time to do this yet, but we have come up with a solution and are planning to implement it.

Fig. 8. Hydroacoustic system

Our hydroacoustic system consists of 3 hydrophones and the board. The board is based on a microcontroller with a set of chipboard functions, a low-noise amplifier and an active gang pass filter that protects frequencies up to 25 kHz and after 40 kHz. At the core of this system is the time of arrival algorithm, the carrier frequency is recognized using FFT.

It is important to remember that we have only one output left in MiddleAUV 1 for connecting the payload. Therefore, we have developed a small case for our board and are planning to fill it with a sealant and lead the wire from the board of the required diameter to MiddleAUV.

In addition, the MUR IDE simulator has the ability to work on finding the pinger, which we actively used to practice.

III. EXPERIMENTAL RESULTS

The process of testing and debugging hardware and software is significantly different from each other, so they should be considered separately.

A. Hardware

We followed an iterative development model when creating payload devices. That is, we did not strive to immediately design an ideal device, but on the contrary, we tried to make a simple layout as soon as possible to test if it works. Sometimes we were lucky and everything worked out from the first iteration, but we are always ready to remake the devices and fix the problems that the previous model had, but usually, no more than three iterations were required. At each iteration, the device goes through 5 stages of testing: in SolidWorks, separately from the vehicle in the air, separately from the sub in water, connected to the AUV in the air, and as part of the robot in water. We created our own test checklist for each device.

B. Software

Testing the software of the subs includes 2 main stages: testing in the MUR IDE simulator and in real conditions. The main principle when testing in a simulator was creating conditions that were similar to real life. Therefore, we have developed a scene in the simulator that was identical to the real one.

In the simulator, we could work out almost all the topside software which included, navigation algorithms, computer vision, and mission planning. In addition, since we used a premade vehicle, where the work with peripheral devices is implemented in the form of API functions, we did not need to worry about writing the code for the onboard software.

According to our plan, all software development and debugging happened in the MUR IDE and the simulator. Still, the adjustment of the coefficients of the regulators, colors, and other parameters should be done on real subs. At some point, testing happened simultaneously in the simulator and in the real world. We believe that the ratio of virtual testing to real testing will be approximately 60/40 but we have yet to verify these numbers since, at the time of writing the technical report, we have not finished the simulator testing and have just started debugging in the pool.
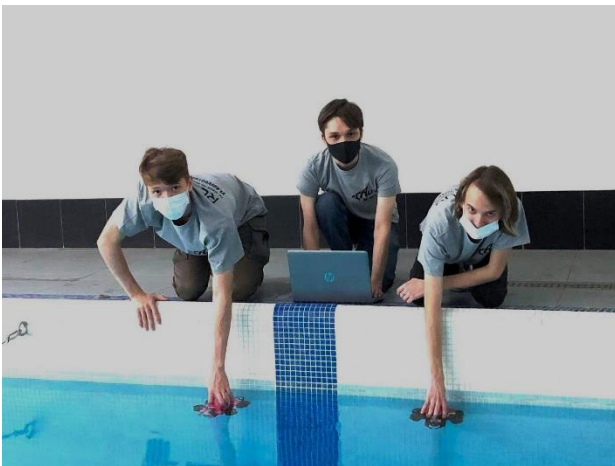

Fig. 9. Testing MiddleAUVs in the pool

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APPENDIX A: COMPONENT SPECIFICATIONS

Component	Vendor	Model/Type	Specs	Cost (if new)	Status
Vehicle №1	MUR Company	MiddleAUV	**_General characteristics_** - Size: 250 x 200 x 90 - Weight: 1 kg - Immersion depth: up to 10 m - Communication: Wi-Fi, Ethernet **_Electronics_** - Raspberry PI compute module 4 - Battery 3000 mAh, 9-12,6V; 25A - 2 Camera (10-20 fps, 640x480 resolution) - Driver for PWM, UART and I2C - Bluetooth module - Depth sensor - Google Coral **_Design_** - Lid (6 penetrators, 2 plugs) - Acrylic pipe (D=60 mm) - Dome (55 mm) - Buoyancy (synthetic foam)	1800$	Installed
Vehicle №2	MUR Company	MiddleAUV	**_Thrusters_** - 2 Horizontal - 2 Vertical - Max thrust- 0.2 KGF - Max value 12 V and 15 A - Each have a size: 37 mm **_Payload interfaces_**: PWM, UART, I2C	Gift	Installed
Hydroacoustic system	RC-AUV 2019	No name	3 hydrophones and the custom board	Legacy	Installed
Solenoid for marker`s dropper	No name	No name	Gangbei-0530B, 12V	1$	Installed
Motors for torpedo launcher	No name	No name	Brushed motor N20, 12V	3$	Installed
Motor for manipulator	No name	No name	Brushed motor N20, 12V	1.5$	Installed

Plastic for 3d printer	REC/ BestFilament	ABS + PLA	2 kg (1,75 mm)	35$	Selected
Algorithms: vision	Custom	OpenCV	Detecting objects, binarization, area thresholding, Gaussian blur	Free	Installed
Algorithms: neural network	In-house	Google Coral	Detecting complex objects	Free	Installed
Algorithms: acoustics	RC-AUV 2019	Time difference of arrival	Detecting angle to pinger and signal frequency	Legacy	Installed
Algorithms: localization and mapping	Custom	Custom	Hydrophones, computer vision	Free	Installed
Algorithms: autonomy	Custom	Custom	Task sequence	Free	Installed
Open-source software		OpenCV, Python, Linux	Computer vision, programming, computer operating system	Free	Installed
Team Size (number of people)	3	Students	University	N/A	Alive
Expertise ratio (hardware vs. software)	2 vs. 1	Hardware subteams: mechanical Software subteams: software architecture, computer vision	Platon Alexey, Vitaliy	N/A	N/A
Testing time: simulation	20 hours	All software	Alexey, Vitaliy	N/A	N/A
Testing time: in-water	5 hours	Propulsion control, payload	Alexey, Vitaliy, Platon	N/A	N/A
Inter-vehicle communication	Guangzhou HC Information Technology Co., Ltd	HC-06	Sensitivity: 80dBm Bases at CSR BC04 Bluetooth technology	20$	Installed

	Arduino	*Arduino Nano*	Microcontroller: Microchip ATmega328P. Operating Voltage: 5 Volts. Digital I/O Pins: 14 (plus 6 can PWM output pins) Analog Input Pins: 8	10$	Installed
Programming Language(s)	Python	Python 3	MUR IDE	Free	Installed

APPENDIX B: OUTREACH ACTIVITIES

We are actively involved in the popularization of underwater robotics in Russia. Each of our team members made a great contribution to the common cause this year.

A. Alexey Zauzolkov

This year, Alexey co-organized three underwater robotics competitions at once: the NTI Contest Aquatic Robotic Systems, the MATE Russia-Far East ROV Competition, and the Innopolis Open iAUV. In all three competitions, Alexey acted as a problem developer and judge.

More than 1000 people took part in the NTI Contest in the first stage, more than 100 passed to the second stage, and in the finals, on March 1-5, 2021, 48 students from all over Russia met.

The regional MATE, which took place on May 7-9, 2021, was attended by 26 teams, the participants were from 7 to 22 years old.

And at the Innopolis Open, June 15-17, 2021, there were 7 teams of students from grades 8 to 11.

Fig. 10. Alexey being a judge at Innopolis Open

B. Platon Pryazhennikov

Platon was actively involved in educational activities and took part in 2 exhibitions, where he talked about underwater robotics. Those exhibitions were Robofest-2021 and Russia - My

History with a total of more than 5,000 participants. He was also a judge for the Ranger and Explorer categories at the MATE Russia-Far East ROV Competition.

Fig. 11. Platon being a judge MATE Russia-Far East ROV Competition

C. Vitaliy Shevchenko

For the whole year Vitaliy was focused on mentoring the high school team from The Center for Robotics Development for the MATE Russia-Far East ROV Competition, where it came first. Now, at the time of writing this document, Vitaliy continues to prepare the team for the International MATE ROV Competition.

Fig. 12. Vitaliy with his team at the award ceremony