Development of a modular multifunctional underwater vehicle: Ivan! 2021

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Maritime State Universitv named after admiral G.I. Nevelskoy

I. Abstract

MSUAUV team has developed a new platform "Ivan!" Which consists of two modules: a basic one, which includes an electronics unit, propulsion systems, a navigation system, and a removable payload module, which can be quickly replaced to perform certain tasks. Sophisticated design solutions have provided great flexibility in using the AUV in various conditions, as well as ease of transportation.

Platform Ivan is equipped with better electronics and software than our previous platform that we used from 2015 till 2018. This platform has expanded functionality due to the presence of optimized program control and implemented design solutions.

II. Competition Strategy

After a two-year break from participating in RoboSub competitions, we have again assembled a team to gain skills in underwater robotics and build a new AUV. Although we had a long break and almost a complete refresh of the members, we have enough experience from past years to start our construction not from a fresh start. However, this does not mean that we will use old equipment, but on the contrary, we decided to create a new AUV, which would follow the current technical and software specifications.

Because most of the members have only recently joined the team, that was actually reassembled, we go through all stages of engineering development, including new design, software, and electronic technology solutions.

This year the team wants to develop a universal hardware and software platform that focuses on the next parameters:

- The AUV should be as light and easy to transport to the place of use as is possible. The maximum weight of the AUV is less than 25 kg.
- The design of the AUV should be modular. This will make it possible to quickly and simply change the equipment to the new operating conditions.
- The AUV should be technically able to move on all axes.
- Develop an effective navigation system.
- Develop a customizable software architecture
- New team members to teach the basics of underwater robotics to the level of knowledge that will allow us to create a working AUV.

III. Design Creativity

There is a clear division in our team into the following roles: designer, programmer of upper and lower level, electronics engineer. The student takes a role depending on the competencies he has. Students are guided by mentors who control the process of building the AUV, give advice on any questions that a student may have, and take part in the coordination of the entire project.

Figure 1: milling on a CNC machine

A. General construction

We plan to participate with the new AUV in different competitions for many years. Every year there are new requirements, tasks become more difficult, which leads to the need to rework and re-equip the machine every year. This is a rather time-consuming process. To simplify this cycle, we decided to make the AUV a modular structure.

The AUV will consist of two elements: a carrier and a payload module. The carrier is an unchangeable part of the AUV that can function autonomously and contains all the main elements of the AUV: thrusters, batteries, an electronics unit, all the main sensors.

The payload module is a changeable part of the AUV that will be constructed for a specific competition or mission set. In example, it may include, if needed, a manipulator, marker dropping devices, sonar equipment, etc.

As the basic material for the making of the AUV frame was chosen a polypropylene sheet

The case for the electronics unit was made by 3D printing from PLA material, which after printing was treated with dichloroethane solvent, which made it possible to achieve the required seal. This technology is rarely used in underwater vehicles and can be thought of as experimental.

The carrier and payload module are connected to each other using standard mechanical fasteners. They communicate through RS232 and Ethernet interfaces (optional).

The size of the carrier is 476 x 215 mm.

The size payload module is from 400 x 135 mm to 440 x 150 mm

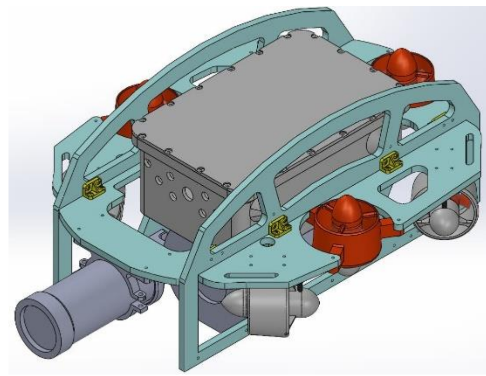

Figure 2: 3D model of the carrier AUV "Ivan!"

The payload module is designed with neutral buoyancy. This also simplifies its connection and does not require additional ballasting of the carrier.

B. Torpedo launcher

The torpedo launcher, shown in Fig 3, is a construction consisting of a plastic tube with a torpedo inside of it, capacity of compressed air and solenoid valve which was installed between them. The solenoid valve is locked and keeps excessive pressure in the capacity before launch. When potential difference (voltage) is applied, it is opened and the air immediately with great speed goes through the tube, and simultaneously pushes the torpedo. An important element of the device is a tube, the length of which was chosen empirically taking into account the initial torpedo rate and its accuracy. Also the team paid much attention to the development and creation of the torpedo. Correct form and proper ballasting of it allowed to achieve the required results. Before each start it is necessary to make pumping and recharge device. The team uses 2 torpedoes launchers. The weight of each of them is 0.8 kg, the shooting distance is 3 m. Fig 3. Render of torpedo launcher.

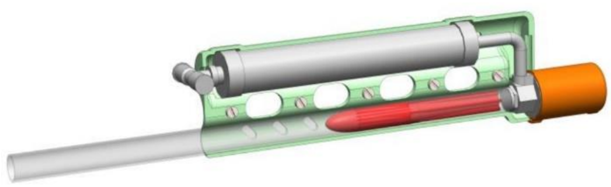

Fig 3. Render of torpedo launcher.

C. Marker Dropper

Marker Dropper, shown in Fig 4, is the device consisting of a plastic hollow cylinder and marker (a golf ball) which is located inside of it. Latch, which is placed in the lower inner part of the cylinder, fixes the marker. Due to the fact that the latch is pressed, marker does not fall out. Reset is carried out using an electromagnet, which controls the position of latch. When the electromagnet starts to work, it attracts the latch and ball falls out of the cylinder. The simplicity and reliability of the design prevents from unintentionally falling out of the marker. The MSU AUV has 2 marker droppers with weight 0.25 kg.

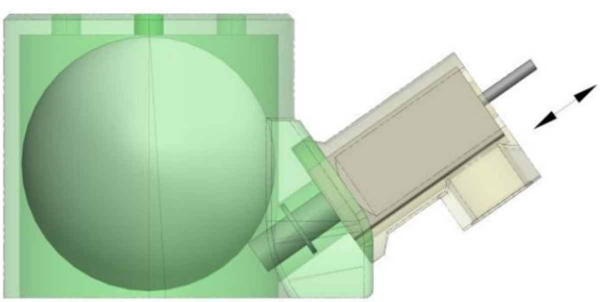

Fig 4. Render of marker dropper.

IV. Electrical system

A. Battery

AUV power supply based on 16.8V, 10Ah Li-Po battery. The capacity of battery is enough for 2-3 hours of the vehicle's work. Battery's switch is based on BTS555 high current power switch. The switch is controlled by an outer waterproof magnetic button. The kill switch is big and bright and located on top of the vehicle. That allows Sir. Diver to turn off AUV immediately. Required power supply voltage for all on-board devices and systems is converted by the power supply board, consisting of DC-DC converters and filters.

B. Sensors

1. Orientation sensors.

The vehicle is equipped with IMU and the depth sensor. The team uses 9 Axis AHRS HWT905. It is a complete inertial system that includes a triaxial gyroscope, a triaxial accelerometer, triaxial magnetometer, pressure sensor, and an extended Kalman filter (EKF) for dynamic orientation sensing. It makes it possible to determine roll, pitch, magnetic heading, and rate of angular motion of the vehicle. Magnetic heading is subject to interferences generated by thrusters and electronic systems. In order to reduce their impact, the team did the best to locate inertial system as far from the interference sources as possible and placed it on a separate housing on top of the vehicle

2. Depth sensor

In order to determine the depth, the team uses MS5803-30BA with the following characteristics:

- Measurement range: 0 to 30bar
- Measurement accuracy: 0.2mbar

3. Hydroacoustic system

To get good results in the competition, it is very important to complete the hydroacoustic tasks. The hydroacoustic system of the old AUV worked well. The developed board based on STM32F405 and software worked stably and allowed to perform the required tasks. The weak part was the hydrophones. They were very delicate and sometimes there were moments when they got damaged and did not function.

We have plans to replace them with the new Russian hydroacoustic antennas RT-1.332820-1. They have greater sensitivity and are structurally very "tough".

Fig 4. Hydroacoustic antenna.

4. Rotary log

To determine the position of the vehicle in the water, we use a path counting system. One of the most important elements of the path counting system is the velocity meter. In underwater robotics, Doppler logs are usually used. But for our team, this is too expensive equipment that we can't afford. So we decided to use an old, but effective way to measure speed - a rotary log. [1,2]

We developed our own rotary log for our AUV. By measuring the rotational speed of the rotor wheel with a Hall sensor we calculate the speed of the AUV.

The negative of this device is that it measures relative velocity, and the water flow will have a major effect on the accuracy of the measurement. But fortunately for us competitions are held in pools where there are no currents.

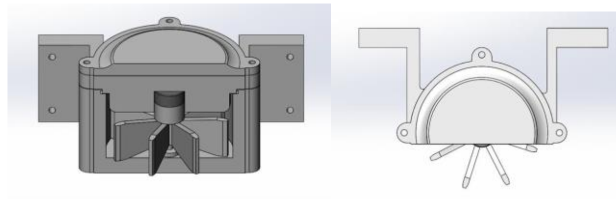

Fig 5. Rotary log.

C. Communication

For data transfer and connection of peripheral devices, the following interfaces are used: Ethernet, USB, RS-232, 1-Wire, i2c. Devices with high bandwidth are connected to Ethernet (main computer, navigation controller, video cameras, Wi-Fi router). In the remote control mode, communication with the ground is also through Ethernet.

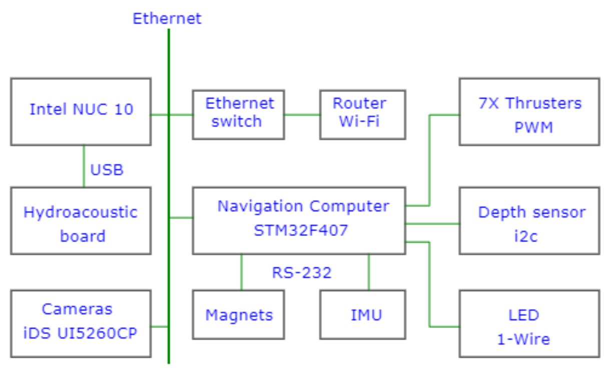

Fig 6. AUV networks.

V. Software

All AUV software can be classified into high-level and low-level software. The low-level software runs on the STM32F407-based onboard controller board, under the FreeRTOS real-time operating system. Here low-load computational tasks that require real time are implemented:

- calculating course, roll/depth, speed, and depth controls;

- sending commands to the thrusters;

- control of executive devices and some sensors;

- performing emergency procedures.

Tasks with "high" computing requirements are performed on an onboard computer based on Intel NUC 10, running Linux Ububtu and ROS. The general scheme of the high-level software is shown in Figure 7.

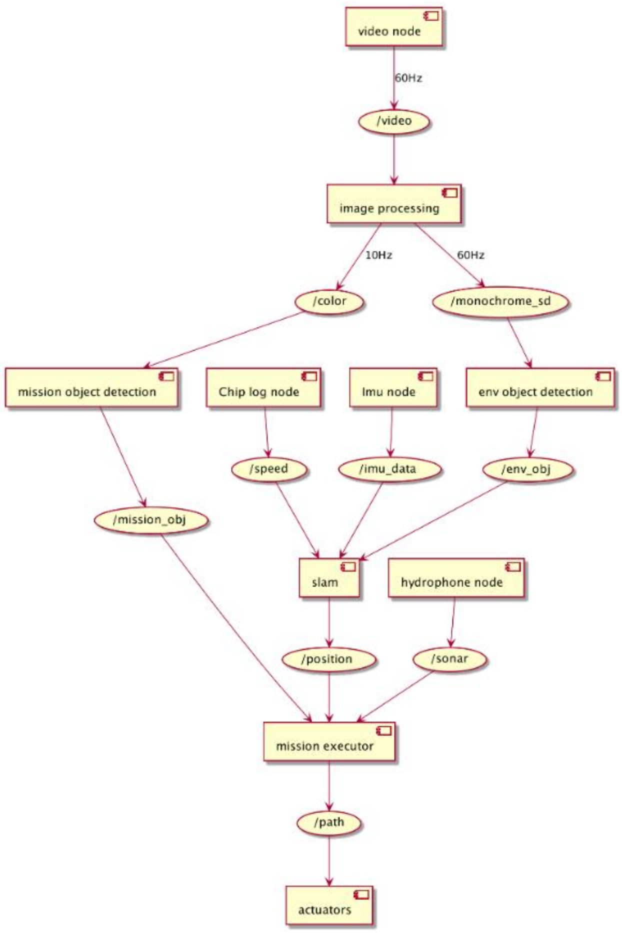

Fig 7 High-level software architecture

The main method of object detection is the use of convolutional neural networks. According to the test results, the Single Shot Detector MobileNet V2 demonstrates the best ratio of accuracy and performance. This neural network is based on Inception architecture. Also, traditional recognition algorithms are used for object detection such as color thresholding and contour analysis.

VI. EXPERIMENTAL RESULTS

The main difficulty with the development and testing of the new ANPA was the COVID-19 epidemic. For a large period of time the University was under quarantine, and we could only work remotely. This mode of work was good for programmers, but it was difficult for designers and electronic engineers, who required personal presence in the lab. So we had to do some tricks, for example, we made a working schedule so that only one person could be in the workshop. Also there were problems with the timing of delivery of components. All of this lengthened the development period and only by the end of June we plan to fully assemble and start testing "Ivan".

Also one of the problems was the insufficient reliability of the new 3D printed underwater housings. After a short period of time, they were no longer airtight. It has taken us a few months to get better at making the underwater housings.

VII. ACKNOWLEDGMENTS

We express our gratitude for the sponsorship of ANO "PLATFORM NTI".

We would like to thank M. V. Holosha, Assistant Rector for Science, for his help in organizing the team's video.

Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Cost(if new)	Status
Frame	In-house	Полипропилен	-	-	-
Waterproof Housing	In-house	PLA plastic, aluminum	-	-	-
Waterproof Connectors	RovMaker	M8	-	-	-
Thrusters	RovMaker	T200	Max thrust: 5.1 kg f Max power: 350 Watts	130$ per unit	new
Motor Control	RovMaker	Basic ESC	7-26 volts, 30 amps, PWM	18$ per unit	
High Level Control	Intel	NUC 10			
Battery		10Ah Li-Po	16,8 volts 4s		
Inertial Measurement Unit	WitMotion	HWT905			
Velocity Log	In-house	Model 1			
Vision	IDS	UI5260CP-C-HQ		600$	
Hydrophones	UC&NL	RT-1.332820-1			
Algorithms: vision			OpenCV 3, Single Shot Detector MobileNet V2		
Algorithms: acoustics			FFT, triangulation		
Algorithms: localization and mapping			Kalman filter		
Algorithms: autonomy			Implemented by member, behavior tree		

Open source software			OpenCV, ROS		
Team Size (number of people	10				
Testing time: simulation	100 hours				
Programming Language(s)			C/C++, Python		

Appendix B: Outreach Activities

Our team members and mentors helped organize the 7th All-Russian Underwater Robotics Competition, which was hosted by MSU on May 7-8, 2021. [3]

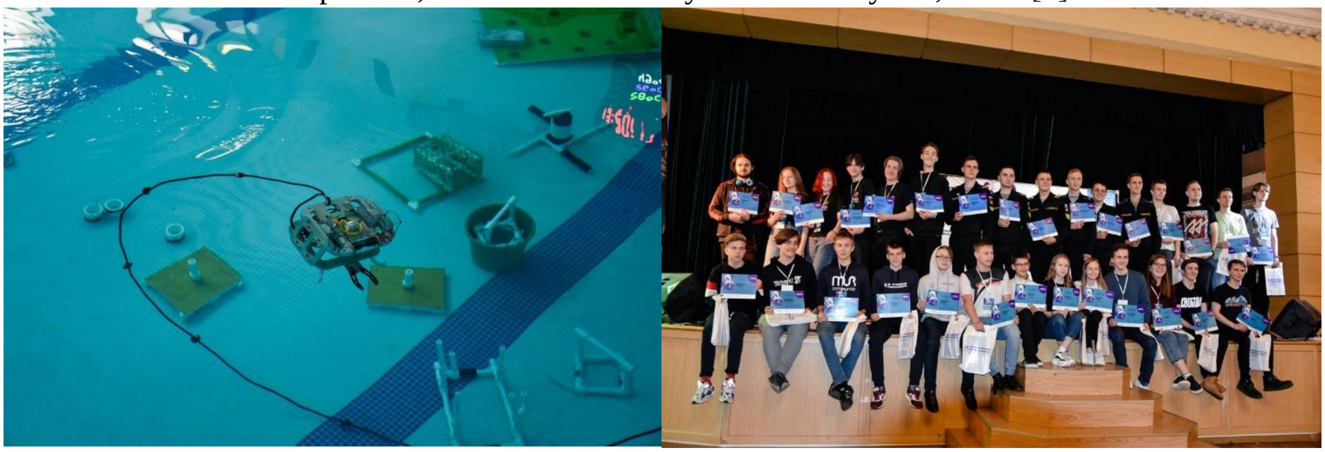

Fig 8. Conducting 7 All-Russian competitions in underwater robotics

Student members of our team conducted master classes for schoolchildren on underwater robotics. They introduced schoolchildren to the types, construction, and potential of underwater vehicles. The schoolchildren got practical experience in piloting the ROV.

Fig 9. Conducting a master class for schoolchildren

We actively participate in scientific conferences on marine robotics. We make reports popularizing our developments.

References

1. Snyder J. Doppler Velocity Log (DVL) navigation for observation-class ROVs //OCEANS 2010 MTS/IEEE SEATTLE. – IEEE, 2010. – C. 1-9.
2. Soylu S. et al. Precise trajectory control for an inspection class ROV //Ocean Engineering. – 2016. – T. 111. – C. 508-523.
3. https://www.msun.ru/ru/news/id-7312