“FEFU and IMTP AUV” Team RoboSub 2022 the New Autonomous Underwater Vehicle

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***Abstract*—We are happy to demonstrate our New AUV. Our team take a part in RoboSub competition for 2012 year. We complete 10 years of adventure with RoboSub community. We have putted all our knowledge and experience into the development of a new AUV. Our team is a group of engineers, scientists and enthusiasts who set a goal to develop technologies and solutions for competitive tasks, as well as for their application in real life. The paper describes the principles of design selection, the new circuit and electronic, and our solutions to advance our beloved “More Mechanics, More Reliability” strategy. Our team takes an active part in activities for teaching students and schools the underwater robotics knowledge.**

I. COMPETITION STRATEGY

We started preparing for the competition and approaches the choice of strategy based on the analysis of Team-Handbook and Forum info. We have created the following tasks.

A. Gate Task

We used the “Start with a turn” the first quality task of move the gate. The solution to this task is largely determine by the accuracy of the AUV navigation system and does not depend on such unpredictable factors as light (glare, shadow) at the competition venue. We have a decision for these problems with new mechanical and design of AUV.

B. Style Task

When the device turns up to 8x90 degrees on the course, roll or trim, receiving additional points by 90 degrees for each turn. We have expanded the new AUV, because added another axis of rotation. This axis will allow the AUV easily perform this task.

C. Bin Task

This task is also independent of the light conditions in the competition venue and can fine-tuned before the trip in the pool.

D. CV Tasks

All tasks related to object recognition based on CV subsystem AUV. This system has a less reliable but bring many points to the team. The task we assigned for our CV system used stereo cameras (two cameras front and bottom views) and machine learning algorithms.

E. Gripper Task

We realised the mechanics gripper using the silicone-wrist system. We updated gripper add magnets to solve the problem of twisting into a cylinder.

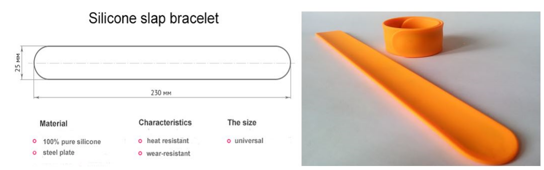

Fig. 1. Silicone-wrist gripper system

F. Torpedo Tasks

We update mechanism of our torpedo. It has become more reliable used the UART to I2C converter. This decision solved the problem of false alarm.

G. “Vorota to Pinger”

We use our well-known strategy, “Vorota to Pinger” (Vorota means Gates in Russian). This strategy based on an unusual hull design that allows us to pass through the gate without any machine vision. We rely on our acoustics to hear beacons and walk towards them.

H. AUV communication

The interaction of several devices, for the joint implementation of the mission. Data transmission performed using a Pinger beacon. For data transmission, use the acoustic system of the Pandora device as the master device. The new craft acts as a slave and is capable of hovering over Pandora. We plan to divide the competition field into two hemispheres (upper level and lower level). Give the lower level to our Pandora AUV to complete the task: collecting objects, dropping balls. The new device performs a task in the upper hemisphere: ascent in the octagon, shooting at targets.

II. DESIGN CREATIVITY

Our team develop the new AUV considering the experience of participating in RoboSub competitions over the past 5 years and the experience of the team developing previous devices. Based on the results of the analysis, a plan drawn up for improvements and update AUV hull design, as well as work on the bugs. In particular, the shortcomings of the existing Pandora AUV.

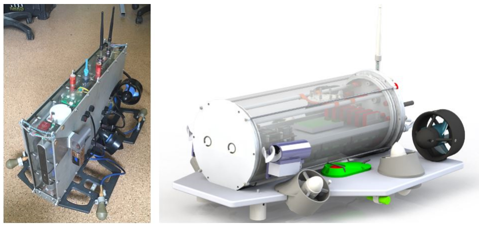

Fig. 2. Old (Pandora) and New AUV

A. New Plan

This was our plan for a deep update of the AUV:

1) We developed a new configuration of the propulsion system and steering system. This task adds the six axes of freedom to perform the competition tasks related. The New AUV have a yaw, roll, and trim control, vertical stabilization (to perform maneuvers such as “Turn”, “Burrel” and “Loop”).
2) We have sex degrees of freedom of our AUV - yaw, pitch, roll, longitudinal, lateral and vertical movement. Robot keeps heading during pass through the gate and able to perform “turn”, “burrel” and “dead loop”
3) We developed a new carrier frame that combines the propulsion and steering systems, the waterproof housing, and the outboard replaceable equipment into a single hardware complex. This minimum set of tasks allows solving the maximum number of competitive tasks.

B. Hull design

We thought about several solutions and worked out the several decisions of hull design.

1) Plastic frame for mounting outboard payloads.
2) Propulsion units of the marching group.
3) Thruster thrusters.
4) Acrylic tube with a diameter 150 mm.
5) Aluminum flanges, providing a tight connection with the flask and acting as a radiator for cooling the internal space with the electronics unit.
6) Ball marker reset.
7) Silicone-wrist gripper system.
8) Stereo cameras: Zed2i and Zed mini.

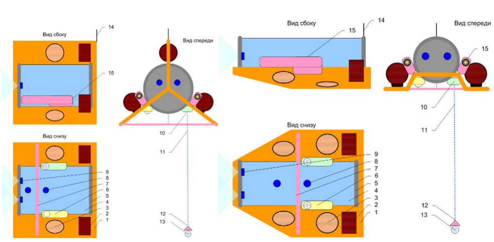

Fig. 3. Choose hull design

9) Stereo cameras – front of view.
10) The mechanism of the descent of the magnetic capture (crane).
11) Height-controlled fishing line or thin thread.
12) Magnet for gripping a metal ball.
13) Metal ball.
14) Wi-Fi antenna.

For further detailed study, we can recommend a variant in a hull with a diameter of 150 mm (Fig. 3), since it has less drag and better fluid flow in the horizontal plane. As a result, the AUV is characterize by lower energy costs for movement in the water column, greater autonomy, and increased stability on the course during longitudinal movement. For a container with a diameter of 150 mm, several variants of the carrying frame were developed. We created the 3D model and divided the AUV into three main parts.

C. Carrying frame

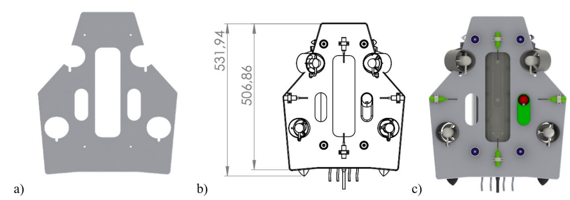

Fig. 4. Projection of the carrier frame of the AUV model on a horizontal plane (a), sizes (b) and 3D model of the frame (c) - top view

D. Waterproof Housing

This block is the main computing unit and contains components for controlling the mechanics of the device. We divided it into two levels:

1) Level of electronics and computing components
2) Level with battery and bottom chamber

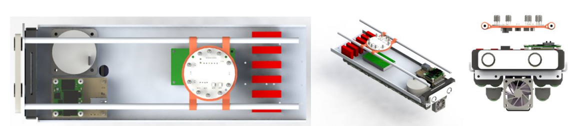

Fig. 5. Waterproof Housing

E. Outboard Payload

We have added outboard payload locations for competitive missions, such as a magnetic capture or a torpedo

F. CAD experiments

Our team used the principles of 3D CAD systems to design the device. At the modeling stage, the team carried out a weight and size analysis of the 3D AUV model. When loading data on the materials used, gave out the dry mass of the underwater vehicle (8.73 kg) and the tensor of its moments of inertia relative to the center of mass along the structural axes.

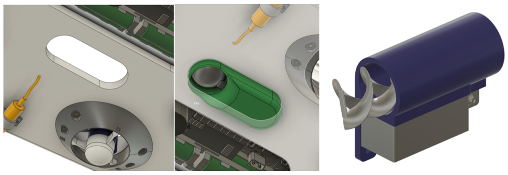

Fig. 6. Outboard payload and torpedo

TABLE I
THE PA INERTIA TENSOR IN STRUCTURAL AXES RELATIVE TO THE CENTER OF MAS

AXIS	X	Y	Z
X	0.07	0.00	0.00
Y	0.00	0.23	0.00
Z	0.00	0.00	0.20

Here and below, the Pantov coordinate system is used: the X-axis is directed along the longitudinal axis of the craft from stern to bow; the Y-axis is directed along the normal axis of the AUV, from the bottom to the top; Z-axis complete the coordinate system to the right side (from port to starboard).

In addition, a hydrodynamic analysis of the AUV 3D model was carried out. Flow visualization for hydrodynamic analysis of the 3D AUV model is presented.

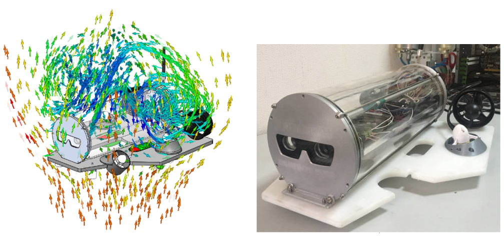

Fig. 7. Flow Modeling for Hydrodynamic Analysis

III. HARDWARE

A. Power System

We have incorporated safety requirements into the design features of the new AUV. For a simple and effective solution, we chose the battery holder option. We power all AUV systems, batteries are used, made up of 18650 lithium-ion batteries with excellent overall power and capable of operating with high currents and voltages. The choice of elements in favor of the 1860 form factor is determined by the peculiarities of participation in competitions, namely, such elements can be ordered in most parts of the world in case of problems during export.

B. Power On/Off system

Safe switching on the AUV, using powerful batteries, two degrees of protection must be applied BMS primary protection board, which is built on Mosfet transistors and comparators, capable of disconnecting the load from the system in case

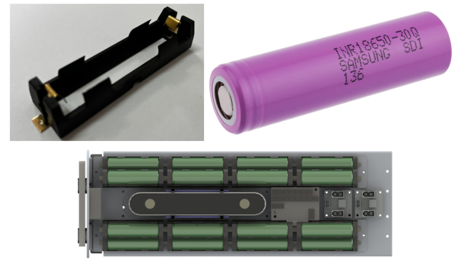

Fig. 8. Holder and Lithium-ion batteries

of damage, short circuit, or low battery. We use intelligent p-channel switches for switching various types of loads, which, however, requires the wiring of a special carrier board. Intelligent keys contain protection against short circuits and overheating. This key is built on the IPS511G chip. To reduce the inductive surge created by the engines, it was decided to add a surge suppressor based on the SMA6J26CA TVS diode to the key.

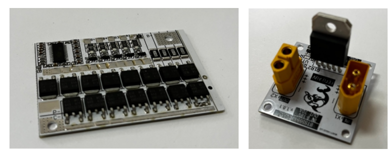

Fig. 9. BMS and p-channel switches board

C. Propulsion control

The propulsion control system designed and manufactured an electronic circuit that distributes energy to the Kotleta 20A electric drive control units.

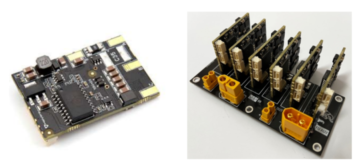

Fig. 10. The Kotleta controller and Kotleta board holder

D. Hardware CV system

Our machine vision system is based on the use of two cameras. One front and one bottom for solving competitive problems. We built the system using ZED mini and ZED stereo cameras

E. Computer module

The main computing unit on our robot is the Jetson TX2 Auvidea J143 expansion board. This expansion board has a large set of available interfaces for connecting components and systems, and has a built-in sensor for determining the angles and accelerations of the device.

Fig. 11. Cameras for CV system

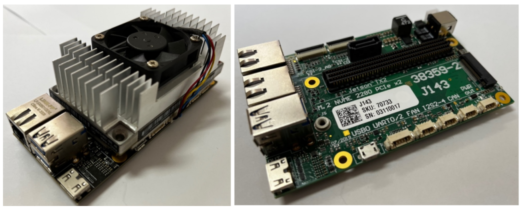

Fig. 12. Computer module

F. Indication

For effective interaction with the device, we have developed our own display board, which allows you to understand what task the robot performs, the current parameters of the device and additional information without connecting to the robot.

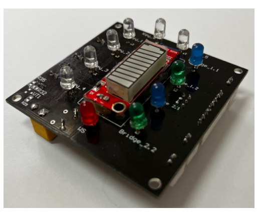

Fig. 13. Indication board

IV. SOFTWARE

At the stage of software development, we pursued the goal of making the code efficient, fast and the easiest for our device to work with. Our technical and electronic solutions required us to solve several basic tasks related to the operation of the built-in systems of the device. Software for Kotleta We used the new Kotleta 20 propulsion control units (ECUs) based on the open-source software Sapog. During experiments with the ECU, it was found that this ECU is not able to provide rotation reversal (changing the direction of rotation on a telecontrol command) without reloading the ECU software. This is due to the specifics of the use of these devices on aircraft.

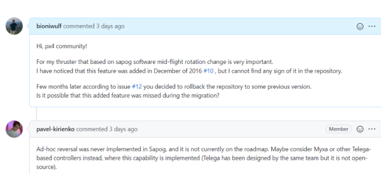

Fig. 14. Discussion of recommended firmware

The team finalized the source firmware code. For this, a fork (branch) of the repository with Sapog software was carried out.

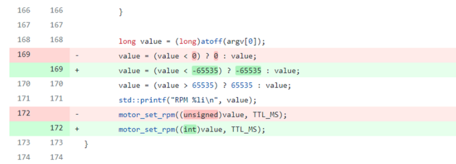

Fig. 15. Fig.15. Editing Sapog source code

A. Control system

We use a software platform that is not standard for Robosub teams. After a year of experience with ROS, we chose the "russian alternative" of this system https://www.researchgate.net/publication/312288175_Reconfigurable_distributed_software_platform_for_a_group_of_UUVs_yet_another_robot_platform,developed at the Institute of Marine Technology Problems. This system is a real-time reconfigurable software platform designed for data exchange between software modules of unmanned underwater and surface vehicles. It is realized as a light-weight OS-independent library that allows integrating AUVs, ROVs and surface vehicles to a single computing cluster. The advantage of this system is the possibility of decentralized information interaction through the low-speed and unstable channels.

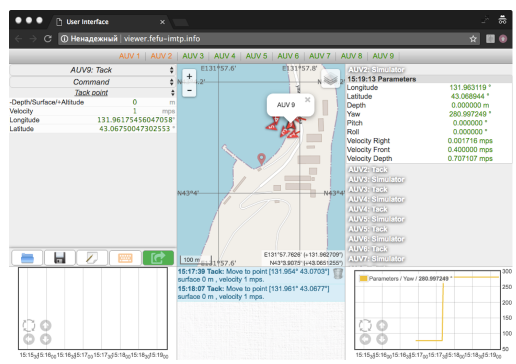

Fig. 16. Web-based GUI of used software platform

This platform does not require any additional tools or software modules installed to the robot control or operation systems. All that is required is a single library for internal process communication, data logging, and a web-based graphical user interface (GUI). The system used is very flexible. For example, it allowed us to deploy on a remote computer our stripped-down control system for several simultaneously online-controlled virtual AUVs http://212.91.197.8/.

B. Software CV system

In our software, we continue to use TensorFlow Lite to minimize the use of computing resources, the amount of memory consumed, and to get more FPS. We also set a goal to include two stereo cameras on one computer in order to reduce the number of computing units. We switched from the J143 board to the board giving a positive effect. We were able to solve the power consumption issue by using a USB3.0 hub with an external power supply.

V. EXPERIMENTAL RESULTS

We conducted several experiments on the new device to test its performance and ability to perform tasks. Our results were confirmed in terms of AUV preparation and assembly. The following main results were obtained:

1) During the assembly of the structure, we realized that there were difficulties with the bending angles of the wire connectors, which required special connectors.

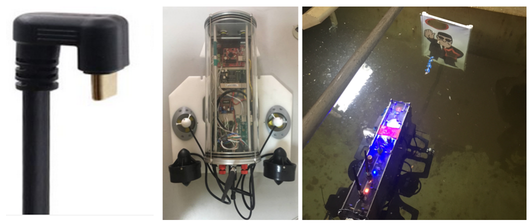

Fig. 17. Equipment and experiments with AUV

2) An experiment was conducted with the interaction of two AUV. To do this, during the experiment, a beacon-pinger was carried along the bottom of the test pool, and the new AUV performed tracking. During the experiments, it was decided to carry out a search at a short distance between the vehicles using the bottom camera, and at the far distance to use the acoustics of Pandora. To solve the second problem, the need for a small upgrade was identified.
3) We developed a new waterproof housing, which designed to accommodate two cameras (front and bottom views) with the possible of stereo imaging for object recognition in three-dimensional space.
4) The new AUV design is easy to assemble and disassemble, repair and adjust systems. We can remove the waterproof housing and leave the electronics on the main frame.
5) Magnetic compass. We tried to use different magnetic compasses (Xsense, VectorNav) in our vehicle but had problems with AUV direction at the most inopportune moment. Because the pool has a lot of metal, the magnetic compass became unreliable. Today we use the Fizoptika-VG1003 fiber-optic gyroscope from the Russian company Fizoptika https://fizoptika.com, which allowed us to solve the problems with the yaw of AUV.

VI. ACKNOWLEDGMENT

The development of our team is supported by Far Eastern Federal University https://www.dvfu.ru/, Institute of Marine Technology Problems of Far Eastern Branch of Russian Academy of Sciences http://www.imtp.febras.ru/, MARINET https://marinet.org, NTI https://nti.one/. We would like to thank our mentors and advisors: Alexander Pavin, Grigorii Eliseenko, Vitaliy Storozhenko, Andrey Makhliarchuk, Pavel Efimov, Anton Tolstonogov and those from FEFU and IMTP who have supported us in this work.

Appendix A
Component Specifications

Component	Vendor	Model/Type	Specs	Cost
Frame	Developed by team	Plastic	-	-
Waterproof Housing	NoName	Acrylic Tube	150mm	-
Thrusters	Blue Robotics	T200	bluerobotics.com/	200$
Thrusters	RovMaker	2216	rovmaker.org	92.90$
Motor Control	HolyBro	Kotleta 20A	https://shop.holybro.com	55.00$
Actuators	Developed by team	-	-	-
Indication	Developed by team	Indication board	-	-
Motor control board	Developed by team	Kotleta board holder	-	-
Power Switches	Developed by team	IPS511G	-	-
CPU	Nvidia	Jetson TX2	developer.nvidia.com	259$
Carrier Board	Auvidea	J143-48	auvidea.eu	379$
Internal Comm Network	MIKROTIK	HAP AC LITE / 1000 Mbps	mikrotik.com	-
External Comm Interface	MIKROTIK	HAP AC LITE & Wi-Fi	mikrotik.com	-
Angular Velocity Sensor	Fizoptika	VG1003	fizoptika.ru	-
Inertial Measurement Unit (IMU)	VectorNav	VN-300	msmedia.surf	-
Vision	Stereolabs	Zed2i	store.stereolabs.com	499$
Vision	Stereolabs	Zedmini	store.stereolabs.com	399$
Acoustics	Aquatelecom	AT-2045	aquatele.com	-
Battery	Samsung	Li-Ion 18650	-	-
Battery holder	NoName	18650 SMD/SMT High-Quality Single Battery Holder	robu.in	-
Algorithms: vision	Tensorflow	Lite	-	-
Algorithms: acoustics	Developed by team	-	Signal delay, FFT, Hilbert transform	-
Algorithms: localization and mapping	Developed by team	-	Kalman filter, Hough Transform	-
Algorithms: autonomy	Developed by team	-	Multiprocessing	-
Open source software	Leaflet, Echarts, Flot Charts, JSON Editor	-	www.leafletjs.com/, www.echarts.apache.org/ www.flotcharts.org/ www.github.com/jdorn/json-editor	-
Team Size (number of people)	6 team members and 3 advisors	-	-	-
Expertise ratio (hardware vs. software)	50/50	-	-	-
Testing time: simulation	100	-	-	-
Testing time: in-water	100	-	-	-
Programming Language(s)	C++, JavaScript	-	-	-