RC-AUV team Autonomous underwater vehicle for RoboSub 2019

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Abstract — The RC-AUV team developed an autonomous underwater vehicle for participation in the international underwater robotics competition RoboSub. It was decided to name the AUV in honor of the famous scientist, founder of Russian underwater robotics, – Academician Mikhail D. Ageev. The team will participate in this competition for the first time, therefore RC-AUV team designed and built a completely new and technologically advanced device.

Eight students of various qualifications worked on the submarine project throughout the year.

During the work, the team developed various peripheral devices.

The AUV consists of systems as a stereo camera for visual coordination and propulsion system with six thrusters. Torpedoing launchers and magnetic devices for dropping markers are on the AUV as a payload.

***Index Terms* — Unmanned underwater vehicles, Underwater technology, Stereo image processing, Neural networks, Hydrodynamics.**

I. INTRODUCTION

In preparation for the competition, we initially set ourselves a global goal: to take first place on RoboSub 2019. To achieve this goal, the team developed requirements for itself: obtaining professional skills in robotic development and project management.

AUV development – technically difficult process. Most of the team encountered this for the first time, some have already designed ROV in preparation for MATE ROV competition, so more experienced team members have taken the role of mentors and lead newbies, distribute tasks and share their knowledge.

The Center for Robotics Development is a company specializing in technical and robotics education of children/teenagers.

Every year, a team is recruited to participate in underwater robotics competitions. Each team member can pick a role: mechanical, electronics or software engineer.

The mechanical engineers develop different parts of the vehicle: frame, payload, waterproof housings for electronics.

Electronics engineers and engaged in the development of boards for the device and their integration with each other.

Software engineers are focused on the development of computer vision, control and navigation algorithms.

We also hold meetings weekly to monitor the work process and set new tasks.

II. COMPETITION STRATEGY

The RC-AUV team will participate in RoboSub for the first time. Therefore, most of the time of preparation, the team was involved in the AUV design and prototyping. The vehicle was assembled only by the end of May, and in the pool, the practice began in June.

The training was held 4 times a week for 4-5 hours.

Due to lack of time, only the tasks that cost the most points were practiced in the pool.

III. DESIGN STRATEGY

The team from The Center for Robotics Development participate in the RoboSub competition for the first time that is why team faced with the necessity to make all components from scratch.

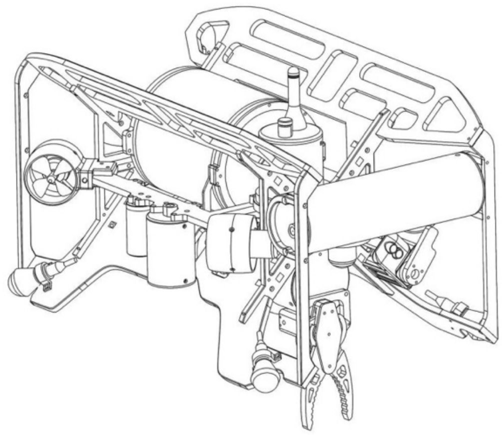

Fig 1. The Academician Ageev AUV 3D model

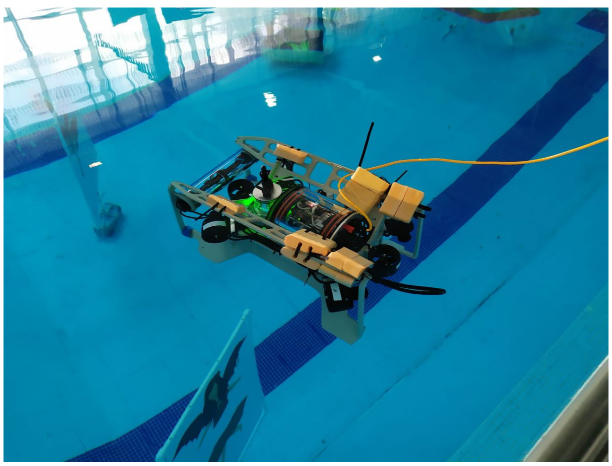

Fig 2. The Academician Ageev AUV in pool

A. *The AUV frame*

The key requirements for the AUV frame are:

1. To provide a rigid and rational layout for AUV components;
2. To protect components of the AUV.
3. To provide low water drag;
4. To be easily adjustable for the modifications;
5. To be cheap in production and provide efficient use of materials.

The team decided to design a frame of the AUV to reach balanced solutions for these aims. To reach affordable weight surfaces areas, form, and rigidity we decide to make bearing elements of the frame from Nylon-6, which strength is like aluminum.

B. *Manufacturing and materials*

For manufacturing components of our AUV, we use CNC milling, lathing and 3D printing. Parts which need to be waterproof like housings were manufactured from PMMA and aluminum with electroplated coating.

C. *Propulsion system*

There are 6 thrusters for the propulsion of the AUV. 4 horizontal thrusters angled at 45 degrees relatively longitudinal axis allow free movement in any direction. This thruster's layout proved its advantages in our ROV which we made for MATE ROV Competition in the last year. 2 vertical thrusters placed in front and back ends of our AUV provide vertical movement and pitch stabilization.

D. *Payload*

To perform the drop garlic task, it has developed the dropper, which works on the basis of the solenoid and 3D-printed pipe. Rubber balls with a diameter of 20 mm are used as a marker. Its feature is low cost and ease of assembly and use.

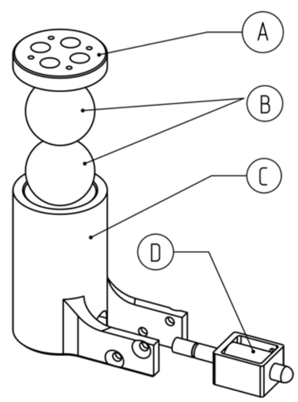

Fig 3. The drawing of the dropper (A - Cap, B - Markers, C - Pipe, D – Solenoid)

In order to carry out the task "Stake through Heart," a torpedo tube was developed. On our device, the mechanism of the start of torpedoes consisting of the acrylic tubes which are specially developed caps printed on the 3D printer from PLA and the retainers cut out on the milling machine from sheet plastic of 8mm thickness is carried out. The starting mechanism is based on stainless steel springs and a shutter that is opened by means of a servo motor. Range is 1.5-2 meters.

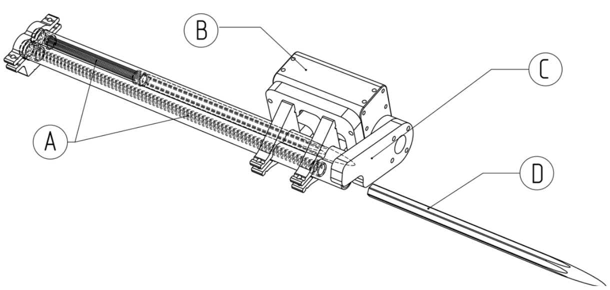

Fig 4. The drawing of the torpedo tube (A – Springs, B - Servo motor, C - Shutter, D – Torpedo)

IV. HARDWARE

We made the vehicle from scratch, including electronics. Our sub consists of different units that are interconnected by various interfaces, such as Ethernet and CAN. We've developed our own SID.

All electronic units in the vehicle have their own purposes. For example, an Additional unit consists of an Additional indicator and an IMU, tilt camera with a stereo camera and servo motor, a power distribution unit with powerful switches, etc.

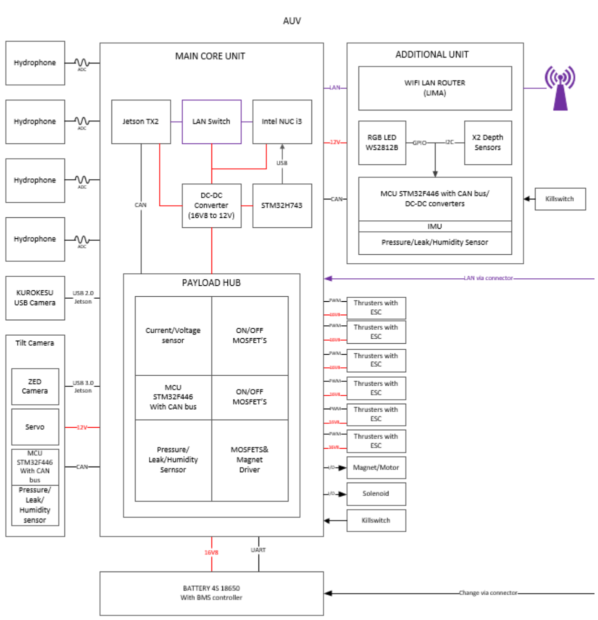

Fig 5. SID

A. *Main Unit*

The main Unit contains NUC, Jetson TX2, Lan switch,

Google TPU, Isolated DC-DC converter, payload HUB board, and hydroacoustic board. Jetson TX2 is the fastest, power-efficient embedded computing device. It's used for image processing and computer vision tasks such as object detection and orientation recognition of objects. Also, neural network accelerator (Google Coral) used for the neural network inference optimization. The main autopilot computer is Intel NUC which is a powerful 4x4-inch mini PC. It's used for the control of thrusters and mission planning of the vehicle. DC-DC isolation based on UWE-12.

B. *Payload Hub*

Most units in the vehicle contain electronic systems that require constant communication with each other and a stable power supply. To provide all the components of the vehicle with a stable power supply, it was decided to develop a load distribution unit. It allows us to control energy consumption and protects important elements of the system. Also, this unit controls the 12 engines and other electromagnetic actuators and distribute about 2 kW of power.

C. *Battery*

Based on the power consumption, we began to choose the battery so that there was a possibility of exploitation for a long time. For this, there was a special aluminum housing designed and a connector like a Subcon. For optimal runtime, we decided to use 2 4s6p BlueRobotics battery's configuration with a total capacity exceeding 42Ah and 16V.

D. *Additional Unit*

Additional Unit is a secondary module that includes a Wi-Fi router, a LED strip, a depth sensor, and an IMU sensor. An LED unit designed to output light commands and minimize EMI effects to an IMU sensor. A special Wi-Fi router and a powerful Wi-Fi antenna are also including inside. The depth sensor installed in the module has ΔΣ 24bit ADC which allows receiving high accuracy data which is ideally suited for use on the AUV.

E. *Tilt camera unit*

One of the most important conditions for the successful implementation of most tasks is the availability of high-quality computer vision systems. Therefore, to ensure a wide viewing angle of the stereoscopic camera, it was decided to use a specially designed rotation mechanism. The electronic unit that allows you to control the operation of the servo also has additional functions of protection against short circuits and leaks.

F. Interunit communications

CAN bus used for communication between vehicle's modules; this technology is excellent for uniting various devices into a single network due to the serial, broadcast transmission mode.

G. Sensors

The sensors of our AUV are 2 cameras (zed mini, kurokesu), IMU, depth sensor and hydrophones.

H. Tether

To connect the device underwater, we have an ethernet cable supporting the speed of 1 Gbit / s, which allows you to debug the device without removing it from the water.

I. Hydroacoustic System

To follow a pinger, we developed our own hydroacoustic system. It is consisting of 3 hydrophones and board. As we developed the system, its cost is lower than that of the ready-made device.

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.

Also, to test our board, we developed our own pinger which emitting a signal at two different frequencies 20 kHz and 40 kHz.

J. Controllers firmware's

All custom boards work on STM32 controllers (STM32H7 and STM32F446).

V. SOFTWARE

A. Computer vision

The efficient computer vision subsystem is required for most of the tasks in the RoboSub competition.

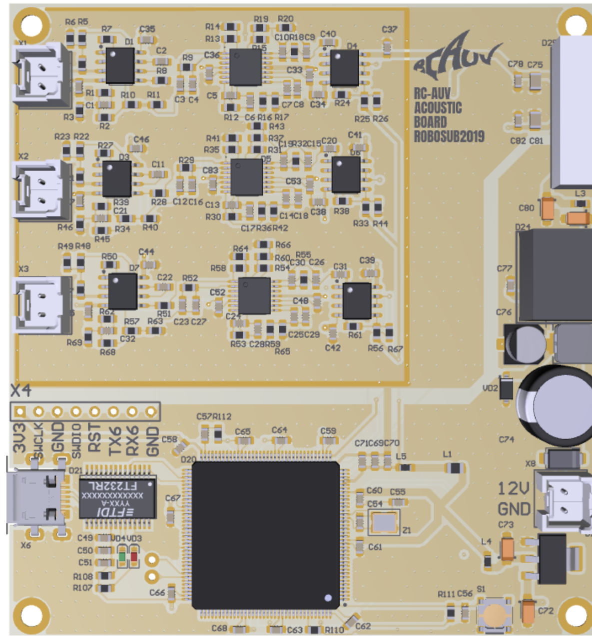

Fig 6. Hydroacoustic PCB design

The vision subsystem converts images into actionable information, e.g. position and orientation of path markers or distance to buoys. For object detection, we have employed both deep learning-based methods and classical computer vision techniques such as color thresholding and contour analysis. Thanks to the quantized aware training [1] and neural network accelerator (Google Edge TPU) we were able to achieve the remarkable performance of our MobilenetV2 SSD [2, 3] based object detection.

Also, stereo vision capabilities are utilized for measuring the distance to objects.

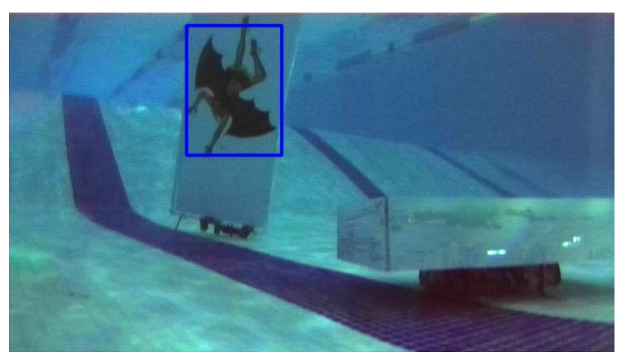

Fig. 7. Example of detection of buoy image

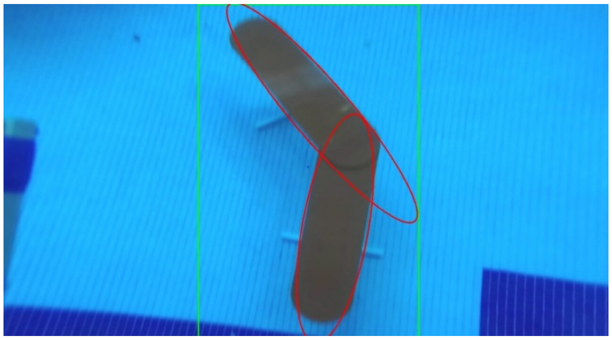
Fig. 8. Example of path marker orientation recognition

B. *Mission planning*

For the high-level mission programming, ChaiScript was used. ChaiScript is an embedded language for C++ which is suitable for the scripting of the AUV action sequences. The mission runner consumes information from the navigation and cv subsystems and produces commands for the low-level control system.

Navigation subsystem receives a depth map from Zed Camera and produces voxel greed of the environment with the Octomap library. Next using a voxel model of the environment collision mesh is generated with the FCL library. Finally, OMPL is used for path planning.

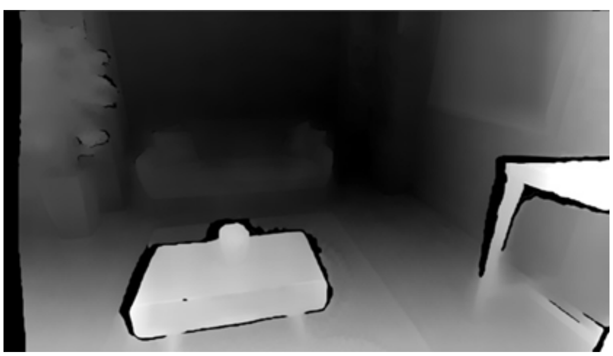
Fig. 9. Example of the depth map

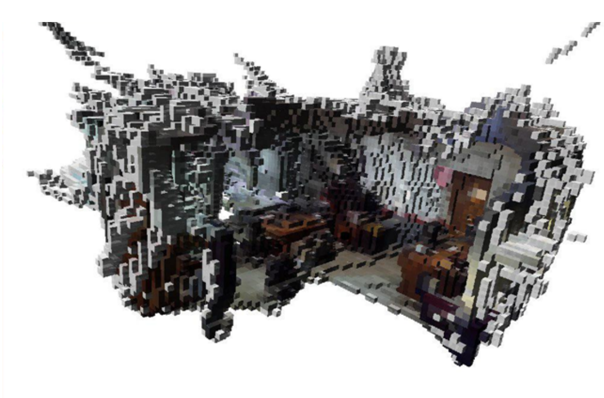
Fig. 10. Example of voxel greed

VI. Experimental Results

RC-AUV team began developing a vehicle in the middle of autumn, initially focusing on the rules of last year. By the beginning of the year 2019, the downed camera was assembled, everything was designed and ordered for 2 vehicle modules. In the next quarter, we finished working with the main modules and started designing the acoustic board, battery pack, and vehicle frame.

In the last quarter, active training was held 4 times a week in the pool at the sports center. Much time was devoted to debugging regulators. Also in April-May tests and development of the torpedo tube and reset were carried out, in June-July the grabber was developed.

VII. Acknowledgments

RC-AUV would like to thank all the companies and individuals who have supported us this year including:

- The Center for Robotics Development for the opportunity to apply professional skills in practice and financial support;
- The Center of Robotics for mentoring and the tools and facilities provided;
- Maecenas Dmitry Alekseev for financial and comprehensive support;
- NVIDIA, Intel for providing onboard electronics.

VIII. References

[1] A. Zhou, A. Yao, Y. Guo, L. Xu, and Y. Chen. Incremental network quantization: Towards lossless cnns with low precision weights. arXiv preprint arXiv:1702.03044, 2017.

[2] Sandler, Mark et al. “MobileNetV2: Inverted Residuals and Linear Bottlenecks.” *2018 IEEE/CVF Conference on Computer Vision and Pattern Recognition* (2018): 4510-4520.

[3] Liu, Weiwei et al. “SSD: Single Shot MultiBox Detector.” *ECCV* (2016)

APPENDIX A: EXPECTATIONS

Subjective Measures		
	Maximum Points	**Expected Points**
The utility of the team website	50	50
Technical Merit (from journal paper)	150	150
Written Style (from journal paper)	50	45
Capability for Autonomous Behavior (static	100	100
Creativity in System Design (static judging)	100	100
Team Uniform (static judging)	10	5
Team Video	50	50
Pre-Qualifying Video	100	100
Discretionary points (static judging)	40	40
Total	**650**	640
Performance Measures		
	Maximum Points	
Weight	See Table 1 / Vehicle	99,8
Marker/Torpedo overweight or size by	minus 500 / marker	
Gate: Pass through	100	100
Gate: Maintain fixed heading	150	
Gate: Coin Flip	300	300
Gate: Pass through 40% section	400	400
Gate: Style	+100 (8x max)	800
Collect Pickup: Crucifix, Garlic	400 / object	
Follow the “Path” (2 total)	100 / segment	200
Slay Vampires: Any, Called	300, 600	300
Drop Garlic: Open, Closed	700, 1000 / marker (2 +	700
Drop Garlic: Move Arm	400	
Stake through Heart: Open Oval, Cover	800, 1000, 1200 / torpedo	800
Stake through Heart: Move the lever	400	
Stake through Heart: Bonus - Cover Oval,	500	
Expose to Sunlight: Surface in Area	1000	1000
Expose to Sunlight: Surface with object	400 / object	
Expose to Sunlight: Open coffin	400	
Expose to Sunlight: Drop Pickup	200 / object (Crucifix	
Random Pinger first task	500	500
Random Pinger second task	1500	1500
Inter-vehicle Communication	1000	
Finish the mission with T minutes (whole +	Tx100	
Total		**6699,8**

APPENDIX B: COMPONENT SPECIFICATIONS

Component	Vendor	Model/Type	Specs	Cost
Buoyancy Control	Custom		Syntactic	$70
Frame	Custom		Polyethylene	$150
Waterproof Housing	Custom			$500
Waterproof Connectors	ROVMAKER	2 Connectors + 45 Cable Penetrator		$343
Thrusters	Custom		Brushless motor	6*$60
Motor Control	Custom			$150
High-Level Control	We fix broken laptop			$300
Actuators	Custom			$150
Propellers	Custom			$15
Battery	Custom	4s12p	36Ah	$250
Converter	Custom			$12
Regulator		BMS Controller		$17
CPU	Intel	Intel NUC		$431
GPU Jetson board	NVIDIA Custom	Jetson TX2		$449 $559
TPU	Google	Coral		$75
Internal Comm Network		Ethernet, CAN, RS-232		
External Comm Interface		WiFi router		$15
Programming Language (PL) 1		C++		
PL 2		Python		
PL 3		ChaiScript		
IMU				$50
Camera	Kurokesu			$150
Rotating Stereo Camera	Stereolab Hightech Custom	ZED Mini Camera Servo Cam board	- $f/2.0$ aperture	$500 $61 $14
Hydrophones Hydrophones board	Custom Custom			3*$230 $33
Manipulator	ROVMAKER	Waterproof Servo		$120
Algorithms: vision		Mobile Net SSD		
Algorithms: acoustics		ToA		
Algorithms: localization and mapping		ZED SDK, OMPL, FCL, PCL		
Algorithms: autonomy	Custom			
Open source software		OctoMap, FCL, OMPL, OpenCV, Tensor Flow, Qt, HAL, PCL		
Team size				8
Testing time: simulation				400hrs
Testing time: in-water				360hrs

A. *Russian-Chinese Robotics Tournament*

In addition to all those Russians who learned a lot about Robotics with the help of our team, we also enlightened several Chinese. A Robotics tournament between Russians and Chinese took place on the 24th of May in the FEFU university. 3 members of our company helped to organize the competitions and also introduced our ROV to the audience, competitors and university students. The competition lasted for about 6 hours and hundreds of people watched it and talked to us. This way we once again engaged the community, spread information about Robotics and encouraged people to study STEM.

Fig. 1.Team leader Anton and Russian and Chinese participants of the competition

B. *Underwater Russian students Tournament in Tula*

On May 14-17, in the Tula Suvorov Military School, employees of the Center for Robotics will organize the “Underwater Robotics” line within the framework of the All-Russian scientific and technical competition “INTERA” among young men. The main organizer of the competition is the Foundation for Assistance to the Development of Small Enterprises in the Scientific and Technical Sphere. Competitions are held in the hackathon format. Participants need to construct a special device for the mini-AUV for three days and program it to perform tasks in the pool. Students arrived from Moscow, Tula, Orenburg, Tatarstan, Smolensk, Stavropol, Kirov, Perm, Tyumen, Dagestan. Especially for these competitions, the Center for Robotics has developed a tiny autonomous underwater robot.

Fig. 2. Vladislav Bolotov, Sergey Mun and team leader Anton are opening competition

C. *Robotics Tournament 2018*

Our teammates had participated in Robotics Tournament 2018 at last weekend. The Robotics Tournament is a local competition where you need to design and program a robot to pass the obstacle course in just 24 hours. This year, 34 teams took part in the competition, a total of 130 people from 13 to 54 years. Our teammates took the first place and won NVIDIA Jetson!

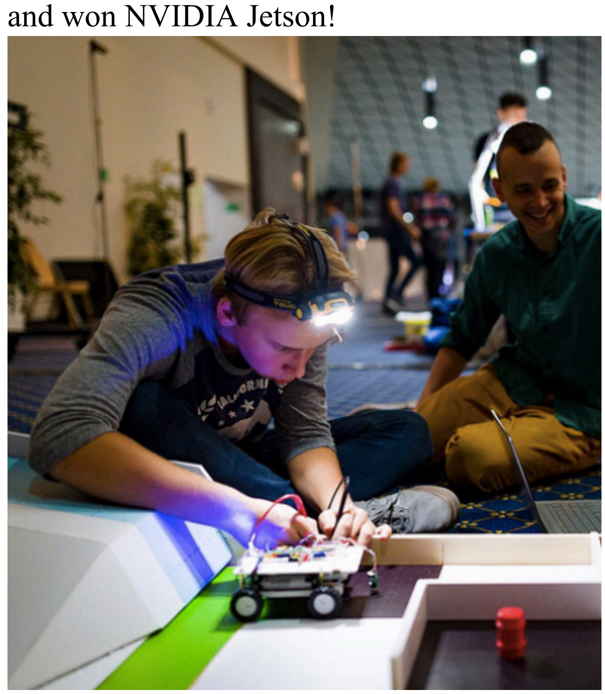

Fig. 3. Anton and Aleksandr are debugging robot

D. *MATE Russia-Far East Regional ROV Competition*

May 10-11, 2019, in Vladivostok at Admiral Nevelskoy Maritime State University hosted MATE Russia-Far East Regional ROV Competition. This is the fifth jubilee competition this year and will be held in three classes: Ranger, Navigator, and Scout. The competition was attended by 13 teams, there are 48 students from 1 to 11 class from Vladivostok, Novosibirsk, Krasnoyarsk, Murmansk, Moscow, and Tolyatti. Anton Konstantinov and Alexander were judges who evaluated the technical presentations of their robots. Anton Lobov evaluated pool missions.

Fig. 4. Sergey Mun and Anton Lobov are evaluating mission of a school team from Tolyatti