THE CENTER FOR ROBOTICS DEVELOPMENT

The Port of LONG BEACH

MATE

RC-ROV

Technical documentation

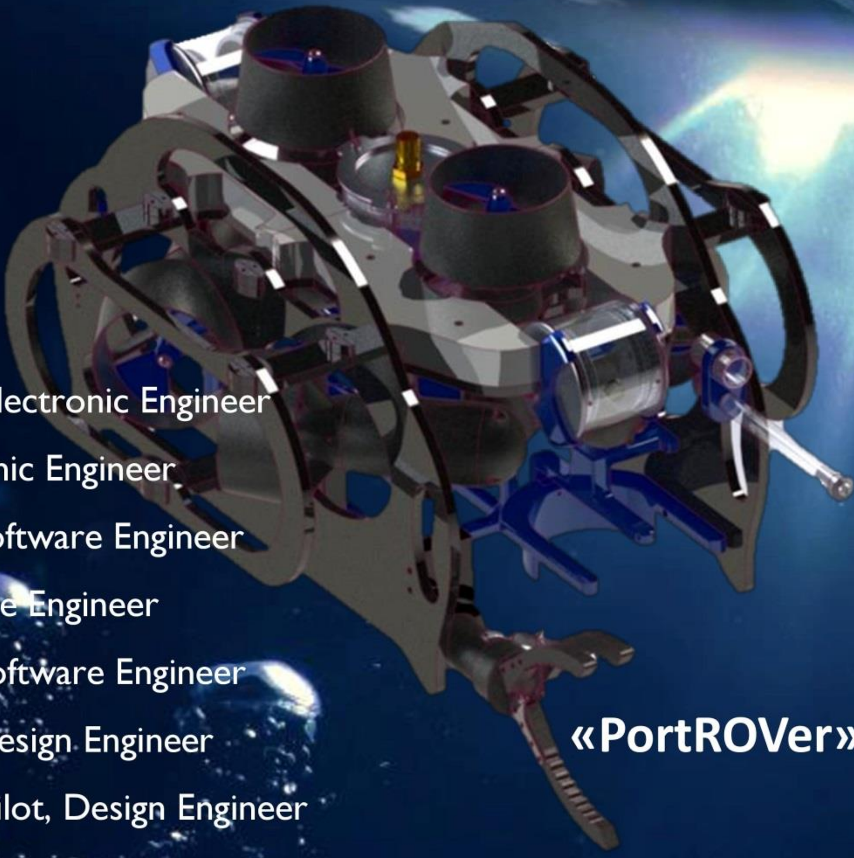
MENTORS

Sergey Mun

Angelina Borovskaya

COMPANY MEMBERS

Anton Konstantinov	CEO, Electronic Engineer
Arseny Zaveryukhin	Electronic Engineer
Nikita Dobrynin	CIO, Software Engineer
Evgeniya Mitrakhova	Software Engineer
Tatiana Ian	Pilot, Software Engineer
Marat Rasulov	Pilot, Design Engineer
Leo Davydenko	CFO, Pilot, Design Engineer
Dmitry Zakharov	Design Engineer



«PortROVer»

LLC "RC-ROV"

1 Komsomolskaya str., Vladivostok, Russia

Phone: +7 (924) 335-44-25, e-mail: toshic.konstantinov@gmail.com

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LLC "RC-ROV"
Phone: +7 (924) 335-44-25, e-mail: toshic.konstantinov@gmail.com

1. Abstract

Our company RC-ROV is taking part in MATE ROV competitions for the first time. Three of our members have already participated in Ranger category, but we are all newcomers in Explorer category. We developed a ROV especially for these competitions and it is capable of completing all the tasks set by the competition organizers. As these competitions' topic is servicing the port of Long Beach, we decided to name our robot PortROVer. The vehicle was built using as many of our designs as possible.

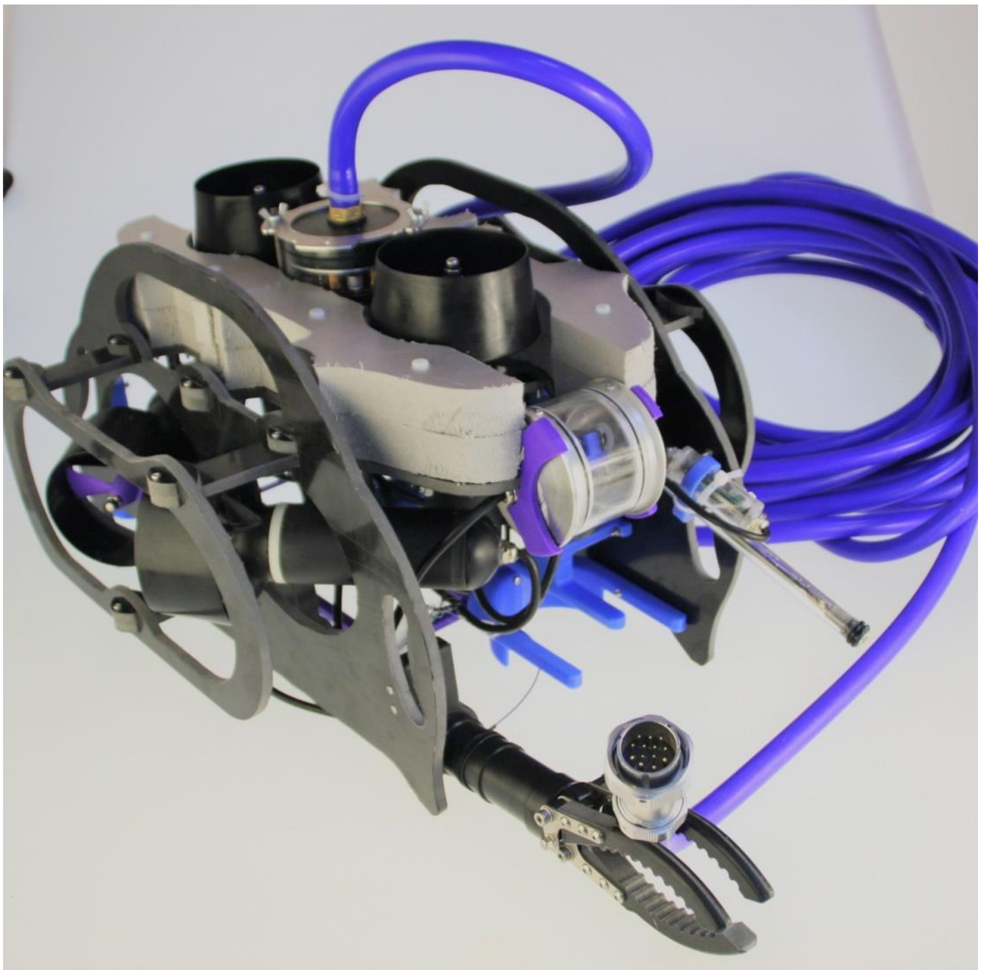
Under this year's rules ROV is to take part in construction of the underwater part of the Hyperloop, research and pick up samples of sea flora and fauna, repair a broken fountain and do work in risk assessment of hazards from sunken containers. Totally, there are 4 tasks to be completed which are subdivided into 24 smaller sub-tasks.

To have all these sub-tasks completed we developed a great number of tools and software. We upgraded a purchased manipulator, developed a collecting basket, an agar collector, a Bluetooth module, a flashlight, and a buoy.

We did enormous work in designing and assembling the vehicle in such a manner that it would satisfy MATE requirements. The work we have done gave us great practical experience in 3D design, 3D printing, card design and making, lathe work, etc.

This paper describes in detail the vehicle development process, including the work in code writing, styling design and electronic component development, as well as in testing and troubleshooting.

Picture 1. Company's staff photo (left to right: Anton Konstantinov, Dmitriy Zakharov, Lev Davydenko, Marat Rasulov, Arseniy Zaverukhin, Tatiana Ian, Evgeniya Mitrakhova, Nikita Dobrinin)



Picture 2. PortROVer photo

2. Design rationale

We started to work on this project before this year's competition rules and tasks were available. Having attentively studied the missions we had a lot of brainstorming and working meetings where following technical requirements to the vehicle were set:

- Vehicle diameter – not more than 0.58 m, weight – less than 17 kg;
- Maximum components of our company own make;
- Maximum specialized tools.

2.1. Use-case model

After this year's MATE Explorer's manuals were published we analyzed all the tasks and started to develop a use-case model, discussing various algorithms of the task completion, and considering different versions of tools. A use-case model is a document reflecting with the help of which tools our robot would be capable of completing all the tasks. Table 1 shows a summary of a use-case model information.

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TASK 1. COMMERCE: HYPERLOOP CONSTRUCTION	
Inserting two rebar	Rebar holder
Installing the frame	Main manipulator
Removing a pin	Main manipulator
Transporting and positioning the hose	Main manipulator
Retrieving the positioning beacons	Sampler
TASK 2. ENTERTAINMENT: LIGHT AND WATER SHOW MAINTENANCE	
Disconnecting the power cable	Main manipulator
Turning the valve to stop the flow of water	Main manipulator
Disengaging the locking mechanism	Main manipulator
Removing the old fountain	Main manipulator
Installing the new fountain	Fountain holder
Re-engaging the locking mechanism	Main manipulator
Turning the valve to restore the flow	Main manipulator
Reconnecting the power cable	Main manipulator
Returning the old fountain	Sampler
TASK 3. HEALTH: ENVIRONMENTAL CLEANUP	
Using a simulated Raman spectrometer	Flashlight
Collecting two clams	Sampler
Collecting a sediment sample	Agar collector
Placing a cap over the contaminated area	Main manipulator
TASK 4. SAFETY: RISK MITIGATION	
Locating the four cargo containers	Camera
Activating each container’s RFID	Flashlight
Obtaining the container’s RFID information via Bluetooth	Bluetooth module
Attaching a buoy marker to the U-bolt	U-bolt grip
Determining the direction and distance	Third pilot software
Make a survey map	Third pilot software

Table 1. Use-case model

2.2. Theme

ROV we developed is designed for operations within the water area of Long Beach Port. To have the vehicle most efficiently complete the set tasks we thoroughly studied not the mission only, but also how similar operations are carried out by professionals in real life.

Our company is based in Vladivostok which is a port city itself. It encounters the same environmental pollution problems as Long Beach Port does due to dense traffic of ships and huge cargo flow. In our city ROVs assist in port servicing (charting, pipeline surveying and the like). The vehicles of the kind proved their efficiency, so when building a robot we looked for help from our colleagues in local scientific and industrial organizations engaged in ROV development and operation (Marine Technology Problem Institute of Far Eastern Branch of Russian Academy of Science, Far Eastern Federal University, Admiral Nevelskoy Maritime State University, Marine Biology Institute of Far Eastern Branch of Russian Academy of Science, Sakhalin Energy, etc.).

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2.3. Payload

Accounting the requirements we set before and experience of our colleagues from other organizations we started designing our vehicle with developing payload tools.

2.3.1. Manipulator

Through the use-case model analysis we specified the tasks demanding interaction with objects without bringing them up to the surface: turning the valve, laying down the hose, installing the power cable, turning the fountain opening mechanism and other tasks. Having analyzed the tasks we found out that we need a two-degree-of-freedom manipulator, that could squeeze an object and turn round its axis.

We had to choose whether to make it ourselves or to purchase an off-the-shelf item. Because of lack of experience in manipulator development with the majority of the team, and additionally because it was us who built most of the components (which is time-consuming) it became clear that we would fail to develop manipulator in time. So we decided to purchase it. Having considered market bids we chose the one most suitable for us: Manipulator manufactured by ROVBuilder.

Picture 3. Manipulator photo

Two motors are placed inside a watertight casing. The first one drives worm-gear drill for squeezing grip lobes. The second motor can rotate the whole casing of the manipulator in any direction endlessly thanks to the current collector located inside the casing.

2.3.2. Fountain holder

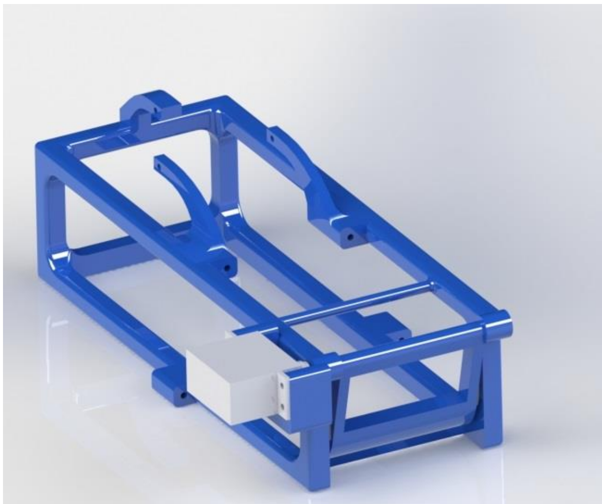
Having analyzed the task for installing a new fountain we decided to build a mechanical attachment with no electronic components. It is essential for us that the new fountain would not fall out during transportation and would come out easily during installation. For that purpose we designed a holder using guidance mechanism that would not let the fountain to fall out and printed it on 3D-printer.

2.3.3. Sampler

One of the tasks implies collecting objects from the bottom, namely Mollusca and beacons. The tool to complete this task should meet the following technical requirements:

- It should be a single tool engaged both in mollusca and beacon pickup;
- In should have a compartment to place these for storage to avoid continuous floating to the surface. This would allow for saving the time.

According to these requirements we built a sampler made of a framework and a net stretched over it, and of a door opened by a servomotor.



Picture 4. 3D model of sampler

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Picture 5. 3D model of rebar holder

2.3.4. Rebar holder

One of tasks requires us to insert rebar pins to have the frame fixed. We demanded that the tool should satisfy the following requirements:

– It should collect the pins one by one but insert both simultaneously to save the time allotted for task completion;

– It should be purely mechanical;

Eventually we designed the tool made of three sides and a fixing cover. The whole tool appears to be two grips located at an appropriate distance apart.

2.3.5. Agar collector

Task 3 implies collecting at least 0.15 L of agar contained in a glass of approximately 0.5 L volume. To have this task completed an agar collector was installed on the vehicle. It is made of a tin can with a small hole in the top side for water outlet. Such a design allows retaining agar at the expense of pressure inside the tin can.

2.3.6. BT module and flashlight

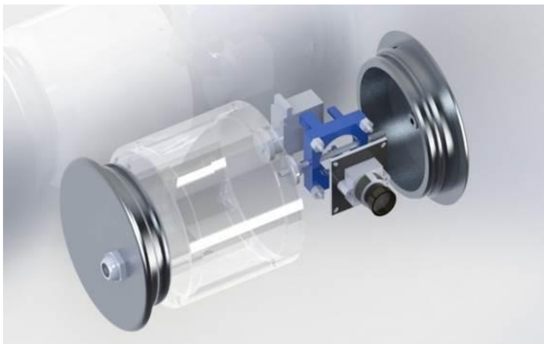
In one of the tasks the vehicle has to activate Bluetooth transmitter by lighting a photocell with a flashlight secured at the end of a 0.17 m acrylic tube. Bluetooth receiver in acrylic casing for water resistance purposes is located right above it. The system is fixed on the vehicle's frame.

Picture 6. 3D model of BT module and flashlight

2.3.7. Buoy

Securing of a buoy to a container is a D-ring with guides for a convenient securing of the grip to the U-bolt. The buoy itself was purchased separately.

2.4. Cameras



Picture 7. 3D model of rotate camera

Having designed payload tools we proceeded to its configuration. Our task was to use as few cameras as possible providing view of all the attachments. As the result we got a ROV with two rotate cameras: main and additional ones.

We designed watertight casings made of acrylic tube and two aluminum caps. Camera is rotated thanks to servomotor connected to the rear part of the camera and two gear wheels. Both cameras can rotate around 360° while the servo angle of rotation is 180°. Such a rotation angle is achieved through the *i*=2 gearing ratio of gear wheels. Gearing ratio was calculated by formula:

$i = \frac{\omega_1}{\omega_2} = \frac{n_1}{n_2} = \frac{2\ m/c}{1\ m/c} = 2$, where *n* is the number of teeth.

Main camera makes it possible to observe the situation ahead and realize where the underwater vehicle is heading to, while the additional one is used to simplify the pilot's duties, increasing the field of view that is needed to perform tasks related to range identification. Thanks to servomotors the necessity in a bottom camera was excluded as both cameras can observe the objects on the bottom.

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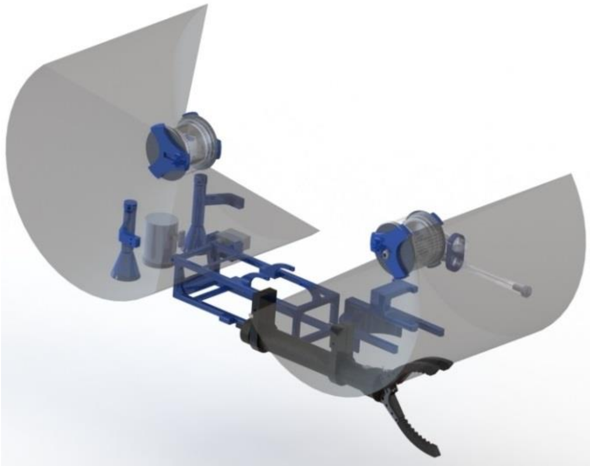
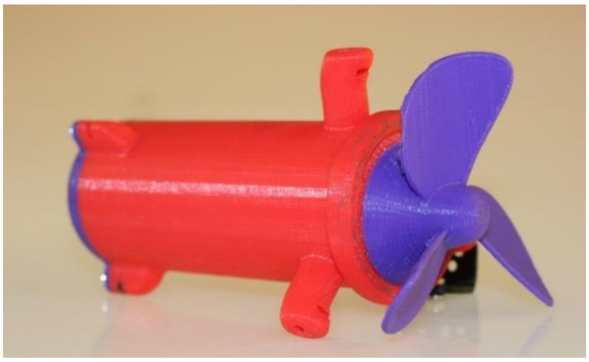
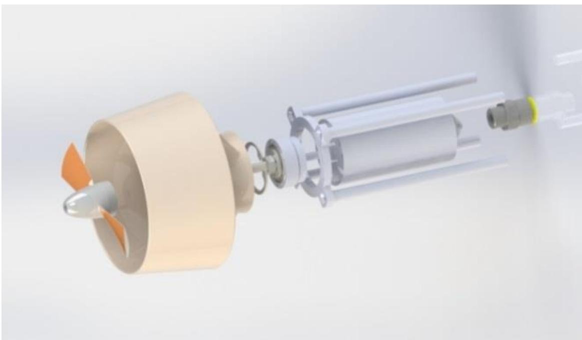


Picture 8. Cameras' fields of view



Picture 9. First version of thruster



Picture 10. Final version of thruster (3D model)

2.6. Frame

Having identified technical requirements to the vehicle, to the number of main tools and payload we were able to start developing of ROV frame.

Our frame consists of a carrier plate, two main longitudinal side walls and two additional ones to protect thrusters, and thanks to that virtually all the systems of the vehicle are protected from mechanical damage.

Cameras 1/3" SONY 639 (1000 TVL) were used as the main sensors of the vehicle board. They have high resolution and no diffraction and interference. Casings which made of acryl were ordered, securings for camera were designed in SolidWorks. Finally they were hermetically sealed. That allows the ROV withstand pressure down to 30m depth.

Drawings of rotate camera casings are shown in Appendix.

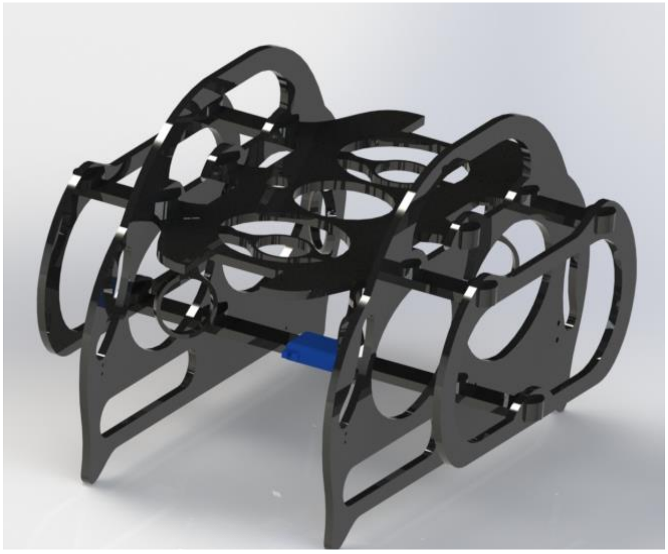
2.5. Thrusters

Having designed payload tools and video system, we commenced creating propulsors. First we identified the number of thrusters. As one of the requirements set is to reduce the weight and size of the vehicle we decided to use two vertical thrusters for going deeper/ floating up and peach control, and 4 horizontal ones for going ahead/ astern, to port side/ to starboard and altering course. We decided to set horizontal thrusters at the angle of 45 degrees.

Brush motors with nominal voltage of 48V and velocity of 3,696 RPM in the air were chosen as the engines.

While developing a casing and a propeller we considered plenty of variants and relied on experimental selection of propellers.

We eventually agreed on a design consisting of a nozzle, propeller, casing, magnetic coupling, front and rear covers. We manufactured the nozzle by casting a 2-component plastics with a coloring agent which gives a more pleasing look. The casings were cut out of PVC tube of necessary diameter. Magnetic couplings and propellers were printed on a 3D-printer. We had to grind the front and rear covers out of caprolon on a milling machine, as these should provide sealing of the propulsor, while parts printed on a 3D-printer fail to provide for that.



Picture 11. Frame (3D model)

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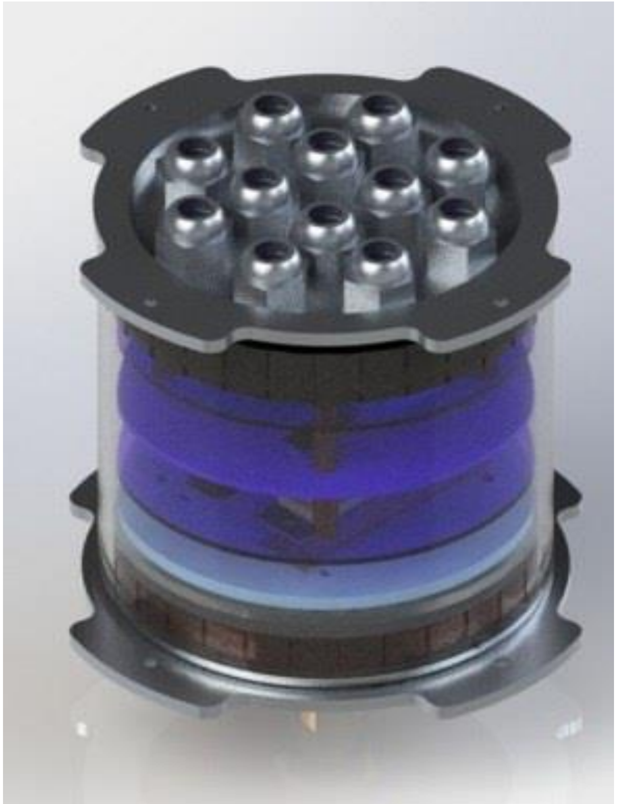
For the purpose of manufacturing frame and clamps (in order to reduce weight) we decided to use 0.008m sheet polyethylene (965kg/m^3) instead of 0.01m polypropylene (910kg/m^3).

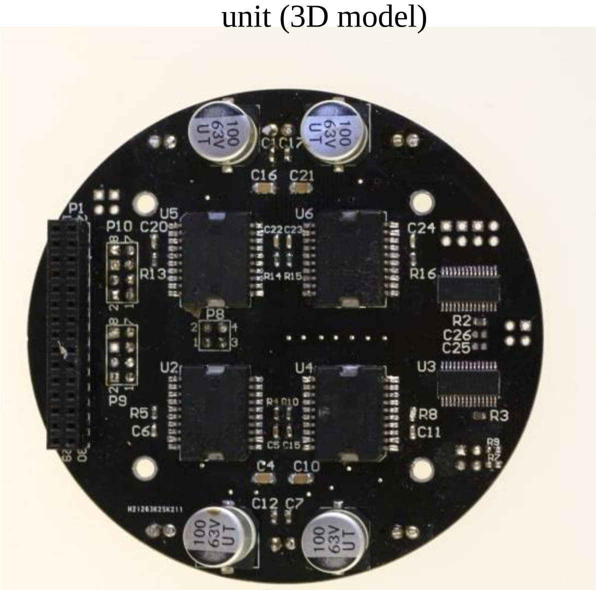
Buoyancy as well as frame was designed in SolidWorks. Buoyancy was designed last, because we needed to know the weight and measurement of all the items and parts of the vehicle.

0.3m penoplex sheets were selected as the material for buoyancy due to it’s low density (35kg/m^3), zero water absorption, high chemical resistance, decay and fungus resistance. We decided to make buoyancy of four parts so that it could be possible to take out electronics unit and remove vertical thrusters without buoyancy dismantling.

For the purpose of ROV ballasting we used lead weights which we cut ourselves from lead sheet piece. We made use of 5 such weights, approximately 0.025kg each. These were attached to the sides of frame and lower beam of the vehicle for the sake of ballasting and improved stability. To have ROV stability calculated correctly we’d studied the underwater craft stability theory[7].



Picture 12. Onboard electronics unit (3D model)



Picture 13. Motor drivers circuit

2.7. Onboard electronics unit

Based on a use-case model we defined the electronics to be used in the vehicle. But as we were not satisfied about ready solutions as per many criteria (size, needless functions, etc.), we decided to develop electric boards of our own.

To design boards we used Altium Designer, Webench designer. The production was divided into several stages: board manufacturing by toner transfer method, testing, polishing and later placing an order for the final version in China.

Based on peculiarities of the electronics used we decided to divide the electronics unit into three parts: motor drivers circuit, microprocessor control unit (MCU) and power supply board.

When developing the motor drivers circuit (Picture 13) we were guided by the parameters of our propulsors (48V, 2A). Maximum output of a single one is equal to 100Wt, while the aggregated output is 600Wt. That’s why we faced a not simple task – to develop a circuit capable of controlling all the motors. For that we chose L6205PD microchips, capable of controlling two brush motors of up to 5A maximum current.

For the purpose of communication, data acquisition and processing we decided to use MSU microcontroller Atmega 2560 as it is much favored by programmers.

For comfort work of the pilot we developed power supply board, featuring galvanic isolation of power supply to protect cameras and sensors from noise signals.

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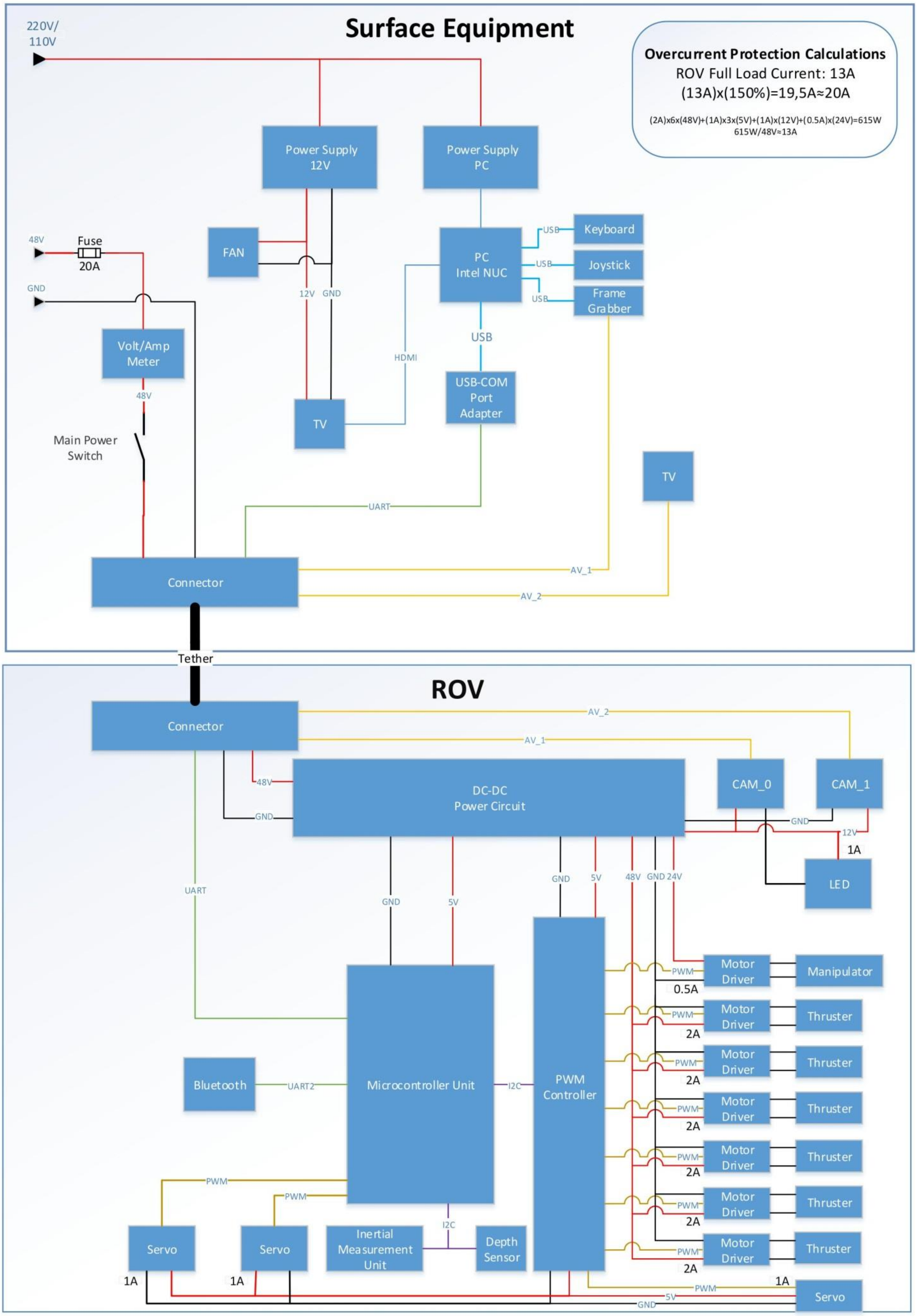
2.8. SID



Picture 14. System Interconnection Diagram

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2.9. Sensors

Having analysed tasks the vehicle has to complete we decided that ROV needs accuracy and ease in control. In our case accuracy means robot stabilization in space. To provide stabilization the vehicle needs current position information, namely: course, list, trim, and depth.

2.9.1. Depth sensor

This item is a high-resolution depth sensor which is sealed to protect the electronics unit from water.

The module is based on a specialized microchip MS5803-14Ba, that can measure pressure up to 14 bar, data exchange is done by Protocol I2C (TWI). With pressure of 0.2millibar the sensor has a resolution of 0.002m.

We made casing of the depth sensor of ABS plastics using a 3D-printer.

Picture 15. Depth sensor

2.9.2. IMU

To obtain vehicle rotation information we make use of inertial measurement unit DFRobot 10 DOF Mems IMU Sensor with 10 degrees of freedom.

The card incorporates the following sensors:

- ADXL345 - accelerometer
- ITG3200 - gyro
- HMC5883 - magnetometer
- BMP085 – pressure transducer

This unit was selected due to its accuracy in measurements compared to its analogs in the same price tier, small size, and also availability of large quantities of study materials on each sensor. Having gaged and tested the card we came to a final conclusion that the accuracy of its measuring satisfies all of our requirements.

Picture 16. IMU

The sensors are based on MEMS technology, they combine both electronic and mechanical components. The basic principle of their operation is a condenser one. The moving part of the system is a weight on suspenders. In case if there is acceleration, the condenser plate that is fixed to the weight shifts against the plate on the fixed part. Capacity changes, with unchanged charge voltage is changing – this change can be measured and weight shift calculated. Then knowing the weight and parameters of the suspend it is easy to find the corresponding acceleration.

2.10. Tether

To have the underwater vehicle connected with the surface our company decided to make a tether of its own from a twisted pair and two power cables, drawn through a silicon hose for protection from mechanical damage and provision of water tightness. Twisted pair is used for transmitting control and video signal, power cables supply power to the underwater vehicle and its attachments.

Picture 17. Tether

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When choosing power cable section we used the following formula:

$S = \frac{2 * \rho * I * l}{U_2 - U_1}$, where S is desired cable cross-section;

ρ – specific resistance;
I – load current;
l – line length;
U_2 – voltage output by the power source;
U_1 – voltage at which the equipment works;

The whole procedure of drawing wires through the hose was carried out as follows:

- Align all the wires;
- Pull shrinks over them for purpose of fixing;
- Pull a wire through the cable;
- Tie wire with twisted pair and power cables and apply mineral jelly for better wire passing;
- Pull the wire through the cable.

2.11. Surface equipment

Surface equipment is a set of devices to control ROV. For space saving and aesthetic appearance it was decided to combine all the necessary components for ROV piloting in one casing – control box. The control box contains:

- Power unit for monitor power supply of 12V
- Controlling computer
- Screen
- Loudspeakers

Saitek Cyborg F.L.Y. 5 Flight Stick joystick was a good choice to control ROV as the number of degrees of freedom in it equals with that of the vehicle. There are also additional buttons for controlling other components (e.g. rotate cameras, flashlight, etc.).

Picture 18. Surface equipment

Built in control box monitor shows the state of vehicle and picture from one of the cameras. Pictures from additional cameras are output to the TV set.

To have the vehicle energized we need power supply of 48V, which as per requirements is located outside the control box.

It receives power of 110V AC (for computer power supply and for converter into 12V DC (for monitor)) and 48V DC which is then supplied directly to the vehicle.

2.12. Software

2.12.1. Remote control software

To control the underwater vehicle we developed an operator’s control on Qt 5.7. The choice of the given framework was determined by availability of a wide range of widgets to create a graphic interface.

The control displays a close-up image received from the front camera, as for most of the time the pilot has to work with it. Besides, a system of notifications on the state of communications and leakage to be shown in the upper part of the image, is provided.

The main work for the remote-control software is to control the robot with a joystick. The control developed makes it possible to send an order packet on board the underwater vehicle. Joystick is processed with library SDL.

One of the tasks is working with Bluetooth. Because of that the interface is added up with components, allowing to set values of corresponding fields in order packets to switch the flashlight on/off and to commence a Bluetooth mark reading.

The control also has a timer developed for training purposes. Moreover there is a debug functionality:

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– Scanning I2C gadgets, showing states;
– Motor adjustment;
– PID coefficients changing, showing stabilization schedules.
– Showing current sensor readings.

2.12.2. Survey map making software

To complete a task means not only to control a robot, but also to do calculations pertaining to map making. Therefore the remote-control provides functions of the kind to the second pilot.

It is necessary to calculate the distance from the most hazardous container to three others. Besides, knowing information about pool line pointing north, one should determine the location of less hazardous containers in relation to the hazardous one. To implement calculations an interface built-in the remote-control was developed.

To calculate distances between containers we stated the following functional requirements:

– Image saving from the vehicle front camera.
– Identifying the ratio of an image pixel number to a unit of length, using a reference object which size is known in advance.
– Highlighting containers and their centers. The first highlighted center is the center of the least hazardous container.
– Automatic calculation of distances between the center of the most hazardous container and centers of the rest, using the ratio calculated.

To calculate directions of less hazardous containers with respect to the most hazardous one several functional requirements were made:

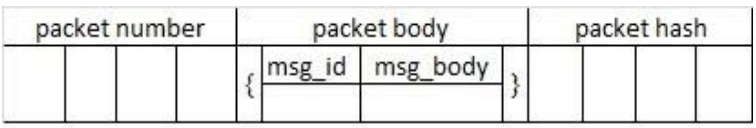
– Highlighting pool line in the image.
– Possibility to show angle of the pool line deflection from the line, from 0° to 180°.
– Rotating all the objects (containers) at a calculated angle to obtain an image where the northern side is located at the top side.
– Automatic identification of each container location.

2.12.3. Firmware

A possibility of monitoring the whole hardware of the robot (namely, propulsors, manipulator movements, reading and filtering sensor readings) is carried out with the help of MCU - Atmega 2560 and software, that was written with the help of Microsoft visual Studio in language C++.

The main objective of firmware update is the vehicle control. To have the control simplified we decided to implement stabilization of course, trim and depth which is carried out by means of regulators. As a regulator we decided to use a PID regulator as it is the simplest in implementation and easy to adjust. Regulator operation is defined through a current orientation of the vehicle in space.

Not a single sensor can supply full information on robot position. It is only when we combine readings from all the sensors that we can obtain an unambiguous orientation of the robot in space. We decided to combine readings from sensors with the help of Madgwick filter as it is the most cutting-edge and fastest algorithm to solve the given task. To facilitate firmware debugging a wi-fi module was used to considerably ease the work with Arduino, as the necessity for autopilot disassembly is eliminated.



Picture 19. Sending packets structure

Out of plentiful methods for data transmission the following were selected: Ethernet, UART, RS232, for the reason of their commonness. Nevertheless there are several requirements to the data transmission: speed, implementation simplicity, noise-protection and range of data transmission.

Due to some problems (our mistakes) when developing electronics we turned to be unable to use Ethernet. The simplest variant not involving electronic components substitution is the use of UART. In the course of trials we found out that when the data are transmitted over UART the noise didn't affect the vehicle operation, as only about 3-7 packets per 1 minute of continuous transmission at a speed of 50 packets per second.

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In the course of operation there may be disturbances in the channel, completely broken connection and microcontroller reboot. That's why it was necessary to develop a protocol for data transmission accounting all the instances mentioned above.

The protocol for data transmission between the user's and built-in software is based on protocol SLIP and takes into consideration a possibility of losing data packets, their distortion, and possible MCU reboot. Apart from this it provides for an opportunity to monitor the number of of packets lost thus allowing for making conclusions on the reliability of the channel for data transmission.

Each packet consists of a packet number, certain amount of messages transmitted and a packet hash. Each message has its unique id, that has been defined in advance, and body – the information transmitted. The message id allows us to identify what type information the message contains. The packet hash allows for checking the packet for intactness.

3. Safety

Following philosophy «Safety comes first», we took all measures to provide safeness when handling equipment. Every team-member is aware of the fact that rules are made not for some third party sake, but firstly for his / her own health.

When making the underwater vehicle we stuck to MATE safety requirements:

- Warning notices;
- Protection grids placed on thruster blades;
- All soldered wires insulated;
- Edges rounded and curved;
- Casing made of non-conductive material and polyethylene sheets;
- Thruster blades brightly colored;
- Underwater vehicle consumes current not more than 25A.

Upon manufacturing of the underwater robot it's necessary to test the vehicle in a pool. In this connection it should undergo preparations as follows:

Safety checklist	
Checks prior to starting	
Fuse check	
Tether check	
Securings check	
Current and voltage check	
Pressure transducer check	
Camera check	
Thruster and manipulator check	
Checks during operation	
Pressure transducer monitoring	
Current and voltage monitoring	
Checks after finishing	
Check for mechanical damage	
Tether check	
Check of thrusters and propellers for intactness	

Table 2. Safety checklist

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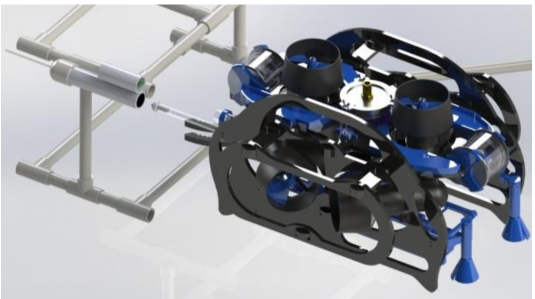


Pictures 20-22. PortROVer testing in SolidWorks

4. Testing and troubleshooting

Before using the vehicle it had to be tested. Testing was done in several stages.

First, vehicle and tools were tested in SolidWorks using models of props supplied to us by MATE. In computer environment we could estimate whether particular solutions would fit for completing the tasks or not.

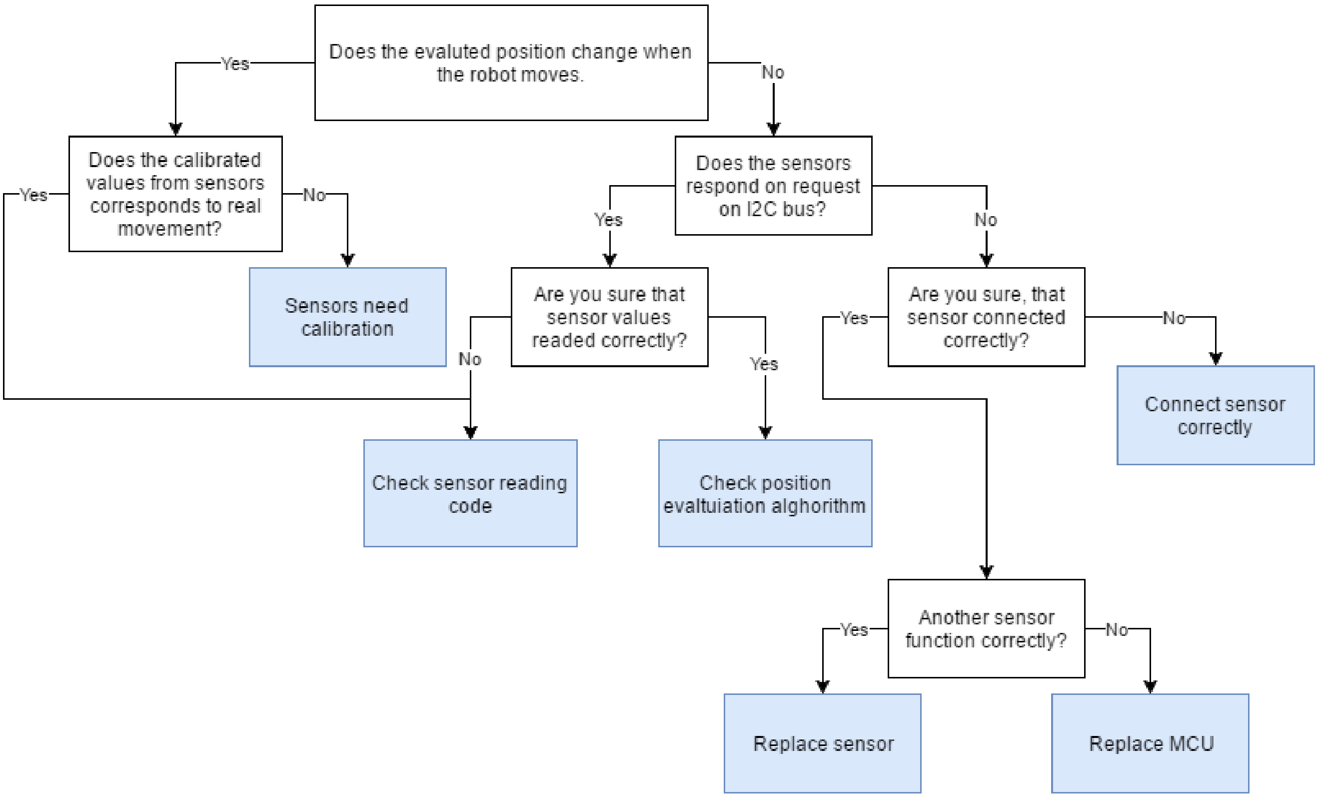
Having made sure that tools satisfied our requirements we manufactured them and started testing them separately for water tightness, strength, possibility of task completion, as sometimes it is impossible to identify whether the tool would work in real life or not.

Having tested all components separately we assembled them and tested the whole ROV.

In case of troubles it is at first we have to locate a possible cause for the trouble occurrence. Then, a list of software and firmware components that could be connected with the trouble is made.

Further, through an experiment we're trying to exclude as many possible causes as possible. We test each of the components beginning with firmware ones and ending with software ones.

For instance, in case of troubles with defining the robot orientation in space, we act as per the following algorithm:



Picture 23. Troubleshooting algorithm

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5. Challenges

5.1. Technical challenges

This year we set ourselves a goal to build propulsors of our own with magnetic coupling, as we wished to make our vehicle with as few purchased components as possible we decided to make them on our own. There is also another reason for refusal to buy propulsors: there are no thruster manufacturers within our region, while buying from abroad is impossible for political reasons.

We defined requirements to our thrusters: they must suit our vehicle in terms of size, styling design, and thrust needed. We designed them in SolidWorks and we had to take into consideration many factors: how to install a motor, as brush motors have no fastenings of their own we had to secure at protruding components of pin insulation. To raise effeiciency we had to calculate the propeller angle of attack and to distribute optimum number and size of magnets for the thruster magnetic coupling. When assembling we encountered some problems. Our motor securing turned to be not reliable enough and we had to additionally secure it with CA glue. But we have overcome all the hardships and have been able to assemble thrusters of our own, having spent over 500 men-hours for their designing and manufacturing.

5.2. Non-technical challenges

All the vehicle development period was accompanied by continuous discussions on what it should look like and what tools it should have to pass through the mission best

There also were some difficulties in interpersonal relations in the team. Most of our team are newcomers, who had not even know each other before their first meeting for the project. Everyone possesses a unique character and way of communicating, and our leader’s responsibility was to coordinate our activities in such a manner that the work process went smoothly and efficiently. By trial and error our Captain succeeded in finding right approach to everybody and arrange it so that our work process wouldn’t lag behind the planned schedule.

Also this year we had difficulties with purchasing electronics components as due to low real cost of our currency (ruble) it was very expensive to buy these from abroad. Furthermore there were no compatibles of the class in our country at reasonable prices, so we decided to buy these from China’s online market place TaoBao featuring rather low prices and wide range of products.

6. Lessons learned

6.1. Technical

We wanted to create a firmware update to be used in the competitions to come, sparing minimum effort. For the purpose an architecture was developed that would allow for easy change of tasks to be performed by the robot.

In the course of implementation and testing a problem was elicited correction of which would have taken too much time, therefore we arrived at the decision to simplify the architecture so that it could solve specific tasks only. This one is much simpler in implementation and more stable in operation.

Thus we were driven to a conclusion that it makes no sense to extremely generalize the software architecture that we should focus on specific tasks set, moreover under the pressure of strict time limits.

6.2. Non-technical

During the robot development a lot of problems of varying character were arising. If you don’t know the solution to the task set to you, you can turn to your teammates. Their ideas might help you find the solution.

Sound simple enough, but in real life situations we are often prevented by something from applying for others’ help. That something can be fear to look silly, pride, or some other cause. Anyway thanks to common deed and right attitudes in the team we managed to learn this lesson in practice. Now we are not afraid of looking silly when asking someone for help.

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7. Accounting

Title	Unit of Measure	Qty.	Amount $	Total $	New/ Donated
ROV Construction					
Waterjet Cutting	-	1	201,75	201,75	Purchased
Turning And Milling	-	1	184,21	184,21	Purchased
Sheet Polyethylene	Pcs.	1	210,53	210,53	Purchased
Aluminum Bar	Kg	1,4	7,37	10,32	Purchased
Fasteners	-	1	37,72	37,72	Purchased
Acrylic Pipe	Meters	1	17,54	17,54	Purchased
PLA Plastic and Work on 3D Printer	Kg	1	228,07	228,07	Donated
Surface Equipment					
Case	Pcs.	1	55,74	55,74	Donated
Power Supply	Pcs.	1	15,28	15,28	Purchased
Display	Pcs.	1	48,16	48,16	Purchased
Board for Display	Pcs.	1	14,04	14,04	Purchased
Nettop	Pcs.	1	350,70	350,70	Donated
Relay	Pcs.	1	6,75	6,75	Purchased
Voltmeter/Ammeter	Pcs.	1	4,19	4,19	Purchased
Board Video Capture	Pcs.	1	56,14	56,14	Purchased
Connector MATE	Pcs.	1	56,14	56,14	Purchased
Thruster					
Driver Motors	Pcs.	6	4,39	26,32	Purchased
Engine	Pcs.	6	7,02	42,11	Purchased
Plastic Casting	Liters	4	33,33	133,33	Purchased
Tether					
Silicone Hose	Meters	20	4,12	82,46	Purchased
Power Cables	Meters	15	1,75	26,32	Purchased
Ethernet	Meters	15	1,75	26,32	Purchased
Videosystem					
Analog Camera	Pcs.	2	22,81	45,61	Purchased
Servomotor	Pcs.	1	6,93	6,93	Purchased
Payload Tools					
Manipulator	Pcs.	1	1 151,75	1 151,75	Discount (602,63$)
Depth Sensor	Pcs.	1	8,54	8,54	Purchased
Servomotor	Pcs.	1	8,00	8,00	Purchased
Electronics Module					
Connectors	Pcs.	12	0,88	10,53	Purchased
Navigation Sensor	Pcs.	1	27,47	27,47	Purchased
Microcontroller	Pcs.	1	7,61	7,61	Purchased
Additional Electronics	-	1	41,75	41,75	Purchased
Custom Boards	Pcs.	3	10	30	Purchased
			Total ROV Cost	3 172,33	
Travel Expenses					
Hotel	Rooms*Days	3*6	90,00	1 620,00	Purchased
Air Tickets	Persons	8	1 580,00	12 640,00	Purchased
Time Mentors Spending					
Mentors	Hours	180	16,70	3 006,00	Donated
			Total Project Cost	20 438,33	

Table 3. Budget

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Phone: +7 (924) 335-44-25, e-mail: toshic.konstantinov@gmail.com

In the course of designing we analysed all the necessary components and elicited the ones meeting our demand and the price / quality ratio, and we made up a list of purchases. Some components we had to refuse because of a long delivery time or high price.

We tried to do as much work by ourselves as possible, having refused services from other companies. We ground out some elements of the design on a lathe and milling machine. Also we used 3D-printers as supplied by the Center for Robotics Development, thus saving financial resources.

Financial resources were channeled to us by the Center for Robotics Development. We accounted for every purchased item to the Center management. We kept strict documentation – all expenses were put down into Google tables.

The total price for the components for the vehicle is $3172.

We also calculated the time our mentors spent on us in terms of money. 3 hours a week during 8 months (September 2016 – April 2017) that is about 96hrs. 4 hours a day for 21 days in May 2017 – that is 84hrs. Totally 180hrs. If we multiply by average salary (in Russia) of professionals of the level as our mentors are at, i.e. about USD16.7 per hour that would approximately make USD3,00 per each mentor. In other words our mentors contributed USD6,000 as a money equivalent of their time into our project.

8. Future improvements

Our team would like to learn how to use cloud storage coupled with CAD systems for more prompt and effective designing, as this would facilitate the process of model exchange and of ROV design discussion without a need to arrange for meetings.

Also it wouldn't be a bad idea to use optic fibre as the basis for the tether connecting ROV with control console. Using optic fiber would make tether lighter and lengthen it with no deterioration of communication quality.

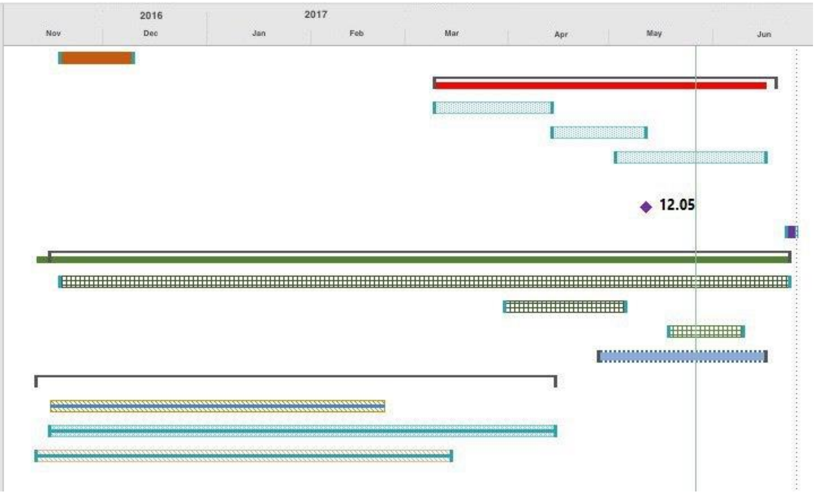
We'd love to improve our skills in operating turn-milling machine to minimize the need to resort to companies offering such services. Thus not to be dependent on tradesmen's pressure of work. And this skill of ours would be reflected in the quality of the item made.

As to the software we'd like to build-up stabilization in horizontal plane judging by pictures received from cameras.

9. Teamwork

Our company consists of 8 staff of varied technical and communication skill level. Many members of our team participated in competitions before, so continuous exchange of experience played an important part. To have our work done efficiently we divided into three work groups: designers-constructors, programmers, electronics engineers. Each group chose its head in charge of their work and monitoring the progress with task performance, and we also developed Gantt chart, with which the Captain monitored the deadline meeting.

Name	Start	Finish
Production of models	Fr 18.11.16	Fr 09.12.16
Testing+Debugging	Fr 10.03.17	Mo 19.06.17
Tests	Fr 10.03.17	Th 13.04.17
Debugging	Fr 14.04.17	Th 11.05.17
Training in the pool	We 03.05.17	Fr 16.06.17
Events	We 15.11.16	Su 25.06.17
Regional competitions	Fr 12.05.17	Fr 12.05.17
International competitions	Fr 23.06.17	Su 25.06.17
Work with documents	We 15.11.16	Fr 23.06.17
Reading the forum	Fr 18.11.16	Fr 23.06.17
Technical documentation	Fr 31.03.17	Fr 05.05.17
Poster	Fr 19.05.17	Fr 09.06.17
Presentation	Fr 28.04.17	Fr 16.06.17
ROV	Fr 11.11.16	Fr 14.04.17
Build	We 15.11.16	We 22.02.17
Electronics	We 15.11.16	Fr 14.04.17
Software	Fr 11.11.16	We 14.03.17



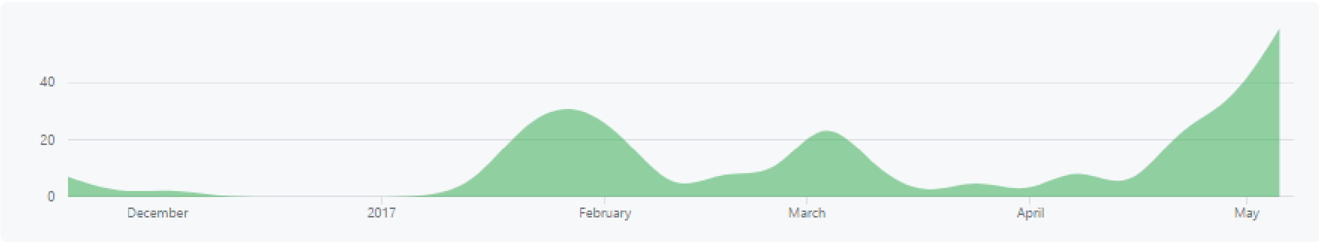
Picture 24. Gantt chart

Programmers, in turn, were divided into two sub-groups. The first sub-group was engaged in control console development, the second one was engaged with developing software for the robot.

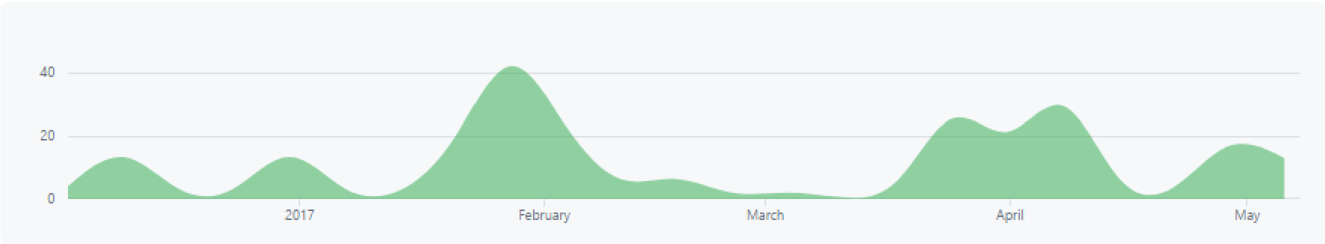
To remotely allocate tasks among the members, and also monitor progress of their fulfillment we integrated our Gantt chart into the web-application for project control “TRELLO”. For communication outside Center for Robotics Development we created conferences in the Internet. We regularly discussed our activities in Skype. Every Wednesday we met as a team in Center for Robotics Development to discuss the passed week progress.

When developing software programmers used the system of versions’ monitoing git and a remote repository within system github, where robocenter-rov organization was established with several repositories: firmware update, protocol library, control console.

To have technical documentation written we used Google Docs, as the program allows for simultaneous editing and viewing one and the same document.



Picture 25. Firmware commit graph



Picture 26. Software commit graph

10. Acknowledgements

We would like to first of all express our gratitude to Center for Robotics Development and especially to our mentors: Angelina Borovskaia and Sergey Mun for their assistance and facilitation in preparations for competitions and precious contribution into our team. Time and effort you spent are really invaluable. Despite your plentiful commitments, you have always found time to give us a useful piece of advice.

We are thankful to Andrei Kushnerik for his consultancy in developing thrusters.

Special thanks to Dmitry Alekseev for financial support and for his general caring attitude to robotics development in Primorye and in Russia as a whole.

We would like to say ‘thank you’ to MATE Center for a possibility to participate in these competitions.

We are grateful to the Admiral Nevelskoy Maritime State University for the swimming pool they provided for training sessions.

11. References

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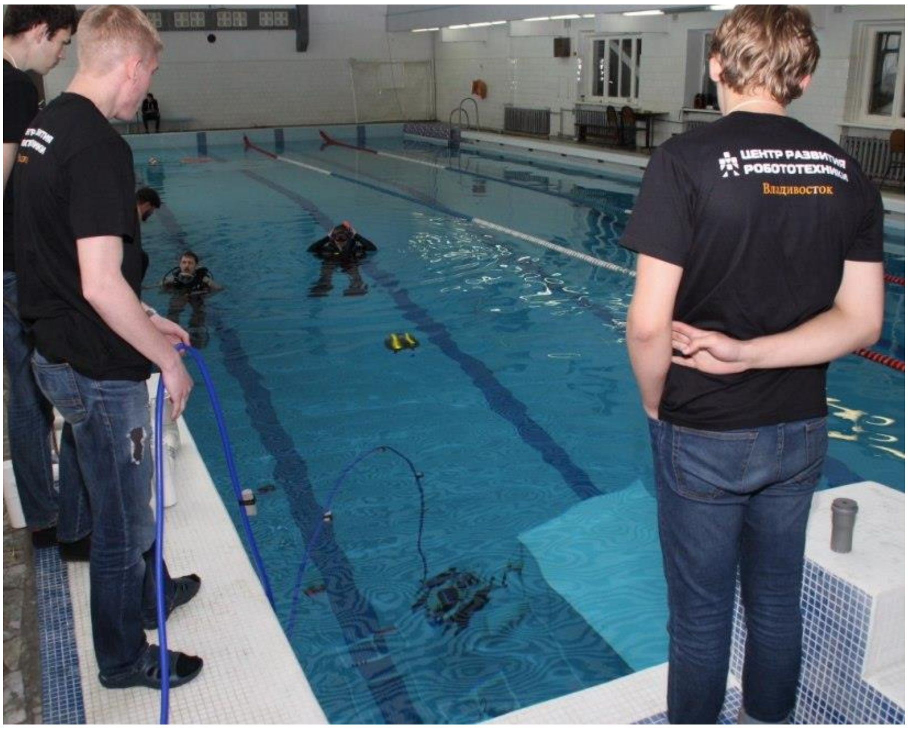
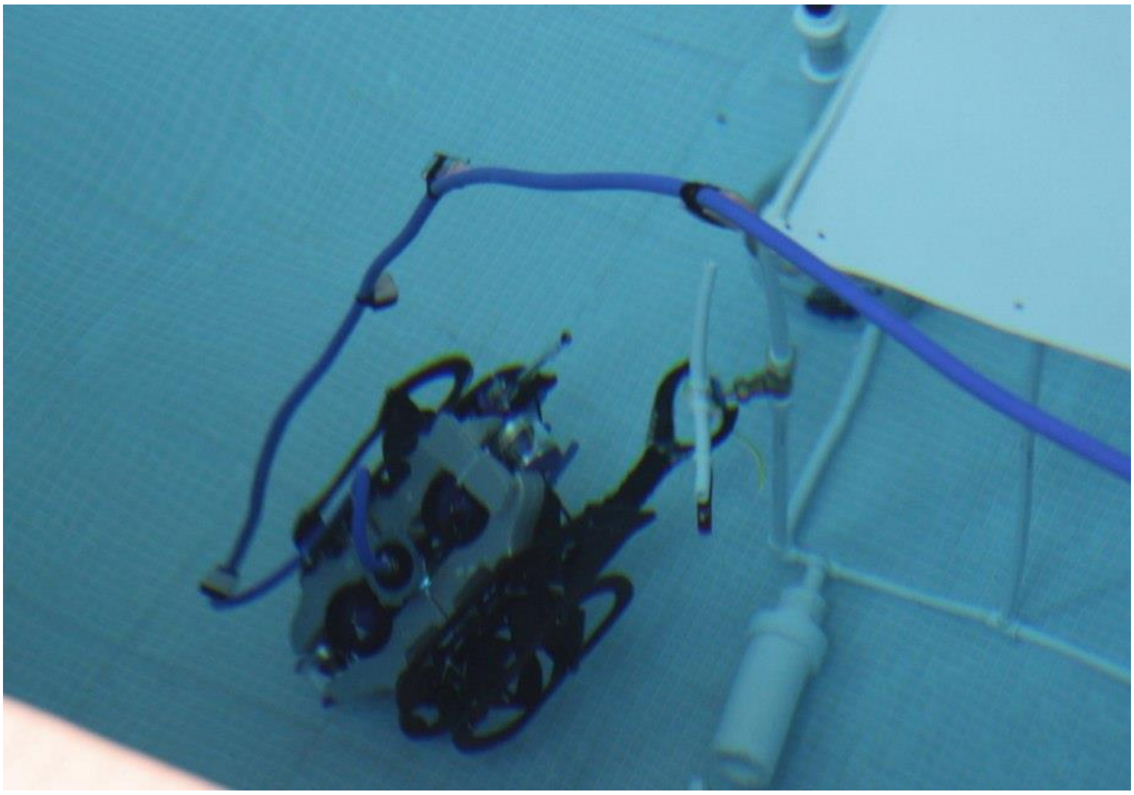
Phone: +7 (924) 335-44-25, e-mail: toshic.konstantinov@gmail.com

12. Appendices

Appendix A. Testing of ROV





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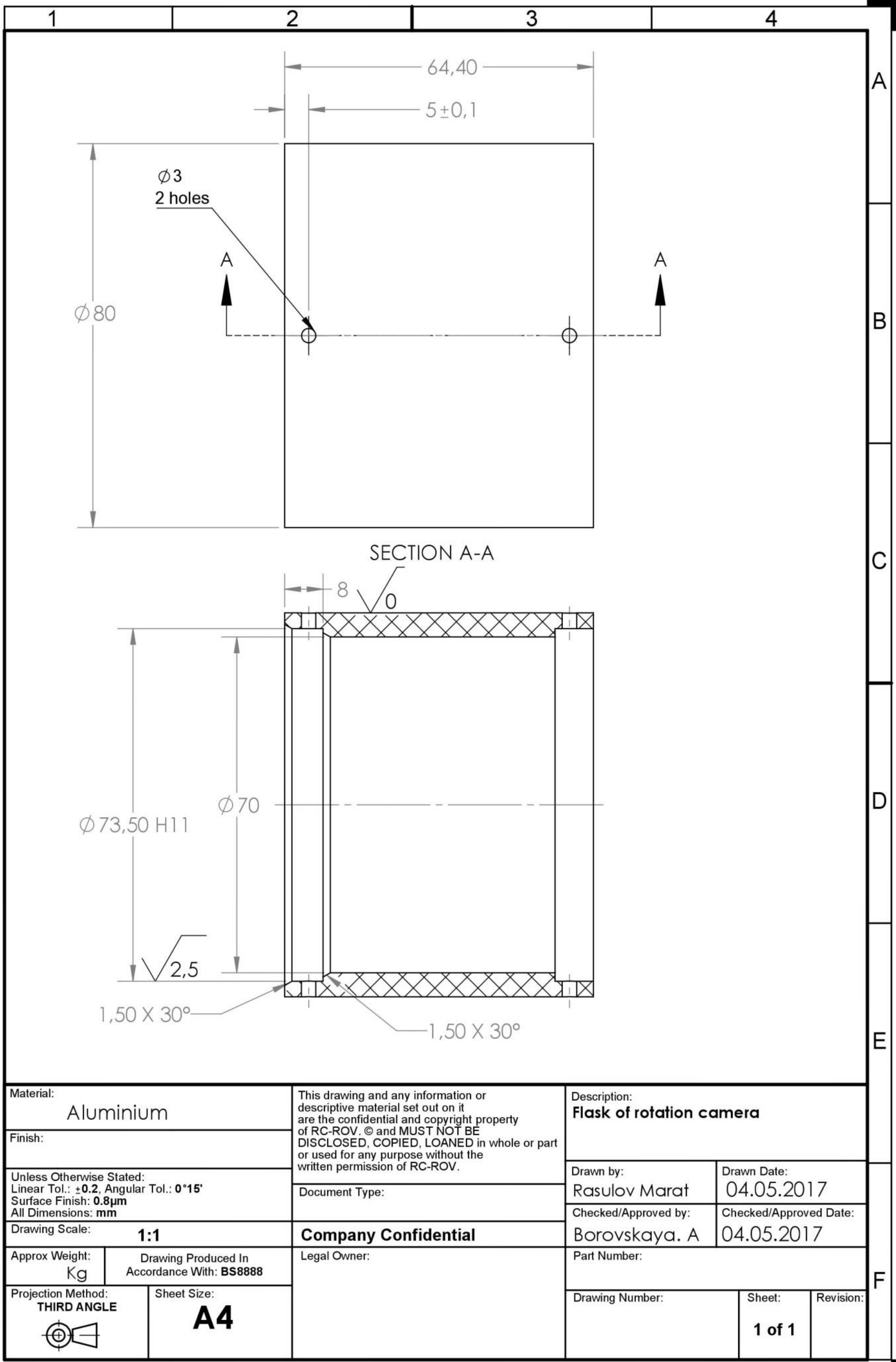
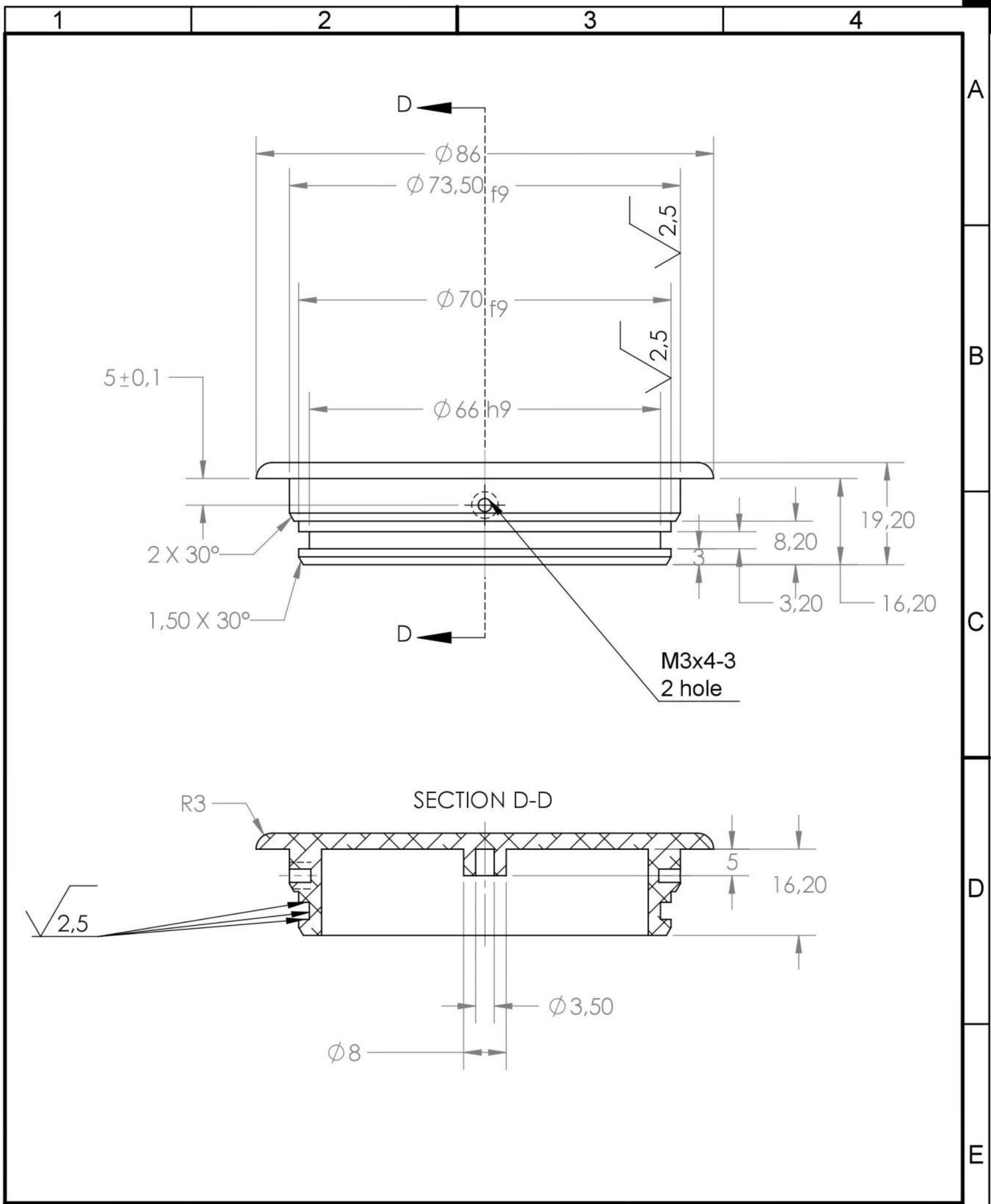
Appendix B. Flask of rotation camera



Appendix C. Cover of rotation camera



Material: Aluminium	This drawing and any information or descriptive material set out on it are the confidential and copyright property of RC-ROV. © and MUST NOT BE DISCLOSED, COPIED, LOANED in whole or part or used for any purpose without the written permission of RC-ROV.	Description: **The cover of the rotation camera**	
Finish:		Drawn by: Rasulov Marat	Drawn Date: 04.05.2017
Unless Otherwise Stated: Linear Tol.: ±**0.2**, Angular Tol.: **0°15'** Surface Finish: **0.8µm** All Dimensions: **mm**	Document Type:	Checked/Approved by: Borovskaya. A	Checked/Approved Date: 04.05.2017
Drawing Scale: **1:1**	**Company Confidential**		
Approx Weight: Kg / Drawing Produced In Accordance With: **BS8888**	Legal Owner:	Part Number:	
Projection Method: **THIRD ANGLE** / Sheet Size: **A4**		Drawing Number:	Sheet: **1 of 1** / Revision:

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