MATRYOSHKA

TECHNICAL REPORT - 2019

company Robocenter

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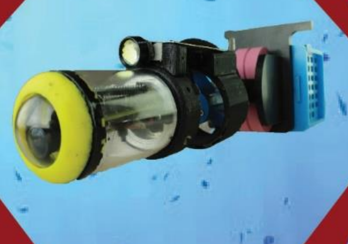

ROV MATRYOSHKA

RANGER CLASS

THE CENTER FOR ROBOTICS DEVELOPMENT

Vladivostok, Russia

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1. ABSTRACT

Our company Robocenter will take part in MATE ROV competition for the fifth time. Our company consists of 12 prospective students from The Center for Robotics Development. There were 5 programmers, 4 design engineers and 3 electronics engineers among them. The team had a task to build a ROV that could perform the following tasks for the MATE ROV competition:

- Inspection and repair of the dam
- Cleaning of water reservoirs
- Protection of history

Matryoshka is a vehicle that was created for the most effective completion of these tasks. Matryoshka shares its name with a famous traditional Russian doll. We chose this name because there is a Micro-ROV inside of the main ROV and the original toy is a small doll inside of a bigger one. Moreover, this title represents the culture of our title

The vehicle is equipped with two cameras, a manipulator and three sensors: temperature, IMU, depth. Also, on the vehicle there are many mission specific features designed by our employees. We tried to make the vehicle as small and light as possible to meet the needs of a potential customer. This was our main concern when we were choosing the material. We ended up using 10mm polyethylene sheet because it is a light and durable material.

Figure 1. Team photo (Photo by Semen Zinkov)
Members from left to right:
First row: Petr Podstavkin, Polina Ibragimova, Igor Balaganskii,
Second row: Viktor Tsoi, Dmitry Khoroshilov, Aleksandr Zagorulko, Vitalii Shevchenko, Valerii Khrolenko Ivan Sukhanov
The last row: Mikhail Duchinskii, Platon Pryazhennikov, Andrei Mudrov.

2. TEAMWORK

2.1. Company Efforts

From the beginning of the year our company's employees met every week to discuss unsolved problems, brainstorm and tell others what they had done. Another purpose of those meetings was establishing new tasks and exchanging ideas. To be competent enough to do it in September every employee was given the task of exploring modern ROVs that are used for repair, maintaining waterways or recovering items. There were a lot of different ideas and we based our decisions on the popularity of different ROVs. To get that information we used statistics of customer reviews and the number of people who had bought them.

Figure 2. Photo of the Matryoshka-ROV

To communicate quickly and efficiently we used a group chat in WhatsApp messenger. We used it to organize emergency meetings, exchange documents, convey important announcements or solve different kinds of problems.

2.2. Project Management

While working on the project, we used the online project management system named Trello to track the work of each team member. All the participants regularly marked the completed tasks, and team leaders were able to monitor the progress of the team and its members at any time.

The roles were distributed as follows:

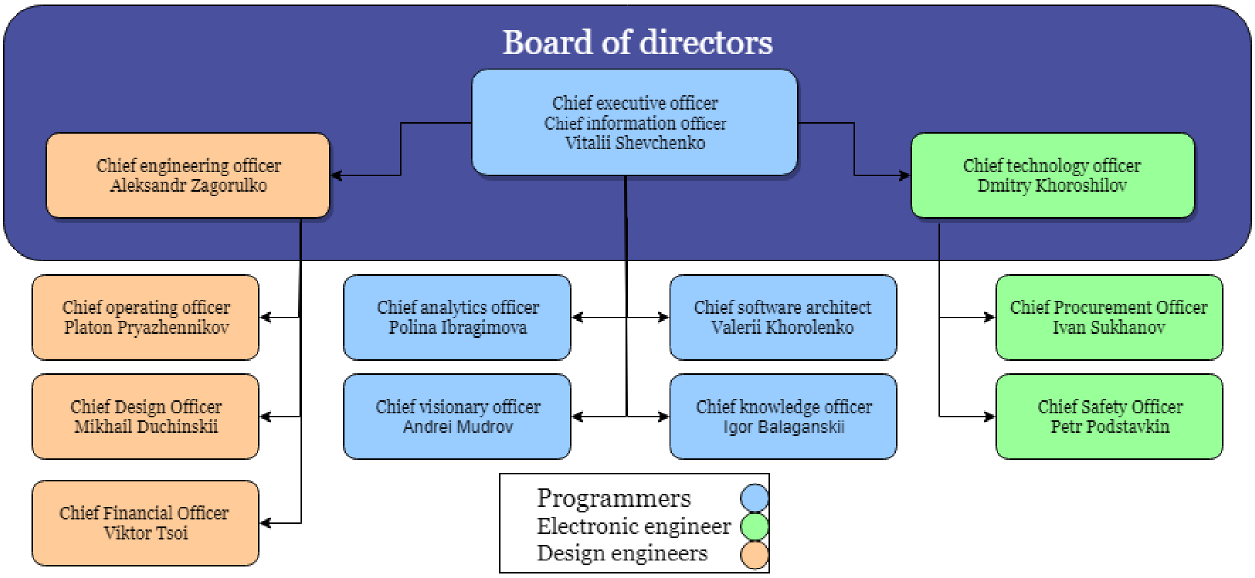

Figure 3. Project team structure

While writing the technical report we had all the parts on Google Drive, so that every member of the team can access them easily. Initially, all parts of the report were distributed among all the employees of the company, then the text was edited and assembled into a complete document. To make the work easier and save time we have created an organization on GitHub (https://github.com/Robocenter-MATE2019). All parts of code written by different people were gathered there, and then combined into a single software. GitHub allowed us to monitor any changes in the code, share our work and in case of emergency, it was easy to recover the code.

This year designers were given a lot of tasks, some of them were quite complex, but thanks to the competent organization and a clear distribution of tasks, most of them were solved in time. This made it possible to make the frame and the mission specific features long before the deadline just like we planned

To manage our work, we used the principles of project management and the Gantt chart (Chart1), which allowed us to control and observe the implementation of tasks and to monitor the whole project.

TASK	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Robotics training	■	■						
Studying the competition regulations			■	■				
Structural design			■	■				
Usage model				■				
Frame				■	■	■		
On-board software				■	■	■		
Surface software				■	■	■		
Electronic unit					■	■		
Control box					■	■		
Cameras					■	■		
Mission Specific					■	■		
SID					■	■		
Assembling					■	■	■	
Testing in the Pool							■	■
Technical documentation							■	■
Preparing for presentation								■
Regional Competition								■
Training for the international Competition								■

Chart 1. Gantt chart for the project

3. DESIGN RATIONALE

3.1. USAGE MODEL

Our ROV usage model is necessary to project it, figure out how it will act, what functions it will perform and what devices are necessary for them. We brainstormed a perfect allocation of our payload for completing missions, in the second chart you can see the result.

ENSURING PUBLIC SAFETY: DAM INSPECTION AND REPAIR		MAINTAINING HEALTHY WATERWAYS		PRESERVING HISTORY	
Following a transect line	Video System, Propulsion system	Measuring the water temperature	Temperature sensor	Calculate the volume of the cannon	Measuring software
Counting the number of cracks	Video System	Collecting a water sample from the bottom	Manipulator	Determining the composition (specific gravity) of the cannon	Video system
Determining the length of the longest crack	Video System , Measuring software	Measure the pH and the phosphate levels of the water sample	Measurement kit provided	Calculating the weight of the cannon in water	Measuring software
Inserting grout into voids underneath the dam	Device for pouring grout	Lifting a rock from the bottom	Manipulator	Returning the cannon to the surface, side of the pool – 2	Propulsion system. Lift bag.

Inspecting and repairing a trash rack	Manipulator	Determining habitat diversity	Shape recognition software	Identifying and marking the location of metal cannon shells/non-metal debris	A metal detector, Mechanical Fish Transporter
Identifying areas of muddy water flow inside the pipe	Micro-ROV video system	Transporting and releasing trout fry	Mechanical Fish Transporter		
		Removing a degraded rubber tire –	Manipulator		
		Installing a new reef ball	Manipulator		

Table 1. Usage model Matryoshka

3.2. Frame And Buoyancy

At the beginning of the year, we identified several criteria that the frame must meet. All projections of the ROV must fit into a circle with a diameter of 600 mm to obtain the maximum points for the size.

The material from which the frame is made must be durable and lightweight so that the assembled vehicle does not exceed 12 kg and we can get the maximum number of points for weight. The frame design should be modern, thoughtful, every detail should be useful. One of the main tasks in the design of the frame was the effective use of space. As a result, it turned out to be 450 mm long, 365 mm wide and 320 mm high. The frame consists of two main plates, two side plates and several fasteners.

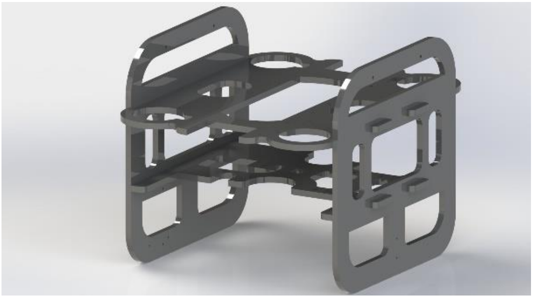

Figure 4. Render of the Matryoshka-ROV frame

Thanks to the special cuts on the side plates and the special shape of the horizontal plates, the frame is assembled as a construction set, and does not require additional fastening. Cutouts for propulsion, buoyancy and cameras are provided on the top plate. On the sides there are wavy cutouts that make holding the vehicle easy, so that the device is easy to carry. On all the plates of the frame there are cutouts to reduce water resistance. Also, there are no sharp corners on the frame, in order to minimize the risk of injury to users of the vehicle. The electronics unit and the camera are on the top plate. On the bottom plate there are Mission Specific Features and Micro-ROV - a smaller robot that is used to perform tasks.

The frame is made of 10 mm polyethylene, because it is a durable and lightweight material and it has a density of 980 kg/m3. Our frame was completely designed in SolidWorks CAD. This allowed us to test some parts of the vehicle without creating a physical model. When the design met the criteria, we carved the frame out of the polyethylene on a CNC milling machine and assembled the frame.

3.3. Sealing

As the main priority of our company is safety, we paid special attention to sealing the vehicle. This was done not only to avoid accidents, but also in order to save time and money, because if water touches the wires, they will stop working

We paid very close attention to sealing the electronic unit. We made grooves in the lids for the rubber bands that do not allow any water to enter.

We purchased thrusters, and therefore we were confident that they were waterproof. However, just in case we checked them. Motors for payload are in plastic cases. There are micro holes in the parts printed on the 3D printer, which could lead to leakage. We solved this problem by sealing the 3d printed parts. All devices passed the test in the pressure chamber. To connect motors and other devices to the electronic unit, located in a sealed flask, we used cable penetrators. The wires connecting the main unit to the Micro-ROV are protected by a cable penetrator, and the wire leading to the motor is sealed.

After sealing, we checked for the possible leaks. To do this we lowered the vehicle into the pool and increased the pressure inside the body of the electronic unit, placing it in the pressure chamber. No water got inside.

3.4. Propulsion

Thruster system is one of the main systems of the vehicle. Thrusters consist of brushless motors with nominal voltage of 12 V and speed of 5600 rpm. They are equipped with a speed controller. The propellers were tested in our laboratory and showed the following results: in a direct course with a consumption of 7.8 A thrust is 1 kg, and on the reverse thrust amounted to 0.86 kg with a current consumption of 7.7 A. The thruster weights just 0.2 kg. For all the engines, we have made protective covers to comply with the MATE safety rules.

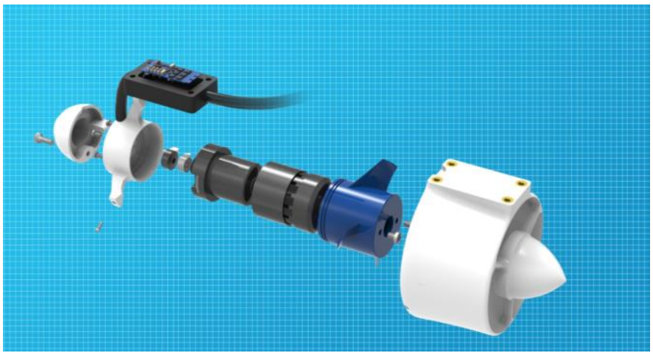

Figure 5. 3D model of the thruster

The vehicle has 8 thrusters, four of which are horizontal and turned at an angle of 45 degrees in order to move at the same speed (forward, back, left, right). If they were installed at a 90 degrees angle, then we would need more thrusters to achieve the same maneuverability. Other 4 thrusters allow us to move the vehicle up and down. Last year our team had 2 of those, however our decision to change that made the ROV more stable and easier to control.

3.5. Video System

The video system in the ROV plays a very important role, because it gives the pilot an overview of what is happening underwater and the objects during the missions. At the beginning of the year we decided to use 2 cameras, the images from which are displayed on the TV and pilots' laptops. T optimal number of cameras and their location are important aspects of the design of ROV because the right choice allows us to keep the weight and the cost of the vehicle low. At the same time there should be enough cameras so that it will be easy for the pilot to control the ROV.

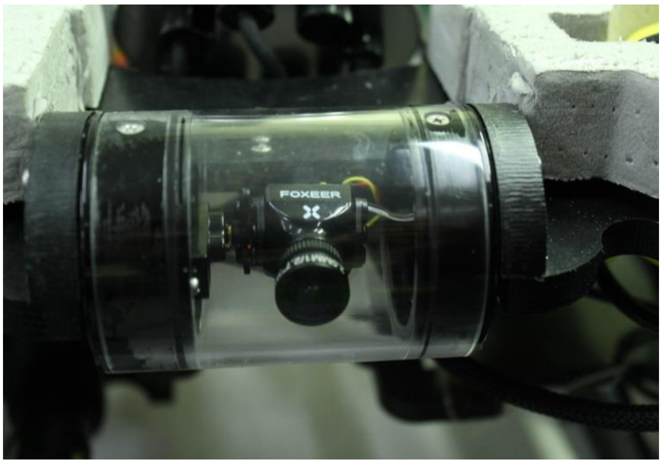

Figure 6. ROV'S Camera

We use Foxeer 16: 9 1200TVL Monster V3 (Monster Pro) Standard FPV camera because it is easy to connect.

The front camera helps to navigate, and it can show the manipulator. It can be rotated vertically 180 degrees by the servomotor to increase the pilot's field of vision.

The second camera provides an overview of the space under the vehicle and helps the pilot use the payload effectively.

Also, when the rear camera is used, the controls of the joystick become inverted, and it is easier to control the vehicle.

3.6. ELECTRONIC UNIT

The Electronic Unit allows us to manage all the mission specific features. It contains 5 circuit boards: Arduino Mega 2560, Custom Shield, Ethernet Shield, a contact printed circuit board and an additional printed circuit board for controlling the engines of the payload and sensors. All of these components are housed in an airtight aluminum cylindrical housing.

Arduino Mega 2560

This microcontroller allows us to manage ROV systems, process data and establish communication with the laptop. We chose the Arduino Mega, as it is powerful enough for our ROV and easy to use and program. We bought a ready-made board since the development of the board takes a lot of time and independent production is much more expensive than the purchase.

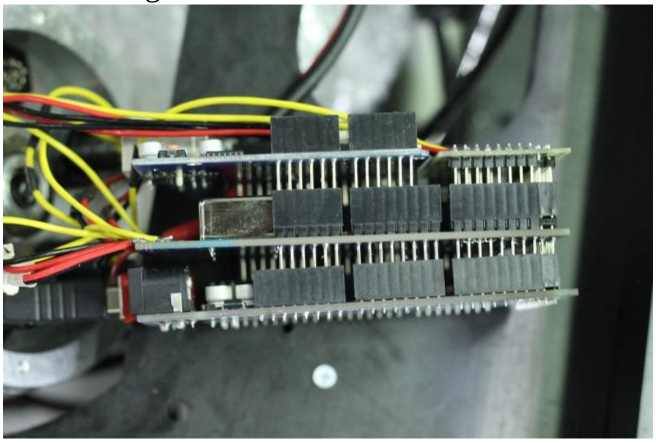

Figure 7. Circuit Boards

Custom shield

A microcontroller installed on an Arduino cannot directly control a large load. We developed Custom Shield, which serves as a motor driver and voltage converter from 12V to 5V and 3.3V. It also has an IMU. We have decided to create our own board, because there are no products that satisfy our needs.

Ethernet Shield

We use standard Ethernet Shield for Arduino, which makes it possible to transfer data from surface equipment and manage the vehicle's systems.

Contact board

The cable and all the wires from the ROV enter the unit through two covers so that it is possible to disconnect the electronic unit parts from each other without damage. Power wires enter through one of the covers and connect to the board. On the other side of the board, tether from cameras and payload is connected to the board. We also designed this board ourselves, because we did not find suitable options in the marketplace.

Additional board for controlling payload motors and sensors

We have developed an additional board, which serves to control two additional vertical propellers, depth, temperature sensors, a metal detector and an electromagnet for the Micro-ROV. Also, this board is used to control the Automatic Tether Reeler.

3.7. SOFTWARE

3.7.1. TOPSIDE SOFTWARE

Our control system consists of several parts.

1. Main computer, which exchanges data between ROV and surface equipment.

2. Second laptop to complete recognition and measuring missions.

3. Arduino Microcontroller which exchanges data with the main computer and controls motors and mission specific features. Also, it receives data from the sensors.

Main software was written in C# because this language allows us to easily use OOP patterns and multithreading. In addition, C# has huge number of libraries and a development environment that is easy to work with. Program structure was built using MVC pattern. The program was divided into classes, which are responsible for specific modules (Connection, Receiving data from the microcontroller, video, etc).

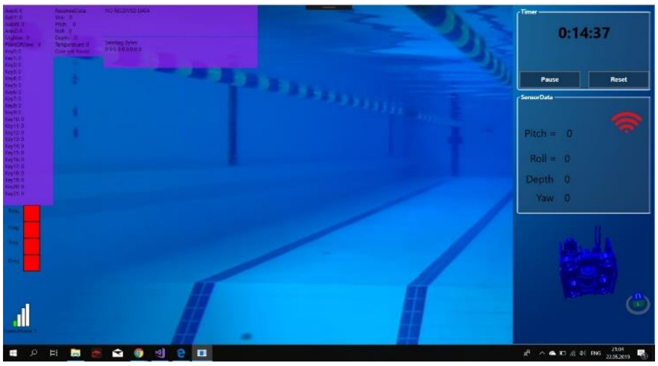

Figure 8. A screenshot of the main program

The program processes signals from the joystick (T.Flight Hotas, which has enough buttons and axes to control all the functions of our ROV) and forms a data packet, which is sent every 100 milliseconds through to the microcontroller using UDP. Our company implemented multithreading. We did that to make sure we can increase computational load on the program without any problems with the graphical interface.

3.7.2. ON-BOARD SOFTWARE

To control the vehicle, we used the ATmega2560 controller. It is programmed by the C ++ language and that is why we chose it.

The on-board software was developed in Visual Studio 2017 with the VisualMicro plugin installed. We abandoned programming in the usual Arduino IDE development environment because of its impracticality. It lacks the possibility of auto-substitution and the complexity of working with multi-file projects is much higher.

From the very beginning of development, we pursued a goal – write fast, easy-to-edit software that allows you to add or remove devices without any problems.

For convenience and fast navigation, each element of the program and each device has developed its own library. This allowed you to quickly fix errors without getting lost in hundreds of lines of code. Creating software, we used object-oriented programming. This allowed us to simplify and optimize the code as much as possible.

All our devices were divided into 3 types: “Input”, “Output” and “InputOutput” (ap.1). This allowed us to create an architecture based on polymorphism, thanks to which we can work with devices as an abstract type. This architecture allowed us to add or remove devices without affecting the rest of the program.

3.7.3. MISSION SPECIFIC SOFTWARE

Measuring software consists of:

- program, which calculates a distance depending on known sizes of another object;
- program, which calculates necessary values depending on preset parameters.
- recognition and black figures (benthic species) counting program.

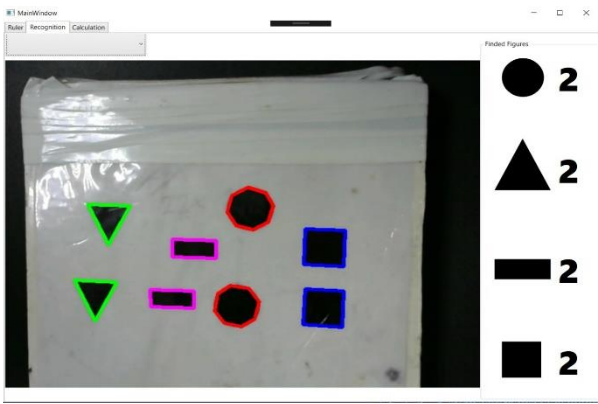

Figure 9. A screenshot of the shape recognition software

We need to determine the longest line in the “Dam inspection and repair” task and calculate weight of the cannon from “Preserving history” task before lifting it. To complete this task, we need know radiuses from which the cannon consists and their length.

Our company decided to perform these tasks with the special program and a ruler fixed on the ROV to determine necessary sizes relative to this ruler.

For the accurate calculation program needs a camera without any image deformations and object which sizes we know (ruler fixed on the ROV).

Measuring software was written on C# language in Visual Studio.

Stages of working with measuring software:

- Make photos of objects which sizes we want to know
- Choose necessary photo from previously made and open measuring window with the right click on it.
- Highlight object side which size we want to measure in opened window.
- Highlight object side which we know and enter its size. Thus, we find out its length in pixels
- The program calculates length of highlighted segments in pixels and creates proportion, thus we determine length of the highlighted line

In the third task companies need to determine weight of the cannon. To do it pilot needs to enter cannon sizes and density of the material from which it was made. The program calculates cannon volume (V = PI * cannon length * (larger radius square * less radius square / 3 - chamber radius square)) and cannon weight (m = cannon volume * material density).

In the second task companies need to recognize and count benthic species, we use geometric shapes recognition program for this task. For accurate recognition all benthic species need to be in cameras field of vision. The Program automatically recognizes and counts amount of different benthic species.

The actions above allow our company to complete missions with a high accuracy and get maximum points.

3.8. Tether

In our ROV there are two major tethers: main and additional. Each of them should have the following properties: lightness, flexibility, durability, neutral buoyancy. To give these characteristics to the tether, employees of our company tied the wires together, avoiding the interlacing of wires, then wrapped them in plastic braided cable sleeve, which gives flexibility and strength. Then they attached pieces of buoyant material along the main cable in order to achieve neutral buoyancy.

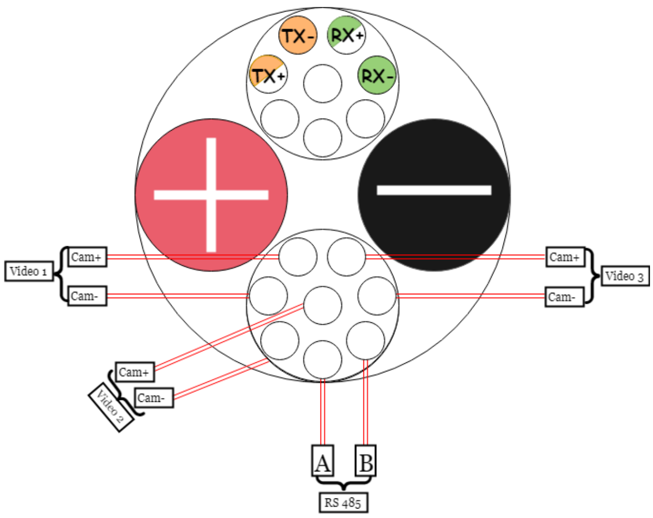

Figure 10. Diagram of the main tether

The main tether connects the vehicle to the control panel on the surface. Its length is 20 meters. It consists of two wires and two 12 AWG power wires, and inside of each of them there are 4 twisted pairs. These twisted pairs are used as follows:

1. 2 twisted pairs for communication with the main ROV.
2. 3 twisted pairs for the camera.
3. 1 twisted for communication with micro-ROV.
4. 2 tethers of 12 AWG power the ROV.

The additional tether connects the Micro-ROV to the main ROV. Its length is 5 m. It consists of two power wires and one wire, and each of them includes 4-twisted pairs. They are used as follows: one pair is responsible for communication with the ROV, and one for the video signal. Employees of our company have specially designed a reeler for an additional tether. We didn't attach a buoyant material to Micro-ROV tether because it would prevent the reeling of the tether.

3.9. Surface equipment

On the surface, the tether is connected to Control panel. It consists of:

- Router
- Voltammeter
- Video output for Monitor

To control the ROV we use ThrustMaster T Flight Hotas X joystick, as it has a sufficient number of degrees of freedom, and also has additional buttons for controlling PTZ cameras and payloads. The joystick is connected to the control panel via USB.

Also, through the control panel power is supplied to the ROV, for which purpose the console is equipped with a 220V AC to 12V converter.

Figure 11. Surface Equipment

Power Supply

Used to supply 12V power to the unit.

Power supply monitor

Serves to power the monitor.

Monitor

Displays an image from a camera.

3.10. Mission Specific Features

3.10.1. Manipulator

This device represents a mechanical claw which is used to move objects. Claw can grab and release, it can also rotate. This device is controlled by two motors. Due to the high price of the manipulator, and the fact that it was easy to fix the one that we used last year from ROV Builder company we decided to use it. During manipulator exploitation last year, it broke but our company was able to fix it. However, the main reason why we decided not to purchase a new manipulator was that the employees of our company were confident in their skills and wanted to show them with a difficult process of repairing. If we did not use the manipulator, we would have to make other devices which would take more place and be not so effective. Even though technically all tasks could be completed by one manipulator, but it would be very time-consuming. Much more efficient was to construct additional devices of payload for determined tasks.

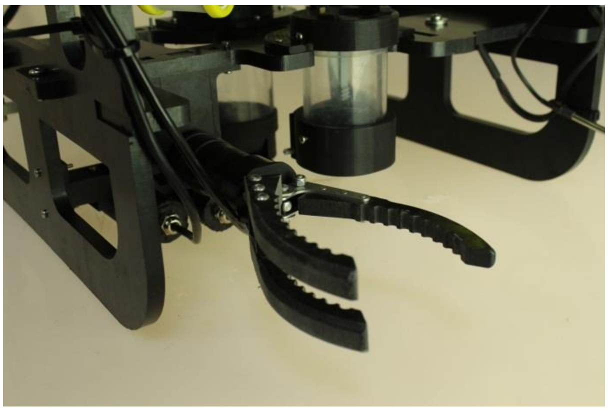

Figure 12. Manipulator

3.10.2. Marker Extractor

Our vehicle can distinguish between shells and debris, but they also need to be noted markers of different colors. For this, our company has developed device for dumping out markers. The device consists of a motor, a screw (a rod with a solid screw surface along the longitudinal axis), as well as a casing, four screws and two rubber gaskets. The form of the device is cylindrical, and it is made of plastic. The vehicle uses two copies of this device - one for red markers and the other for black ones. Some of the parts were purchased, but not all of them met the requirements of the company in terms of functions and dimensions, so the auger and housing were printed on a 3D printer.

The working mechanism was assembled at the second attempt. In the first version there were several flaws that led to the leaking of the hull. Nevertheless, they were immediately corrected by the designers of our team.

The principle of operation of this device is as follows: in a hermetic hull there is a motor, the rotation of the shaft of which drives the screw on which the marker is suspended. When the auger rotates, the markers are reset to the desired zone, which is the task. The device was fully assembled and designed by team members for the most effective implementation of this mission, as well as for maximum user convenience.

Figure 13. 3D model of the Marker Extractor

3.10.3. Mechanical Grout Inserter

We had to make a device that could “pour grout” into the crack we need. We decided to make such a device, which will be based on mechanical properties and does not require supply power. We managed to make it compact. Its principle of operation is based on the fact that when we find a crack where we need to pour grout, we press down on the pump with the weight of the vehicle, the sash of the vehicle opens, the grout “flows out”, and we complete the task without any problems. The sizes and shapes of the valves were changed from the original version, a more practical design was created. We also created the final method of holding the valves together, for which magnets were chosen. As a result, we got a very effective device.

Figure 14. Mechanical Grout Inserter

3.10.4. Mechanical Fish Trout Transporter

Mechanical Fish Trout Transporter

This device is used to restore the habitat of fish by placing fish trout there. It is also intended for their transportation. This device consists of a body in which fish are stored. The hatch at the bottom of the body keeps them from falling out.

We wanted to make a completely mechanical device that could drop fish whenever we wanted. We gathered our team to discuss how the device should work.

We created a first prototype and tried to figure out how the device will look and work. In this version, we made it with flaps that were supposed to open when we ROV touched the bottom of the pool

The second prototype was a lot better in all the aspects. In this version, the device has been completely remodeled, considering all previous shortcomings.

Now the lever at the bottom of the device sets the flaps in motion and the fish falls out of the container, which is the point of the task. Most of the components were printed on 3D printer. However, there is also an unusual component that consists only of Lego parts. The reason why we decided to make it was the fragility of 3D printed parts

To sum up, the device works like this. We lower the ROV to the bottom of the pool. Under the weight of the vehicle, the lever is pressed, and the hatch opens, throwing the fish into the right place. This device works mechanically, and it does not use any energy supply. This has allowed us to save time during production, because we did not have to hermetically seal this device. Also, the energy consumption has decreased, because you do not have to use additional motors.

Figure 15. Mechanical Fish Trout Transporter

3.10.5. Micro - ROV

Micro ROV is connected to the main vehicle with a tether. But the tether is quite long, this causes the risk of tearing or entanglement of cable. That is why our team has developed a convenient tether reeler and container for tether.

That device has the following functions: winding of the tether and pulling micro ROV out from the pipe. There were no automatic analogues of this device, that’s why we decided to create it ourselves.

It consists of two makeshift rollers which are casted from silicone rubber, plates holding them, a motor and cable storage. The rollers are made of silicone rubber, and the form for their cast was printed on a 3D printer.

Figure 16. Micro-ROV

For optimal speeds of pulling the cable in and out, our company has experimented with the diameter of the rollers. We made two experimental models, but they did not satisfy our expectations. Initially, high hopes were pinned on the winder with only one roller, but after creating prototypes, it was decided to use a two-roller system, because it was more efficient.

3.10.6. Metal Detector

The third task, called “Preserving History”, is a combination of several subtasks and one of them is marking metal shells and non-metallic debris with markers of different colors. To accomplish this task, our company designed a metal detector. The device can detect metal objects at about 3 cm with an accuracy of 0.5 cm.

Initially, the team made the trial model itself, but it was not sensitive enough, so we decided to buy a ready-made one. They do not sell many metal detectors online, but we chose the most suitable option. However, it did not suit us in several ways. First, the board was not sealed and it would break. This problem was solved by placing the board in a sealed case. Second problem was that the board started working when the button was pressed. Accidental pressing of the button could lead to the termination of work. We fixed it by getting rid of the button. The modified board version was efficient enough to complete the task.

Our metal detector works on the principle of OR (Off Resonance), that is, the simplest method: placement a metal object into the electromagnetic field of a metal detector causes vortex currents in the metal, because the metal produces its own field, which causes the change of metal detector inductance. The MDS-60 board captures these changes and the transistors change the voltage of the electric current so that when there is no metal, the voltage getting low, and when there is metal, the voltage reaches the maximum value (5V).

Figure 17. Metal Detector

3.10.7. Automatic Tether Reeler

Micro-ROV is connected to the main vehicle with a tether. But the tether is quite long, this causes the risk of tearing or entanglement of cable. That is why our team has developed a convenient tether reeler and container for tether.

That device has next functions: winding of the tether and pulling micro-ROV out from the pipe. There were no finished automatic analogues of this device, that’s why we decided to create it ourselves.

Figure 18. Automatic Tether Reeler with the Micro-ROV

It consists of two makeshift rollers which are casted from silicone, plates holding them, a motor and cable storage. The rollers are made of silicone, and the form for their cast was printed on a 3D printer.

For optimal speeds of picking up and throwing out cable, our company has experimented with the diameter of the rollers. We made two experimental models, but they did not satisfy our expectations. Initially, high hopes were pinned on the winder with only one roller, but after creating prototypes, it was decided to use a two-roller system, because it was more efficient.

3.11. Sensors

3.11.1. Temperature Sensor

The sensor we have chosen to measure the temperature is DS18B20. We chose it because of the speed and accuracy of the measurements. Moreover, this sensor was used in the MATE demo video.

Figure 19. Temperature Sensor

Software for this digital sensor was taken from open official source on the GitHub and modified for our needs. On average, this sensor can take the most accurate measurements in 2 minutes with different initial temperature of more than 60 degrees Celsius.

3.11.2. Depth Sensor

This sensor was developed by SparkFun to measure temperature and depth. However, we only use it to measure pressure, because we use another more efficient sensor to measure temperature. The temperature sensor uses the I2C interface, the software for it, was also

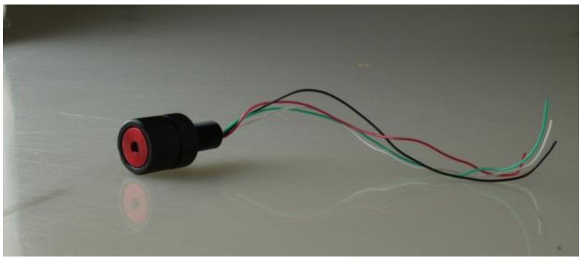

Figure 20. Depth Sensor

taken from an open official source on GitHub. This sensor we use to measure the depth of immersion of the robot.

3.11.3. IMU

We used the sensor model HI21X, developed by HiPNUC. This sensor is used to show the position of the vehicle using the three angles of Euler. The device works using the built-in gyroscope, accelerometer, and microcontroller that filters the data from the sensors and calculates the angles of the vehicle in three axes.

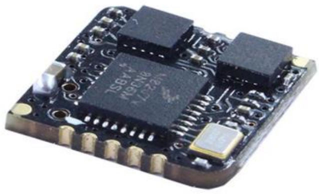

Figure 21. IMU

The sensor returns data using a special protocol, based on this protocol, we developed a software, with the help of which we get information about vehicle angles in space.

4. SAFETY

4.1. Safety Philosophy

One of the priorities of our company is to ensure the safety of both our employees and the staff. Therefore, all our employees follow a strict set of safety rules in the workshop and at the pool. Each team also applies security protocols to ensure the safety of personnel, equipment and the environment.

First, we try to ensure the safety of our employees when they work with dangerous tools. To do this, we made several rules that all members of the company should follow. To begin with, all members of our company must be instructed in the safe use of tools and wear clothing that is suitable for work: goggles, work gown and gloves. Also, when painting or when working with caustic, melting substances are used respirators. A prerequisite for working with any tools is the presence of a mentor.

We designed our ROV to minimize the possibility of an accident. All parts that can potentially be dangerous are marked with warning labels. The frame has no sharp corners and it is designed in such a way that the person serving it could safely and comfortably do it. Propellers are equipped with protective grills to prevent debris and other bodies from getting into the propeller. Also, our vehicle has many different fuses to protect us from high currents.

4.2. Protocols and Checklists

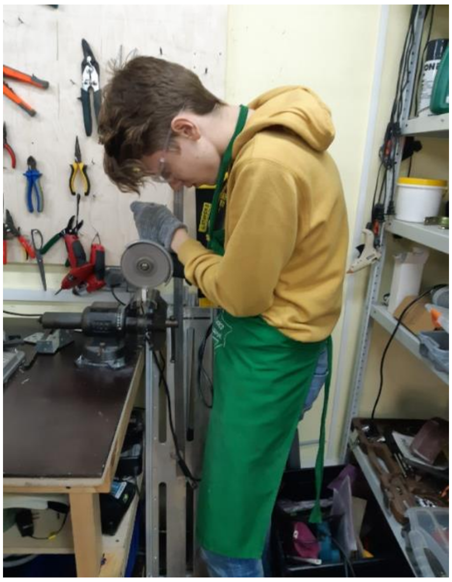

Figure 22. Our COO is working wearing proper equipment

Safety protocol

Our employees should always:

- Wear close toed shoes to protect the feet if a heavy object is dropped
- Wear safety equipment (glasses, apron, gloves) and have long hair tied back while working with dangerous machines
- Be careful while working
- Our employees should never:
- Start working without having proper training first
- Use dangerous machines or equipment if they feel sleepy
- Use equipment without mentors' permission
- Run in the workroom or get distracted

IN CASE OF EMERGENCY

Electrical Shock

- Switch off the power supply
- If it is not possible to use non conducting objects such as a broom or a chair to get the victim away from the electricity
- Check for the person's response and breathing when it is safe to touch the person
- Treat the injuries with the first aid kit if the victim's breathing is steady
- Call the ambulance
- Tell the mentors

LIGHT PHYSICAL INJURY

- Check the severity
- Call the mentors
- Help with the first aid

DROWNING

- Take the person out of the water
- Check if the person is breathing
- Call for help

CHECK LIST

Monitoring during the missions	√
Monitoring detectors of leak	
Monitoring information from detectors	
Monitoring current and voltage levels	
If a problem arises, you must disconnect the device from the power supply and remove it from the water.	

Checking after the mission (out of water)	√
Checking for mechanical damage	
Checking all connectors	
Checking cables	
Integrity test of the motors	

Checking before running	√
Fuse checking	
Checking all connectors and cables	
Fastening checking	
Checking current and voltage levels	
Checking detectors of leak	
Checking detectors on the ROV	
Checking the display of video from cameras	
Checking motors and manipulator	
Checking out of water	

Check before the mission (in the water)	√
Checking detectors leak	
Checking detector of depth	
Checking the display of video from cameras	
Checking the operation of motors	
If a problem arises, you must disconnect the device from the power supply and remove it from the water.	

5. TESTING

5.1. TROUBLESHOOTING

Testing is the main stage in the development of any complex technical vehicle. At this stage, many problems are identified that require immediate correction. That is why we took this stage very seriously.

The vehicle was debugged in 4 stages: debugging the code, testing individual devices, testing the vehicle the surface, testing the vehicle in water.

The first stage included the development of libraries for all devices of the vehicle. After the libraries were created, testing of devices and searching for defects in the code began. As soon as all devices were tested, we proceeded to the next stage.

The second is the longest stage. At this stage, all devices connected to the microcontroller and tested . Some devices conflicted with each other, and so we had to remake the boards or change the libraries.

The third stage is to connect all devices to the vehicle to test them on the surface. We connect all payload devices and sensors to the vehicle and try to ensure that the device works.

At the fourth stage, we repeat the procedures of the previous stage, fully assemble the device and test it in water. This stage is closest to the actual conditions in which the ROV will be used. At this stage, a lot of problems arise, because the vehicle that often works perfectly on land often does not work in water.

During testing, we encountered many problems. After connecting all the devices, the connection between the PC and the vehicle stopped working. We spent a lot of time looking for the causes of this problem. Initially, we thought that the problem was in the cable, so we re-soldered it. However, after re-soldering, the connection did not improve, and after checking with a multimeter and an oscilloscope, we completely excluded this version. We decided to check the code, but there were also no problems identified. Then we began to think that the problem was the lack of power supply, as we tested with propellers, but turning them off also did not solve the problem. Thus, there are only two reasons why the communication did not work: a microcontroller or an Ethernet shield. Replacing the microcontroller, did not fix the problem. This year we decided to use a Russian-made Ethernet shield based on the W5500 chip, but for some reason it broke at the last moment, and we installed the last year's Ethernet shield based on the W5100 chip. This solved the problem and we completed the testing of the device.

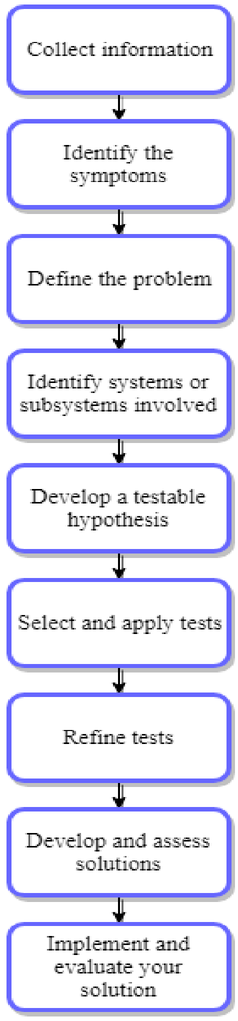

Figure 23. Our Troubleshooting protocol

5.2. PROTOTYPING

Our task was to build a device that should pour concrete into the glass. The team decided to discuss how the device will look and how it will work. After discussing the design, we were faced with our first problem. We had to decide how the valves (mechanical opening doors) would open. We had 2 ideas. The first was to open the valves with the help of servos. And the second was simpler, it was based on mechanics, namely, the lever pressed on the valves and they opened. From this point on we started to design and construct it. There were 3 prototypes.

Figure 24a) First prototype of Mechanical Grout Inserter

1st prototype

Like most devices, this device was printed on a 3D printer. Its task was to determine how the valves will look and work. We did not care about the sizes in this version.

2nd prototype

It already looked much more decent and we could already experiment with it. In this version, we decided to help the pilots and invented a nozzle to increase accuracy for them in order to simplify the process of putting the device on the glass.

Figure 24b) Second prototype of Mechanical Grout Inserter

Creating multiple prototypes and testing them helped us create the ROV that could complete all the tasks efficiently. Furthermore, we learnt how not to give up and how to learn on our own mistakes.

6. CHALLENGES

6.1. Technical

The process of creating the vehicle was not easy. We had such problems as a lack of knowledge since most of the team members were newcomers, and we had to learn "on the go."

The main challenge for programmers was trying to use more complex concepts, which was too difficult for most of the employees. For example, neural networks or software implementation of the PID controller. Many ideas had to be declined, because it was impossible to learn some complex techniques in such a short period of time. Even the most experienced programmer of the team could not avoid difficulties. This year, we decided to add a 3D model of the vehicle to the program. This was done in order to be able to understand the position of the vehicle in space, without resorting to digital data from sensors that are more difficult to understand. Although no one from the team has ever faced anything similar, we managed to tackle this task by joint efforts and long hours of hard work.

The main difficulty for design engineers was the necessary size of the vehicle. The most difficult was the development of the frame, as it was necessary to place a variety of payload devices in a small area. It was impossible to reduce their size and quantity, since otherwise we could not complete the task. This problem was solved when all 4 design engineers used brainstorming and exchange of ideas. Thus, the most successful position for each device was found, in which they did not interfere with each other's work and occupied the minimum amount of space.

The design of Micro-ROV also caused a lot of problems, the reason being the size limitations. The vehicle was supposed to fit into a six-inch pipe, but relatively large size of thrusters made it difficult. The design engineers had to leave only one thruster and abandon the original idea of using three. Fortunately, this did not interfere with the work of the vehicle. Even though many things were difficult for us, we handled most of them, but that was only possible thanks to the joint efforts of the whole team.

6.2. Non - technical

Our team now is a strong alliance, but we were not always like this. We used to have serious problems. Firstly, it was a problem with the organization of time. For a long time, we did not work together, and despite the weekly meetings and planning, there were problems with cooperation. Also, often there were conflicts between the team members.

One of the most serious problems was the inexperience of many team members. Since most of the participants were newcomers, they were not ready for a huge amount of work. The school performance of most of the team members began to decline, and many of them decided to devote less time to the team, and more to their studies and hobbies. However, we were able to solve this problem by really loving what we are doing and thus we no longer want to spend more time on entertainment. We learned to receive moral pleasure by working on the vehicle and began to get tired less.

Also, due to the persistent efforts of each team member and informal meetings we were able to rally. Every day our team became more and more friendly, and our activities became more and more organized, which eventually allowed us to create an excellent vehicle.

Figure 25. Company's employees working together to fix a problem

7. LESSONS LEARNED

Most of the tasks we faced while preparing for the MATE ROV competition were new to us and we had to learn how to solve them. Since within the team, we were divided into three groups: the design engineers, electrical engineers, and programmers, each team member learned something new. Thus, the designers learned how to 3D print, how to work with the Solidworks environment, machine tools. A very important task of sealing was assigned to designers, which they had to learn from scratch. Programmers, in turn, have mastered the methods of working with microcontrollers, studied C # and C ++, having analyzed such complex topics as using 3D models in a program and polymorphism. Electrical engineers also had to learn a lot, for example, some complex boards had to be created manually, and the creation of a control unit and cables required new skills from them.

From a non-technical point of view, MATE also demanded a lot from us. During the preparation for the competition, we had to learn such personal qualities as time management, and ability to support and help members in a team, in a situation when the work plan could suffer from inaction. We also gained experience in teamwork and project management.

8. FUTURE IMPROVEMENTS

Now our vehicle meets the key requirements, but despite this we have prepared several possible improvements:

- Replace copper wires with fiber optics to increase signal quality and eliminate noise.
- We also plan to make Micro-ROV more self-contained with the help of local power supplies.
- Use on Micro-ROV smaller motors to achieve greater maneuverability
- Change the frame to improve its hydrodynamic properties

9. FINANCE

9.1. Budget Planning

Budget planning is an essential part of work on any project. We responsibly approached this part of the project management, recorded all expenses in Google sheet, saved checks. One of the main tasks was the pursuit of the ideal price/quality ratio of the device.

During the work, the Center for the Development of Robotics sponsored our company.

At the beginning of the project, we made a budget table that displayed the approximate cost of the entire vehicle based on the market price of the items found on the Internet. This table was approved by the CEO of the Robocenter.

9.2. Budget

Capital of company				
Source				**Total**
The Center for Robotics Development				$20 000
Capital of company members (payment of mentors and visas)				$6 000
DNS sponsorship				$3 300
Costing				
Category	**Type**	**Category of expend**	**Assessed cost**	**Running balance**
Mission Specific Features	Reused	Manipulator	$1 150	$0
Electronic control unit	Reused	Body with a cover	$60	$0
Electronic Control Unit	Reused	Joystick	$100	$0
Video System	Reused	Monitor	$50	$0
ROV Frame	Purchased	Frame with fastening	$100	$100
Electronics	Purchased	5 main and 2 extra printed circuit boards	$200	$300
Video System	Purchased	2 Cameras, video capture card	$200	$500
Sealing	Purchased	Sealant, penetrators, cable gland, inlet seals	$100	$600
Sensors	Purchased	IMU, temperature, depth	$135	$735
Thruster System	Purchased	8 thrusters	$2 000	$2 735
Tether	Purchased	4 main and a lot of sides tethers	$150	$2 885
Work of Mentors	Purchased	To control our work teach us	$5 200	$8 085
Mission Specific Features	Purchased	Motors, electromagnet, metal detector, additional payload tools	$300	$8 385
Product demonstration notes	Purchased	They were used for trainings	$100	$8 485
Training in swimming pool	Purchased	Improving pilot skills	$350	$8 835
Visa	Purchased	Visa for traveling to the competition	$1 800	$10 635
Tickets	Purchased	Tickets for traveling to the competition	$15 000	$25 635
Hotel	Purchased	For accommodation for the period of the competition	$2 500	$28 135
		Total company budget	**$29 300**	
		Total cost	**$29 495**	
		Total spent except for donations	**$28 135**	
		A lack of capital	**- $1 165**	

Table 2. Project budget

The company's budget was initially quite large, and we had a clear picture of how we will distribute the funds. Most of the funds belonged to the company members, and they were spent on mentors, checking the work and giving new knowledge. The DNS company sponsored our company and gave money to buy materials and equipment. The Center for the Development of Robotics also provided a significant amount of funds for organizing training sessions and creating props for the competition. We knew the approximate amount of future expenses and understood that our company had more than enough funds. Our calculation was quite successful, after the completion of the project we didn’t need additional funds and the costs predicted by us differed only slightly. Since we have deviated minimally from the original plan, it can be concluded that the team correctly planned their expenses and reasonably used the available funds.

9.3. Project Costing

Date	Type	Category	Expence	Description	Sources/Notes	Amount	Running balance
10.10.2018	Reused	Mission Specific Features	Manipulator	For moving items	From the last year's ROV	$1 150	$0
10.10.2018	Reused	Autopilot	Body with a cover	Waterproof	From the last year's ROV	$60	$0
10.10.2018	Reused	Electronic Control Unit	Joystick	To control the ROV	From the last year's ROV	$100	$0
10.10.2018	Reused	Video System	Monitor	To show video from the cameras	From the last year's ROV	$50	$0
17.04.2018	Parts Donated	ROV Frame	Frame	Frame made out of Penoplex	By the employee of Center for Robotics Development	$100	$0
10.10.2018	Purchased	Work of Mentors	3 mentors	To control our work teach us	Employees of of Center for Robotics Development	$5 200	$5 200
15.10.2018	Purchased	Thruster System	8 thrusters	To control movments under the water	Replacing old worn out thrusters	$2 000	$7 200
23.10.2018	Purchased	Electronics	5 main printed circuit boards	20+50+10+20+30	Aditional printed circuit board, custom shield, ethernet shield, contact printed circuit board, Arduino Mega	$130	$7 330
23.10.2018	Purchased	Electronics	2 extra printed circuit boards	In case of one of malfunction	To be ready	$40	$7 370
03.11.2018	Purchased	Video System	2 Camers	Mini WDR FPV	with a body	$120	$7 490
03.11.2018	Purchased	Video System	Video capture card	Analog signal to Digital	We lost the one from last year's ROV and bought a new one	$90	$7 580
10.11.2018	Purchased	Tether	4 cabels	2 power cables,1 ethernet, 1 for the Micro-ROV	The one's from the last year's ROV were worn out	$120	$7 700
10.11.2018	Purchased	Tether	Wires	"female to male", "male to male", "female-femaler"	We bought a lot of them because they were often used	$15	$7 715
03.12.2018	Purchased	Sensors	Temperature	Shows the temperature	Last year's sensor was broken	$45	$7 760
03.12.2018	Purchased	Sensors	IMU	Shows specific force and angular rate	Helps the pilot navigate	$45	$7 805
03.12.2018	Purchased	Sensors	Depth	Shows the depth	Can show a temperature too, but in that regard it is not efficient	$45	$7 850
15.12.2018	Purchased	Mission Specific Features	3 motors	To control Mission Specific Features	Are used in Marker Extractor and Automatic Cable Reeler	$30	$7 880
21.01.2019	Purchased	Mission Specific Features	Electromagnet	Connecting Micro-ROV to the main ROV	Also helps to hold Micro-ROV in place	$10	$7 890
21.01.2019	Purchased	Mission Specific Features	Metaldetector	Distinguishes between the metal shells and nonmetal debris	The purchased version was much more efficient than the created one.	$100	$7 990
21.01.2019	Purchased	Mission Specific Features	Silicone rubber	For the manufacture of the cable reel	Making it cost less than buying one	$50	$8 040
21.01.2019	Purchased	Mission Specific Features	Magnets	For shutters of the concrete pouring device	Simple and efficient	$25	$8 065
21.01.2019	Purchased	Mission Specific Features	Liftbag	To lift heavy items	Because of the low price we bought extras	$6	$8 071
03.02.2019	Purchased	Sealing	Sealing	Sealant, penetrators, cable gland, inlet seals	All of those were purchased in large quantities, because we sealed a lot of parts of the vehicle	$60	$8 131
22.02.2019	Purchased	Electronic Control Unit	Case	Electronic components are inside	The old case was broken	$30	$8 161
22.02.2019	Purchased	Electronic Control Unit	wi-fi router	For communication between the ROV and the computer	Also it was used to program the microcontrollers	$15	$8 176
22.02.2019	Purchased	Electronic Control Unit	Power Supply	To turn the ROV on and off	Part of the Electronic Control Unit	$65	$8 241
22.02.2019	Purchased	Electronic Control Unit	Converter	Voltage Converter	From 220V to 5V	$10	$8 251
02.03.2019	Purchased	Product demonstration notes	Consumables for models	They were used for trainings	Also they were used on regionals	$140	$8 391
15.04.2019	Purchased	Buoyancy	Penoplex	Maintains buoyancy	Several batches were Purchased	$10	$8 401
22.04.2019	Purchased	Training	Swiming pool	In the pool we could practice assignments	This helped to test the ROV and increase the pilot's skills	$350	$8 751
21.05.2019	Purchased	Competition	Visa	USA Visa	We needed it to take part in the competition	$1 800	$10 551
21.05.2019	Purchased	Travel expenses	Tickets	Trip to the competition	Airport in Charlotte	$10 000	$20 551
21.05.2019	Purchased	Travel expenses	Hotel	Accommodation during the competition	Red Roof Inn Kingsport	$2 300	$22 851
						Total raised	**$0**
						Total spent	**$22 851**
						Final balance	**$22 851**

Table 3. Project Costing 2018/2019 year

9.4. New Vs. Used

Many times, our team had to make a choice whether to buy the desired item or to use the old one. We solved this issue as follows.

Our main priority was quality, so even if we suspected that the part was a little outdated or damaged, we replaced it with a new one, if it was a rational use of money. This had its advantages, because a new part is always better than the worn out one. However, this decision cannot be the best strategy in any situation, as the purchase of new parts costs a lot of money. Therefore, if the item was in good condition or it was less expensive to fix than to buy a new one, we used it. However, the problem with such solutions was not only in the quality of reusable devices, but also using last year's materials limited our choice and did not allow us to consider all possible options. However, often we were quite satisfied with the re-used parts and in case of failure, we could easily fix it. For example, since last year we have had motors, but even though they worked, their efficiency has reduced by long-term usage and it was impossible for us to fix them. We were not satisfied with that, and we made a logical decision to replace them with new ones in order to make our ROV faster.

On the other hand, when the manipulator was broken, we made a different decision. One of the reasons we decided to fix it was the high cost of the new manipulator, but equally important was that we wanted to test our abilities and try to fix it ourselves. In the end, our engineers did it with great success.

9.5. Build Vs. Buy

Also, there were a lot of situations, when we had to choose whether to buy a thing or create it ourselves. We tried to create parts ourselves, as it not only allowed us to save the budget, but also gave us the opportunity to gain valuable experience. However, under no circumstances were we going to sacrifice the comfort of our future buyers. That is why we decided to create our own devices only if we were sure of the quality of our work or if there were no devices satisfying our needs.

There were a lot of mission specific devices on our ROV that we needed to do rather specific tasks. However, we couldn't find any of those devices in the stores or online. That is why we decided to create them ourselves. Our devices were quite simple and thus the fact that we created them did not affect the quality of the device negatively.

On the other hand, in some cases we had to abandon the creation in favor of the purchase due to the complexity of the devices. Thus, several attempts were made to create a metal detector, but each prototype did not have enough range and efficiency, so we decided to use the purchased one and did not regret our decision.

Each time we needed to create a new device, we usually discussed it with our teammates. We wisely weighed the pros and cons in order to make a right decision.

10. ACKNOWLEDGMENT

The path to the competition was very difficult. During hard work, support helped us a lot. For support and much more, our company would like to thank:

The Center for Robotics Development for providing the company's working space, tools and financing. Also, we want to thank the CRD for organizing regional competitions, with their help we received the experience of participating in this contest and learned the weaknesses of our vehicle.

Dmitry Alekseev’s company for financial support.

Our mentors Angelina Borovskaya, Vadim Sorin, Semen Zinkov and Sergey Mun for controlling our discipline and for their incredible patience that they needed to give us the knowledge that we needed to build our ROV.

Palace of Sports “Unost” for providing the pool for training.

Our parents, who were understanding us, allowed us to work late and provided emotional support.

And most importantly MATE for the new skills and invaluable experience the company gained during the preparation for the competition and participation in them and for a unique opportunity to visit another country and get acquainted with its culture.

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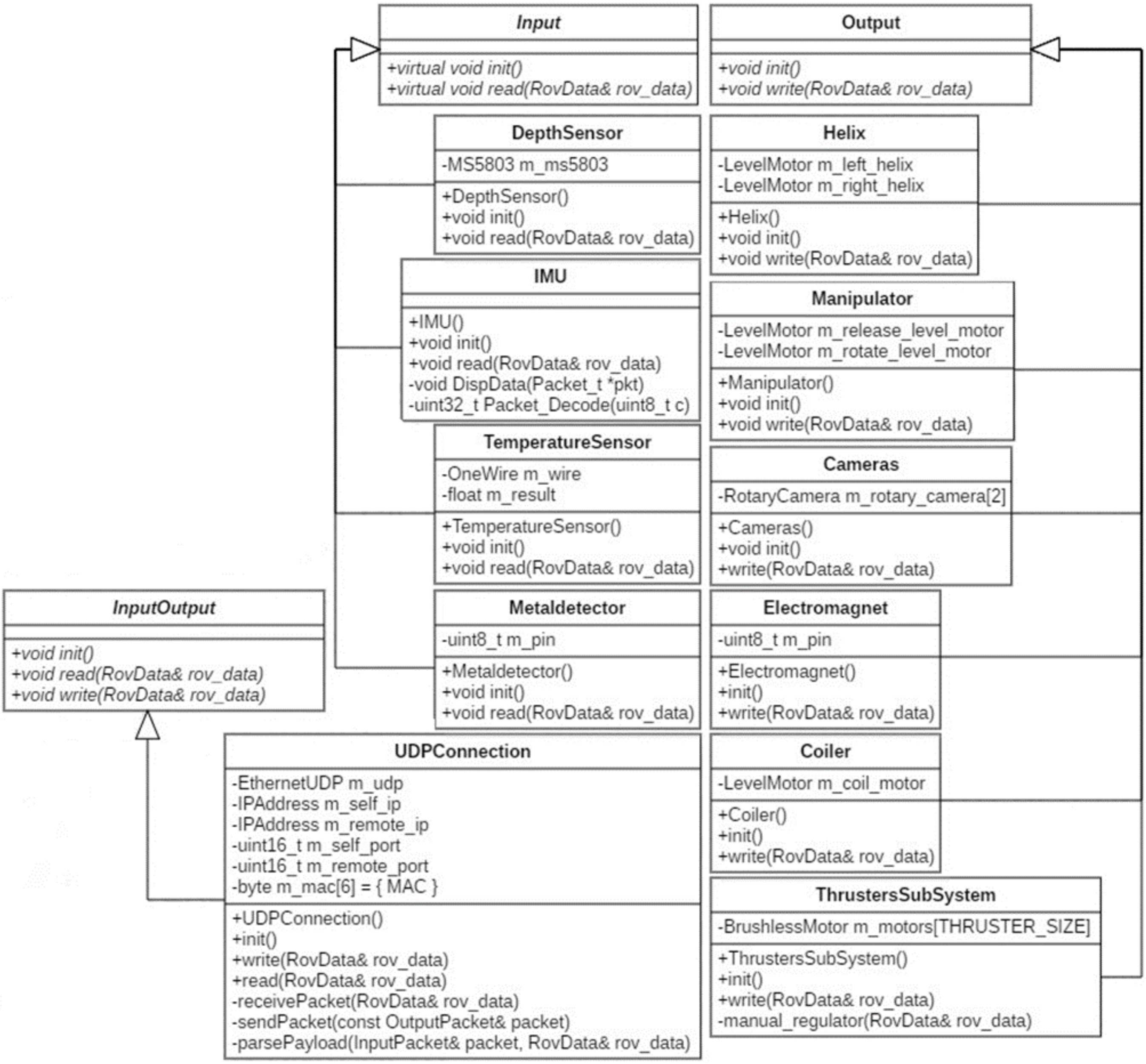
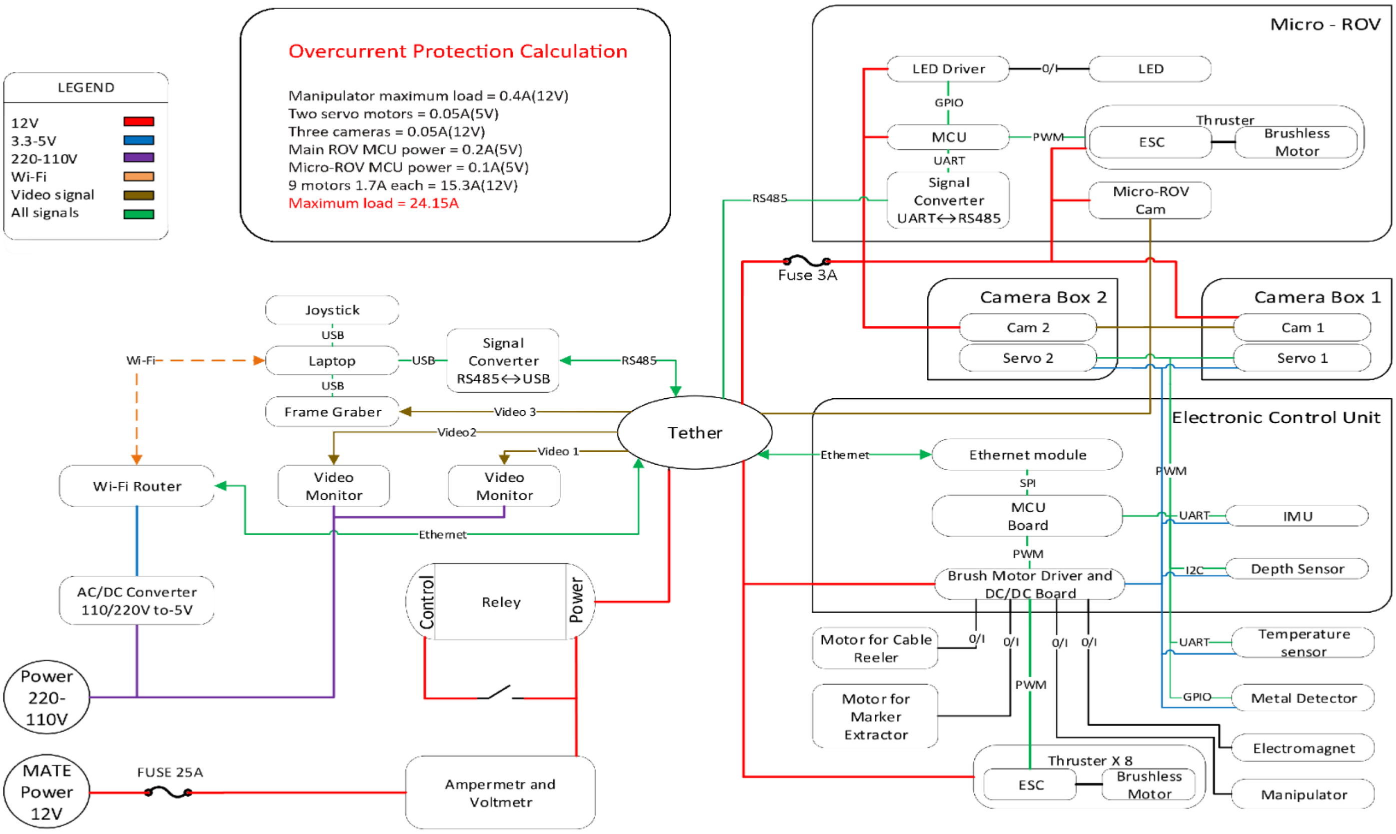
12. APPENDICES

APPENDIX 1. UML DIAGRAM OF FIRMWARE CLASSES



APPENDIX 2. SID



APPENDIX 3. TECHNICAL DRAWING OF LID OF THE ELECTRONIC UNIT WITH CABLE CONDUIT