

company **Robocenter**
Vladivostok, Russia

Technical Documentation

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ROV “Black Box”

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Оглавление

Раздел	Page	Раздел	Page
1. Abstract	2	4. Safety	11
2. Teamwork	3	5. Testing/ ROV checkout	13
3. Design rationale	4	6. Challenges	14
3.1 Frame and buoyancy	5	7. Lessons learned	15
3.2 Housing	5	8. Feature improvements	15
3.3 Thrusters	6	9. Accounting	15
3.4 Video system	6	9.1 Planning budget	16
3.5 Electronic unit	7	9.2 Budget	16
3.6 Control system	7	9.3 Buy vs Original	16
3.7 Tether	8	9.4 New vs Used	17
3.8 Surface equipment	9	10. Acknowledgments	17
3.9 Payload	10	11. References	17
3.9.1 Manipulator	10	12. Appendix №1	18
3.9.2 Liftbag	10	13. Appendix №2	19
3.9.3 OBS	10	14. Appendix №3	20
3.9.4 Measuring software	10		

1. Abstract

In 2018 MATE Center with The Applied Physics Laboratory the University of Washington has issued a request for proposals (RFP) for a remotely operated vehicle (ROV) that can perform specific tasks including:

- Locating the wreckage of a vintage aircraft and returning its engine to the surface
- Installing or recovering a seismometer
- Installing a tidal turbine and instrumentation to monitor the environment

Our team Robocenter decided to take part in MATE ROV Competition for the 4th time.

For achieving assigned tasks, we made ROV "Black Box". Its name reference to the first task "Aircraft", in which we need to find and bring to surface wreckage of sunken airplane, also our ROV reminds us of real black box – flight data recorder.

"Black Box" is equipped with powerful manipulator, 2 cameras (front and back), depth and IMU (yaw, pitch, roll) sensors. We set target to make payload and ROV components to be suitable as far as it possible. For instance, the frame is made of polypropylene sheets, because it's lightweight, solid and easy to process; electronic housing and camera's caps carve out from aluminum, since this material is comparatively light and has high resistance to rust.

For accomplishment, we conduct a lot of meetings, discussions and brainstorming. Our company consists of 7 members: 3 programmers, 3 electronic engineers and designer, each one spends hundreds of hours on work.



Figure 1. Company Robocenter: Sofia Sulzhenko, Sofiia Lukasheva, Kirill Leontyev, Valery Khrolenko, Yury Zadorozhnyi, Ivan Sukhnov, Ilya Borisov

2. Teamwork

During the project our company get together once a week at the meeting, where we were consult with mentors, discuss issues, report about done work, formulate and rationally spread purposes between team members and so on.

Effective communication among people was organized by e-mail, instant messenger WhatsApp and social network Vk.vom. Due to them we were able to instantly share picture and documents, resolve questions.

We used interactive task list as a work management tool. Our members frequently marked succeeded tasks, so mentors anytime could track work progress. Besides, we created Gantt chart (Fig. 2), which help us to monitor the whole project.

On Google Drive we gathered technical documentation's parts. All members were involved in writing process. First our mentors distribute parts between team members, afterwards text was edited and compiled into finished product.

Our way of working cannot be described as the best, as low-level software was belonging to first programmer, high-level to second, and third programmer was a coordinator of those two at all. In our opinion it would be better if we make everyone's GitHub repository, where entire program would be located. That could allow us to control development process and increase our performance.



Figure 2. Gantt chart

3. Design Rationale

3.1 Frame and buoyance

At the beginning of the design stage, we have identified several criteria, which frame must conform to:

- **All projections of the device** must fit in a circle with a diameter of 60 cm to obtain the maximum number of points for the size
- **The material** from which the frame is made must be strong and light, so that the assembled unit does not exceed 12 kg and we can get the maximum number of points for weight.
- **The design of the frame** should be modern, thoughtful, each detail should bear the functional load.

One of the main tasks in the development was the effective use of space. The frame consists of two main plates, two side cheeks and several fasteners. Due to the special cutouts on the side cheeks and the special shape of the horizontal plates, the frame is assembled as a designer and does not require additional fastening.

On the top plate are provided cut-outs for thrusters, cables, and cameras. On the lateral cheeks made in a wave-like cut-outs make it convenient to carry. On all plates of a frame cuts for reduction of resistance of water are made. The electronics unit and the manipulator are attached to the frame with clamps.

The frame is made of polypropylene, because it is durable and lightweight, has a density of 980 kg/m³. Our frame was completely designed in CAD SolidWorks. This allowed us to test some components of the structure without creating a physical one models. When the design met the criteria, we made the frame cutting, sawed it on the CNC milling machine and assembled the frame.



Figure 3. 3D-model of the frame

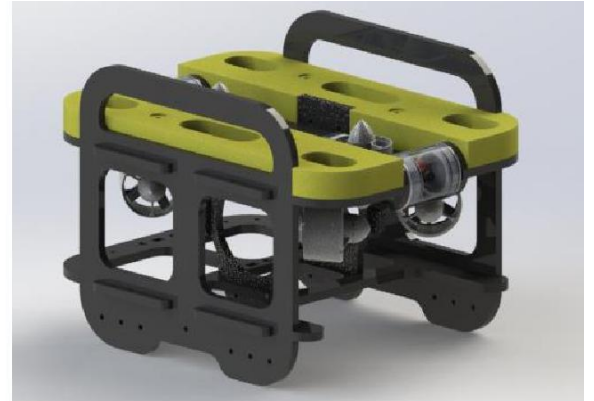


Figure 4. 3D-model of our ROV

3.2 Housings

To ensure the underwater operation of the electronics, it was necessary to place it in a sealed housing, which is designed and manufactured by the Center of Robotics for our team.

- The **housings** are made of aluminum. One of the reasons why aluminum was used is its lightness and strength. It is also quite plastic and easy to process, the polished surface has an aesthetic appearance, does not require additional coating. On the caps were made slots for o-rings. Threaded holes were made on the inside of the caps so that the contact board and the mounting for the control board of the ROV electronics unit could be fixed. Also made holes for the penetrators (Appendix 1). OBS and electronics housings were made using the same method, except that instead of penetrators a hermetic drive was used.

- The material from which the **flasks for cameras** and electronics OBS, was acrylic, as it is transparent and easy to process. We used clear acrylic to be able to check the system for integrity and leaks without opening the case, and to provide an overview of the cameras. The flask edges have been chamfered to facilitate the process of closing the lid.

- We used conventional purchase penetrators. They are screwed into the holes made in the caps and onto the thread of **the penetrator** is wound nut with sealing ring. To seal the cable in the penetrator, a special two-component sealant was mixed. To avoid leakage of the sealant from the thread side, the remaining space was filled with hot melt glue.

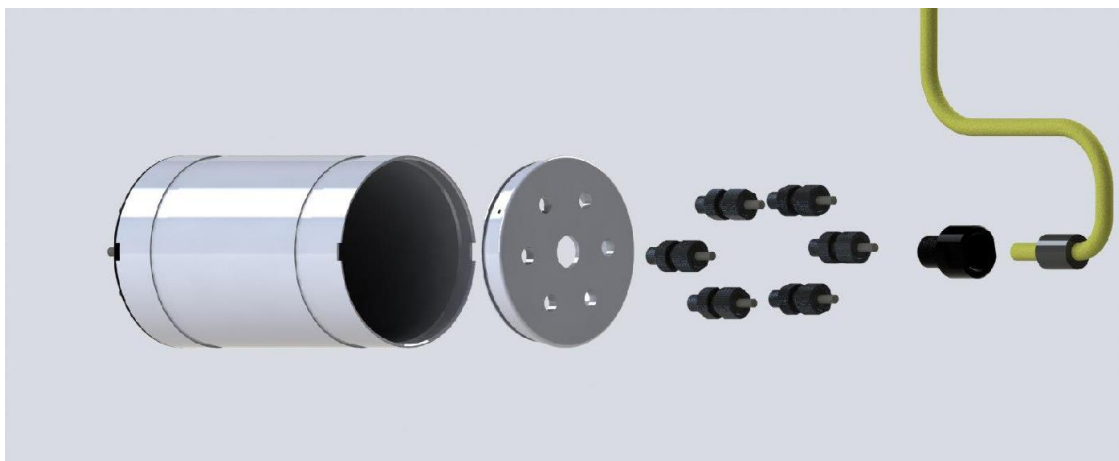


Figure 5. 3D-model of the housing for electrical unit

3.3 Thrusters

The propulsion system is one of the main systems of the ROV.

Thrusters are made of brushless motors with a nominal voltage of 12 V and a speed of 5600 rpm, Thrusters feature their own, built into them, a speed controller. Thrusters were tested in our laboratory and showed the following results: the thrust of 1 kg at direct stroke with a consumption of 7.8 A, and the reverse thrust was 0.86 kg with a consumption of current of 7.7 A. Its weight of the on the air for only 0.2 kg. For all propellers we produced covers to fit the safety philosophy MATE. The ROV has 6 thrusters: two vertical and four horizontal. Our horizontal motor vectoring orientation maximizes the ratio of forward/backward, left/right, and rotational thrusts, providing superior maneuverability and allowing us to move through tasks with increased speed, efficiency, and control.



Figure 6. Photo of thruster

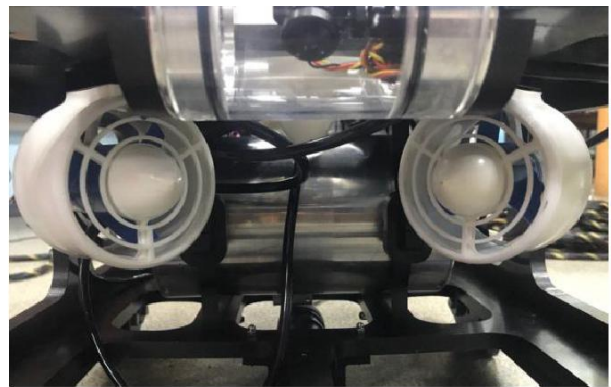


Figure 7. Photo of thruster installed on the ROV

3.4 Video system

ROV video system gives an operator an overview of the underwater environment and mission facilities. On development stage we made a decision to install 2 cameras, the image is displayed on TV and operator's laptops. Choosing the optimal number of cameras and their location is an important task in the design of ROV, the solution of which allows to avoid excess weight and cost of the device, as well as to give to operator the necessary overview. We use the FPV camera 1/2.7 800TVL CAMERA, model MS-1700 OSD, because it is compact and easy to connect.

- **The front camera** helps to navigate in space, in its field of view located the manipulator. It can rotate vertically by 180 degrees using a servo.
- **Back camera** provides rear view and view of Doppler lag layout (for task #3).

For the cameras, we have designed the housing, which consists of an acrylic cylinder, closed on both sides with aluminum caps. To seal the cameras, we used o-rings.

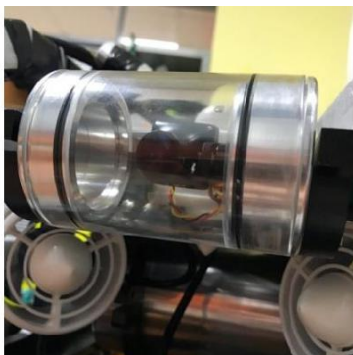


Figure 8. Photo of camera installed on ROV



Figure 9. Render of cameras view on the vehicle

3.5 Electronic Unit

The electronics unit allows us to control the entire payload on the ROV. It contains 4 boards: Arduino Mega 2560, Custom Shield, Ethernet Shield and Contact board. All these components are placed in a sealed cylindrical housing, which is made of aluminum.

- **Arduino Mega 2560.** This microcontroller allows us to manage ROV systems, to process data and to communicate with ROV. We chose Arduino Mega, so as it is powerful enough for our robot, easy to use and programming. We bought board because the development of the board takes a very long time and self-production is much more expensive than buying the finished board.

- **Custom Shield.** The microcontroller installed on the Arduino cannot directly control the heavy load on its digital outputs. We have developed Custom Shield, which serves as a motor driver and voltage converter with 12V to 5V and 3.3 V. It also has a navigation-flight sensor GY-80. We have decided to create our own board as there are no products on the market that meet our request.

- **Ethernet Shield.** We use the standard Ethernet Shield for Arduino, which in its turn gives the possibility to transfer data from the surface equipment and our ROV «Black Box».

The cable and all wires from the ROV devices enter the unit through two caps, so that it is possible to disconnect parts of the electronics unit from each other without damage. Through one cap come "power wires " and are connected to the Contact board. On the other hand, wires from the cameras and the payload are connected to the Contact board with the help of a loop. We also designed this Contact board ourselves, because we did not find suitable options in the electronics market.



Figure 10. Boards:
1 – Ethernet Shield, 2 – Custom Shield, 3 – Arduino Mega

3.6 Control system

Our control system is designed for mutual work of three pilots. The first pilot controls the ROV, the second pilot monitors the actions of the first and plans its work to minimize the number of possible errors, the third pilot performs calculation tasks: to determine the search zone for the wreckage and to calculate the maximum possible megawatt generation.

The first pilot uses the joystick to generate a control signal for the ROV. We chose this joystick because it has enough axes and buttons to control all the functions of the ROV.

First pilot software processes the signals from the joystick and forms a data package that is sent to the device 10 times per second using the UDP Protocol. Multithreading was applied so that in the future we could increase the computational load on the program without any problems with the operation of the graphical interface. MS Visual Studio 2017 development environment was selected for the interface.

Firmware main controller receives a data packet the first pilot, handles and generates control actions to the actuators of the ROV: thruster, servo, manipulator, acoustic system. For the low-level microcontroller, we chose the Atmega2560.

For easy and prompt cross-flashing of the microcontroller we used TFTP bootloader, which helps upload new versions of software on our ROV via Ethernet without the need to exposure of the electronic unit. TFTP bootloader starts up with starting Atmega2560, and within the first several seconds of operation the

microcontroller creates a TFTP server, waiting for a binary file of a new firmware update. Should with expiration of time a new firmware update not be placed onto the server, old firmware is started. However, it is very inconvenient to manually compile the firmware, to obtain a binary file from it and to succeed to send it to the TFTP server, and we therefore optimized the actions by writing an additional cross-platform software for the vehicle's firmware update. The advantages of this microcontroller: low price, enough power to create on-board ROV software, simple and understandable even for a beginner programming environment Arduino IDE. Among the disadvantages are the following: a small amount of memory requires code optimization, the lack of the necessary set of libraries to work with sensors.

The controller firmware collects data from the HI219M navigation sensor and the 30 Bar high-resolution depth sensor. The data packet with the values from the sensors is then sent back to the control panel via UDP. To obtain more accurate values, we use the Kalman filter implemented through the freeware Arduino library. The values of the trim, course and depth we use in the program to stabilize the ROV (flowchart in Appendix № 3).

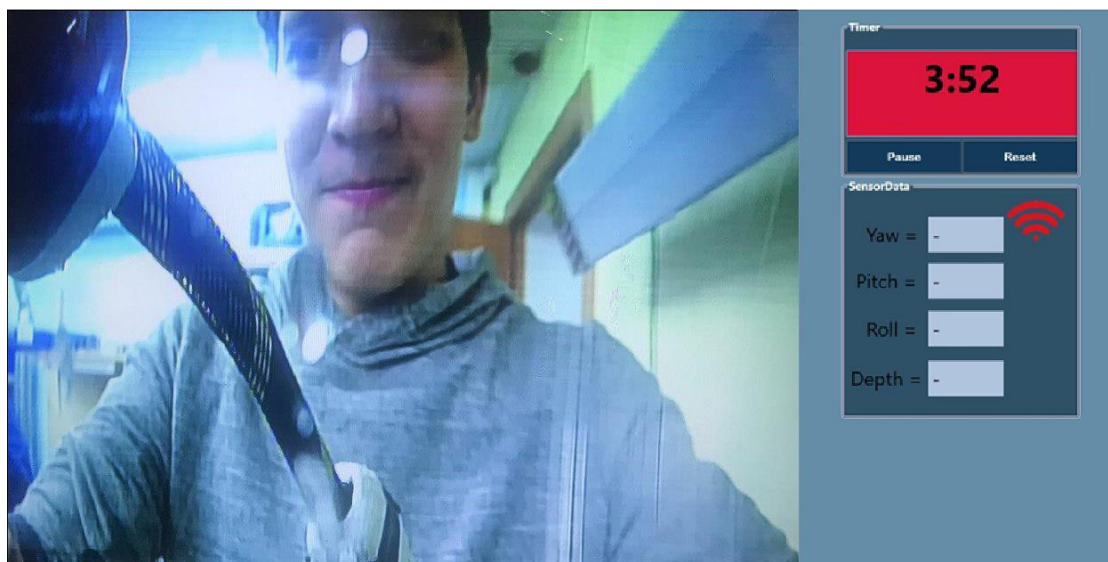


Figure 11. Screenshot of control interface

3.7 Tether

Tether connects our ROV to surface equipment. It consists of two power wires and an eight-wire twisted pair, which is used to transmit control data and video data from cameras. We chose twisted pair because of its low cost, availability and ease of installation. For optimal operation of ROV tether should be flexible, light, thin and have a small voltage drop. Heavy and rigid cable degrades the maneuverability of ROV. Also, with a large voltage drop, the ROV will not be able to function. To avoid this, we have calculated the appropriate cross-section of the power cables – 0,6 mm² according to formula, where U is the voltage, L is the length of cable, P - power, r is the specific resistance of a material, U is voltage drop. The buoyancy of the cable is provided by floats of foam attached along the length of the tether. This ensures the neutral



Figure 12. Tether

buoyancy of the tether so that it does not pull the ROV down. To protect the tether, we used a plastic mesh braid. The reason why we chose this type of braid is its lightness, cheapness and availability. Also, the tether braid prevents damage.

3.8 Surface equipment

Surface equipment consists of a control box, joystick, monitor, two laptops for the first and third pilots.

Control box must perform the following tasks: launching ROV, monitoring voltage and current consumption, the connection with the laptop wirelessly, capture two analog video streams from the cameras. The control panel allows you to power the device in two ways: using AC/DC power supply from a conventional 110 or 220 V outlet or from an external 12 V power supply. The control panel allows you to power the device in two ways: using AC/DC power supply from a conventional 110 or 220 Volt outlet or from an external 12 Volt power supply. AC / DC PSU is necessary for pilot training, as it eliminates the need to carry an additional external power supply along with the surface equipment. However, it was also realized the power from the external power supply that satisfies the conditions for participation in the competition MATE.

Sensor (multi-meter) helps to make full consumption monitoring and voltage ROV. We decided to install in our control panel Wi-Fi router to provide communication between ROV and the pilot without wires. This helps to increase the distance to the computer and the lack of Ethernet port on some laptops. For this purpose, one of the most high-performance, small in size and reliable routers from TP-LINK was chosen. The router receives a UDP packet from the device, which is then wirelessly sent directly to the PC.

To capture video from the device with a coaxial cable, two AverMedia video capture cards were installed, which convert the signal to digital for video output to the high-level software of the first and second pilots.

It was very important for us to make the control box as safe as possible, so the control panel was made of textolite to completely eliminate the possibility of short circuits. To perform different tasks pilots, **use two laptops and a joystick**. The first pilot controls the device with the help of a joystick, the movement of the vehicle is monitored by cameras, images from which are displayed on the screen of the first laptop. The same laptop serves as the middle link in the pilot's communication system with the ROV. The pilot, who deals with the calculation tasks, uses a second laptop. It is written special software to perform these tasks.



Figure 13. Photo of surface equipment: control box, laptop, joystick

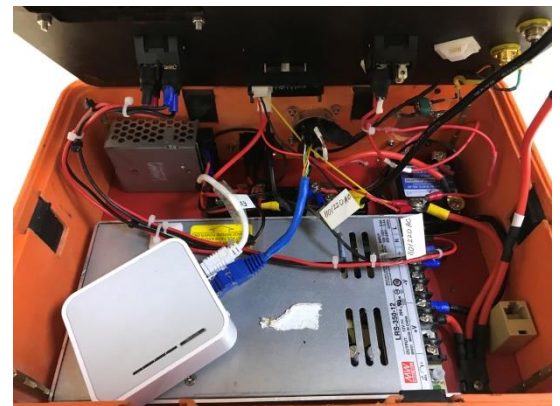


Figure 14. Inside control box

3.9 Payload

3.9.1 Manipulator

After analyzing the tasks of all missions, we came to the conclusion that most of the tasks can be performed with the help of our last year's manipulator from the RovBuilder company.

If we refused using it, we would have to make a lot of other devices that would take up a lot of space and be not so effective.

However, one manipulator is not enough to perform all tasks in a limited period of time, so we have designed other payload devices.



Figure 15. Photo of manipulator

3.9.2 Liftbag

To perform the task 1 we need a liftbag. Based on the parameters specified in the manual,

we have chosen 101SNORKEL lifting bag for the objects that need to be lifted to the surface. It can lift a weight of 13 pounds.

With the help of a manipulator we cling to the carbine attached to the bag, to the U-bolt on the motor/garbage. The speaker installed on the device sends sound waves to the microphone attached to the OBS.



Figure 16. Photo of liftbag

3.9.3 OBS

To accomplish the No2 task, we designed OBS, which satisfies the following parameters:

Height up to 0.5 m, diameter from 0.25 to 0.60 m

Together with the anchor must have negative buoyancy

OBS is a rectangular parallelepiped made of PVC pipes, covered with a fabric mesh and having a hole in the side face. This design allows you to place the connector in it with a minimum of time. To detach the OBS from the anchor, we created a mechanism that takes an wi-fi signal from the device. ROV sends signal to OBS microcontroller (Arduino Nano), that sends a signal to the motor, which opens a pin holding the OBS.

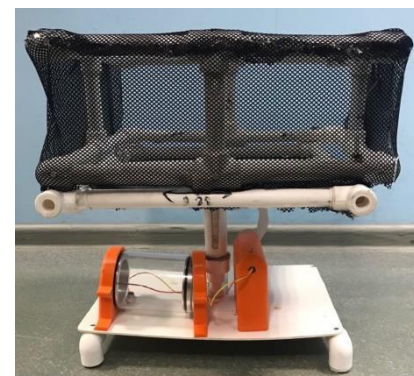


Figure 17. Photo of OBS

3.9.4 Measuring software

Measuring software consists of:

- Program that considers the distance relative to the known size of an object,
- Program that calculates the required values based on the specified parameters.

In task 3 "Energy" , we need to measure the height at which the Doppler lag mount, as well as the distance from the base of the turbine to the installation site of the berth. We decided to do this task with a special program rather than a payload such as, for example, roulette. This will allow us to save a lot of time and to start the following tasks more quickly.

For correct calculation requires a camera without image distortion, as well as the object whose size we know for sure. To write the program, we chose Visual Studio C# - this is cross-platform software development tools in the C# programming language.

Stages of work with the measuring program:

We distinguish the required distance from the bottom to the buoy or from the base of the turbine to the installation site of the berth, which we want to find out

Select the side of the object, the size of which we know. This way we know the length of one meter in pixels. The program calculates the length of these segments in pixels and automatically makes a proportion, so we know the length of the selected line.

In task 1, we must calculate **the place of the crash of the aircraft** by the provided data. To do this, you must enter the flight data, and the program will calculate the length and direction of the vectors.

In task 3, it is necessary to calculate **the turbine power**. To do this, you must enter the tide data.

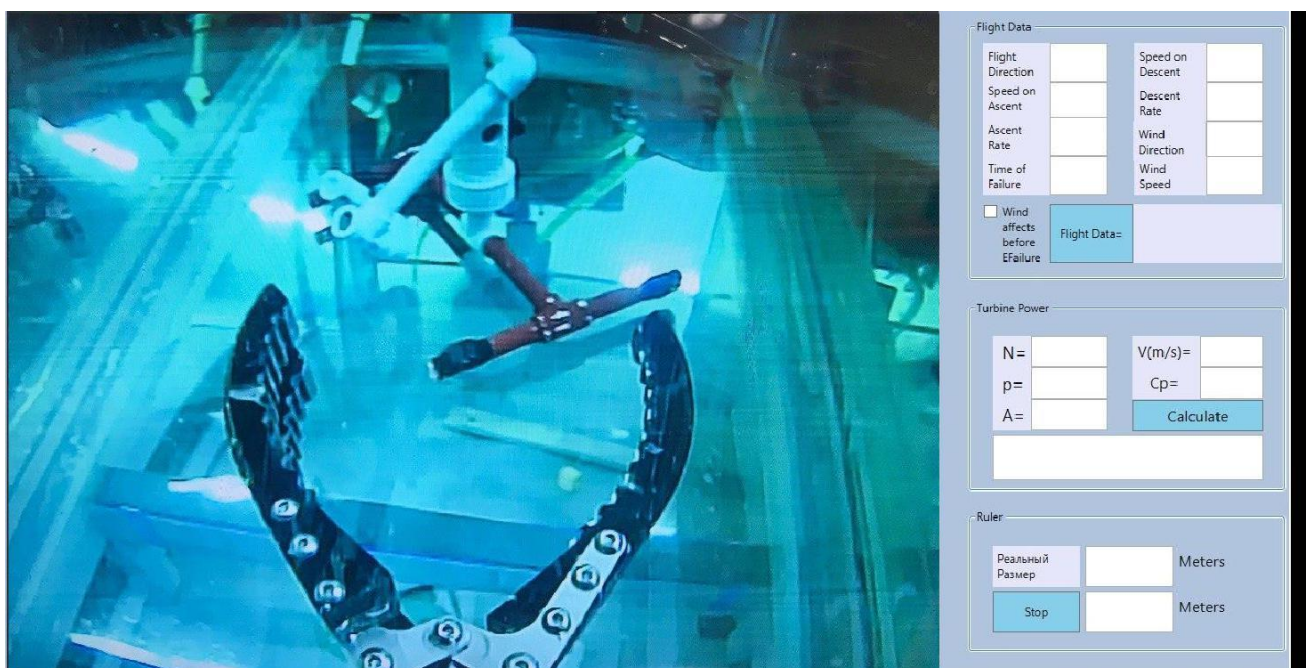


Figure 18. Screenshot of interface of measuring software

4. Safety

One of the company's main target is to ensure the safety of our employees. First of all, our members strictly follow the set of rules both in the workshop and pool. Before all, team members must get instructed about tools safe usage and wear proper outfit: safety glasses, robe, gloves. While paintjob or work with acid, melting materials members use respirators. Necessary requirement of any working with tools is supervision of mentor.

All members must keep their workplace clean in order to avoid injuries and wasting time searching for tools and details.



Figure 19. Photo of marked wires



Figure 20. Member of team in proper outfit

Features

One of the main safety problem was to ensure full protection for user. For this purpose, we made:

- **Protective covers** for thruster's propellers, they provide safety to employees who might adjusting ROV, as well as propellers that may be broke without protection, because of objects got into them. Also housing allow us direct the flow of water reducing the ROV speed.

- **Handles carved in the frame** that allow us to carry ROV in arms. In addition, the frame has got no sharp edges for employee's safety.

Besides we made safety check-list and protocol for verification before the mission, monitoring during it performing, after it finish.

Check-lists

Prior to plunging (prior to switching on)	✓	During operation in water	✓
Fuse check		Leakage sensor monitoring	
All coupler and wires check		Data from ROV navigating sensors monitoring	
Securings check		Current and voltage monitoring	
Prior to plunging (after switching on)	✓	After plunging	✓
Current and voltage monitoring		Check for mechanical damage	
Leakage sensor check		All coupler and wires check	

Data from ROV navigating sensors check		Thruster and manipulator check for intactness	
Camera check			
Thruster and manipulator check			

5. Testing/ ROV checkout

Testing – one of the most important creation phase of vehicle, which let avoid future problems and carefully track errors right in the moment of constructing a particular part. For convenience, we separate the debugging of the ROV in steps.

Checking all devices separately. We determine what "Hardware" we will use and after organizational questions (supplier choice, purchase), we begin to check the efficiency of the sensor, get acquainted with the libraries and code, customize and calibrate to meet our need, sometimes debug in case of unforeseen problems.

Checking on the table. When programmer of on-board software made sure, that "Hardware" is working correctly, we proceed to the next steps:

Programmers write software, which includes simultaneous operation of sensors, motors and cameras; Accepting and sending packets from surface software.

Electricals create electrical schematic, do pinout in accordance with documentation of "Hardware", are responsible for power supply.

When software is done and electrical soldered all components together, programmers start checking software in reality, do the first corrections.

Checking "in the air"(with fully-equipped ROV). In difference with previous stages, this step mainly depend on engineers. Electronics unit fixed to the frame, cable and wire are adjusted to the dimensions of the ROV, work is carried out on sealing the apparatus (filling penetrators, etc.)

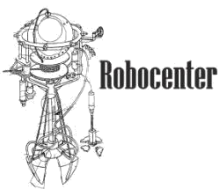
Checking under water. When the ROV completely in working condition, we go to the pool, check the device for leaks during a long stay under water, prescribe speed regimes, select the coefficients for the electronics unit, correct the color rendering of the camera for better picture.



Figure 21. Photo of checking ROV on the table



Figure 22. Photo of ROV checking in the water



After finishing any stage of debugging, we waited for the approval of the mentors before moving on to the next stage, because we might not notice any shortcomings. On the example of the navigation-flight sensor we will show **our debugging algorithm**.

After soldering the cameras to the installation, we found that the surface equipment stopped receiving packets. We fixed the error in the lower software and directly in the sensor, since the IDE port monitor is stably sent data that responds to changes in position in space. We decided roll back to those conditions with which the device worked in the previous time, cameras were repaired from the circuit board, but that did not help. We assumed that the problem lies in the Ethernet Shield and microcontroller of the machine, and replaced they are on a new board, which cyclically sent one variable. So we eliminated an error in the surface software, so it took the value of this variable. When we brought back the original electronics and attached the Shield, we found source of problem, which was caused by our negligence: after soldering the cameras, we bent the legs responsible for the contact between the boards that caused them incapacity.

6. Challenges

Technical

By reason of most of the team consist of newcomers all assigned tasks were serious test. For example: programming high/low-level software, tuning-up ROV, making control box, electronic unit. But the most difficult was to create frequency-selective acoustic system for second task "Earthquake". First of all, we encounter difficulties with components selection. Originally we made system from Arduino acoustic sensors and it didn't function under water. After rethinking we decide replace sensor to hydrophone, which was specially design to work under water. Then acoustic system began to function properly. Down below the full-detail investigation will put in.

ROV has hydrophone-transmitter that sends signals to the receiver, located on the OBS prop.

Getting into the receiver the signal passes through the amplifier so that Arduino control board can recognize it. After that, Arduino sends voltage to the motor so that they begin to spin. To operate to 12V motor we used Custom Shield, as Arduino max voltage is 5V. Custom Shield allows to use additional 12V power supply.

After we made sure the system works on land, it was necessary to develop sealed housing, as system would be installed to OBS. There were also difficulties in setting up the system for correct operation under water, which took a long time, since we couldn't find the cause of the system malfunction The problem was in the signal amplifier which was malfunctioning. After replacing the resistor on the amplifier board, the system started working. Thanks to joint effort, we were able to assemble and configure the acoustic system.

Non-technical

Among the non-technical challenges, the unity between members was the hardest one, as the main part of team are quite introverts in some ways, so there were troubles in establishing links. To solve such problems, we organized events where we playing and chit-chatting. Important condition of work was attendance at the office, despite it not so comfortable as being at home. That how people spend time together more often. In the beginning due to absence of social cohesion we had trouble with deadlines. When there was month and a half left to regional competitions we were way behind schedule. This

lead us to work late, everyone didn't get enough sleep, but after all team became very friendly and productive.

7. Learned lessons

During the work we acquired many special abilities: working in SolidWorks; 3D-printing; manipulating with hazardous materials, tools; learned new processing techniques and skills that you can get only by practicing. For example, work with the sealant, pulling a cable, filling the cable penetrator. We learned how to finish objectives in the minimum amount of time. Also we understand that software must be tested and compiled while it writing part by part.

At first we paid little attention to keep our cabinet clean, and slowly it became impossible to work in here. After we draw conclusions we put in place weekly housekeeping.

Another problem we bump into was lack of time spend on low-level software. That's why we couldn't check high-level software in action in time. We spend huge amount of time on refactoring and debugging low-level software meanwhile the control box was abandon. We took a lesson and now agree on a timetable for organizing the process.

8. Featured improvements

Near the beginning of the year we set a task to accurately follow our development plan, however for the various reasons, we didn't complete the task. So next time we won't repeat the same mistakes.

First, while planning the job we will take into account not only individuals tasks, but also team up tasks questions (in other words, a schedule and speed of work each member and more).

Second, we will precisely track our assigned and completed tasks to be sure that our development plan reflects the real situation - how progress go, how much time is remaining before competitions.

Furthermore, we have great desire to improve our ROV technical specifications. Next year we want design own 2-axis manipulator, in order to make much smaller and lighter product than purchased. Of course it will be challenge to us, as for many years' company had used commercial manipulator.

9. Accountings

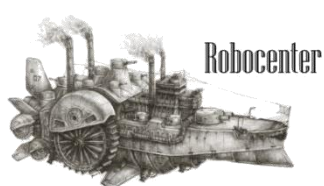
9.1 Planning budget

Planning budget is any project work's mandatory part. It includes budget allocations by type of job, time requirements, project expenses. We responsibly approach this management part: save bills, note expenses in Google Drive spreadsheet. One of the main objective was the best price-quality ratio.

During the whole work The Center of Robotics Development (CRD) was an Official Sponsor.

In the beginning of project, we made budget spreadsheet, which display possible cost of ROV according to the Internet sources. This budget was approved by CRD's director.

In the middle of development, we were barely within budget framework. We spend the most of our money on electronic devices and components. We were trying offset growth in spending by reducing the costs on other details, searching for cheaper analogs.



Despite such problems we managed stay within budget. If we denied re-use manipulator and joystick, we wouldn't save 1300USD.

Investment				
Source			Donated	
The Center of Robotics Development			\$	1 300,00
Personal investments			\$	960,00
Mentors			\$	4 800,00
Expenses				
Category	Type	Description	Cost	Balance
Payload	Bought	Electromagnet, acoustic system	\$ 300,00	\$ 300,00
Electronic unit	Bought	Electronic unit element for ROV control	\$ 250,00	\$ 250,00
Video system	Bought	Analog cameras	\$ 50,00	\$ 50,00
Propulsion system	Bought	Thrusters	\$ 600,00	\$ 600,00
Mentors	Granted	Mentors work	\$ 4 800,00	\$ 4 800,00
Travelling	Bought	Visa application	\$ 960,00	\$ 960,00
Travelling	Bought	Trips to the swimming pool	\$ 100,00	\$ 100,00
Payload	Re-used	Joystick	\$ 66,70	\$ -
Payload	Re-used	Manipulator	\$ 1 250,00	\$ -
Control box	Re-used	Control box, tether	\$ 550,00	\$ -
			Amount of donations:	\$ 7 060,00
			Amount of expenses:	\$ 8 926,70
			Amount of expenses (except reused and donated):	\$ 7 060,00

Figure 23. Planned budget table

9.2 Budget

Date	Type	Category	Name	Description	Notes	Price	Total expenses
03.01.18	Bought	Frame	Turning work	ROV frame		\$ 191,60	\$ 191,60
11.12.17	Bought	Payload	PVC pipe	OBS	OBS making	\$ 2,00	\$ 193,60
17.02.18	Bought	Payload	Motor	Motor for opening the OBS holding mechanism	OBS making	\$ 3,80	\$ 197,40
17.12.18	Bought	Payload	Пьезо приемник/излучатель	Acoustic signalReceiver/transmitter	For OBS holding mechanism	\$ 8,50	\$ 205,90
05.03.18	Bought	Payload	Cloth	OBS	OBS making	\$ 3,45	\$ 209,35
27.02.18	Bought	Electronic unit	Aluminium housing	Electronic unit housing	For tight electronic unit	\$ 27,80	\$ 237,15
15.03.18	Bought	Electronic unit	Rubber sealant rings	For sealing the electronics unit	For tight electronic unit	\$ 41,67	\$ 278,82
27.02.18	Bought	Electronic unit	Metallic cup	Electronic unit covering cap	For tight electronic unit	\$ 3,33	\$ 282,15
09.02.18	Bought	Electronic unit	Depth sensor	Depth sensor	For getting telemetry data	\$ 14,17	\$ 296,32
09.02.18	Bought	Electronic unit	IMU sensor	IMU sensor	For getting telemetry data	\$ 66,67	\$ 362,98
19.01.18	Bought	Video system	Rubber sealant rings	For sealing the cameras	To seal the cameras	\$ 35,00	\$ 397,98
10.01.18	Bought	Video system	Acrylic shell	Two camera's shells	To seal the cameras	\$ 18,20	\$ 416,18
16.02.18	Bought	Video system	Analog cameras	2 analog cameras	For taking video from ROV	\$ 16,67	\$ 432,85
30.01.18	Bought	Control box	Wi-Fi router	For wireless connection with PC		\$ 16,70	\$ 449,55
03.07.18	Bought	Control box	Voltage converter	Voltage converter from 220V to 12V		\$ 16,60	\$ 466,15
12.12.17	Bought	Control box	PSU		To turn on the control box	\$ 66,76	\$ 532,91
16.01.18	Bought	Control box	Connectors	Tether connectors	For tight connection	\$ 6,83	\$ 539,74
18.01.18	Bought	Propulsion system	Thrusters	6 ROV thrusters	For ROV movement	\$ 559,00	\$ 1 098,74
01.10.17	Granted	Mentors	Mentor's work	Mentor's help in project	1hour =16,6\$, 96hr *3 mentors= 288hr	\$ 4 780,00	\$ 5 878,74
15.03.18	Bought	Travelling	Visa's	Visa application	For international competiton participation	\$ 960,00	\$ 6 838,74
01.05.18	Bought	Travelling	Trips to the pool	Trips to the swimming pool for training		\$ 50,00	\$ 6 888,74
13.12.17	Bought	ROV construction	Expendable materials	Sealing compound, цианолак, heat shrink	Sealing materials	\$ 37,00	\$ 6 925,74
23.01.18	Bought	Control box	Tether	Tether for ROV connection	For ROV connection to surface	\$ 83,33	\$ 7 009,08
	Re-used	Control box	Joystick	Joystick for ROV control		\$ 66,70	\$ 7 075,78
	Re-used	Control box	Case	Control panel	For ROV control	\$ 23,50	\$ 7 099,28
	Re-used	Payload	Manipulator	Manipulator	To move objects under water	\$ 1 250,00	\$ 8 349,28
						Total donation:	\$ 8 349,28
						Total spent:	\$ 8 349,28
						Total balance:	\$0,00

Figure 24. Coast-accounting table

9.3 Buy vs original

This year we bought ready-made motors and lift bag, because no one could make it due to lack of experience, so any mistake could cost a fortune. Furthermore, this labor-

intensive process takes too much time, which is always isn't enough for things we can't buy such as: writing software, constructing a frame.

Our electronic engineers ourselves made Custom Shield, which we mention early, because there were no compatible to ROV thrusters. Also we made sealed housing, which showed amazing results: never leaked, occupy a little space.

9.4 New vs used

We are trying avoid using previous ROV components, because new are often much more effective in use. This year we designed original frame, made sealed housing and custom circuit boards, bought motors, rebuilt control box. This isn't first year we re-use manipulator gifted to us by RovBulider company (despite one motor broke, but we fix it on fly). Same year we use second time T. Flight Hotas joystick. It is easy to use, and has enough buttons to control ROV.

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We are thankful to MATE Center for their global initiative that gives numerous young people new skills and experience.

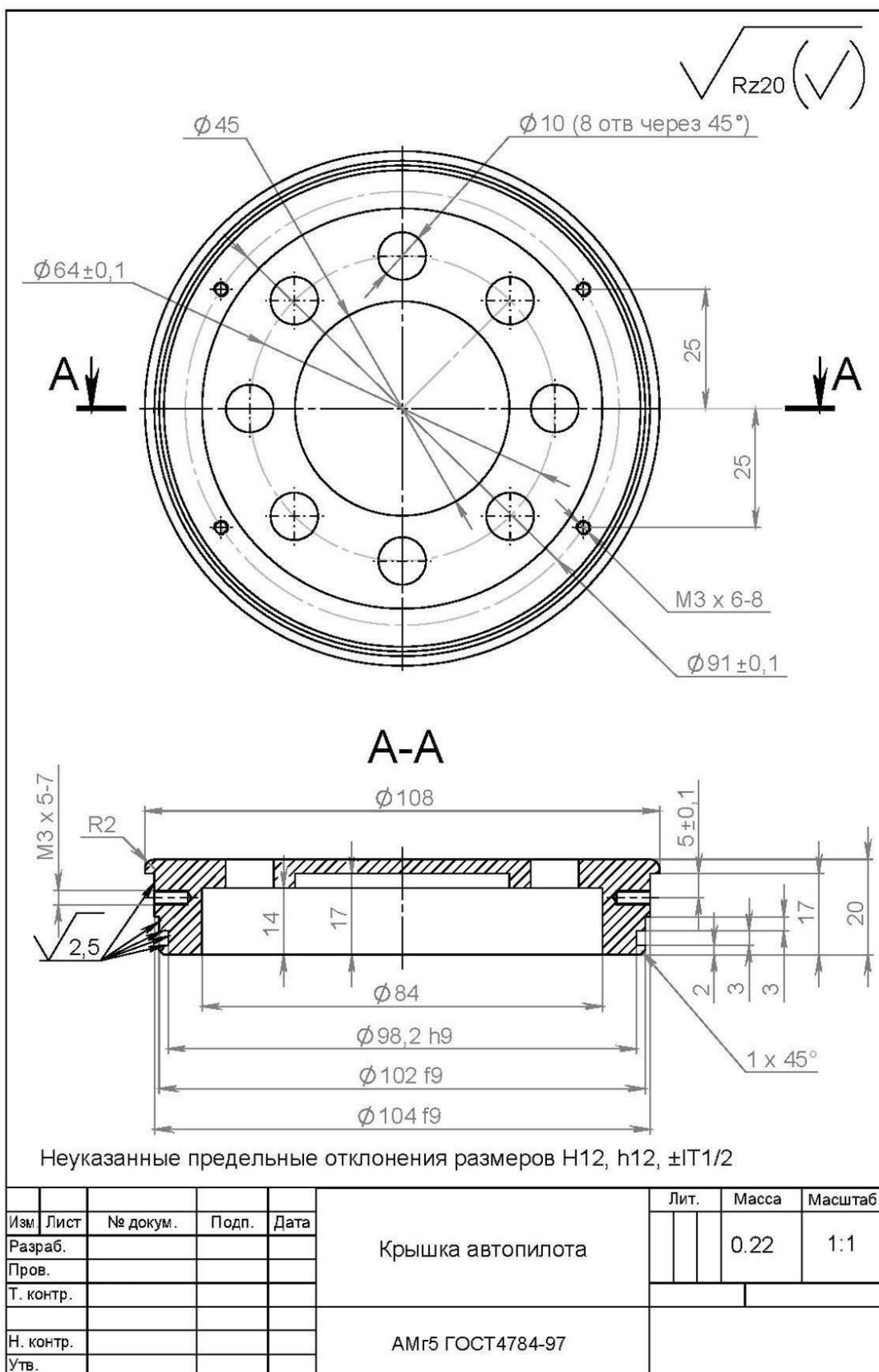
And of course, we appreciate the great participation on the part of our parents. Should there be no patience and understanding of yours (especially when we returned from training sessions late at night) and no support from you we would never be able to fulfill the project.

11. References

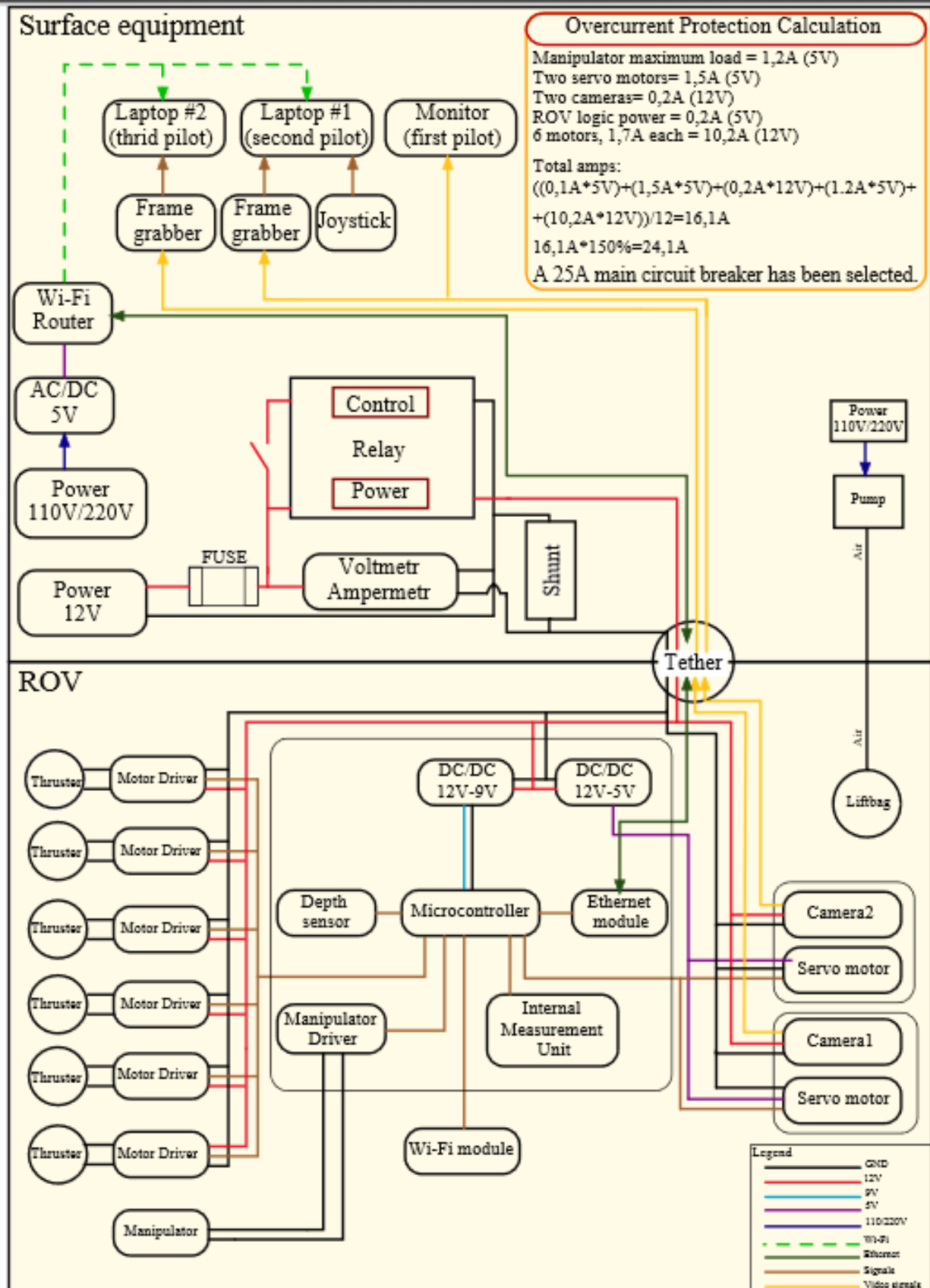
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12. Appendix №1 Drawing

Cover drawing of electronics unit



13. Appendix №2 SID



14. Appendix №3 Software flowchart

