THE CENTER FOR ROBOTICS DEVELOPMENT

RC
REMOTELY OPERATED VEHICLE

MATE II

ROV SENIOR

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Image 1. RC-ROV company, from left to right: Aleksandr Omelianenko, Semyon Zinkov, Pavel Zubarev, Anton Konstantinov, Rusln Mambetov

Abstract

In 2018 MATE Center declared the following tasks for execution by contestants:

- Detection of wreckages of the fallen aircraft and raising of its engine on a surface.
- Installation and restoration of a seismometer.
- Installation of the tidal turbine and instruments for monitoring of the environment.

Our company RC-ROV is taking part in MATE ROV competition already by 2 times.

For execution of objectives we designed the vehicle (the name of the device) equipped with the powerful manipulator, 3 cameras, depth sensor, the navigation and flight sensor. We aimed to make payload capacity and elements of the vehicle the most suitable for execution of tasks of a mission. For example, the frame was made of sheet polyethylene as it easy, strong also is plain in processing, and covers of the autopilot and cameras turned from aluminum as this material rather easy and has high resistance to corrosion.

To execute this project, we held a set of meetings, discussions and brainstorming sessions. Our company consists of 2 programmers, 2 electronics engineers and one designer, each of which spent more than 400 hours for creation of the ROV.

Design rationale

Use-case model

After the publication of a manual MATE Explorer we analyzed all tasks and developed use-case model, having discussed different approaches to execution of tasks and various of payload tools, came to the decision provided in table 1.

Subtask	Payload tool
Task 1: Aircraft	
Determination of area search zone of wreckage	Specific software for task
Identifying the aircraft	Specific software for task
Transportation of a lift bag to a debris	Main manipulator
Capture of a debris lift bag	Main manipulator
Transportation of a debris on a lift bag	Main manipulator
Release of a debris	Lifting system
Returning the engine	Lifting system
Task 2: Earthquakes	
Inserting the power connector	OBS connector
Leveling the OBS platform	Mechanism for installing OBS platforms
Receiving OBS Wi-Fi data	Specific software for task
Creation of the diagram	Specific software for task
Task 3: Energy	
Determination the optimum location for a tidal turbine	Visual comparison
Calculate the maximum possible megawatt generation	Specific software for task
Installing the base	Main manipulator
Installing the turbine	Main manipulator
Latching the turbine in place	Main manipulator
Installing I-AMP onto stand	Main manipulator
Locking I-AMP	Main manipulator
Measurements of distance for installation of an mooring	Specific software for task
Placing the mooring	Main manipulator
Measurements of the height of the installation of the ADV	Depth sensor
Installing ADV	ADV holder

Table 1. Use-case model

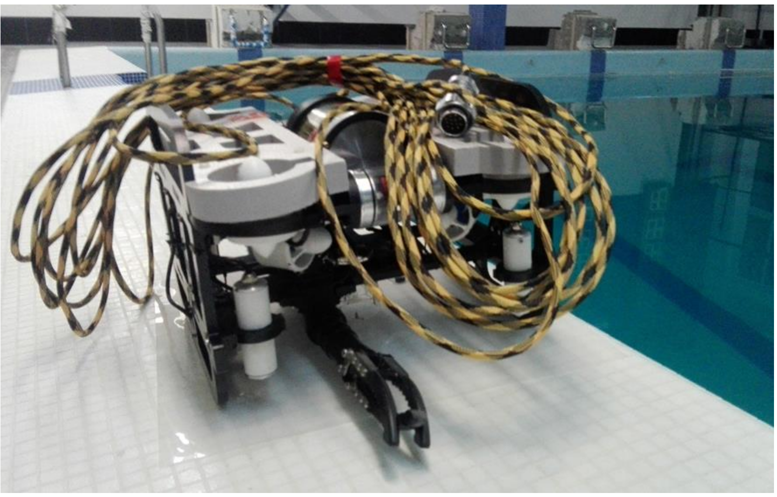

Image 2. ROV "Senior"

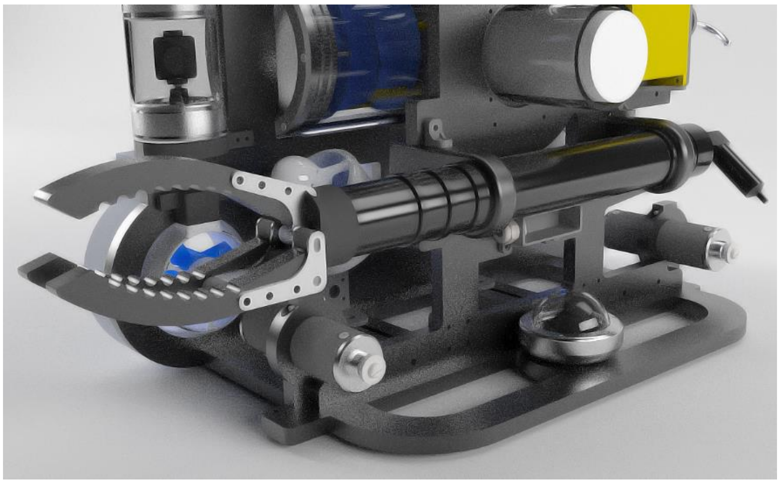

Image 3. Manipulator on the ROV

Payload tool

In our vehicle we designed the most part of components of payload tool, it is the system of regulation of height of an inclination of the platform, capture of a lift bag and release mechanism, the OBS connector, ADV, a software of identification of the aircraft. We only use the buyed manipulator.

Manipulator

Having analyzed tasks which our vehicle shall execute we concluded that for their execution we will need the manipulator with the wide fellow and a rotational level of freedom.

Such tasks as installation of the base of the turbine, and the subsequent assembly last and installation and assembly of I-AMP can be executed without problems by such manipulator. One more task for our manipulator is holding of the capture attached to a lift bag.

At the very beginning of the project before our company there was a difficult question, to use the last year's manipulator or to make new. After much debate and thoughts, we decided to use buyed, because of complexity of production, high cost of development (by our calculations development and manufacture of the new two-degree manipulator would cost us more than $1000) and a shortage of employees and lack of experience with them. Therefore, we the reuse manipulator manufactured by ROVBuilder which was bought last year from the vendor with a good discount.

Maximum voltage of our manipulator 24V, for more convenient control of the manipulator we use PWM.

Leveling OBS system

In the second task "Earthquake" it is necessary to leveling a seismometer (OBS), rotating four tees, to connect a custom transmitter to the receiver, and collect data via Wi-Fi. At the same time positioning accuracy of the platform with Wi-Fi the transmitter and the connector shall be less than 5 degrees on a roll and a trim of the instrument. That to achieve it, we decided to use directly 4 identical twisting devices which were set in the lower part of the ROV. Therefore, to begin leveling a OBS, we need "to sit down" on it so that the twisting

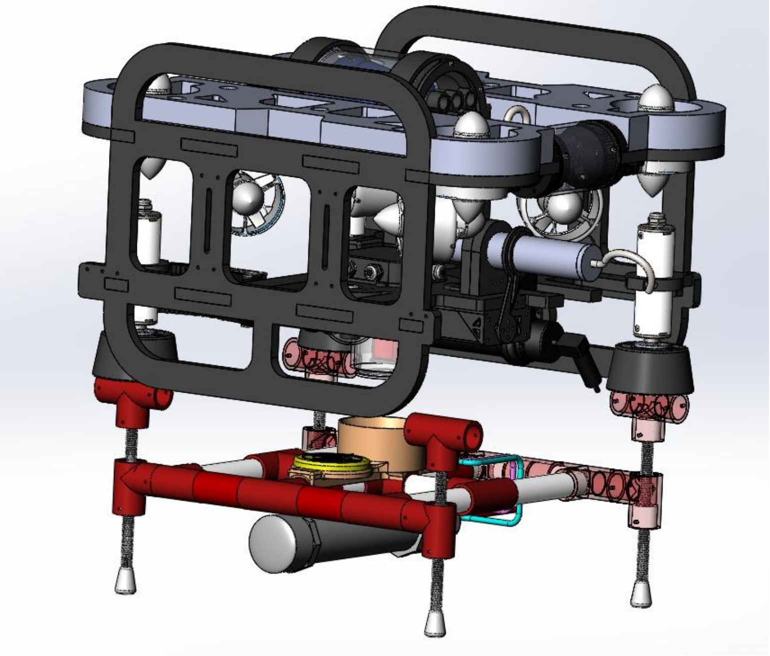

Image 4. Landing ROV on the OBS

devices matched OBS tees.

This decision allows to regulate quickly a platform inclination and by that to save time and it is good to fix the ROV precisely to drop the power connector in the port.

In case of manufacture of twisting devices as the drive was we used the 12V motor reducer with 125 rated frequency of rotation. The casing for sealing of the drive was produced from PVC for reduction of weight, and a cover from aluminum alloy.

For receiving of a signal from the transmitter we used Wi-Fi module with antenna capable to accept this signal at distance of 0,2m under water. We sealed up receiver in epoxy resin in the casing printed on the 3D printer and have fixed it on a vehicle bottom.

OBS transmitter

We manufactured the casing of the transmitter which it is necessary to lower the transmitter in OBS of an acrylic pipe with a diameter of 0,05 m. The bottom of the casing was cut out from sheet acrylic, and a cover from a caprolon in which we flooded epoxy resin, the metal washer allowing to attach this device to an electromagnet. By means of this magnet the transmitter is fixed on the device.

The choice of materials of the casing and cover is caused by their low cost, simplicity of processing, and small weight. It does possible use of less powerful electromagnet.

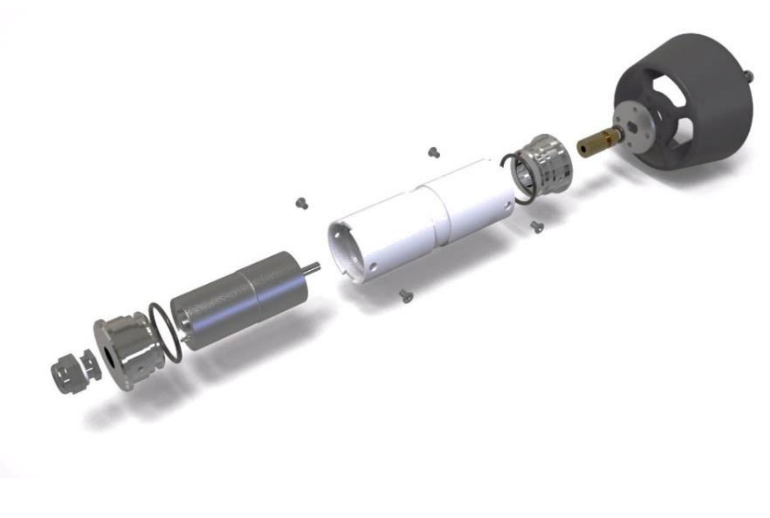

Image 5. Disassembled twisting device

Image 6. OBS connector

In order that the transmitter was not disconnected from the device during movement under the influence of resistance force and also for increase in chance of inserting in the port, the transmitter is fenced with an acrylic pipe with a diameter of 0,06m.

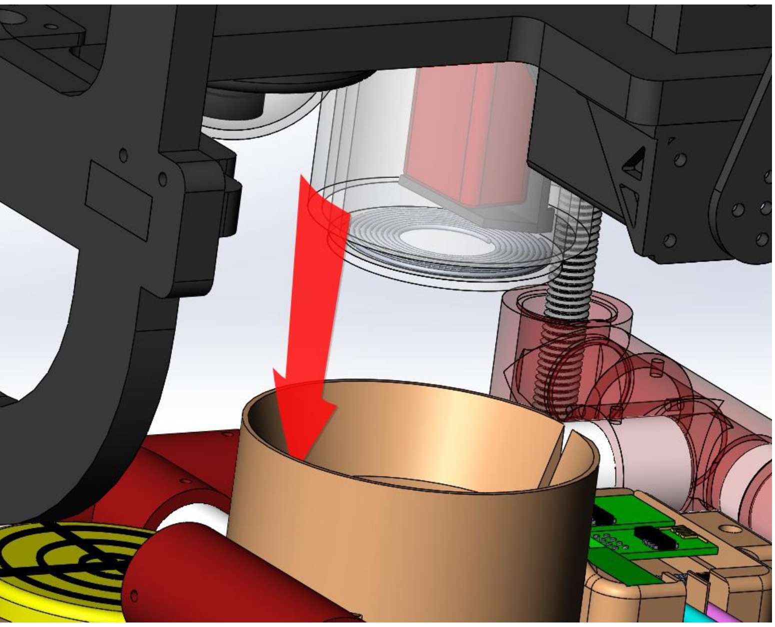

Image 7. Placing OBS connector

For a supply of the inductive port we used accumulator of 1604 type, and the transmitter is below flooded by the epoxy resin sealing and shifting its center of gravity down because of what the transmitter does not turn over and falls directly in the transmitter.

Lifting system

In an Aircraft mission, our team needs to use a liftbag to lift heavy debris from the bottom and an engine that cannot be lifted by a small ROV. For these purposes, we came up with a capture, which is attached to the liftbag.

This device is an acrylic tube with lids, one of which is a powerful electromagnet, whose task is to hold and release at some point the hook with the load. This grip allows us to easily catch on the garbage and remove it from the

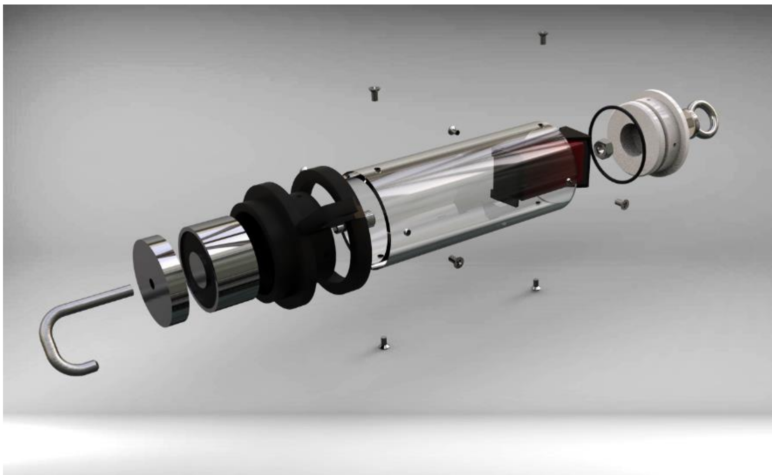

Image 8. Liftbag hook

engine. In order to unhook the load with the hook, we just need to turn off the electromagnet. We used the wi-Fi module to receive the signal from the device because of its ease of use compared to the acoustics. In order to power the electromagnet and the wi-fi module, there is 1 battery type 6F22 or similar in the housing. Since the engine we do not need to let go, we hook it with one additional hooks attached to the cover and lift to the surface.

Acoustic Doppler velocimetry holder

The Acoustic Doppler velocimetry – is device measuring motion speed of ship, or other objects in the water.

In “Energy” task is necessary attaching made by company device, imitating ADV. In our device this device was simulated by a pipe from PVC with a diameter of 0,032m. To avoid detaching of the ADV, during the movement ROV, the device addition kept by capture, for regulation of force of hold we used powerful waterproof servo actuator.

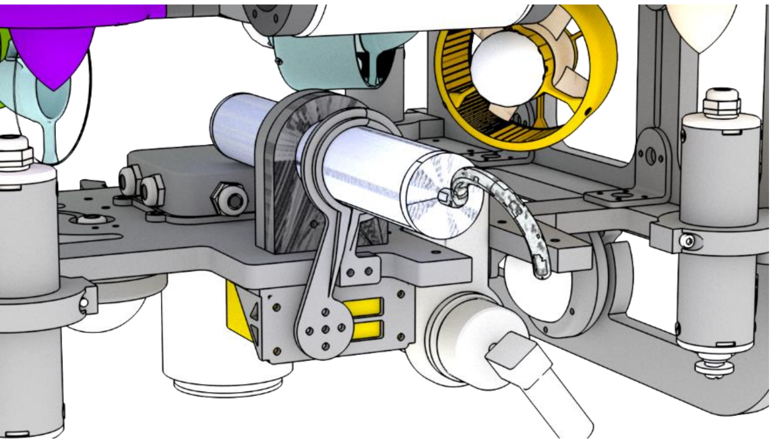

Image 9. ADV holder

On the end our ADV has the hook allowing to attach it on #310 U-bolt of mooring.

Specific software for tasks

For the decision of specific tasks, we developed special software for a third pilot. This software includes the following modules:

1. Ruler.
2. Module of determination the search zone for the wreckage
3. Module of OBS data displaying.
4. Module of determination of type the aircraft.

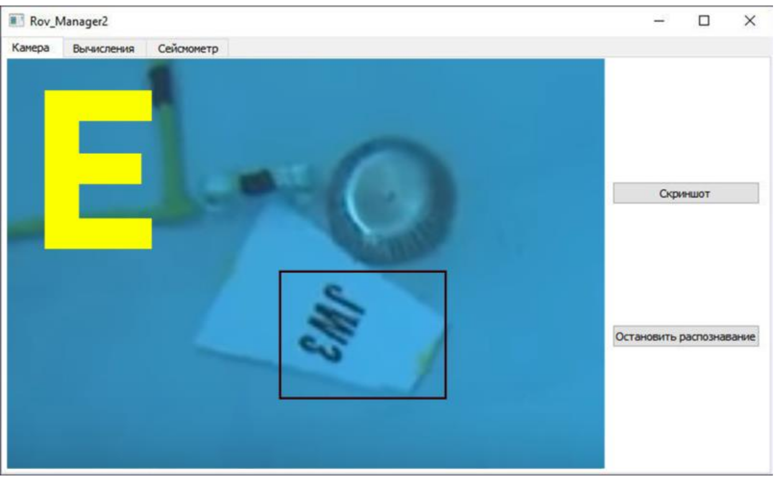

Image 10. Screenshot from software for Aircraft identification

Ruler - the module allows to determine distances on the image from camera, knowing length of any object on the image.

Module of determination the search zone for the wreckage - the module allows according to input data, such as - horizontal and vertical speeds of falling, horizontal and vertical speeds of take-off, the wind speed equation, time of take-off and an angle of take-off to determine a aircraft crash point.

Module of OBS data mapping – the module receive from the device of the of OBS and display data in the form of the chart.

Module of determination of type the aircraft – the module receive image from the camera and according to this image by means of the search algorithm of special points, determine type of the aircraft.

All modules are switched on in one application developed on a programming language C ++ with use of a Qt framework.

Frame

After we decided on technical requirements to the device, on the number of the main devices and payload tools, we could start development of a frame of ROV.

Our frame consists of two cross plates, two main longitudinal sidewalls, and all devices of payload tool, the electronics unit and thrusters are fixed inside on a frame. therefore to it practically all systems of the device are protected from mechanical damages. For manufacture of a frame we decided to use 0,01m sheet polyethylene (965 kg/m3).

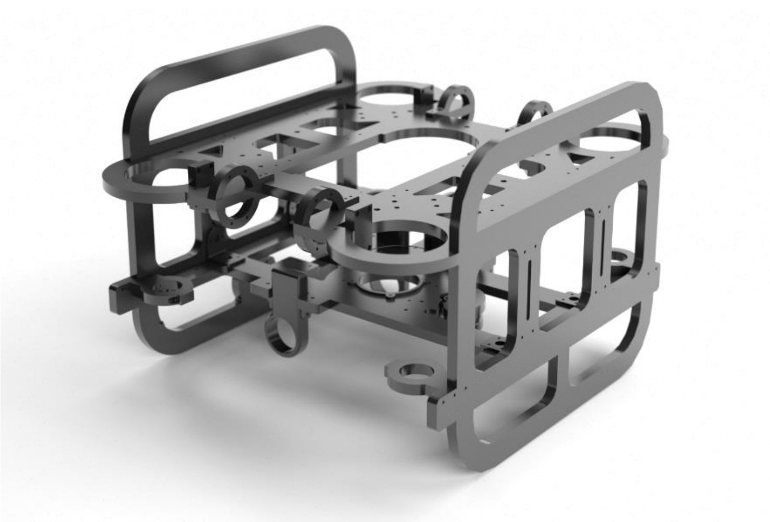

Image 11. ROV frame

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

Material for manufacture of buoyancy we selected 0.03m penoplex sheet due to it’s by low density (35 kg/m3), zero water absorption, high resistance to chemical influence, resistance to rotting and a fungus. We decided to make buoyancy of two half that it was possible to derive the unit of electronics and to remove vertical thruster, without removing buoyancy.

We made use of 5 such weights, approximately 0.025kg each. These were attached to the sides of frame and lower beam of the vehicle for the sake of ballasting and improved stability. To have ROV stability calculated correctly we’d studied the underwater craft stability theory.

Onboard electronics unit

According to requirements imposed to ROV by the rules MATE ROV and to necessary characteristics we developed the unit of electronics providing a supply, control of the device about surfaces, interaction with sensors and payload capacity. We divided all electronics into 3 boards. For support of logical distribution of electronics on the carried-out tasks, we developed for the unit of electronics and made 3 boards:

- The controlling board;
- Power supply board;
- Contact board.

The controlling board contains the Atmega2560 microcontroller, a board of NanoPi NEO Core 2, the navigation and flight sensor and step-down DC-DC from 48 to 5 volts.

For control of ROV microcontrollers and transmission of digital video signal and telemetry to a surface we selected the Cortex A-Series microprocessor having a sufficient capacity for processing of a digital video. As manufacture of the platform for the microprocessor of such level – the expensive task, we stopped the choice on the ready decision – the NanoPi NEO Core 2 which we placed on the controlling board.

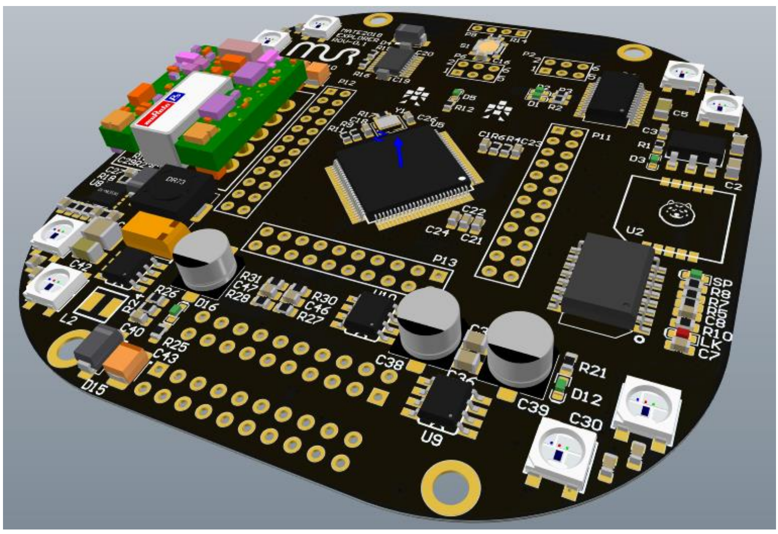

Image 12. 3D-model of the Control board

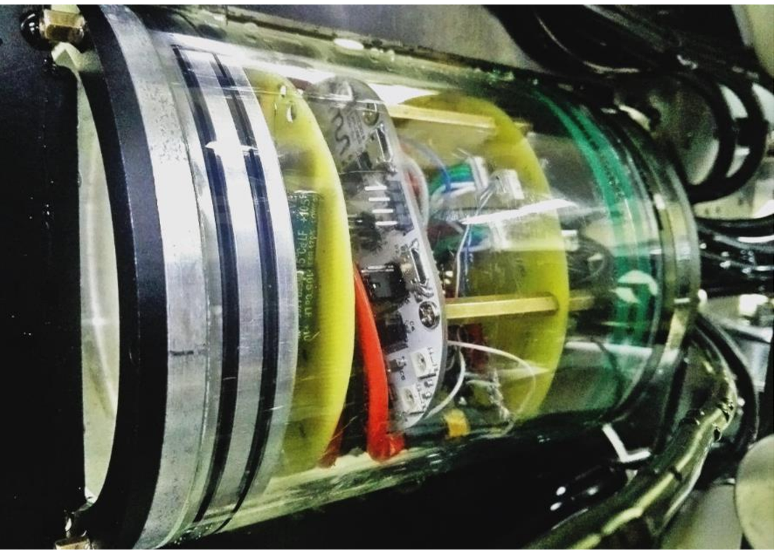

Image 13. Onboard electronics unit installed on ROV

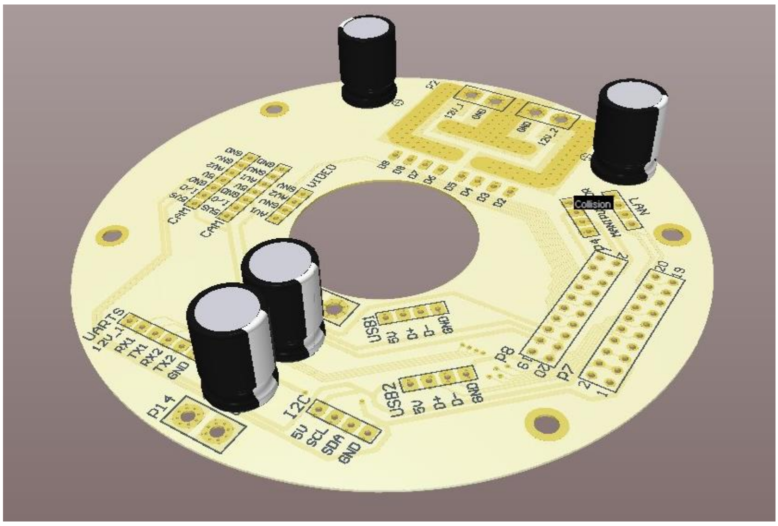

Image 14. 3D-model of the Contact board

The Atmega2560 microcontroller which well proved in the previous competitions executes a role of a binding element between the Cortex microprocessor and payload tools by means of UART and I2C interfaces. Also, for support with a supply of microcontrollers and NanoPi we placed the interference-immune industrial transformer DC-DC 48V-5V on the controlling board.

General purpose of a power supply board – reduction of voltage of 48Vcoming to the ROV up to 12V. Voltage of 12V – the main working stress of thrusters of our vehicle and a part of payload tools. On a board of a supply DC-DC are placed and integrated 2 industrial. One of the tasks standing in case of design of this board – to provide compact layout and sufficient cooling for DC-DC. We use of 8 12V-thrutsers with peak consuming to 7A at everyone led to increase in requirements to a feed system. Aiming at compactness and reliability of a product, we made the decision to use 2 industrial DC-DC reducing the transformer with high efficiency, capable in the amount to provide current 66A. Also, a part of the current provided with this board is utilized by payload tools.

The contact board is intended for connection of contacts of payload tools. It was developed with the purpose to group connections of payload capacity and to provide convenience of assembly of the device.

In the course of manufacture of boards we used Altium Designer software, allowing to control all development cycle of a board. All board was designed by us and manufactured at the factory in China. We made this choice in connection with the requirement to the increased compactness of a product and need for placement of a large number of components, on the controlling board total number of communications between components exceeds 10000.

Thrusters

One of main systems of the device is a propulsive system. Last year's self-made propulsions unit did not give us sufficient thrust (about 0,6 kgfs), often broke and they had to be repair what took away too much time. Therefore, this year after the analysis of the market of underwater thrusters the made decision to buy 8 thrusters (4 vertical and 4 horizontal) from our partner LLC Centre of Robotic.

In these thrusters there are brushless motors with rated voltage of 12V and the speed of 5600 RPM. These motors are equipped with the built-in ESC. Thrusters were tested in our laboratory and showed the following results: on a forward thrust 1 kg with consuming in 7A, and on a reverse thrust 0.86 kg with consuming of current at 6,9A. Thruster weight on air 0.2 kg.

For horizontal control four thrusters were set under angles 45 that allowed to achieve high maneuverability and speed, and the resultant thrust vector allows to move in any direction.

Cameras

The video system of ROV gives to the pilot the review of an underwater situation and mission objects. On a development stage of model of use of the device, we made the decision to use 1 static and 2 rotation cameras. A choice of optimum number of cameras and their position – the important task in case of design of ROV which solution allows to avoid excess weight and cost of the device and also to give to the operator the necessary field of view

Two analog rotation cameras provide the frontal and rear view. Cameras are supplied with fastenings with the servo allowing to change a camera inclination in the range of 180 degrees down. The body of these cameras

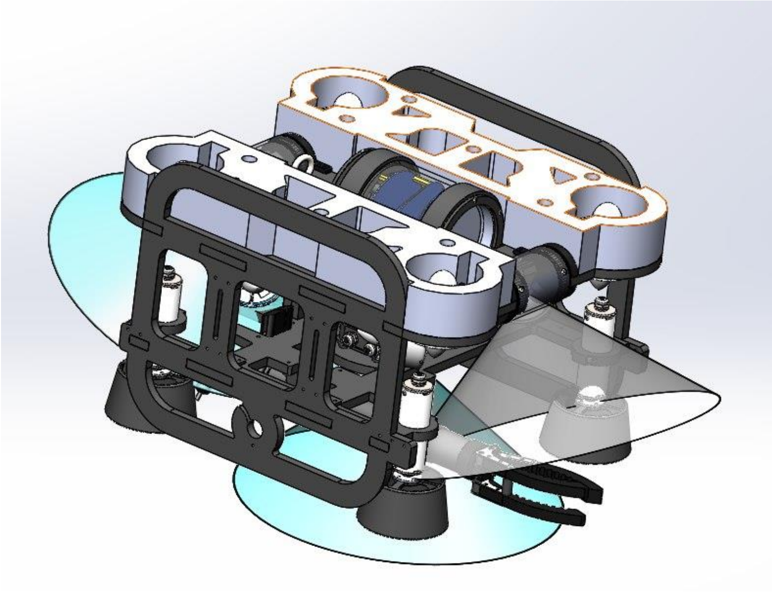

Image 15. Fields of view

is manufactured by us of cuts of a transparent acrylic pipe with aluminum covers. Rotation cameras provide convenience to the pilot in control of the device when maneuvering, giving a video information with the minimum delays about objects in front of the device and also behind and under the device.

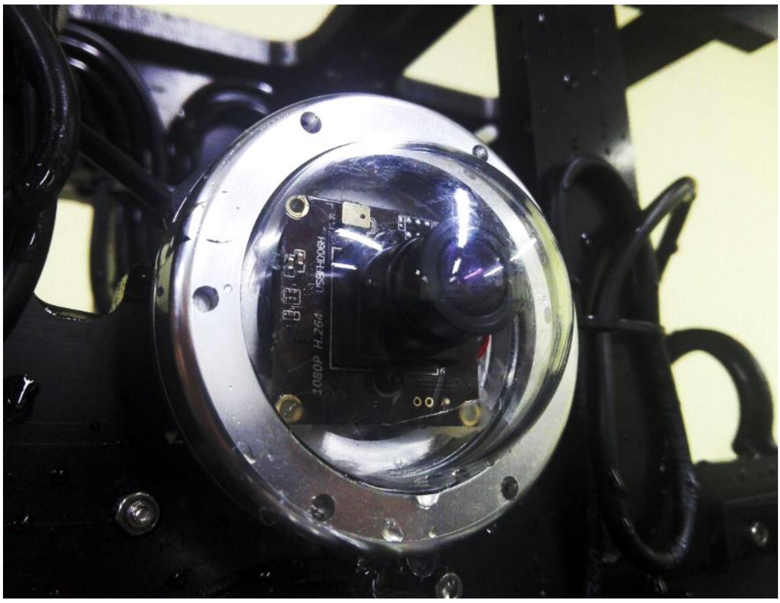

Image 16. Digital camera installed on the bottom of ROV

Image 17. Analog rotation camera

Static digital cameras carry out a supporting role at a performance of the mission and are supplied with lenses with focal distance of $2.8*10^{-3}$ m. These cameras are located under the device for providing the maximum overview of objects of one of missions – a LED and the bubble OBS level. For static cameras the body with a spherical dome of production of LLC Center of Robotics was purchased. This decision is proved by the requirement to the increased compactness of the cameras located under the vehicle.

We chose the digital camera, constructed on the basis of the Sony IMX322 chip for their excellent technical characteristics – high photosensitivity and FullHD-compatibility. The choice of analog cameras is proved by their more affordable price and high resolution 800 TVL

Depth sensor

For measurement and automatic stabilization on depth we decided to use depth sensor from our partner LLC Center of Robotics MS5837-30BA. This sensor has a form factor of the tight penetrator made of corrosion-proof aluminum that allowed to twist it in an auto pilot cover. The sensor is capable to measure pressure to 30 bars, data exchange happens on the I2C interface. With a pressure of 0.2 Mbar has permission in 0,002m.

Navigation and flight sensor

In our vehicle implemented automatic control modes at the yaw, roll and pitch. For creation of automatic stabilization, it is necessary to have exact information on rotation of the vehicle. To obtain of rotation angles of the vehicle we use the navigation and flight sensor manufactured by HINUC.

The module is equipped with two inertial MEMS the sensors which are 3-axis accelerometer, a gyroscope and the magnetometer. And also, the sensor is equipped with the microcontroller for operational data processing, received from inertial sensors. The built-in algorithms of filtering and data processing include: static calibration of drift, dynamic calibration and merges of data from both sensors. The sensor sends the obtained data via the UART interface with a frequency from 0 to 1 kHz.

The sensor offers the accuracy of measurements of a roll and pitch ±0.4 °, and the measuring accuracy of a yaw is ±2 °. Accuracy, high frequency of updates and simplicity of interaction with the sensor, allowed us to precisely stabilize ROV what strongly simplified work of the pilot.

Tether

The tether is necessary for us for contact of the vehicle with the surface equipment. We were faced by the choice to use a last year's tether or to make new.

Last year's represents the equipment tether the patch cord and two power

cables stretched in a silicone tube. Because of a tube we felt discomfort at controlling of ROV therefore it was decided to replace it with PET-sleeving.

At the choice of wires, we set some requirements:

- Thickness

The main criterion in case of a choice of power cable. Thickness shall be sufficient that in case of the maximum consuming of sagging of tension did not influence remaining electronics. We calculated the necessary thickness of cable cross-section proceeding from a formula:

$$S = (2 \times \rho \times I \times l) \;/\; (U2 - U1),$$

where S - the necessary cable cross-section of a cable; ρ-unit resistance; U1 - tension given by the power supply; U2 - tension at which the instrument works; I - loading current; L - cable length.

- Flexibility

The cable shall be the most thin and elastic therefore we selected cable of AWG14, they consist of thousands of hairs of copper and are silicone insulation. It give enormous flexibility of power cable. A patch cord we decided to buy the most thin of nowadays existing CAT6e. We use it for connect of the vehicle with the surface equipment and video transmission.

The general cover is executed from the PET-sleeving having the small weight and good flexibility. Assignment of the general cover:

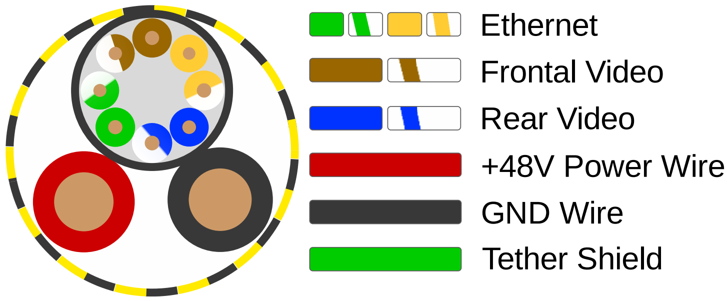

Image 18. Tether structure

- Combining of cables for tangling preventing;
- Protection of a cable against friction.

Tightness of electrical connections is provided with filling places transition of a cable to connectors a penetrator. The total length of a cable makes about 20 meters, weight - about 2 kg.

Surface equipment

The surface equipment - set of devices for control of ROV. This year we need make a lot calculations and analytical operating an during of the mission. Therefore we have three pilots. The first pilot directly controls the device, the second helps, plans its operation, and the third pilot - does computation and analytics.

For space saving and aesthetic appearance it was decided to combine all the necessary components for ROV piloting in one casing – control box. The third pilot uses a notebook on which it is installing a special software for execution of calculations, image identification and displaying of chart.

Control box contains:

- Power unit for monitor power supply of 12V
- Computer Intel NUC
- Screen

Image 19. Control box

- Loudspeakers
- Router
- Voltmeter\ammeter

For control of the vehicle we selected a joystick of Logitech Flight X52 as it has enough levels of freedom and also has additional buttons for control of rotary cameras and payload tools. The joystick is connected to control box.

For effective accomplishment of all tasks we need displaying of images from two cameras. The image from the main camera and information on a vehicle status display on the main screen. As the screen which is built-in control box is too small for a display of images directly from two cameras, we decided to display the image from the back camera on the another TV.

For a movement of the vehicle need the supply transformed in required the MATE 48V which according to requirements is placed out of the control box.

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

Control system

During of development of the ROV control system we formulated some requirements to system, namely:

- Receiving full information about vehicle status;
- Intuitively easy-to-use;
- Fail safety;

For creation of fault-tolerant ROV control system before development we studied with industry standards of software development for embedded systems such as MISRA and JSF AV. That allowed us to develop requirements to developing of program, for reduction time of debug a software at a development stage.

In view of features of the hardware architecture which allow us to add easily new devices payload tool, without requiring at the same time redesign of all system, in development of the control system we paid much attention to simplicity of scaling of a code, for this purpose was developed separate libraries of packages serialization and deserialization for transfer between system modules.

ROV control system consists of two subsystems: remote control software and onboard software. (see Appendix)

Remote control software

To control the ROV we developed an operator's control on Qt framework. The choice of this framework is caused by existence of a wide set of widgets for creation of the graphic interface and also a set of examples and detailed documentation.

The first pilot receives the image from three cameras of the ROV. One camera is displayed in widget of the main camera, and two others are shown in a scaled-down below. Because during missions for the pilot can be necessary another view, we can select camera which will be displayed in a main camera widget.

The main objective of the remote control

Image 20. Screens from ROV remote control software

software is control of the ROV from a joystick. The developed operator's control allows to send a packet with commands to ROV and to see the sent status from the vehicle. For joystick processing with SDL library.

On board software

The architecture design of a hardware and software system of our ROV consists of the following control units:

- The controlling server on NanoPi;

The module of periphery control on the basis of the Atmega2560 microcontroller;

- The module of payload tools control on the basis of Arduino Leonardo;

Decision about such distributed control system was made because it is very flexible, convenient and allows to easily scale system, adding new functionality, not affecting logic of operation of other modules,what excludes need of repeated test of not changed modules

Communication between all ROV control modules (NanoPI, Atmega2560, Arduino Mini Pro) happens via UART interface. We developed the communication protocol, proceeding from that the message shall occupy minimum admissible number of bytes, shall be flexible and easily expanded and to have convenient API for operation with it. We developed the cross-platform library for encapsulating operation with the protocol.

The controlling server on NanoPi is a communication point with the pilot's panel, opening TCP\IP a socket and expecting connection, clients. Also, the server is responsible for calculations of the given signals on propulsions unit, and all remaining periphery. Also the server obtains data from the navigation and flight sensor. Also opening the flow video from digital camera to operator console. Server is based on Boost.Asio library.

The module of periphery control, divides all periphery into three types:

- Input device;
- Output device;
- Input/Output device;

Such subsystems partition, is allowed to develop the flexible architecture allowing to describe the generalized object-oriented system, operating with the abstract types of devices (an input \output \input-output).This architecture is easily debugged, and expanded as allows to create the objects which are not influencing each other.

The module of payload tools control repeats architectural design of the periphery control module. Controlling a magnet for descent of the OBS connector, the mechanism of installation of OBS platforms and the ADV holder.

Safety

1. Safety Philosophy

The safety philosophy includes safety and algorithms correctly of the operation, for each task which is carried out in design process, creations, testing and uses of the device. Check lists of safety for each stage of operation were created for this propose and also all employees of a company were repeatedly instructed about the correct using of all necessary equipment.

2. Safety Features

Requirements during development were the following:

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

3. Safety checklist

Checks prior to starting:	
Fuse check	
Check of all connectors and cables	
Fixings check	
Current and voltage check	
Pressure transducer check	
Sensors check	
Cameras video check	
Thruster and manipulator check	
Dry start-up to make sure of operability of the device	

Checks prior operation (water):	
Pressure transducer check	
Depth sensor check	
Check of correctness of the image on cameras	
Thruster check	
In case of origin of malfunctions, it is necessary to disconnect the device from a supply and to derive it from water	

Checks during operation	
Pressure transducer monitoring	
Sensors monitoring	
Current and voltage monitoring	
In case of origin of malfunctions, it is necessary to disconnect the device from a supply and to derive it from water	

Checks after finishing (air):	
Check for mechanical damage	
Fixings check	
Tether check	
Check of thrusters and propellers for intactness	

Build vs. buy, new vs. used

Build vs. buy

We tried to build the is as much as possible devices. We purchased at only the fact that we could not build this year (thrusters, depth sensor, and joystick). The rest (the control box, cameras, a cable, payload capacity, the unit of electronics, etc.) we made self.

New vs. used

For the purpose of saving of money we tried to use as much as possible of last year's elements. But because of big number of the new ideas which we wanted to implement and news rules of competition, we can be re-used only manipulator, video capture board and router.

Testing and troubleshooting

Prototyping

During development of devices of payload tools, each of them was tested and debugged

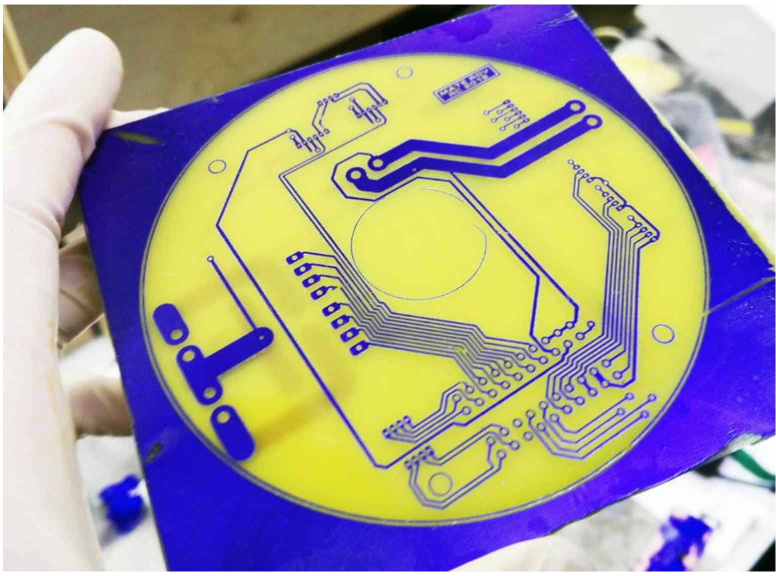

Image 21. Etched PCB prototype

separately from all system to be sure, that this decision will work on ROV.

For example, for development of the underwater Wi-Fi receiver, we thought how to strengthen force and range of a signal. During tests of different strengthening Wi-Fi-antennas, we dipped in water of the Wi-Fi access point which executed on MATE model and of the our receiver and measured RSSI, at different distances and it was written into the table. After the analysis of the received results we selected the antenna by means of which, we established connection with access point at distance of 0.25 m. We considered this distance in location of Wi-Fi receiver on our vehicle.

During creation of the first version of the ROV, we made contact and supply board. It was caused by the fact that we could not formulate the requirement to a supply board because of the high limiting current proceeding through this board that demanded singular engineering solutions. For increase in conductivity over tracks the was imposed layer copper wires. We made a supply and contact board with photoresist method, with the subsequent etching in a reagent and tinning. After specification of requirements to boards, we ordered their production in China.

Troubleshooting

Troubleshooting - very important and take a long time a part of development. When we received manufactured printed circuit boards of the unit of electronics, first of all we were engaged in their troubleshooting. All input/output ports were checked for existence electrical connection, an inspection on absence of short circuit in all circuit portion was also carried out. After wiring of components, we made repeat inspection, was checked correct operation of ports of an input\output on the controller and NanoPi.

In case of troubles it is at first we have to locate a possible cause for the trouble occurrence. Then, a list of software and hardware components that could be connected with the trouble is made. Further, through an experiment we're trying to exclude as many possible causes as possible. We test each of the components beginning with firmware ones and ending with hardware ones. For instance, in case of troubles with defining the robot orientation in space, we act as per the following algorithm:

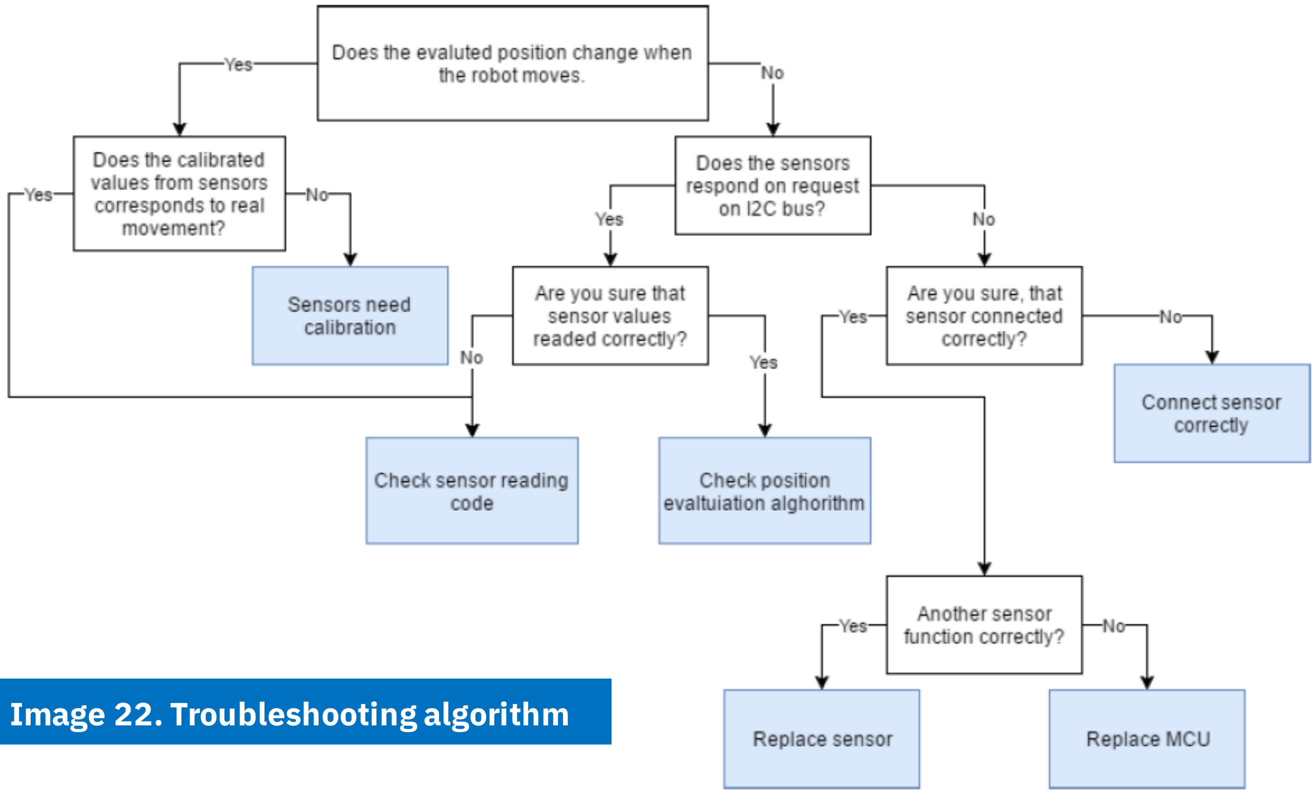

Image 22. Troubleshooting algorithm

Challenges

Technical challenges

This year we set as the purpose to develop such device which could be remade easily under other needs and was reliable. It demanded a lot of team efforts at a design stage of all components of the device.

The decision of the task with identification of a wing of the airplane became a big problem for us. In case of the decision of this task we tested different methods of recognition of the image. The neural network did not give us the necessary accuracy in case of text recognition whether the problem was in not a qualitative data set or in its smallness. As a result we decided to stop on the easiest way of recognition - binarizations the colors for recognition of color of a figure and the form, and for the text we used the search algorithm based on key points.

Non-technical challenges

Four of five of our employees except study in higher education institution still work in the different companies. And therefore for us full-time team working became a serious call. It was necessary to combine study, work and this project. It was necessary to refuse private life, to focus on underwater robotic technology, and the last month generally to work at night. Also we needed to place accurately priorities, it is good to plan the time and activities and also to refuse the majority of our normal entertainments.

Lessons learned

Technical

During development of ROV we are improved skills of C ++ programming, got experience of debugging of difficult multilayer systems. Improved skills of development of printed circuit boards by means of Altium Designer and also self-produced printed circuit boards. Increased the level of operation on the lathe and on 3D - the printer.

During a choice of the main microcontroller, we stopped on Arduino Mega 2560. This decision seemed to us successful in view of simplicity of programming, huge the number of already written libraries for operation with the periphery, and big community of developers. But in development process of ROV, we had a lot of problems, because of simplicity and the controller's universality. Arduino framework - has many places with unobvious behavior of the program. Also at Arduino not detailed documentation which often does not help with understanding of function behaves. All this forces to debug very long the program, finding out more and more places of a possible failure.

It led us to a thought that it is better to use more highly specialized controllers and to spend more time for understanding programming of this controller, than to spend time for fight against windmills when using the universal device.

Non-technical

The most important interpersonal and administrative lesson which we learned, - the fact that it is impossible to force someone to work in not hierarchical system if you do not work. At first we tried to influence on irresponsible members of the team, explaining that we had not enough time, but all this did not work while we did not begin to select daily to the project of more than 6 hours in day.

This quite general lesson and the universal, it belongs also to service of an order and to discipline, and to other aspects of cooperation.

Accounting

Before operations, the budget was planned. We tried to minimize expenses, without changing at the same time quality of components of the device. The Center For Robotics Development provided us two mentors who within 16 weeks, for 2 hours a week helped a team with creation of the device. Also we used the control box and Manipulator for a last year's performance. Visas of the USA were paid with a company independently. After compilation of the budget The Center for Robotics Development allocated all necessary means, therefore need for search of additional investment disappeared. The table of calculation of the budget, and the table of costs of creation of the ROV is given in attachments.

Future improvements

For creation of more universal and flexible architecture of control system, would like to change all protocols of communication to flexible, declarative protocol of ProtoBuf or nanopb. What will reduce time for development and updating of the protocol, will make it more flexible.

For creation high level of communication with ROV, it is necessary to transfer from pure TCP/IP of connection to the WebSocket protocol that will allow to add quickly and more qualitatively of new functionality to the vehicle. At the same time data transmission rate will almost not change.

From the point of view of development process and project management we have important future improving. Next year during planning we will put more time for debugging of systems and the vehicle entirely. By our estimates, considering experience of this year, it is necessary to select up to 50% of time of development for troubleshooting.

Teamwork

For the organization of team working, it is very important that each member of the team accurately understood the role and duties laid to him. In our small company, with distribution was simply, everyone undertook tasks which were more interesting and close to it.

To organize worker process, operation on decomposition of tasks on development of ROV was carried out. We broke all development of the ROV into 83 small tasks which could be solved for a short period. On the basis of the task list it was easy, to select the most important tasks thanks to what it was possible to make the optimum plan of operations for development of ROV.

For visualization of the plan, the Gantt chart was made and for distant distribution of tasks among members of the team the project management system of "Trello" was used. All this allowed to see always relevant progress of operations and also it is easy to understand the current priority tasks which needed to be solved.

For the organization of operation of department of software engineers, git version management system was used. The created account of the organization on github, allowed to control and synchronize all processes on software development for control of ROV.

At weekly meetings each member of the team, was divided progress by the direction, and all employees participated in solution of the problems.

Acknowledgements

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

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

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

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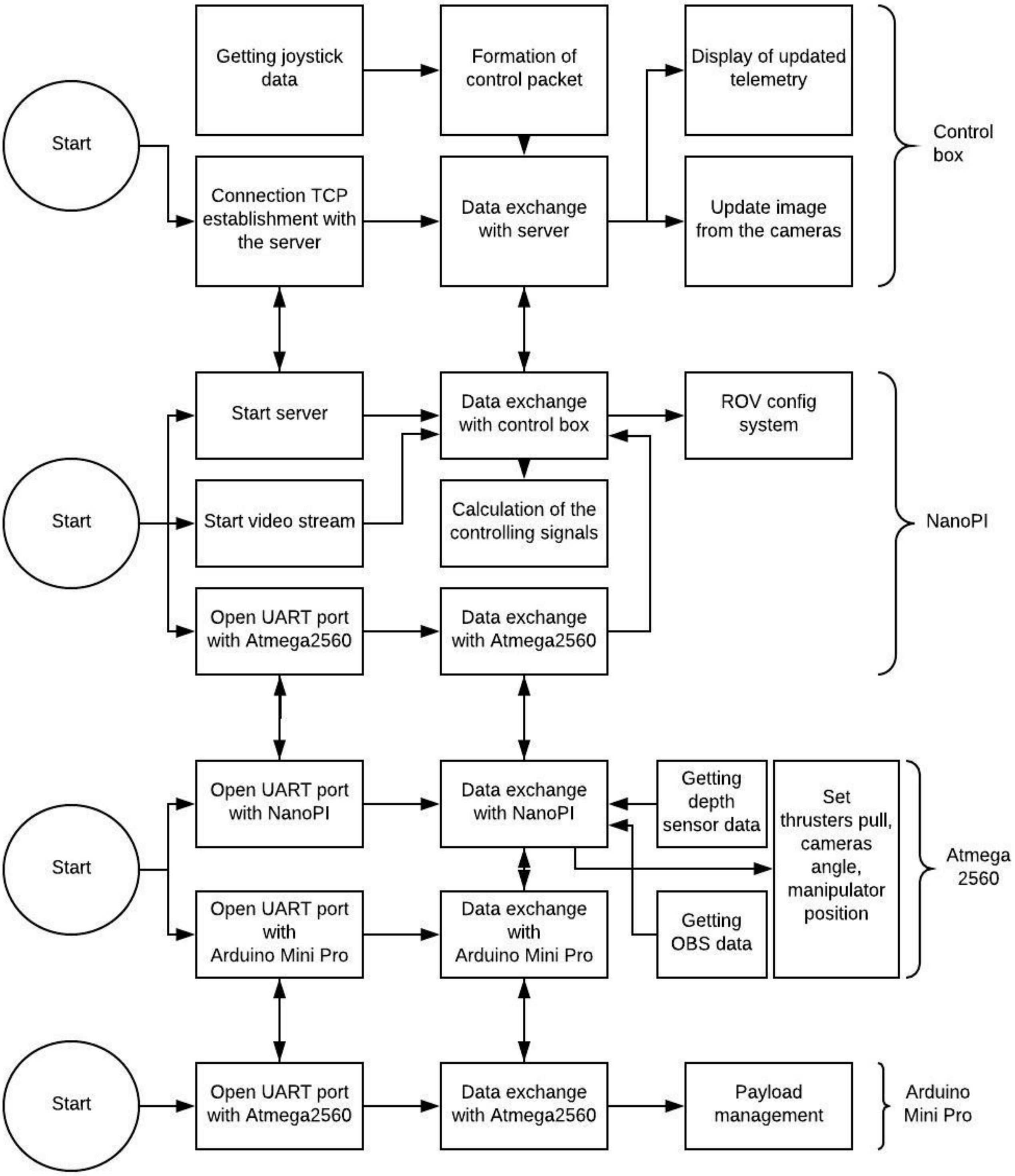
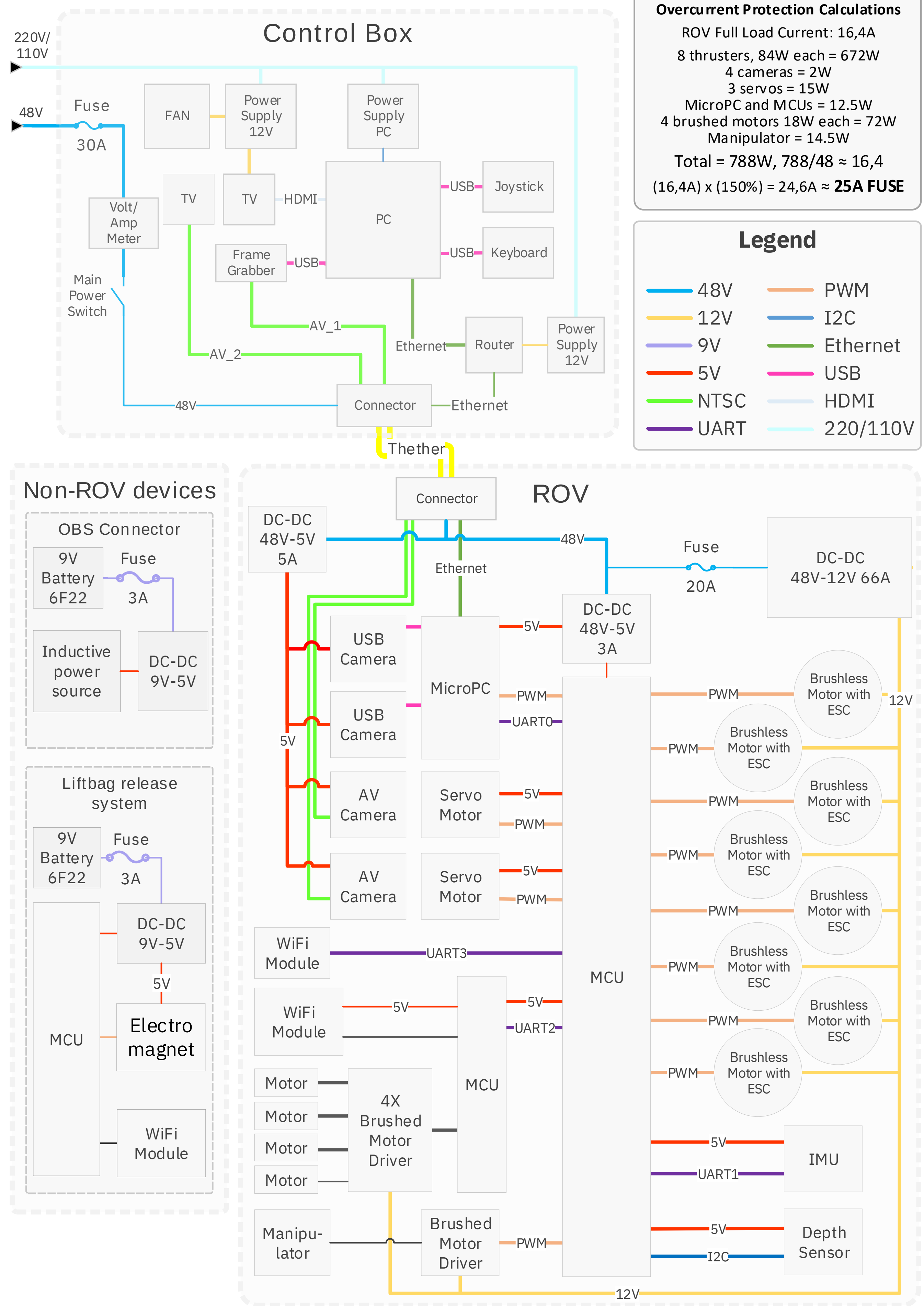
Appendices



Appendix A. SID: Software Flowchart

SID: Electrical



Overcurrent Protection Calculations

ROV Full Load Current: 16,4A

8 thrusters, 84W each = 672W
4 cameras = 2W
3 servos = 15W
MicroPC and MCUs = 12.5W
4 brushed motors 18W each = 72W
Manipulator = 14.5W

Total = 788W, 788/48 ≈ 16,4

(16,4A) x (150%) = 24,6A ≈ **25A FUSE**

Legend

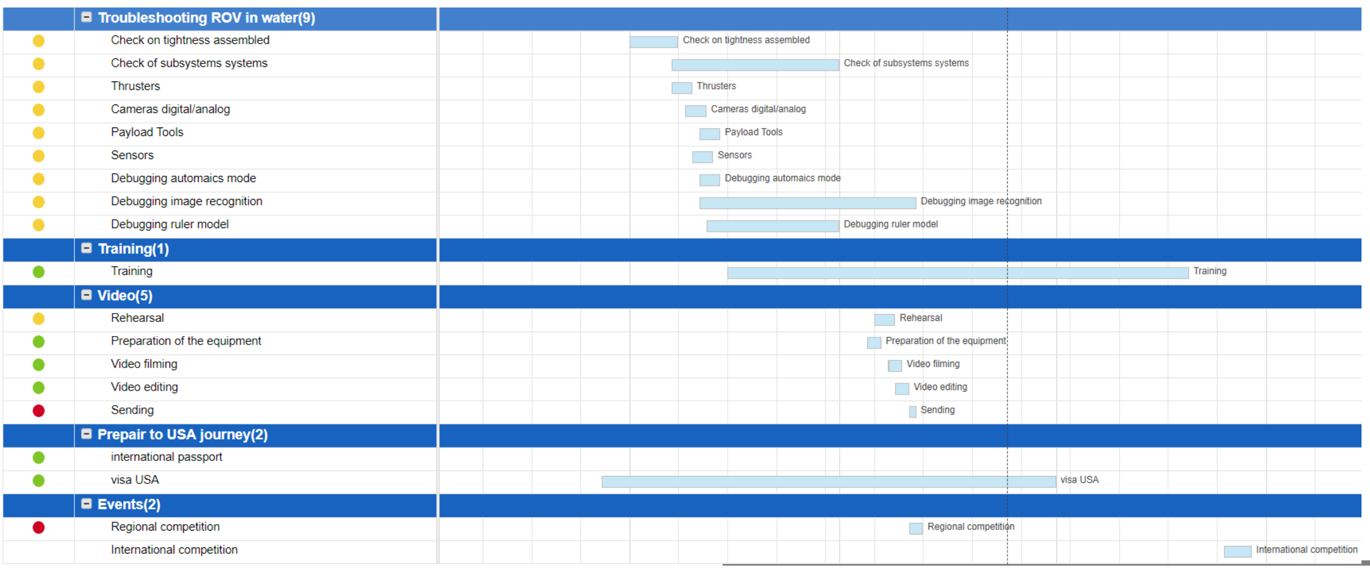
48V	PWM
12V	I2C
9V	Ethernet
5V	USB
NTSC	HDMI
UART	220/110V

Income				
Source				**Amount**
Participants of a command				$ 850,00
The center for robotic development				$ 1 700,00
Expenses				
Category	**Type**	**Description/Examples**	**Projected Cost**	**Budget value**
Payload tool	Purchased	Electromagnet, acoustics, leveling OBS system	$ 300,00	$ 300,00
Onboard electronics unit	Purchased	Control boards, wire	$ 250,00	$ 250,00
Video system	Purchased	Digital and analog cameras	$ 200,00	$ 200,00
Thrusters system	Purchased	Thrusters	$ 800,00	$ 800,00
Travel	Purchased	Trips to the swimming pool	$ 100,00	$ 100,00
Travel	Purchased	Costs of the visa	$ 900,00	$ 900,00
Mentors	Donation	Mentors support	$ 2 000,00	$ -
Payload tool	Re-used	Manipulator	$ 1 250,00	$ -
Control box	Re-used	Control box, cable	$ 550,00	$ -
			Total Income:	$ 2 550,00
			Total Expenses:	$ 6 350,00
			Total Expenses-Re-used/Donations:	$ 2 550,00
			Total Fundrasing Needed:	$ -

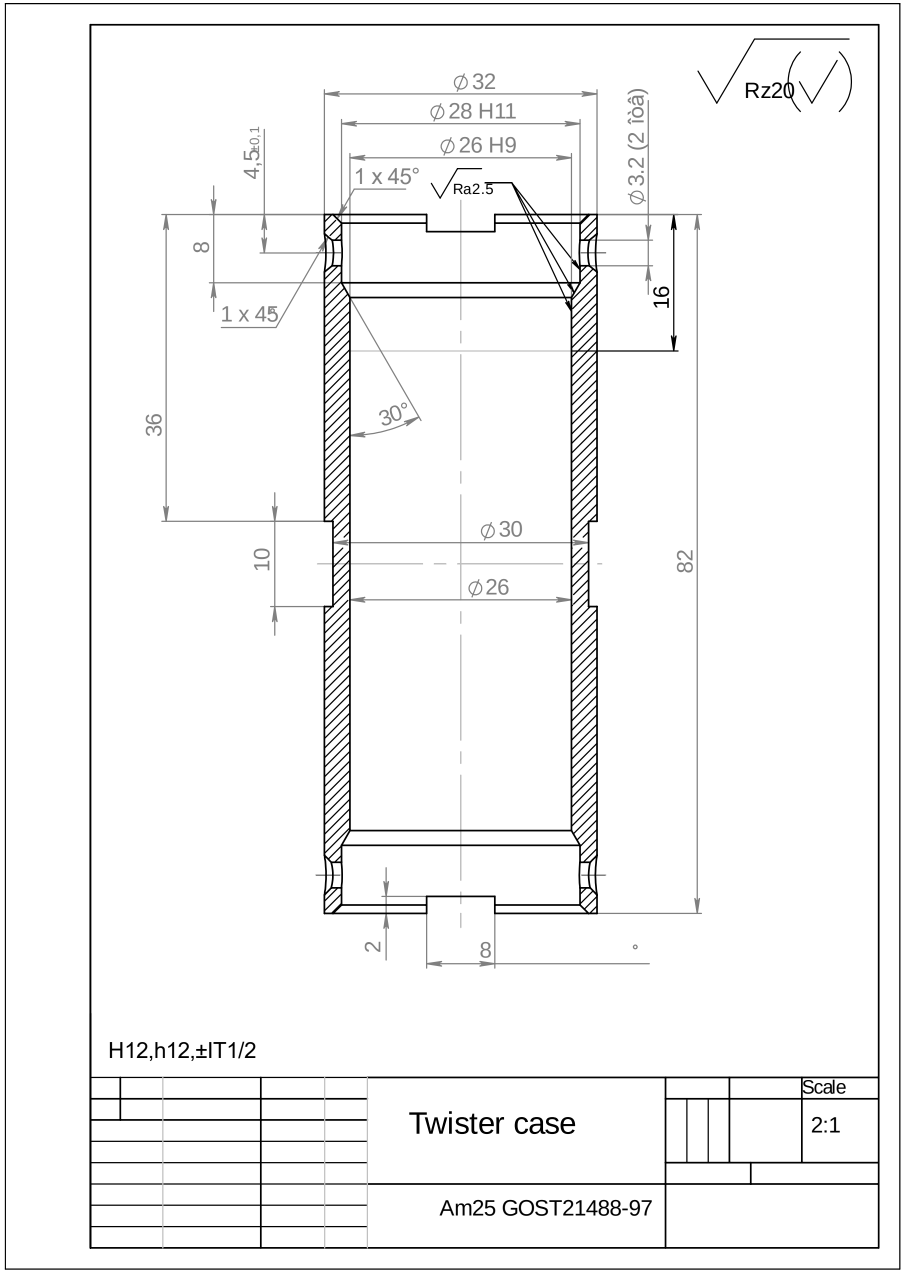
Appendix C. Budget

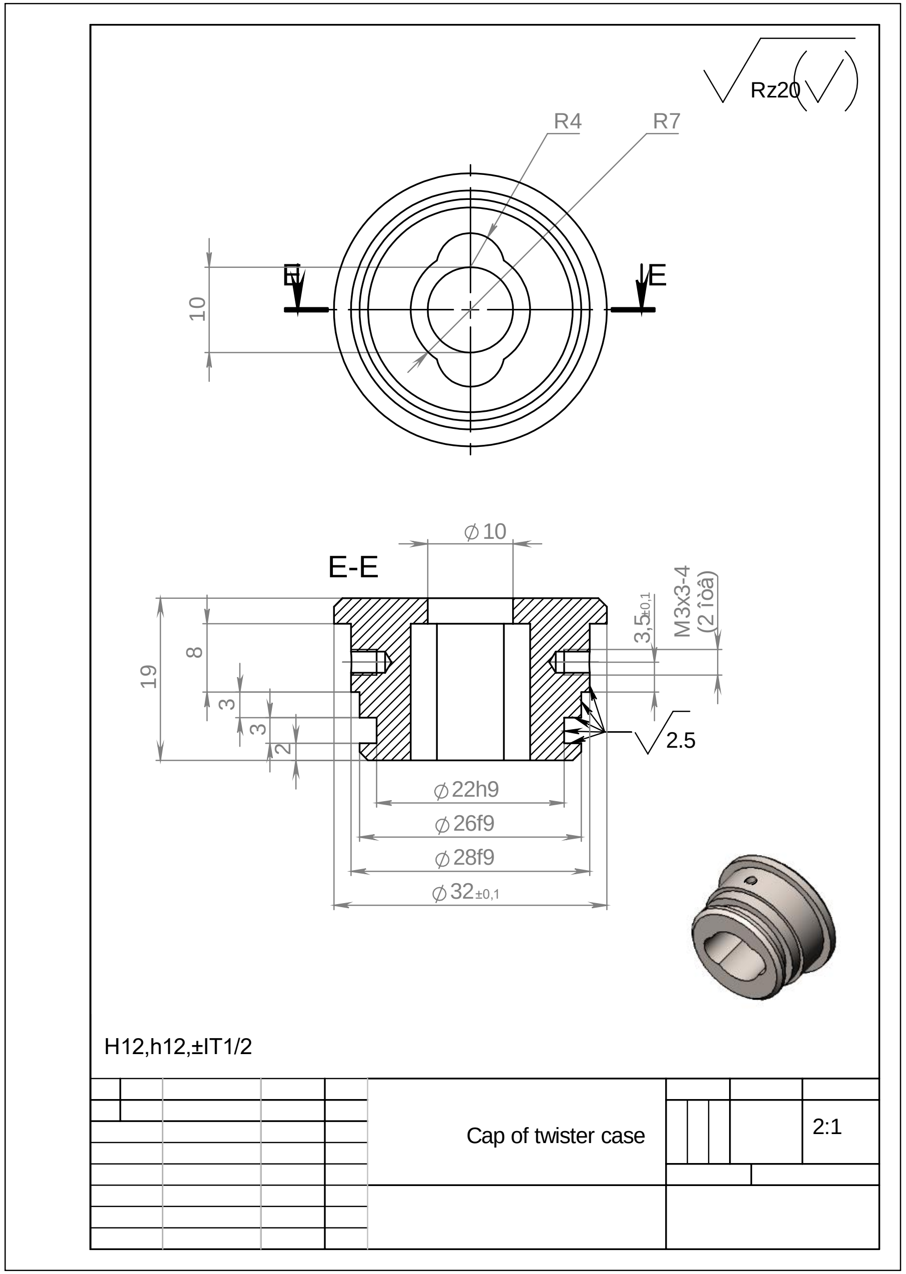
Type	Category	Expense	Description	Notes	Amount	Running Balance
Purchased	Payload tool	Services of the turner	Manufacture of leveling OBS system	For leveling OBS system	$ 191,67	$ 191,67
Purchased	Payload tool	PVC pipe	Material for leveling OBS system	For leveling OBS system	$ 33,33	$ 225,00
Purchased	Payload tool	Thrusters	4 thrusters for leveling OBS system	For leveling OBS system	$ 15,33	$ 240,33
Purchased	Payload tool	Piezo receiver/transmitter	Receiver and transmitter of acoustics signal	For lifting bag ystem	$ 8,50	$ 248,83
Purchased	Payload tool	Electromagnet	Electromagnet	For OBS connector	$ 15,00	$ 263,83
Purchased	Onboard electronics unit	Acrylic flask	Flask onboard electronics unit	For sealing of onboard electronics unit	$ 7,50	$ 271,33
Purchased	Onboard electronics unit	Rubber sealers	Sealing of onboard electronics unit	For sealing of onboard electronics unit	$ 41,67	$ 313,00
Purchased	Onboard electronics unit	Metal cover	Cover for onboard electronics unit	For sealing of onboard electronics unit	$ 3,33	$ 316,33
Purchased	Onboard electronics unit	NanoPi NEO	Single board computer	For ROV control system	$ 33,33	$ 349,67
Purchased	Onboard electronics unit	Debug board NanoPi	Debug board for testing		$ 14,17	$ 363,83
Purchased	Onboard electronics unit	Navigation and flight sensor	Navigation and flight sensor	For receiving telemetry of ROV	$ 66,67	$ 430,50
Purchased	Video system	Digital cameras	2 digital cameras	For obtaining video from ROV	$ 120,00	$ 550,50
Purchased	Video system	Analog cameras	2 analog cameras	For obtaining video from ROV	$ 16,67	$ 567,17
Purchased	Control box	Connectors	Connectors for cable		$ 6,83	$ 574,00
Purchased	Thrusters system	Thrusters	8 thrusters of ROV	For movement of ROV	$ 745,33	$ 1 319,33
Purchased	Travel	Trips to the swimming pool	Trips for trainings		$ 50,00	$ 3 369,33
Purchased	Travel	Visa	Visa for travel		$ 833,33	$ 4 202,67
Donated	Mentors	Mentors support	Mentors support		$ 2 000,00	$ 3 319,33
Re-used	Control box	Control box	Control box	For ROV control system	$ 500,00	$ 4 702,67
Re-used	Control box	Cable	Cable to connect ROV	For connecting ROV	$ 83,33	$ 4 786,00
Re-used	Payload tool	Manipulator	Manipulator	For relocation of objects in water	$ 1 250,00	$ 6 036,00
				Total Raised:		$-
				Total Spent:		$ 6 036,00
				Final Balance		$ 6 036,00

Appendix D. Project costing



Appendix E. Gantt Chart





Appendix F. Twister's cap and case