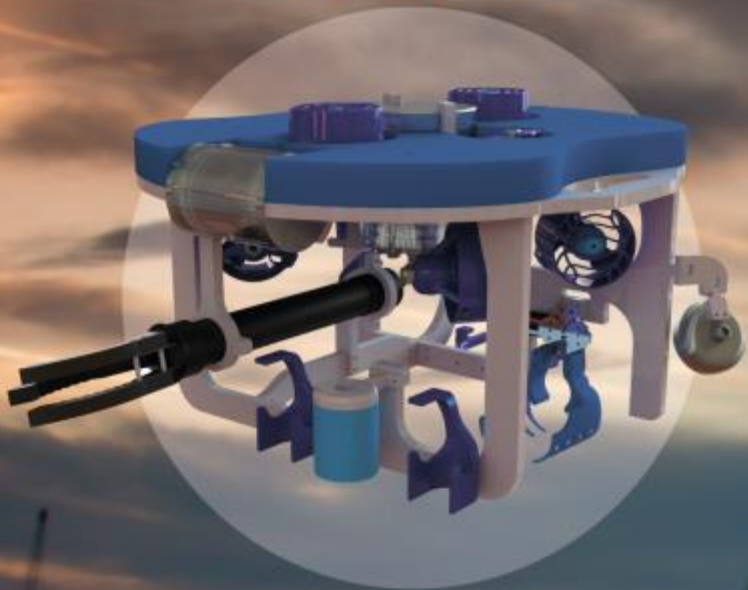
COMPANY robocenter

VLADIVOSTOK, RUSSIA

Technical Documentation

MATE, 2017

GlueROV



Company Members	Role
Anton Lobov	CTO
Anton Iakovivskiy	Programmer
Aleksey Kozhushko	Electronics
Daniil Proshin	CSA
German Berdnikov	CFO, Programmer
Iaroslav Proshin	CEO, ETO
Ignat Lebedev	Engineer, Designer
Ivan Apanasevich	Engineer
Kirill Leontev	Designer
Sofia Sulzhenko	Engineer, CPO

Mentors

Sergey Mun, Angelina Borovskaya

THE CENTER FOR ROBOTICS DEVELOPMENT

Table of contents

Abstract

Our company is named LLC Robocenter, we come from Vladivostok and have taken part in MATE ROV Competitions for the third year. During this period of time our staff has been almost completely renewed. Only two members survived from the original 2015 staff. Our primary objective in participating in competitions is to get engineering and team work experience.

This year competitions are devoted to servicing Long Beach Port using ROVs. We have designed a new vehicle, capable of fulfilling all this year's tasks. For the purpose, we have designed and made a great number of various dedicated payload tools and mounted these on our robot. Also, this year we have renewed most parts of the vehicle to meet new requirements: thrusters, video system, electronics unit, frame, tether, surface equipment, completely re-wrote software for the robot and the pilot.

Our vehicle "GlueROV" is made predominantly of strong pressed polypropylene and fitted with three cameras, two manipulators and a lot of payload tools. The vehicle buoyancy is made of extruded foam polystyrene and additionally strengthened. Most of electronics is accommodated in the electronic unit, made of acryl and aluminium.

Eventually we acquired tremendous experience in various technical and technology fields. We made, admitted and pondered over a lot of mistakes in management and inter-personal relations. But most important is that we came to understanding that there's a lot we're not aware of, and that we need to study more and harder.

Figure 1. Photo of the Robocenter company staff with GlueROV (standing: Sofia Sulzhenko. Ivan Apanasevich, Daniil Proshin, German Berdnikov, Alexei Kozhushko, Anton Iakovivsky; sitting: Ignat Lebedev, Anton Lobov, Iaroslav Proshin, Kirill Leontev)

Mission theme

This year's tasks are devoted to the Long Beach Port service. This is very complicated mission which consists of environmental observations and building assist. It demands a multifunctionality of our ROV and complex development of all our systems to fit requirements. Having read tasks description, we searched for cases in Vladivostok (because this is the port city) of using ROV in underwater buildings [1], [2], environmental analyse and cleanup [3], sea flora and fauna investigations [4], [5]. Also, we have met with creators and real users of ROV to get their experience of working with it. Analysis of industrial, scientific technical solutions and real practice of using ROVs allowed us to create more efficient payload tools and ROVs systems.

Design rationale

Start of the project

We had started this project and designing the vehicle one month before this year's rules and mission were published. During this month, the team was being shaped, our requirements to the future vehicle were being defined, and challenges we'd like to meet were being worded.

First of all, we decided that we wanted to do as much independent design/manufacturing as well as organizational work as possible. To make the vehicle capable of performing all the tasks within the time limits set. To handle all project design and management issues up to top professional standards.

Once this year's Technical documentation score sheets were released we first developed several use-case models to understand which of tools would be needed to complete the mission. Each task was thoroughly examined, principles of its performing were discussed, brainstorming took place, consequence of fulfilling the tasks were thought over. And a month later we agreed upon the final version of a use-case model with a complete list of payload tools.

We started development of the vehicle from its payload.

Commerce: Hyperloop construction	
Inserting rebars	Bottom grabber
Installing the frame	Main manipulator
Removing a pin	Main manipulator
Mounting hose with concrete	Main manipulator
Beacon collection and transportation	Hook & loops
Entertainment: operation of a light show	
Disconnecting the power cable	Bottom grabber
Turning the valve	Main manipulator
Disengaging the locking mechanism	Main manipulator
Removing the old fountain	Main manipulator
Installing the new fountain	Fountain holder
Re-engaging the locking mechanism	Main manipulator
Turning the valve	Main manipulator
Reconnecting the power cable	Bottom grabber
Returning the old fountain	Main manipulator
Health: environment protection	
Contaminated zone scanning using Raman-spectrometer	Flashlight
Collecting 100ml of samples from contaminated zone and its delivery to the surface	Agar collector

Collecting 2 molluscs and their delivery to the surface	Bottom grabber
Placing a cap over the contaminated area	Main manipulator
Safety: risk mitigation	
Locating 4 containers	Rotate camera
Container scanning	Camera
Identifying a contaminated container	N/A
Mooring a buoy marking the contaminated container	Main manipulator
Identifying the distance from the contaminated container to others	Special software

Table 1. Use-case model

Payload

Having discussed last year mistake we have arrived at a conclusion that the most incorrect and critical solution of the previous year was relying upon a universal device and attempting to complete almost every task with it. So, this year we decided to pay special attention to the development of specialized, specific task-tailored tools. Prior to developing attachments of our own we had studied research papers, video materials on performing industry (underwater construction, underwater structure monitoring) and environmental protection tasks.

Manipulator

Having walked through the mission in detail and while developing a use-case model we noticed that practically half of the tasks could be completed with the help of our previous year's manipulator. Moreover, it's this manipulator that could allow the quickest and best task completion. If we had opted not to use the manipulator, we'd have had to manufacture a number of attachments of worse efficiency and to spend more resources for their development and make.

Therefore, having compared advantages and disadvantages of our (a re-used item) two degrees of freedom manipulator RovBuilder we decided to keep it.

However, a single manipulator is not enough to complete so many missions within a limited period of time, so here's our next payload tool is the bottom grabber.

Bottom grabber

Having analysed all the tasks we found out that disconnecting/connecting power cable in task «Entertainment: Light and Water Show Maintenance» and collecting clams in «Health: Environmental Cleanup» were very similar: it's necessary to grab an object or objects from the bottom and hold these for a long time. So we decided to make a separate tool for these tasks, as the manipulator is almost all the time employed. Through a brainstorming, we arrived at three options: a bottom grabber; a small cavity with a hook, grabbing objects; a manipulator and a basket.

We failed to make a satisfactory model of the cavity, while the manipulator-and-basket option shows worse time compared to other ideas, therefore we decided to make a bottom grabber.

We used a standard Arduino grabber and modified its claws (printed on 3D-printer), had these tailored for quick lifting and safe holding of objects: power cable and clams. As a motor, we used an ordinary servomotor that we sealed on our own.

Though the bottom grabber is one of the most convenient tools to collect tiny objects from a pool's bottom it features rather a small area of collection, that's why we decided to use a hook & loops which makes the next part of payload tools for our ROV.

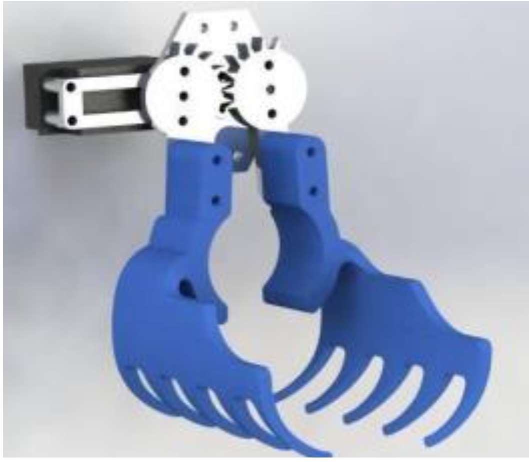


Figure 2. 3D model of the bottom grabber

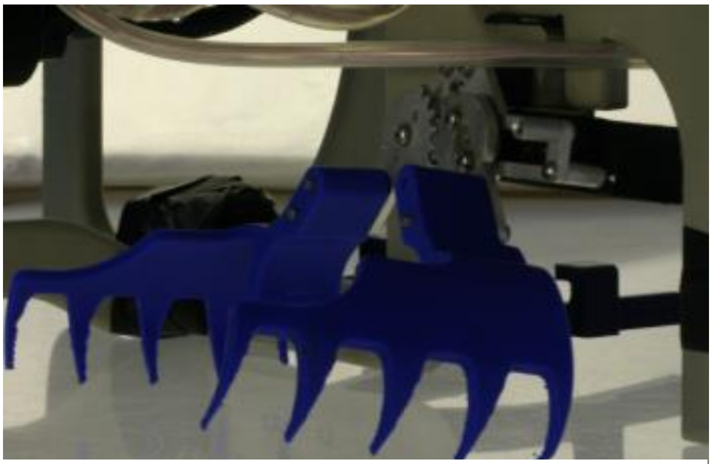


Figure 3. Bottom grabber, mounted on our vehicle

Hook & loops

Task one - «Commerce: Hyperloop Construction» implies that the vehicle has to collect positioning beacons. These are pieces of polypro tube 0.06m long and 0.03m in diameter. It took time to find a solution to the task (a cavity, a manipulator, a bottom grabber, studs, etc.), and eventually realized an evident fact. A piece of Hook & loops 0.05x0.02m is stuck at the side of each beacon. We decided to make use of the feature and to stick a reverse side of Hook & loops at the side of the vehicle. Trials proved this to be a very reliable and fast method.

Agar collector

Task 3 «Health: Environmental Cleanup» implies collecting 0.0001m^3 (100ml) of jellylike sample of contaminated sediments simulated by boiled agar. The task raised huge amount of discussion, and various solutions were proposed, ranging from backfill syringe to ratchet brace.

We argued at length about it and couldn't arrive at a common opinion. So, we opted an experiment as a means to find the decision. We boiled some agar and just for fun tried to collect it with an ordinary empty can. Surprisingly it worked. We repeated the experiment with the same positive result. Thus, we made our Agar collector at minimum cost.

Agar collection is also accompanied by scanning two vessels with this substance by means of the flashlight.

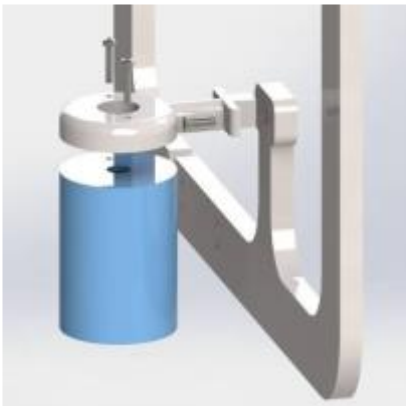


Figure 4. 3D-model of agar collector

Flashlight

Task 3 «Health: Environmental Cleanup» implies investigating a contaminated sediment area, scanning contaminated zones (vessels with agar) by means of Raman-spectrometer, which can be simulated by a flashlight or a laser. As the flashlight is easier to make and doesn't require any special documentation we chose to make a flashlight. In order not to increase the number of couplers in the electronics unit we placed a LED into the rotate camera, which is described in chapter «Video system».

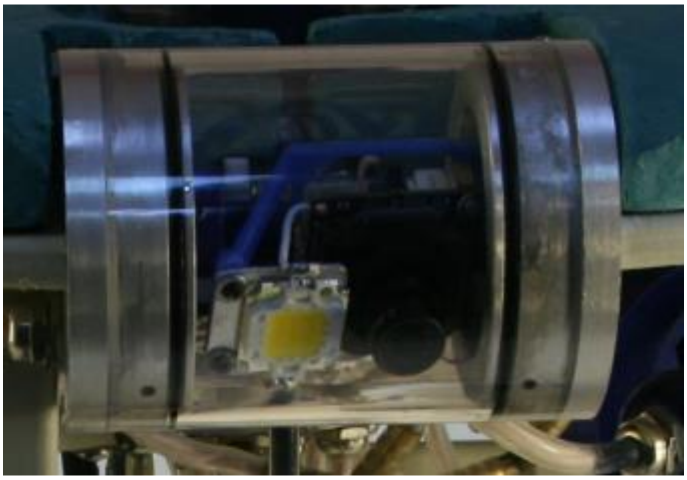


Figure 5. Flashlight, placed into the rotate camera housing

Fountain holder

In task «Entertainment: Light and Water Show Maintenance» the vehicle has to pick up from the surface a fountain puppet and install it onto a special platform. Our company had several ideas how to complete the task: using a manipulator, using a bottom grabber, making a separate tool to have fountain installed. Accounting the high workload of the former two, we decided to develop a separate tool for having the fountain installed. It had to meet the following requirements: to safely hold the fountain, easily remove the fountain when installing, be a mechanical one. As a result, we made an attachment looking like sledge on which a fountain is securely held by means of friction force, and easy to be removed from the sledge after installation. The holder was completely printed on the 3D-printer.

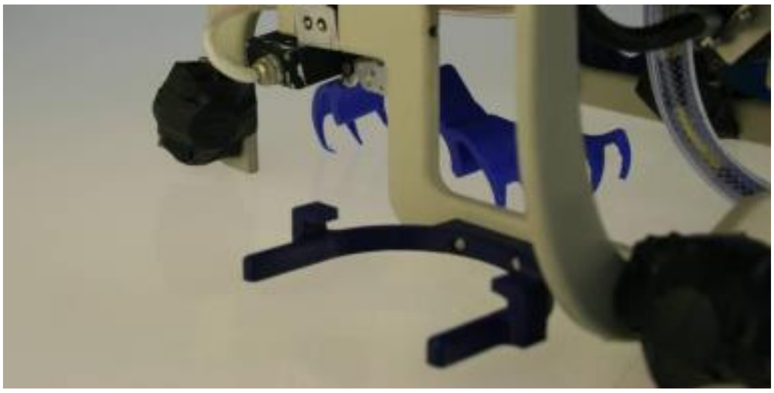


Figure 6. Fountain holder, mounted on the vehicle

Buoy

In Task 4, upon identifying the most hazardous container, a marking buoy should be affixed to the latter, so that it makes no difficulty to locate this container from the surface. The container has a U-bolt, to which the marking buoy is to be affixed.

We invented several variants of securing the buoy to the U-bolt: by means of a latch hook, by means of magnets, by means of retracting mechanism looking like an arrow. We implemented all the variants and tested these under water. Magnets tended to magnetize poorly, while an «arrow» was hard to hit into the U-bolt. So, we chose a latch hook which is easy to be affixed to the U-bolt.

As both the latch hook and the buoy are to be separated from the vehicle, these when engaged should have neutral buoyancy not to create additional listing/trimming. Therefore, we made the buoy from extended foam by ourselves, so that it would completely balance the negative buoyancy of the latch hook and the rope.

Also, container-related is the next payload tool, which work is done not on the vehicle but on the surface equipment with the help of specialized software.

Program for calculating container positions

Task 4 «Safety: Risk Mitigation» requires finding out and indicating the distance from the centre of the most hazardous container to the centres of the three least hazardous containers, followed by identifying their position relative to the line seeking north and draw a graphical scheme of all the containers' position, having identified their direction. To have this task completed we decided to work out a special program, processing photo images of containers, instead of payload, such as is a tape ruler. Thanks to it we could save much time and start next tasks faster. For an accurate calculation, we need a distortionless camera and also a reference object of an exactly known size.

Work with the program includes several steps:

1. Taking a picture of containers (a screenshot video).
2. Highlighting a side of the reference object. The program calculates its size in pixels.
3. Calculating necessary distances.
4. Highlighting a line in the photo seeking north.
5. The program will schematically redraw containers, indicating their direction.

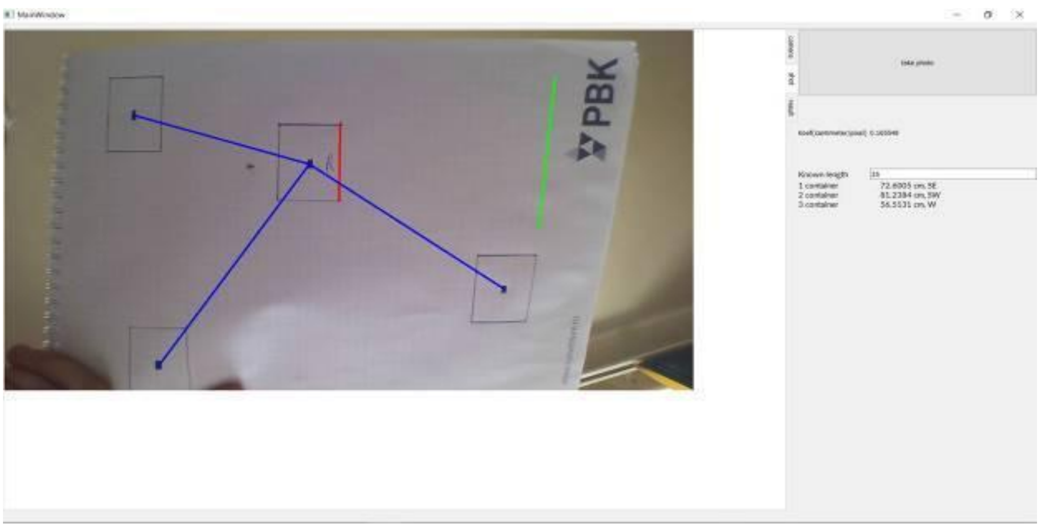


Figure 7. Program for calculating container positions (highlighting an object and directions)

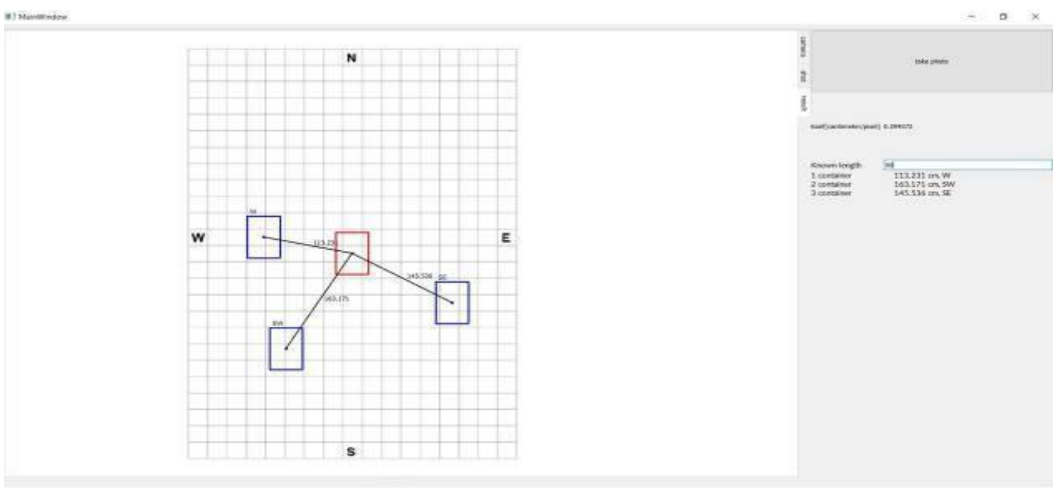


Figure 8. Program for calculating container positions (schematically redrawing containers)

To have containers photographed and all the payload tools reviewed we need video cameras. The next part of the presentation is devoted to video system.

Video system

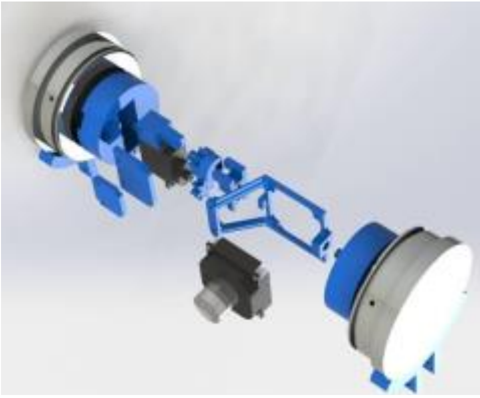


Figure 9. 3D-model of rotate camera

Figure 10. 3D-model of bottom camera

Right after the entire payload tools were designed, we fronted the following problem: to locate all the attachments and cameras in such a way that all the payload is visible to the pilot, using as few cameras as possible. We tried many layouts of the tools and cameras. Eventually we achieved the desired result, having minimized the number of cameras to three: front rotate, bottom and rear ones.

The rotate camera is aimed at orientation in space and observation of the payload in the vehicle's front: main manipulator, tool for inserting rebars, agar collector.

The bottom camera is used for taking pics of containers, and it is looking at the bottom grabber and hook & loops.

The third camera is placed on the outboard mount behind the vehicle and is looking at fountain holder.

We formulated the following requirements for the rotate camera: camera to rotate 120° downwards, it should carry a LED and it should have a viewing angle of not less than 120°.

The housing consists of an acrylic tube and two aluminium covers of our own design, having calculated grooves for sealing rings. To have camera rotated we use servo and pinion drive. LED is mounted on a heat dissipating plate. The camera is mounted on the supports close to bulbs, so that due to a wide viewing angle the housing covers would not get caught in the lens.

Prior to designing the bottom and rear cameras we'd formulated our requirements to these: we must make them ourselves, having minimized the size, and the housing must be easily and quickly dismantled.

Camera housing consists of an acrylic cupola, aluminium casing and a hold-down nut. We designed it in such a way that its lathe-machining is inexpensive. The cupola allows for minimizing the camera weight as it covers the protruding part of the lens and there's no need cover it by housing walls. A hold-down nut allows for a prompt access to the camera. We placed board cameras, which are perfectly intact from the previous year's vehicle and satisfy our specification requirements, inside the housing, while the new ones are rather expensive. We haven't even tried to consider purchasing off-the-shelf cameras, because cameras available on the market do not suit our needs. We understood that if we make our cameras ourselves these will meet all of our requirements.

Video system is one of the most important parts of the vehicle as it is it that the first pilot relies upon when operating ROV.

Thrusters

After we had designed all the payload and video system we calculated that we need draft of not less than 1kg per one thruster, is we would install 2 vertical and 4 horizontal thrusters. On the market there are off-the-shelf thrusters, e.g. BlueRobotics or SeaBotix, but their delivery from abroad is nowadays a difficult task and these are quite expensive. Furthermore, we were very keen on plunging into the process of thruster building, on studying the theory of main thruster parts' functions and of feeling triumphant when a thruster of your own make propulses the company made vehicle under water surface.

Having studied drawing of thrusters made by such companies as BlueRobotics and SeaBotix, we were inspired to build innovation thrusters meeting or exceeding their compatibles in particulars.

We have chosen for our thrusters watertight motors of ROVMAKER Company, especially designed for underwater vehicles.

Watertightness of the motor freed us from casing tightness, that's why we printed parts on the 3D-printer. We had to seal only motor contacts and prevent water from ingress into electronics unit through the tubes connecting the motor and the unit.

The thruster, apart from motor, consists of six components: a flange, coupled with securing; a casing; a retention ring; a screw; a boss and a mesh.

We chose 3D-printing for the ease and promptness of prototyping, for inexpensiveness of manufacturing and small resulting weight.

The motor was on purpose developed to be as compact as possible to score additional points for vehicle size and weight.

Screw particulars were chosen via experiment: each screw was printed on 3D-printer and bench checked.

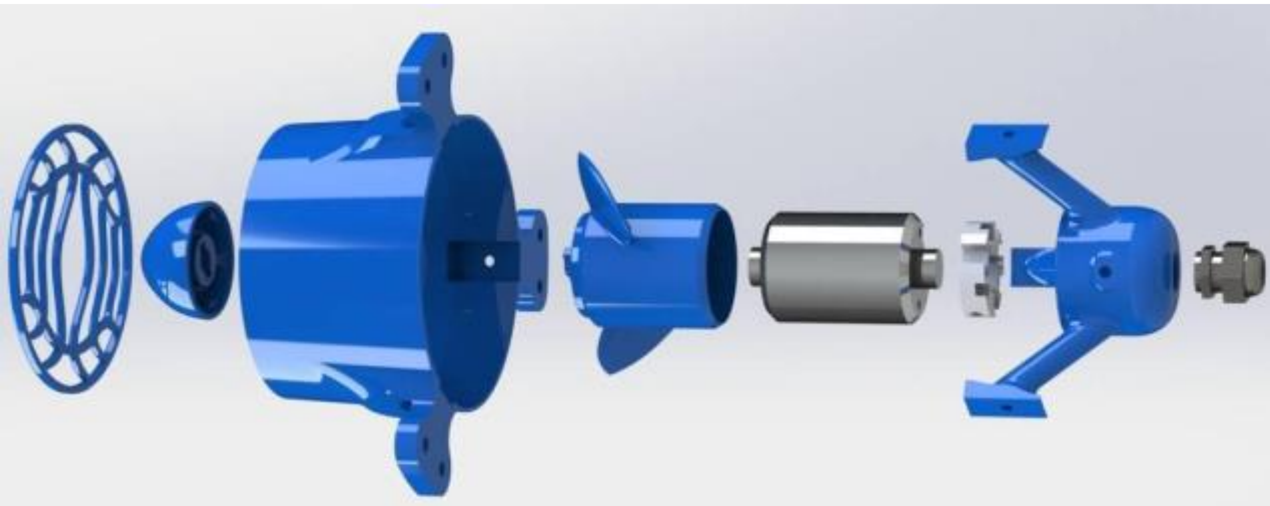


Figure 11. GlueROV's thruster model (disassembled)

SID

Having analysed all the payload and attachments our company developed SID.

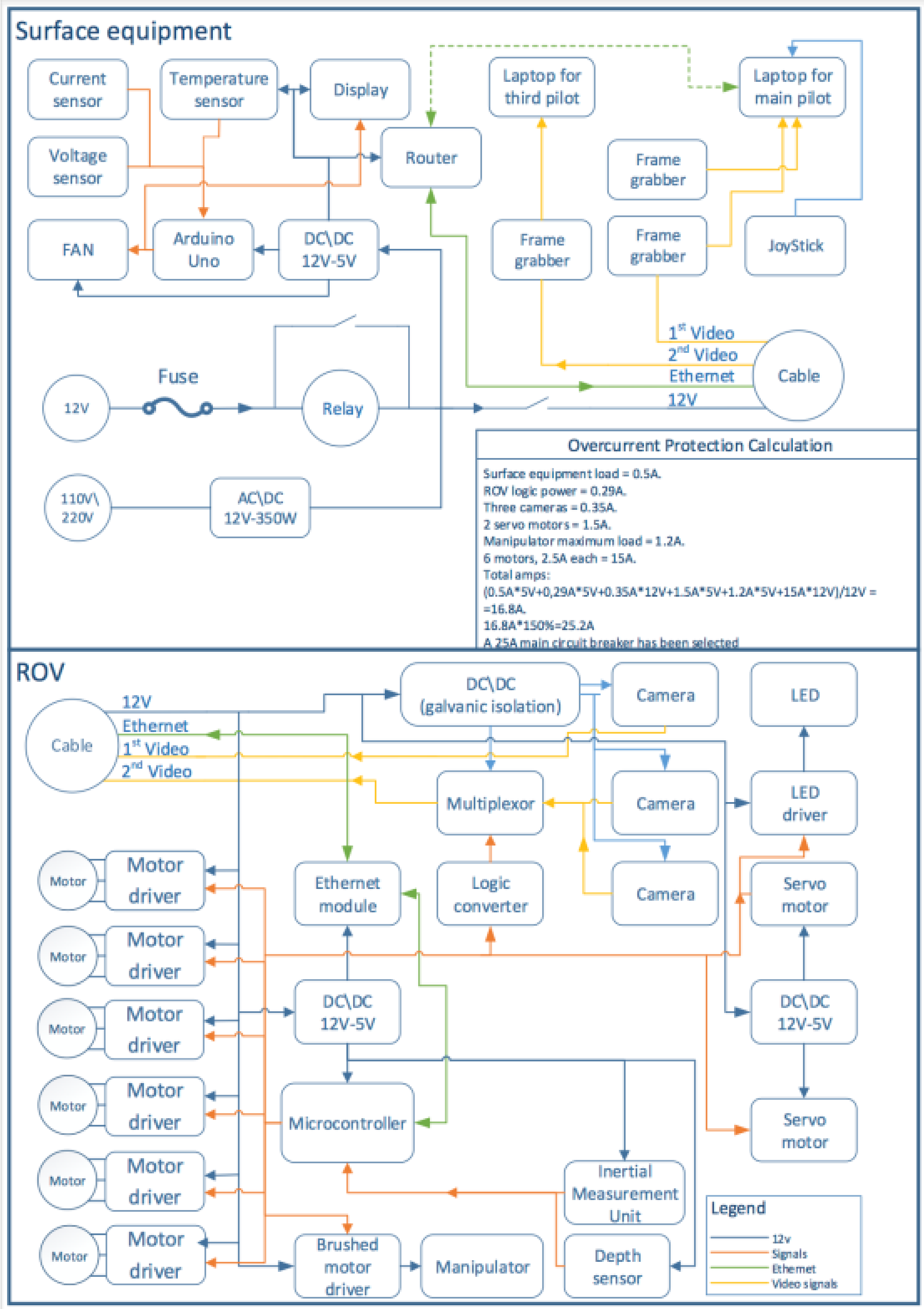


Figure 12. System Interconnection Diagram

Electronics unit

For the electronics unit, we independently made all the cards in Altium Designer and placed an order for their manufacturing via TaoBao, to gain an experience in electrical card development and reduce the end device size.

The electronics unit consists of two boards of our own design, 6 drivers of brushless motors and a networking card.

Our first board hosts microcontroller Atmega 2560 that controls all the peripheral devices and provides for communication with surface equipment by means of networking card based on Wiznet 5500 microchip. The board also carries navigating-piloting sensor GY-80, allowing for course and trim stabilization. To operate the main manipulator, we use a bi-channel driver of brush motors L298p. Moreover, this board provides for galvanic isolation of video system power supply and logic, thus ensuring stable power supply for all cameras and elimination of distortion occurring in the main power supply line with working propulsion and other systems fed with heavy currents. This ensures comfortable piloting (no distortion of images) and video system long life.

All the wires of the tether and peripheral devices are brought in through the same cover, therefore it was very important to provide for arranging these wires throughout the electronics unit. This is a function of the second board having necessary number of contacts and couplers to connect all the wires brought in from the side of the cover and from the side of the first board.

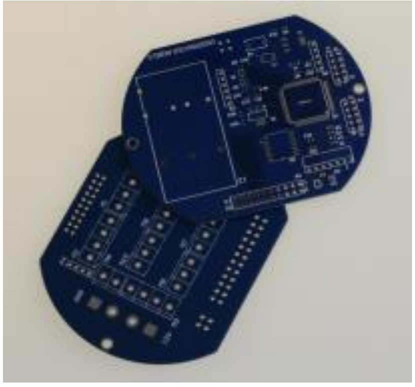


Figure 13. Our custom circuit boards

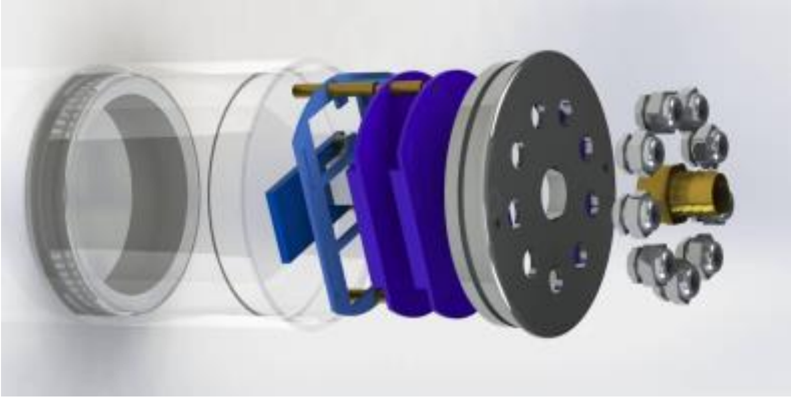


Figure 14. Electronics unit housing model

Sensors

IMU

To find bearings in space and operation in automatic modes we decided to use IMU GY-80. This sensor incorporates three-axis accelerometer (ADXL345 chip), gyroscope (L3G4200D chip) and compass (HMC5883L chip).

Accelerometer ADXL345 measures acceleration along three axis and is a microelectromechanical system (MEMS), possessing both electrical and mechanical parts.

Figure 15. GY-80 IMU

The mechanical part provides for movement of inertial mass, while the electrical one converts this movement into a value by means of changing capacity, piezoresistive or piezoelectric effect. Gyroscope has a similar construction, but it returns the velocity of angle change along three axes. Operation of compass is based on crystal anisotropy and, in particular, on the property of some of these to change their resistance under effect of weak magnetic field.

Depth sensor

This year for the sake of piloting convenience the company installed pressure sensor on basis of MS5803 chip to provide for the vehicle's stabilization as per depth.

We etched away the chip card, soldered components and placed the card into a watertight casing printed on 3D-printer.

Figure 16: Depth sensor

Watertight housings

There are two types of watertight housings in our vehicle that we designed ourselves: a bulb with caps for autopilot and rotate camera and housings for stationary cameras. Water ingress inside the devises is crucial, so we treated watertightness issues very carefully. We used radial sealing in autopilot and rotate camera housings, and for the purpose when designing covers in SolidWorks we calculated a groove for sealing rings. We stated the depth, diameter and allowances of the rings strictly up to GOST (Russian Standard System). A stationary camera housing uses a face seal, again calculated strictly up to GOST. The sealing ring in a stationary camera is tightly pressed by a nut. After making a model we produced drawings and gave these to a machine shop for manufacturing. A sample of the drawing is given in Supplement 1.

For securing all the watertight housings, payload, cameras and thrusters the company developed its own innovation frame.

Frame

Even before the rules became available we set an objective to ourselves: to score maximum additional points for vehicle size and weight. We started designing the frame with a horizontal plate, we built a circumference of 0.48m in diameter not to exceed the size stipulated by MATE. The plate secures: autopilot, all the 6 thrusters, rotate camera, bottom camera. The frame sketch indicated the flows of water from motors so that there's no obstruction for these. To ease carrying we provided for comfortable ergonomic handles. When designing frame fins we made use of the payload layout. We created this layout when deciding on camera number. Each of the three fins is loaded with various clamps and attachments to maximum degree.

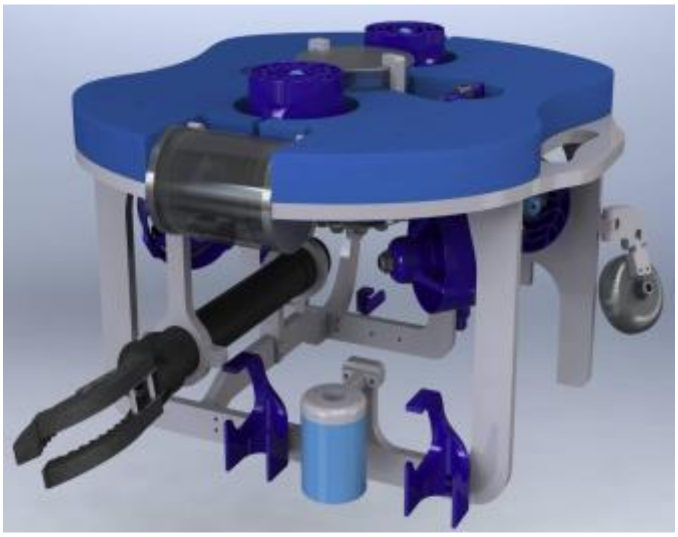


Figure 17. GlueROV's 3D model

Tether

The tether connects our robot with surface equipment. The tether conveys electrical power supply, control signals and video data.

When selecting the tether, we started out from optimum ratio of voltage drop, thickness and flexibility.

A heavy and rigid cable impedes control and worsens vehicle’s manoeuvrability and propulsive performance.

We transmit data via two twisted pairs, and video – via coaxial.

We built the tether independently: bought a garden hose, drew a metal wire through it, tied wires to it, lubricated these and drew threw the hose.

Nevertheless, the main function of the tether is unchangeable – connection between the vehicle and surface equipment.

Surface equipment

Surface equipment is necessary for switching on/off and controlling the vehicle, power supply to ROV, voltage and power consumption monitoring, video signal digitizing.

Figure 18. Surface Equipment. Backwards

Vehicle power supply can be done in two ways: with an AC-DC supply from ordinary 110V or 220V socket coupler or from an external power supply of 12V. AC-DC supply is needed during the pilot trainings, as it eliminates the need to carry an extra external power supply unit along with surface equipment. External power supply is needed during MATE competitions.

To facilitate transportation, we placed all the surface equipment but for the joystick and laptops, into a separate watertight and crushproof case.

Figure 19. Surface Equipment. From above

Complete monitoring of ROV voltage and power consumption is facilitated by Arduino, which also adjusts the speed of the built-in fan and outputs the data on electrical power supply and temperature inside the case on a special screen.

We decided to install a Wi-Fi router into our case which allows for controlling the vehicle from any computer/laptop over any distance, even via Internet.

To have video from the vehicle digitized we installed two AverMedia video capture cards.

We paid special attention to reliability and safety of our surface equipment. We used wires capable of passing a current of up to 50A, high quality mechanical buttons, AC-DC power supply unit of Platinum category from MeanWell Company. We implemented the principle of complete disconnection for every component.

The rest of the surface equipment, i.e. the laptop requires own original software (hereinafter – surface software) for the purpose of controlling our innovation ROV.

Surface software

At the beginning of the year we analysed surface software of the previous years. We also discussed with our last year's pilot all the advantages and disadvantages of the 2016 robot control. This helped us work out main requirements to the software on the pilot's side: to minimize pilot's actions for creating control, reduce the amount of information distracting the pilot from piloting.

Thanks to convenience of making graphic interface and a great number of various libraries we chose shareware framework Qt, version 5.7.

For communication with the vehicle we chose to use UDP Protocol, and developed our own data batch for it. We also implemented multithreading to have in future the computation load on the program increased without causing problems to the graphic interface operation.

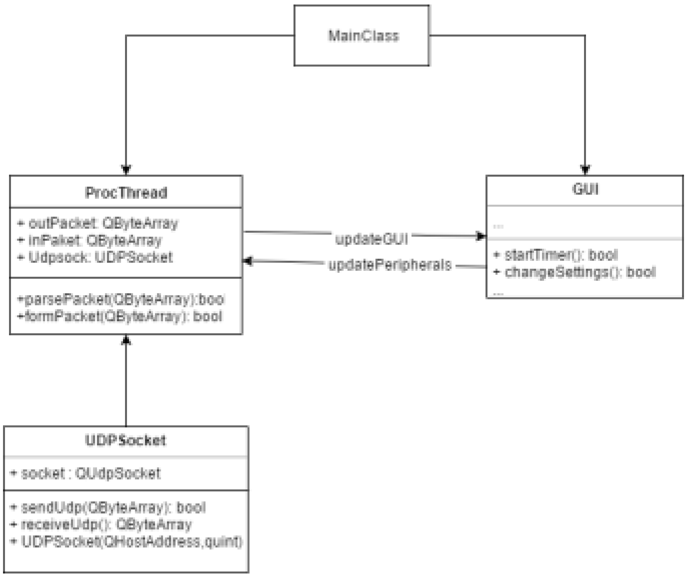


Figure 20. UML diagram of surface software

UDP batch from surface software is later received by the vehicle using its own software called on-board software.

On-board software

On-board software is written for the on-board microcontroller to solve the following tasks: motor control [6], obtaining data from sensors (magnetometer, depth sensor, gyroscope and accelerometer), and electrical working load control.

Data from sensors are double-filtered through median filter and Kalman filter (implemented via free library Arduino), facilitating obtaining accurate values without physical errors and sensor's own inaccuracies. Afterwards the data collected are sent via UDP Protocol to the surface software in the pilot's laptop.

As is seen from the flow-chart, the principle duty of software is collecting data from all the sensors, receiving the input UDP batch, sending output UDP batch and control of propulsion system. In case stabilization is switched off the control of thrusters and all the payload on the vehicle is carried out in compliance with the input batch values. With stabilization switched on, calculation of discrepancies (offsets) and control of the propulsion system takes place by means of proportional-integral differential control (PID).

For easy and prompt cross-flashing of the microcontroller we used TFTP bootloader [7], which helps upload new versions of software on our ROV via Ethernet without the need to autopilot's exposure. 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.

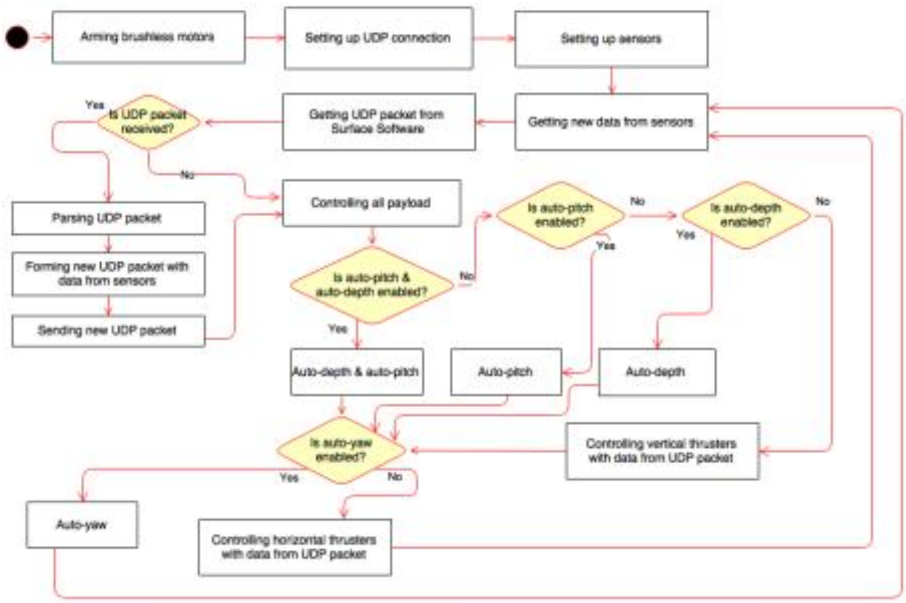


Figure 21. On-board software diagram

Safety

Safety provision is one of the top priorities of our company. We decided that all our processes should strictly but reasonably meet main safety requirements: those by Center for Robotics Development, MATE Center, and our own.

First and foremost, experienced participants and mentors briefed the newcomers on how to use protection gear (overalls, goggles, gloves, breathing mask inhalers, etc.), on how to work with electrical equipment, and forming tools. We demanded from each other that our work places to be kept in good order. Our philosophy with respect to safety can be stated as follows: «Awareness, order and checking are the basis of safety».

Our vehicle was built in full compliance with MATE safety standards: all the electronics and wires sealed, the vehicle consumes current of not more than 25A, vehicle voltage is not more than 12V, the frame is built with no sharp angles nor undulations, thruster propellers protected with mesh. Prior to and after operation of vehicle in water functioning of all systems is checked according to the check-list as worked out by us.

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			

Table 2. Safety checklist

Critical analysis

Testing and troubleshooting

A skill of great importance at the stages of assembling and testing is that of preventing mistakes in assembling and of correcting these. For the purpose, we worked out algorithms for debugging and troubleshooting. A problem-solving algorithm for every aspect of a robot building is approximately the same.

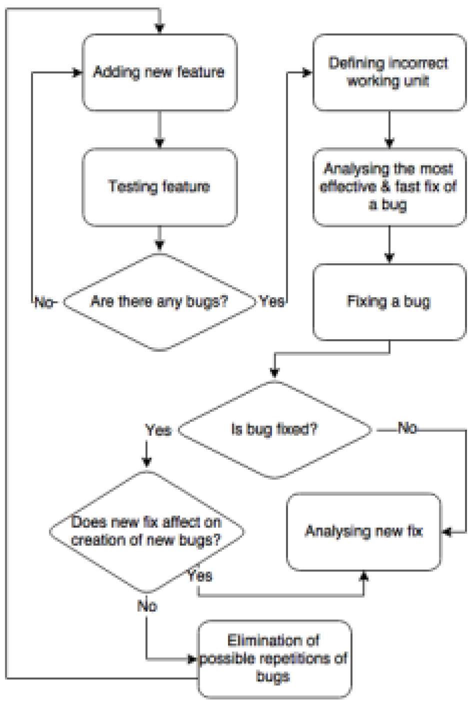


Figure 22. Debugging algorithm

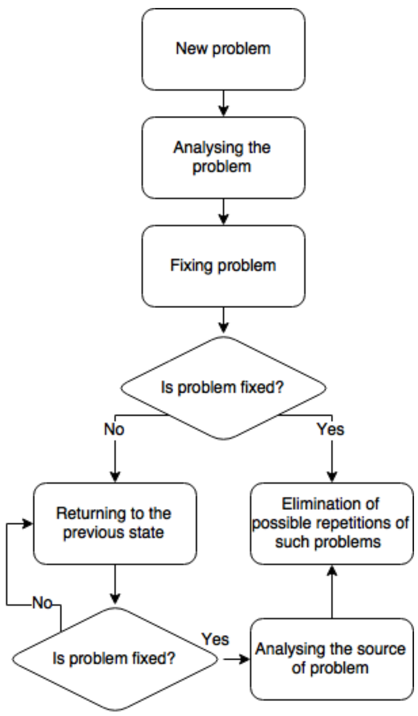


Figure 23. Troubleshooting algorithm

Challenges

The longer the tether, the more difficult it is to maintain stable electrical power supply to the vehicle, therefore one of the challenges was to design and make electronic components in such a manner that with the tether of 20m length there were stable 12V or 5V at the peripherals’ inputs. We solved the problem by means of galvanic isolation of cameras’ power supply.

Another challenge for us was to make vehicle’s electronics unit smaller in size and the number of various couplers and wires fewer in number, and also to simplify its debugging, assembling and repairing. For the purpose, we’d set a task of developing the cards by ourselves and accommodate all the components on these in the manner most suitable for us.

Throughout the project, we struggled with the major, as we think, problem: organizational challenges. There were huge problems in interpersonal communication in the team. Many team members rarely communicated with each other and did not contribute enough into the team common activities, which was most typical of the beginning of the year. Doing any task or correcting any mistake took us more time that it had been planned initially, resulting in consequent failure to meet the deadlines.

We found a solution to the problem by starting to use the system of collaborative project management “Trello”. We found out that once management went to online mode, staff found it easier to communicate and communicational barriers started to disappear.

Lessons learned

At the very beginning of the project we made prototypes of practically all attachments and newly-developed components. We made these on 3D-printer, and it was rather expensive and took a lot of time sometimes. Or we made these from other materials which again was time and resource consuming. Most of the prototypes were then naturally re-built, and that was actually their function – to evaluate an idea and check the principle of operation. But as we had spent so much effort and money it was hard to refuse them and to proceed to make the final version.

This lesson helped us understand that first prototypes need to be made as fast and cheaply as possible. Re-making these should not make one feel sorry and then we would have a possibility to check and select from a greater number of ideas.

In the course of work, we obtained lots of technical skills. We learned 3D designing in SolidWorks, 3D-printing, learned how to operate some forming tools, got familiarized with some previously unknown for us procedures of underwater vehicle manufacture.

However, it wasn’t only technical lessons that we learned. We learned and realized much about teamwork and project management. And the most important is that we became aware how much we didn’t know in this field. Here’s a vivid example of our typical managerial mistakes.

When we decided to make a company’s logo, we charged one of our staff with the task. For several weeks, he was diligently drawing various sketches and offered us these variants but we didn’t like any. It took a whole month for to understand that we hadn’t formulated any requirements to the logo, hadn’t discussed the company’s mission and objectives, hadn’t agreed upon our preferences as to the design concept. Once we did it we obtained a logo in 3 days, and that was the logo everybody liked.

This and alike situations taught us a very important managerial lesson: you need to thoroughly treat task setting, consider the level of competence of the performer, clarify the main requirements. It would be desirable even to resort to various methods of formulating the problem, e.g. SMART.

Future improvements

Our company has been participating in MATE competitions for the third year and every year a decision is made to use microcontrollers Atmega on board ROV. Such solution has advantages of its own, such as simplicity of operation, of mounting on the card, and of writing software. However, there's a serious drawback in Atmega, namely its performance. Insufficient performance rates of Atmega2560 affected automatic mode operation (stabilization as per depth, course and trim). Propulsion system response to deviations is 0.15sec, which is rather much for instant stabilization. That's why our company plans to install more productive microcontrollers/microcomputers made by BeagleBone, Raspberry Pi and some others, to rectify this drawback, maintaining all the advantages of Atmega.

Teamwork

Our company's staff is 10 people of varied technical and communicative skill levels. Some of the company staff took part in competitions of 2015 and 2016, so there's a constant exchange of experience between the «vets» and newcomers. To have the work efficiently organized we have, first of all, split into 4 work groups: electronics people, programmers for the surface and on-board software, and constructors; newcomers from the beginning had some previously acquired skills in one of the fields, therefore it was not a problem to be divided and every member chose his / her field according to preferences and available skills. Heads were appointed within each group from among experienced participants to be responsible for work allocation within their team and for meeting the deadlines. Deadlines were determined after we jointly did task decomposition and the Captain worked out a detailed plan of work using Gantt chart.

N	Tasks	Beginning	Ending
1	Use-case model	10.11.2016	23.11.2016
2	Payload tools	23.11.2016	16.12.2016
3	Cameras	19.12.2016	06.01.2017
4	Frame	20.01.2017	02.03.2017
5	Thruster	24.11.2016	04.01.2017
6	SID	15.12.2016	04.01.2017
7	Electronics unit	05.01.2017	20.01.2017
8	Control box	05.01.2017	03.03.2017
9	Assembling	06.03.2017	14.04.2017
10	Training	14.04.2017	12.05.2017
11	Training in pool	25.05.2017	16.06.2017
12	Surface software	05.12.2016	06.03.2017
13	On-board software	04.01.2017	14.04.2017
14	Technical documentation	31.03.2017	25.05.2017
15	Presentation	10.05.2017	19.06.2017

Figure 24. Gantt chart for our project

The Captain elaborated the Gantt chart on the basis of the previously gained experience in preparations for MATE competitions and determined bets time periods for fulfilling the tasks needed for the ROV building and the project implementation as a whole.

Throughout the project our company gathered together met once every week (on Fridays) to meet the mentors and to jointly discuss the tasks completed and to tell mentors about the results of the work done during the week. Each week’s meeting was accompanied by discussing new tasks for the heads of groups, which they tried to distribute within their groups in most reasonable manner.

Time-efficient communication between the staff was organized via email and a group organized in VKontakte social network. That also gave us a possibility to promptly exchange documents and photos, solve technical and organizational issues within shortest time possible.

We used Trello as task manager: subordinates regularly reported in it on tasks fulfilled, while heads of the groups and the Captain could at any given time monitor the work progress by the groups and individuals.

With the help of Google Docs, a joint work on technical report was carried out. Technical report was prepared by a group of three: Anton Lobov, German Berdnikov, and Daniil Proshin. Initially all the report parts were distributed among all the company members to write a “raw” text, then the text was corrected, amended and executed by the team of technical report authors.

For the sake of convenient joint development of software our company employed Github. This solution facilitated management to a great extent and consequently raised the productivity of developers. So far there are more than one hundred software updates in our repository already which means that the software is being improved with every new update.

There are 7 project in the repository: 2 projects of on-board software, software for the first pilot for Windows, software for the first pilot for Mac OS X, cross-platform software for simpler firmware update via TFTP bootloader and software for container position calculation. Also at the design stage there’s another project – implementation of the first pilot joystick on the Android platform.

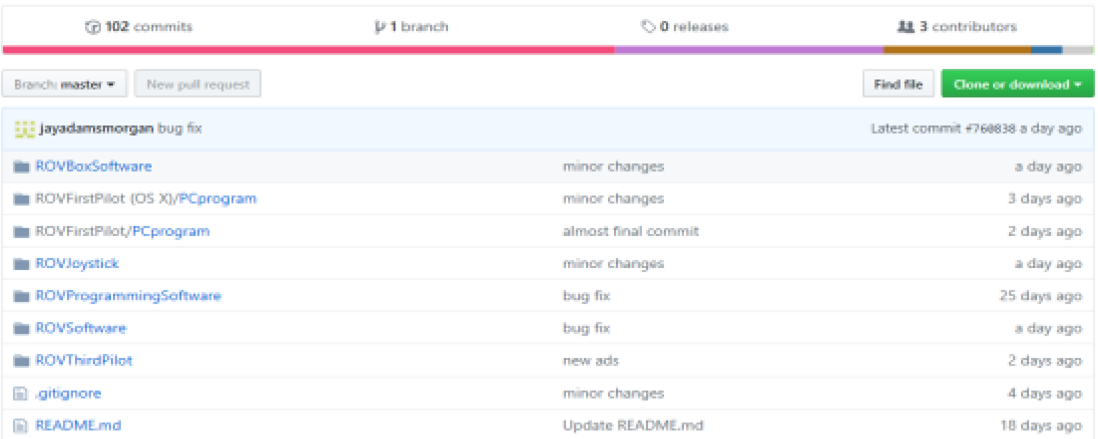


Figure 25. Company’s repository in Github

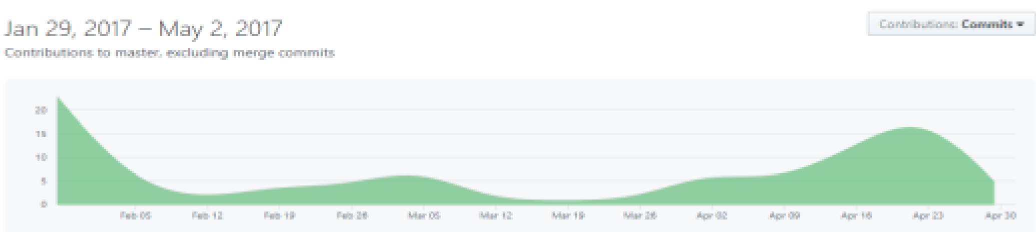


Figure 26. Software update schedule in Github

Accounting

One of the main objectives our company had set was the drive to the ideal cost/quality ratio of the vehicle.

The moneys throughout the development were channelled to us by the Center for Robotics Development. We accounted for every item purchased to the Director of the Center. We also kept strict records and recorded all the expenses into the Google tables.

We had to purchase some items but we didn't buy a single finished product, apart from the manipulator, only components and materials.

The vehicle's overall cost was 2,895.89$, but mere 1,466.75$, for us thanks to contributed or re-used items.

Category	Name	Expenditures, $	Contributed/purchased	Self-cost, $
Electronics	Power supply MeanWell AC-DC	20.29	Purchased	20.29
	Fan 0,06m PWM	3.00	Purchased	3.00
	Joystick	0	Contributed	44.36
	Sensors	56.33	Purchased	56.32
	Tether and wires	3.69	Purchased	3.69
	Mechanical button 30A	5.24	Purchased	5.24
	Manipulator	0	Contributed	887.48
	Microcontroller Atmega2560	15.18	Purchased	15.18
	Module Wiznet W5500 Ethernet	10.21	Purchased	10.21
	Motors	228.44	Purchased	228.44
	Multiplexor AD8184ARZ	2.98	Purchased	2.98
	Video capture card EzCap	11.89	Purchased	11.89
	Boards ordered	13.31	Purchased	13.31
	SMD-components	348.92	Purchased	348.92
	Converters	16.86	Purchased	16.86
	Solder alloys	10.12	Purchased	10.12
	Servomotors	70.49	Purchased	70.49
	Power contacts	14.80	Purchased	14.80
	Stabilizer P6CU	31.95	Purchased	31.95
	ESC drivers for brushless motors	101.90	Purchased	101.90
	TFT LCD display 20x4	7.79	Purchased	7.79
	Wi-Fi router Gl-Inet	23.50	Purchased	23.50
	Wiznet W5500 Ethernet Chip	9.71	Purchased	9.71
	Expended for electronics	1,033.68	Total for electronics:	1,938.43
Build	3D-printer	0	Contributed	355.00
	C & E materials	114.99	Purchased and Contributed	185.99
	Acrylic materials	13.53	Contributed	49.03

	Parts' waterjet cutting	168.27	Purchased	168.27
	Aluminium materials	18.28	Purchased	18.28
	Paint	11.04	Purchased	11.04
	Stationary for design purposes	13.15	Purchased	13.15
	Box for surface equipment	0	Contributed	63.90
	Expended for build:	339.26	Total for build:	864.66
Others	Agar in sachets	12.82	Purchased	12.82
	Delivery of stabilizer P6CU	14.73	Purchased	14.73
	Containers	47.18	Purchased	47.18
	Film for printing	14.82	Purchased	14.82
	Expended for others:	89.55	Total for others:	89.55
	Expended overall:	1,466.75	Total overall:	2,895.95

Table 3. ROV cost-accounting table

Our company also wants to note huge contribution of our mentors to project. They spent a lot of their time to consult and discipline us:

Name	Amount, hours	Cost per hour, $	Total, $
Mr. Sergey Mun	243	15	3,645
Ms. Angelina Borovskaia	228	15	3420
		Total:	7,065

Table 4. Mentors cost-accounting table

Also, we spent a lot of money for travelling to Long Beach and living there:

Name	Amount	Cost, $	Total, $
Tickets to Long Beach	8 tickets	1,595.79	12,766.30
Hotel	3 rooms * 7 days	35.46	744.70
		Total:	13,511

Table 5. Travelling cost-accounting table

Considering all our expenses, including ROV development, contribution of mentors and expenses for flight to Long Beach, we spent 23,471.95$ for the whole project.

Acknowledgements

First of all, we would like to thank Center for Robotics Development for provided accommodation, equipment and tools to have our work possible. Also, we thank the Center for organizing regional MATE competitions and in general for invaluable contribution into promoting educational underwater robotics in Vladivostok and in Russia.

We are grateful to our mentors Sergey Mun and Angelina Borovskaia for their technical and moral support.

We would like to say ‘thank you’ to Dmitry Alekseev for maintaining the fund from which our team was financed.

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

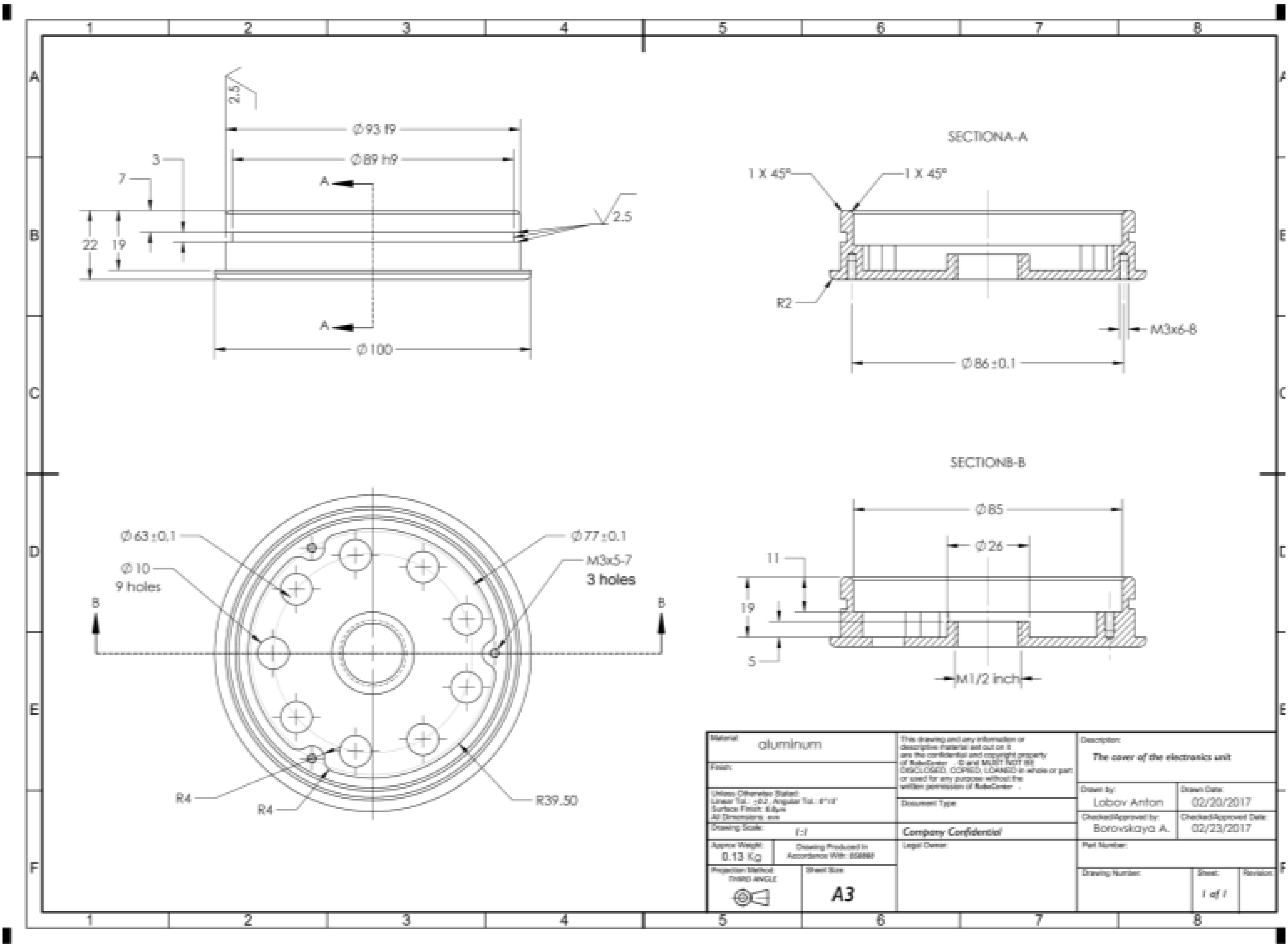
We are thankful to MATE Center for their global initiative that gives numerous young people new skills and experience.

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 fulfil the project.

References

1. Summit ROV (2012). Available at: http://www.tetis-pro.ru/news/1576/ (In Russian) (accessed 27 May 2017)
2. Danger in Vladivostok bays (2016). Available at: http://www.zrpress.ru/incidents/vladivostok_19.10.2016_80495_v-bukhtakh-omyvajuschikh-vladivostok-obnaruzheno-bolee-2-5-tysjach-opasnykh-predmetov.html?printr/ (In Russian) (accessed 27 May 2017)
3. Pollution of Zolotoy Rog Bay in Vladivostok (2017). Available at: https://ria.ru/ecology/20170428/1493294090.html/ (In Russian) (accessed 27 May 2017)
4. Collection of rare samples (2016). Available at: http://www.newsvl.ru/stories/2016/10/20/152762/ (In Russian) (accessed 27 May 2017)
5. Unique organisms in Okhotsk sea. Available at: http://www.newsvl.ru/stories/2016/10/20/152762/ (In Russian) (accessed 27 May 2017)
6. Drones and ROVs and Arduinos (2010). Available at: https://dronesandrovs.wordpress.com/2012/11/24/how-to-control-a-brushless-motor-esc-with-arduino/ (accessed 27 May 2017)
7. Ariadne Bootloader for Arduino (2011). Available at: https://github.com/codebendercc/Ariadne-Bootloader/ (accessed 27 May 2017)
8. Easy Electronics (2000). Available at: http://forum.easyelectronics.ru/ (In Russian) (accessed 27 May 2017)
9. Radiokot (2005). Available at: http://www.radiokot.ru/forum/viewforum.php?f=57/ (In Russian) (accessed 27 May 2017)
10. Kompel (2008). Available at: http://www.compel.ru/lib/ne/2011/4/7-galvanicheskaya-razvyazka-novyie-retseptyi-ot-texas-instruments/ (In Russian) (accessed 27 May 2017)

Appendix 1. Drawing of Electronics Unit Cover



Appendix 2. Drawing of Bottom Camera Cover