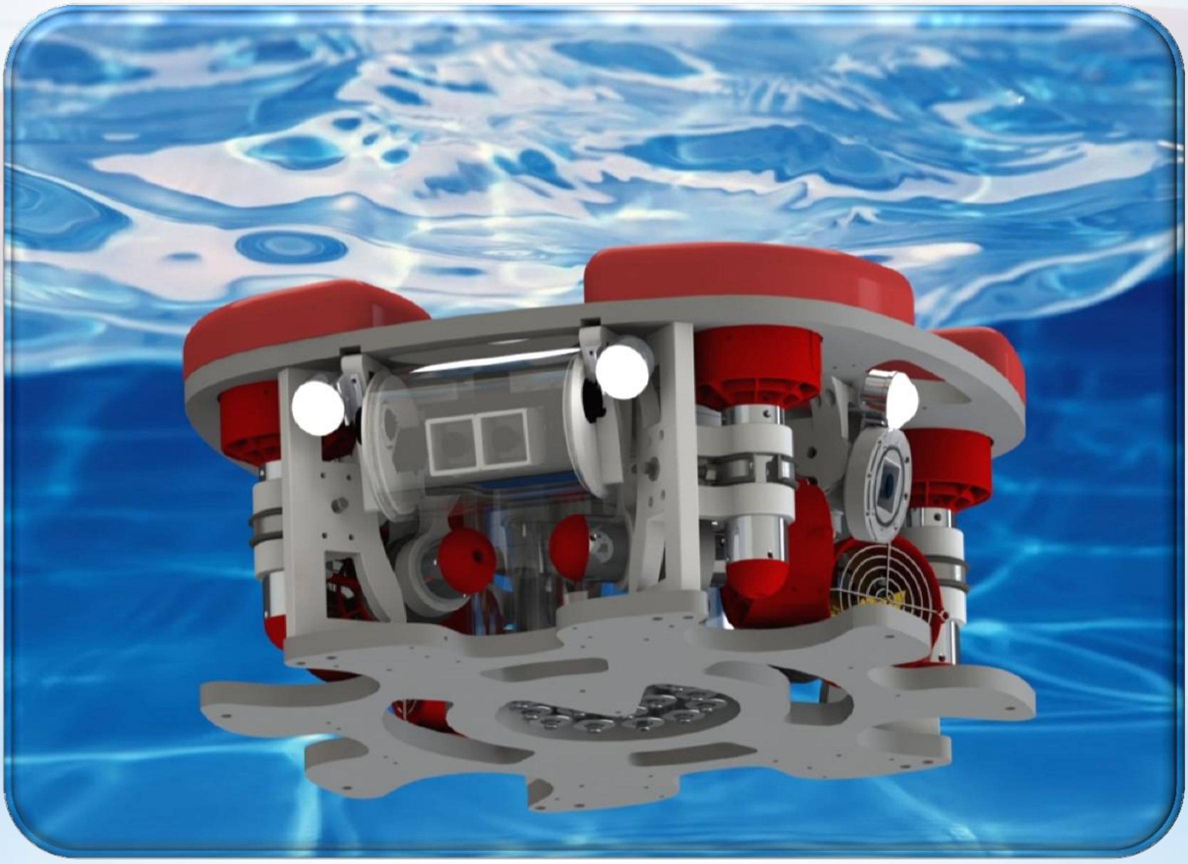
2014 MATE International ROV Competition

Bauman Moscow State Technical University
Team "Bauman GidroNAV"

AKVATOR Jellyfish

Explorer Class



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Moscow, Russia, 2014

1. Abstract

The Bauman GidroNAV company was founded in 2010 at the Bauman Moscow State Technical University. We build underwater vehicles using knowledge and skills obtained at the Underwater Robots and Vehicles department, using modern production technologies. There are also students from Mechatronics and Computer Sciences departments that are heavily involved in the company's operation.

This year our company is devoted to shipwrecks: identifying the ship, studying marine environments and conservation of the shipwreck. For performing these tasks, we have designed the low-cost underwater vehicle “AKVATOR Jellyfish”. Its main advantages are small size, field of view angle of 270 degrees, full symmetry of movement (the pilot can choose the front side) and two grippers. We have also designed fully replaceable tools: the Goo Sucker for collecting microbial samples and an in-house designed conductivity meter. We developed image recognition software for measuring a ship's size, as well as to count zebra mussels.

We kept within strict deadlines due to the division of roles and precise scheduling of work by using a Gantt chart and mind maps. In our work, we use modern methods of design and modeling. For example, Solidworks CAD was used for structural design.

For the production of parts, we used the latest technologies: milling using CNC machines, 3D printing, laser-cutting. Our vehicle is made from easily processed and cost-effective materials: polypropylene, Plexiglas, aluminum, ABS-plastic.

Akvator Jellyfish can serve as a prototype for industrial grade ROV that can explore the wrecks in the rivers and lakes of Russia.

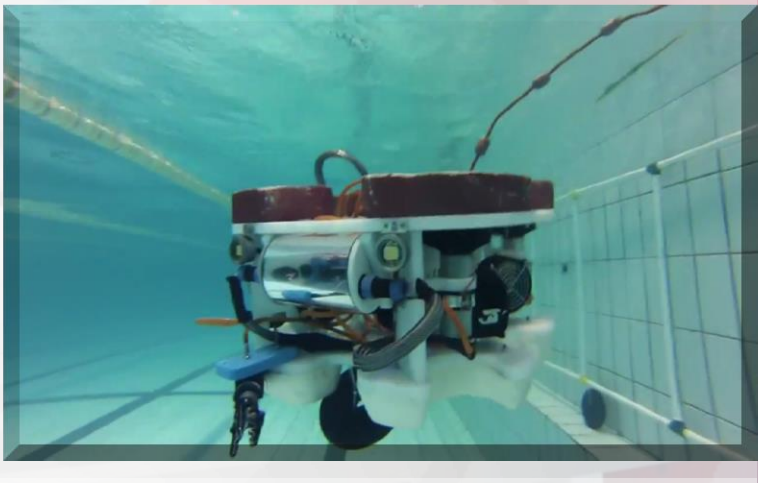

Fig. 1.1. AKVATOR Jellyfish

Fig. 1.2. Bauman GidroNAV company

2. Table of Contents

3. Step-By-Step Development

3.1. Concept and Principles

Designing an ROV requires lots of time, a good knowledge of robotics, high financial spending and, of course, a solid team of workers with their endless flow of ideas.

The development process was done in several consecutive steps:

1) Compiling the ROV specifications
2) Choosing the number of thrusters and their arrangement
3) Design of the pressure hulls
4) Software development
5) Design of the microprocessor control unit
6) Development and testing of auxiliary tools
7) Assembly of the ROV
8) Testing and troubleshooting of all systems
9) Aesthetic decoration and design

The development timeline is shown in Fig. 3.1.1.

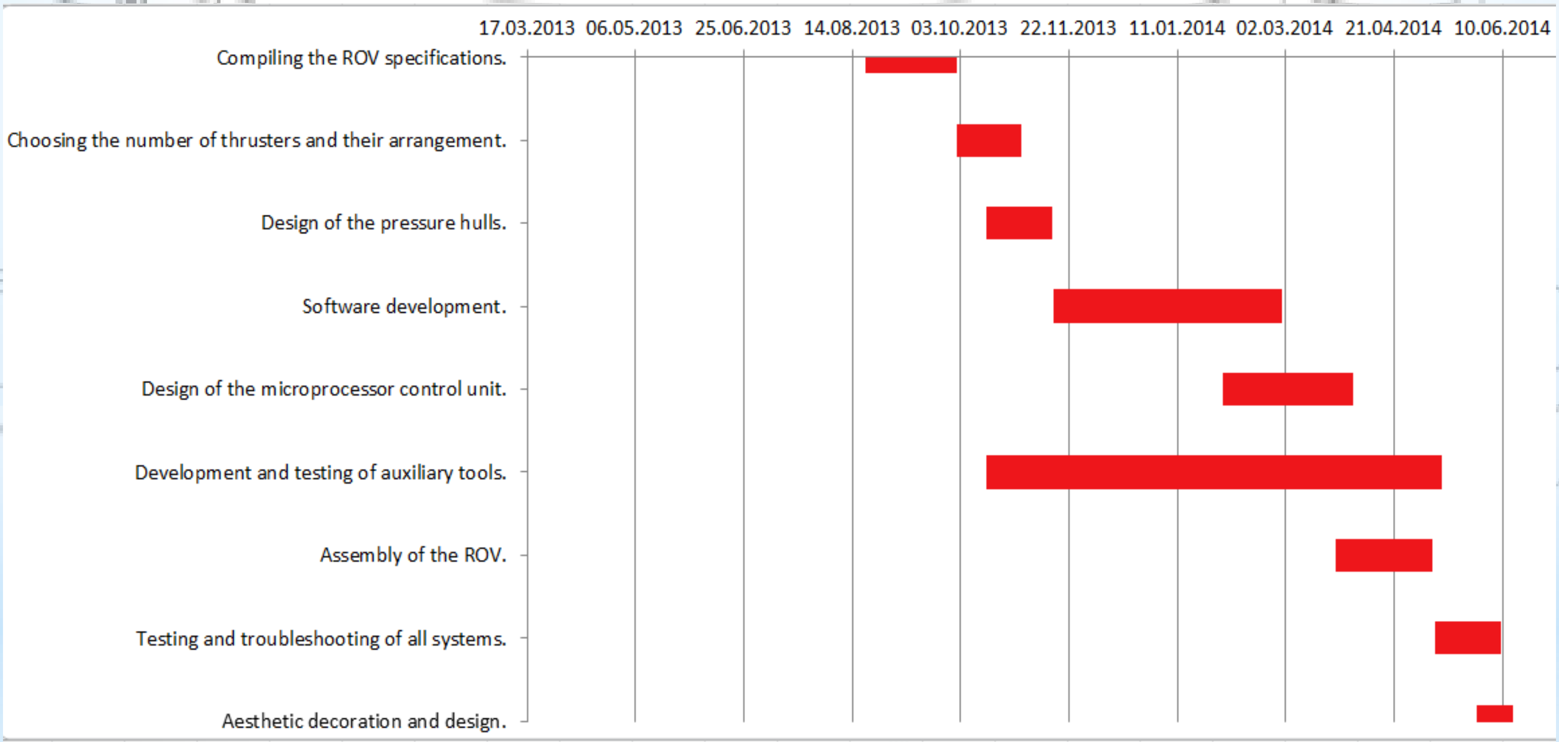

Fig. 3.1.1. The development timeline.

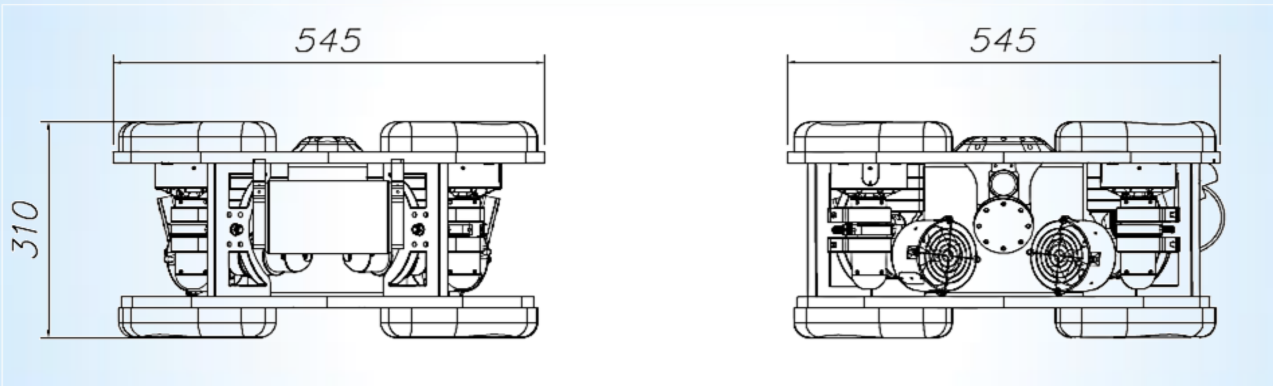

Fig. 3.1.2. Drawings of AKVATOR Jellyfish

3.2. Safety

While working on the AKVATOR Jellyfish we concentrated our efforts not only on development and assembly, but also on many safety issues and concerns. A set of rules was applied to everyone working on a project in the lab.

1) Team members working with mechanical tools and machinery were required to wear protective coats, gloves and glasses. (Fig. 3.2.1)
2) Before getting access to any machinery everyone had to listen to a short operating briefing.
3) Operation of the lifting mechanism (electric hoist) was only allowed by at least two people at the same time. (Fig. 3.2.2.)
4) The electric hoist was equipped with an emergency off-switch to prevent an accident in case of any mechanic failure.
5) All electrical equipment is shut off before closing the lab, thanks to many reminding placards.

Still from time to time, some minor incidents happened. For example, first time the ROV Control Station was used, it shocked the operator! The cause of that was a cheap ungrounded power strip. Once it was replaced, the problem was solved.

Fig.3.2.1. Working at the laboratory

Fig.3.2.2. Lifting AKVATOR Jellyfish

Safety Features of the AKVATOR Jellyfish

- ✓ Warning stickers on moving parts
- ✓ No sharp edges
- ✓ A safety fuse in the main power line
- ✓ Metal gratings on thrusters, making them 100% safe
- ✓ Software indication of different hardware faults, that can occur during the ROV operation, such as loss of connection

4. Electronics

4.1. Electronics Systems Layout

There are seven boards inside of the electronics housing:

- Two boards with sealed connectors
- Power supply board
- Main controller board
- Thrusters drivers board
- Auxiliary equipment drivers board
- Depth sensor board

Power supply board.

The voltage converter board contains 3 DC-DC converters. Two TEN-40-4811WI modules convert the input voltage from 48 volts to 5 volts for powering the servos for tools; another module (SMB60) transforms 48 volts to 12 volts for powering the cameras and logic controllers.

Power consumption of the whole system is limited by 2 Kilowatts, and to ensure that, a 40 ampere current fuse is used. Power supply diagram is shown on Fig. 4.1.1.

Main controller board

Main controller board includes a Seeeduino Mega board, a USB-hub with 7 inputs, and an amplifier of USB-signal for transmitting it to longer distances. The amplifier allows reprogramming of the controller using a five meter long cable. Seeeduino Mega (known as Connection controller) performs data transmitting and receiving to the shore using RS-485 interface, it distributes data between each of electronics unit controllers via I2C serial bus. Connection controller also performs data reading from Vectornav VN-100 sensor via UART interface.

Thrusters' drivers board

There are eight Pololu drivers, used for controlling the ROV's thrusters. Each driver has a built-in short-circuit and overheating protection. In order to make repair of the vehicle process more convenient, each of the driver boards can be easily installed on or removed from the driver board. Two Arduino Mini boards are used for sending signals to the vertical and horizontal motion drivers accordingly.

Safety comes first!

Each Pololu driver had a built-in current sensor. This way we can monitor motors currents. High motor current can tell us that the thruster is blocked and needs to be stopped. Therefore, Thrusters Controllers are programmed to shut down the motor when it has a current exceeding four amperes.

Auxiliary equipment drivers' board

The main part of this board is equipment controller (Seeduino Mega). It is connected to the I2C bus, from which it gets commands from the connection controller. Its main task is forming control signals for tools of the ROV, such as servos, grippers and lighting. Two Pololu drivers are used to control grippers' motors and regulate lighting. These drivers are set up on special sockets on the board. They have embedded current sensors that allow controlling the grip strength and monitoring possible electrical failures.

The equipment board also includes a slot for installing the depth sensor board.

Depth sensor board

Depth sensor is based on strain gauge pressure sensor. Signal processing board is an easy to remove module, connected to vehicle's network via I2C bus. This approach allowed us to perform a number of experiments using different kinds of schematics for the processing of the signal.

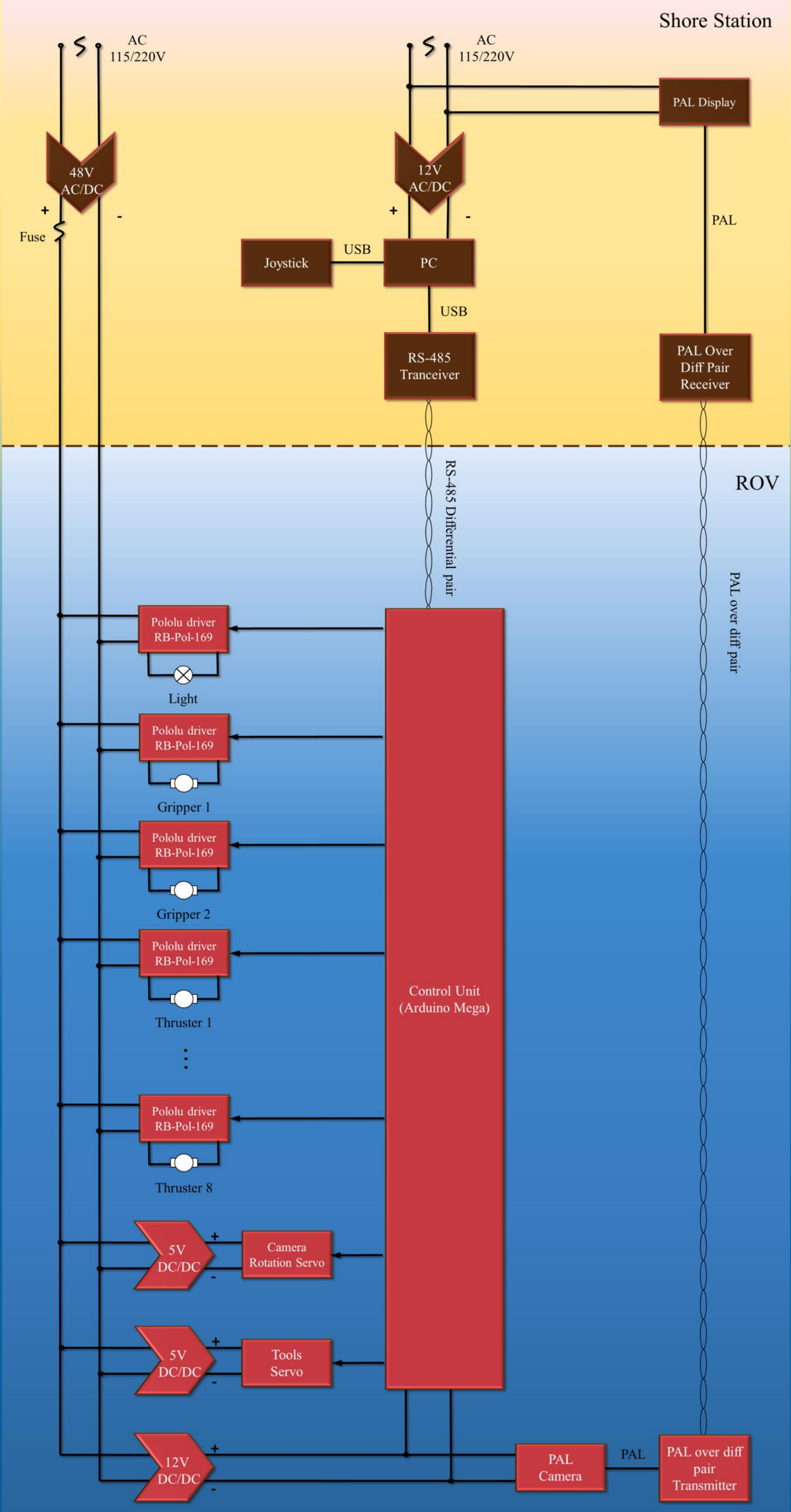

Fig. 4.1.1. System Interconnection Diagram

4.2. Depth Sensor

Depth sensor was designed using a strain gauge pressure sensor (Fig. 4.2.1) with additional signal processing schematic. It can measure pressure with a value up to 100,000 Pascal, which is the approximate value of pressure at a depth of 10 meters below the water's surface.

Signal processing board (Fig.4.2.2) contains power supply unit for the sensor and a low-pass filter to eliminate noise in the signal.

A 14-bit analog-to-digital converter is used to send the signal to Arduino Mini controller, which then performs additional software filtering of the digital signal.

The output value of the depth sensor can be accurate up to 10 mm.

Fig.4.2.1. Strain gauge pressure sensor

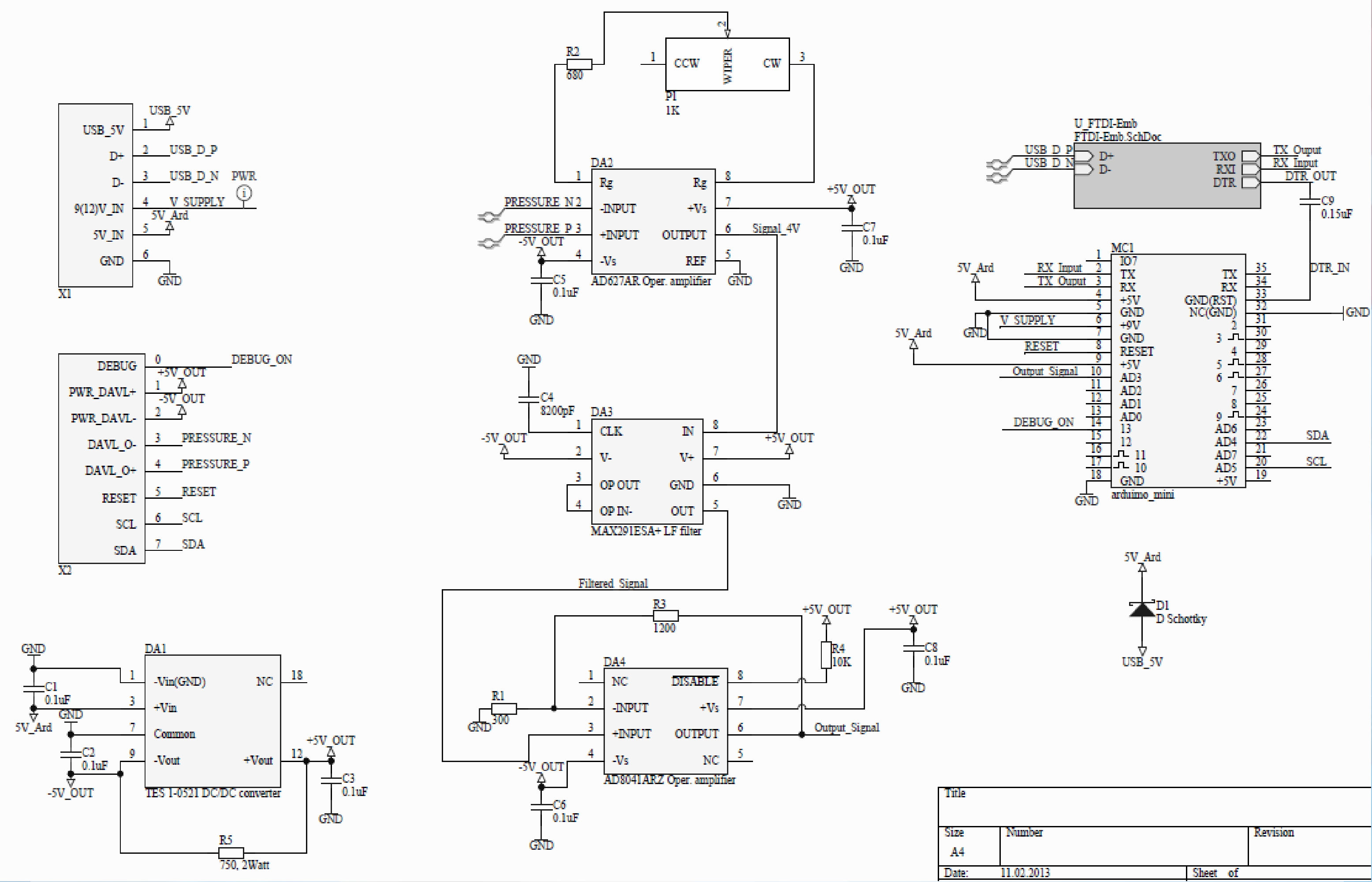

Fig.4.2.2. Signal processing board

4.3. Orientation sensor

For determining the orientation of the vehicle, we use VectorNAV VN-100 sensor (Fig. 4.3.1). It provides us with absolute values of Euler angles (yaw, pitch, roll) as well as circular velocities and linear accelerations along the X, Y and Z axis. Using a built-in Kalman filter, we can ensure that these readings are highly accurate.

Clocking signal from the VN-100 sets stabilization system working frequency. This sensor can provide up to 200Hz data update rate, which allows us to create a fast-responding ROV control system that includes several types of passive and active stabilization. Smooth ROV movement and convenient control allows it to perform the tasks of MATE 2014 underwater missions.

Fig.4.3.1. Orientation sensor VectorNav VN-100

4.4. ROV connections

ROV connections.

There are two communication systems on the AKVATOR Jellyfish (Figure 4.4.1.):

- Connection between shore and ROV via RS485 interface
- Connection between onboard controllers via I2C bus

ROV to shore communication.

This connection should provide a satisfactory bandwidth along the 20 meter tether. We decided to use RS-485 interface that allows us to have a half-duplex connection with speed up to 115200 baud per second. As the network topology is primitive (point-to-point), we decided not to use any of the existing "high-level" industrial standard network protocols and to write our own instead. With this simple asynchronous protocol, we can elongate tether up to hundreds of meters without losing channel efficiency.

On the shore side, a x86 PC is used to communicate with the ROV. To be exact, it is an embedded PC board inside of the ROV control station. The shore side software was created in Processing. This language and IDE allow us to work directly with PC ports and to draw a GUI. We have also used a Processing library to work with Saitek S-52 Pro controller.

The shore side software sends data to the ROV with a frequency of about 20-30 Hz. This frequency is only limited by the performance of the PC.

Onboard communication channel.

For inter-controller communications we chose I2C interface, which is supported by the AVR microcontrollers by design. This way we were able to make the electronics unit in the form of a board stack. The communication controller as the Bus Master exchanges data with other controllers (Slaves). This exchange takes place inside of an Interrupt Service Routine that is called on with a fixed frequency of 50 Hz. Software logic diagram is represented on Figure 4.4.2.

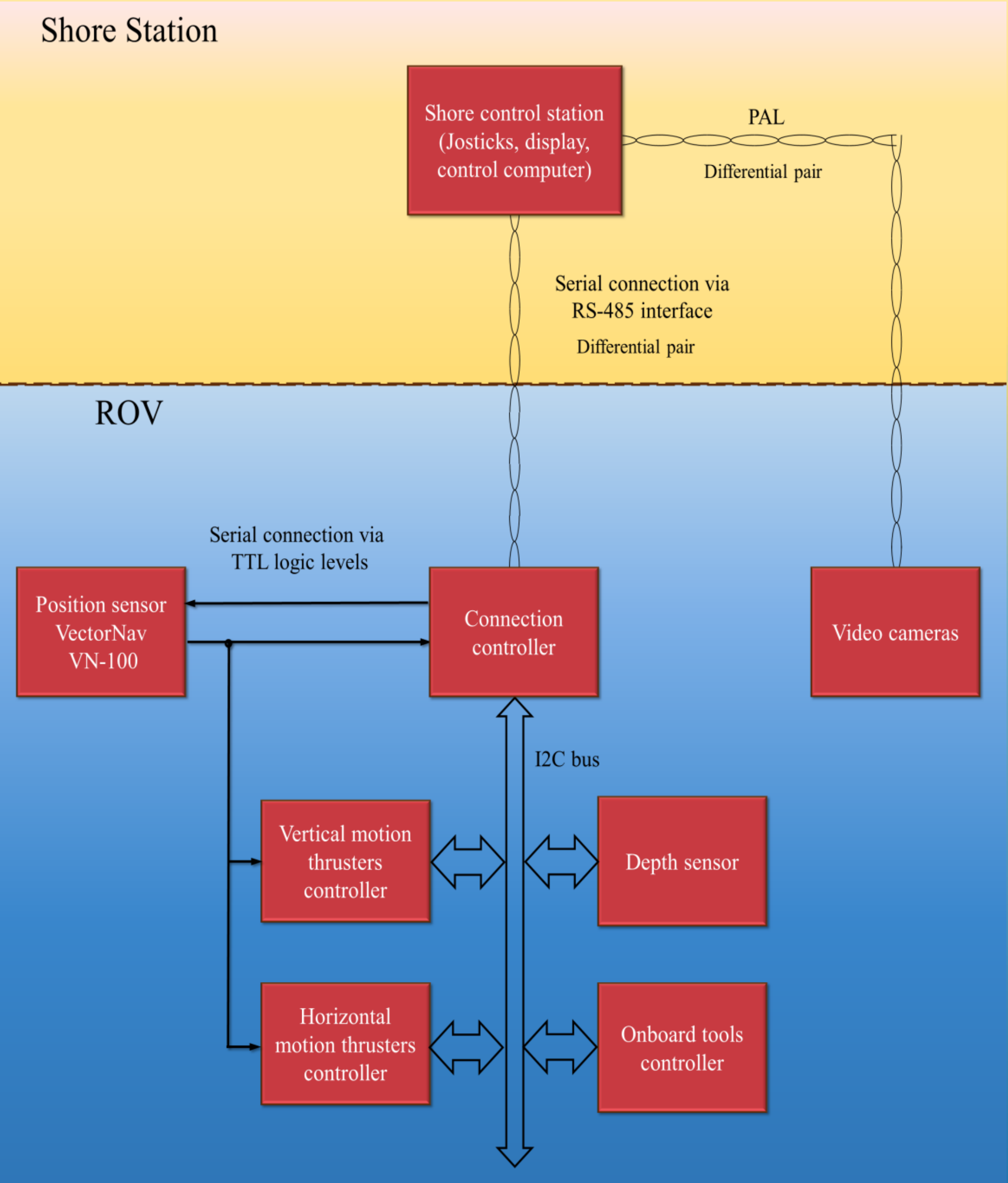

Fig. 4.4.1. ROV connections

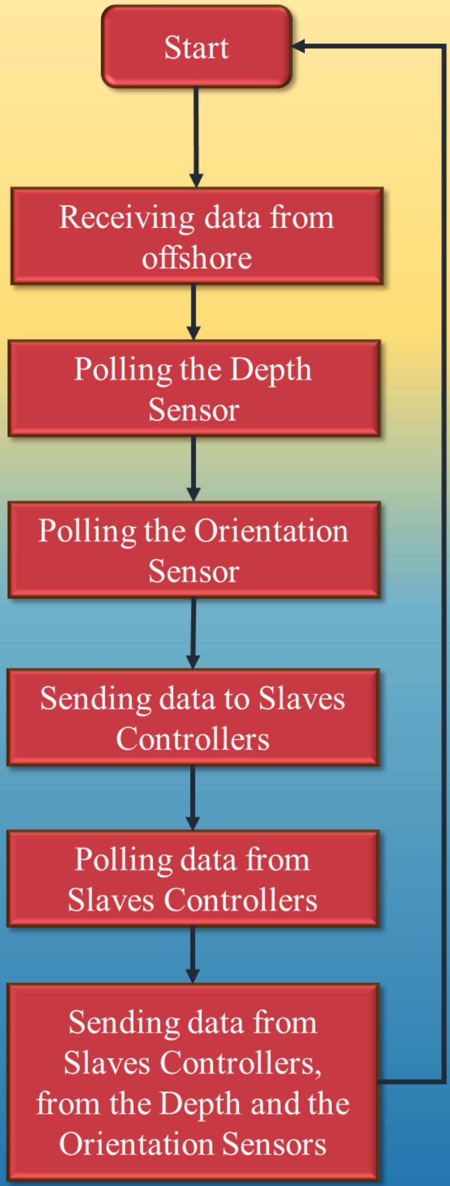

Fig. 4.4.2. Software logic diagram

Safety comes first!

Safety features of the AKVATOR Jellyfish electronics, communications and control systems:

- *All additional connectors placed on the boards are asymmetrical and have different shapes. That makes it impossible to mix connectors or plug detachable modules on the wrong side.*
- *Fuse in the 48V power circuit protects electronics from damage in case of a short circuit.*
- *Modular implementation of the main electronic boards allows placing the boards in any order while assembling the electronics unit thus preventing possible mistakes.*
- *All voltage converters used in the vehicle have short circuit protection.*
- *Humidity sensor inside of the electronics housing can monitor even the slightest changes in the humidity value. If the value exceeds the dangerous level, it sends a signal to the ROV control station and lights an LED.*
- *Both onboard and shore side software constantly check for data link validity. In the case of a lost connection, all ROV systems are automatically shut down.*

5. Software and Algorithms

5.1. Stabilization System Algorithms

To make pilot's work easier our embedded systems programmer **Mikhail Alekseev** developed an automatic system of stabilization on 4 degrees of freedom: yaw, pitch, roll angles and depth position. The model of the feedback control system is shown in Fig. 5.1.1.

A proportional-integral controller is used to compensate for external perturbations and ensure stability of the vehicle on several degrees of freedom. We determined parameters of the regulator using system modeling in Matlab Simulink.

To coordinate stabilization contours we have written algorithms that process control signals from the shore to calculate the amount of thrust on each motor. The flowcharts of the algorithms are shown in Fig. 5.1.2.

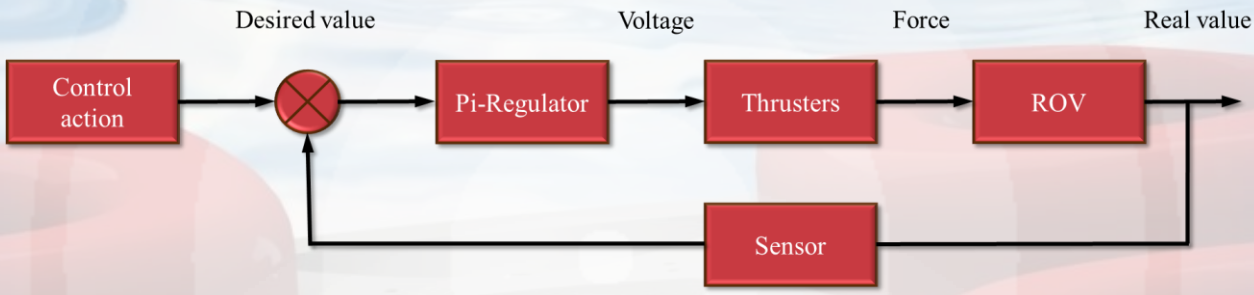

Fig. 5.1.1. The model of the feedback control system

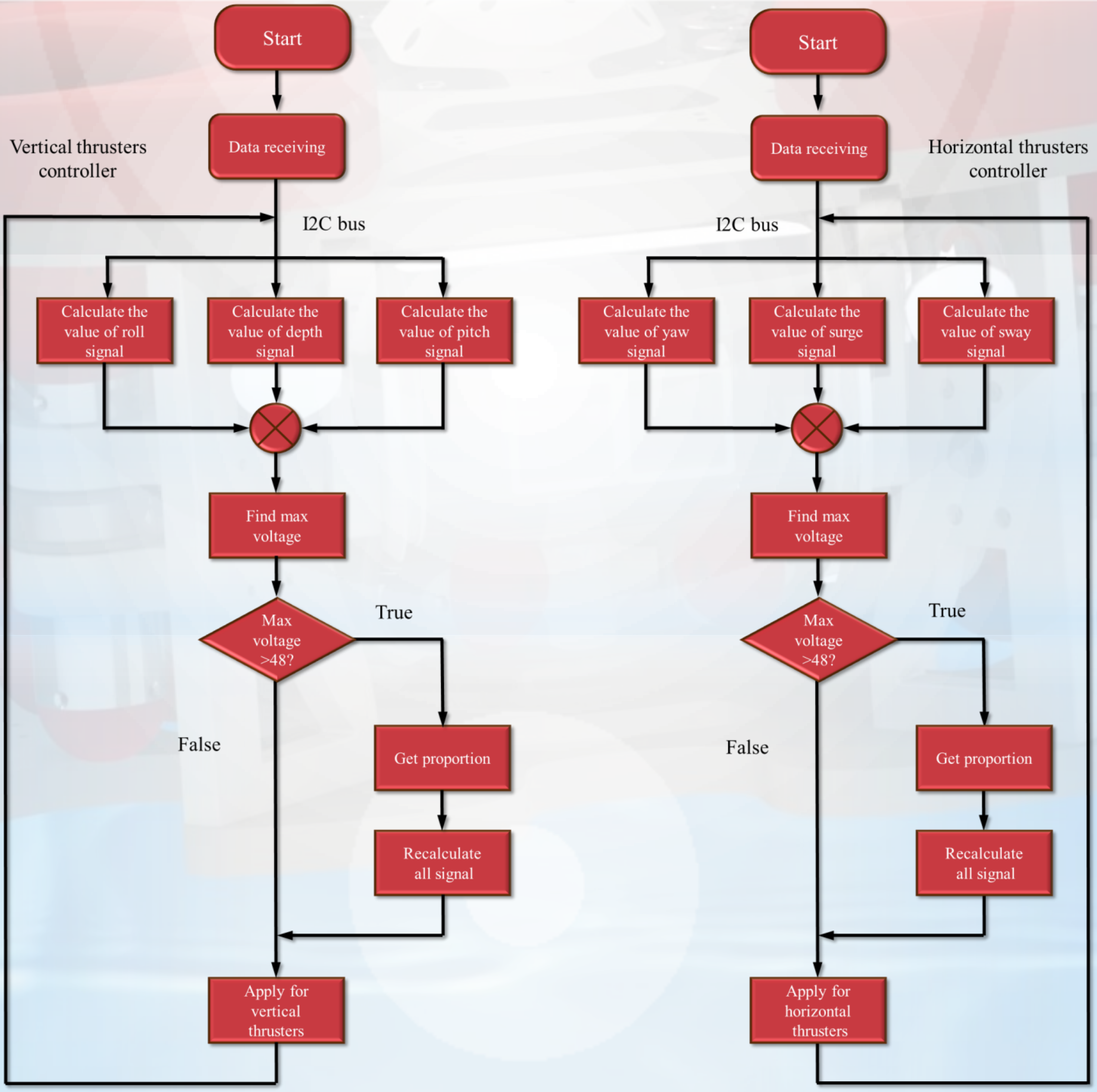

Fig. 5.1.2 . The flowcharts of the stabilization algorithms

5.2. Stitching a panorama

Software for image stitching was written by company programmer **Anton Aleschenko** in C++ language with some elements from the OpenCV library. OpenCV is an open source C++ library for image processing and computer vision.

There are two modes in the program: automatic stitching, and semi-automatic stitching. In both cases operator captures five frames for further stitching, using video feed from ROVs cameras as a viewfinder. In order to capture video from onboard analog cameras, we use the USB capturing device EasyCAP.

In automatic mode stitching is performed by algorithms, provided by OpenCV library. Advantage of this method is that the operator does not need to point particular points on the image.

Limitations are that automatic stitching does not always provide clear results because OpenCV algorithms are not always capable of adapting to different distortions and interferences from the input image.

In semi-automatic mode we use our own simplified algorithm of image stitching that consists of three steps:

- Operator captures 5 consecutive images from the video feed
- Operator specifies two particular points on each obtained image, which mark the colored junctions on each snapshot location.
- Stitching algorithm combines adjacent images with each other using specified marks as reference points.

Advantages of this process: the algorithm is not affected by any distortions or interferences.

Disadvantages: operator has to be very accurate when marking particular reference points, otherwise stitching will result in low quality image.

The main difficulty during software development was choosing appropriate stitching algorithm. During the trial runs of the vehicle, the semi-automatic mode proved to be the most reliable one. In that mode human operator performs all image recognition, while the algorithm performs only the stitching. The flowchart of this algorithm is shown in Fig.5.2.1.

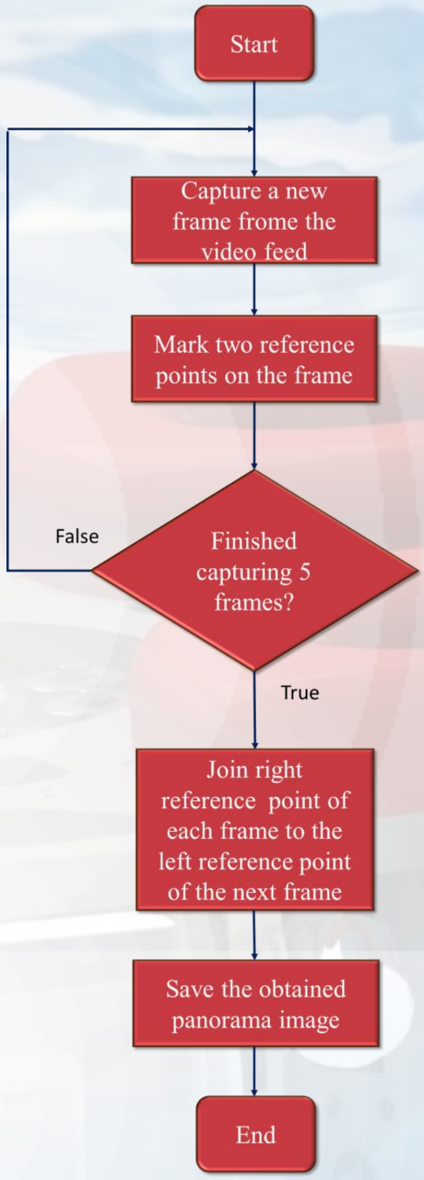

Fig.5.2.1. The flowchart of the semi-automatic stitching algorithm

5.3. Mussels Counting

One of the science-related tasks of the mission is counting the number of zebra mussels on the shipwreck. In order to do that our company programmer **Anton Aleschenko** has developed video capturing software.

This program captures video feed from analog cameras using methods of OpenCV library. Operator can press a key to stop and capture a single frame. Then he manually puts marks on the captured image to point to every mussel inside the selected area, so the mussel count increases. In the case of user mistake, there is also the ability to delete a mark or delete all marks. When the operator has marked all mussels, the captured image is saved and the resulting number of mussels is outputted to the display.

6. Construction Rationale

6.1. Framework

The main feature of AKVATOR Jellyfish it that it has a modular structure, with separate units performing different tasks. Each unit can be easily removed from the main frame for repair and maintenance.

Polypropylene framework is what holds everything together: thrusters, pressure hulls, buoyancy, etc. We use Polypropylene because of its durable nature, rigidity and innate positive buoyancy. We decided that a frame made of plates is much better than frame made of tubes, because of less hydrodynamic resistance and inertia.

The frame was manufactured using CNC milling machine (Figure 6.1.1) by the company CTO **Anatoly Strelnitsky** with the support of construction engineers **Sergey Kuznetsov, Olga Kiryukhina and Vadim Efarov**. After preliminarily training, they could perform all steps of manufacturing frame components without any help.

It is necessary to note that we had created a 3D model of the entire ROV in Solid Works before we started to fabricate parts for it. Later, while assembling, we were strictly guided by this 3D model.

To achieve the best maneuverability, stability and velocity in all directions we have decided to design the frame to be of symmetrical shape along X and Y axis, so both sides of the ROV can serve as a "front" side. This way we can place several video cameras on the vehicle's perimeter to achieve a wide field of view. Aside from that, this allows for the placement of additional tools on the vehicle without obstructing any cameras or thrusters. It requires only 16 screws to assemble the frame, which makes it easy to maintain the ROV.

Compared to the previous model AKVATOR-3D, developed by the Bauman GidroNAV company for the 2013 MATE competition, AKVATOR Jellyfish is has smaller external dimensions and weight, as well as better maneuverability and durability.

Safety comes first!

The frame does not have any sharp corners and edges, to prevent even the slightest harm to the personnel.

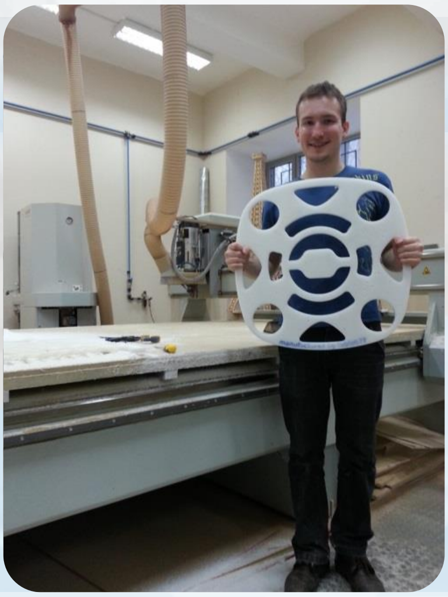

Fig.6.1.1. Framework manufacturing (on the left). Complete framework (on the right)

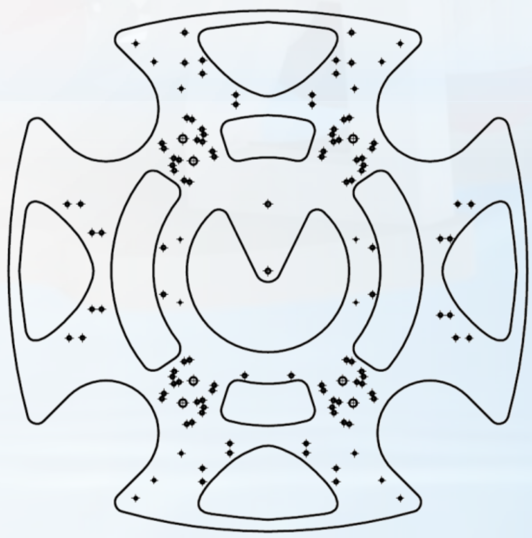

Fig.6.1.2. Drawing of the framework

6.2. Tether

The AKVATOR Jellyfish tether is twenty meters long and consists of thirty wires, and two coaxial cables in a protective braid. In the main body of the tether, twenty of the wires are used for power supply, are 0.35 mm in diameter. Another ten wires are 0.12mm diameter and are dedicated for control signals transmission;

- Two of them are reserved for RS485 interface,
- Four are for additional analog camera signals.
- The remaining 4 wires are kept in reserve in case of tether damage.

Pieces of polypropylene foam are installed on the tether, providing it with positive buoyancy. This design provides high flexibility of the tether, as well as high durability in the event of fouling.

6.3. Buoyancy

Buoyancy units are fastened on the frame along with other equipment (Figure 6.3.1). These elements balance residual buoyancy of the ROV. Their shape and dimensions were computed in Solid Works software as well. Their geometry was chosen to provide neutral buoyancy of whole vehicle and absence of any torque about the pitch and roll axis. The resulting positive buoyancy of the vehicle varied from 20% after initial assembly to 5-10% with the entire payload installed. We used diving weights to adjust the vehicle's buoyancy and balance. As a result, the slightly positive buoyancy of the AKVATOR Jellyfish ensures its return to the water surface even in the case of thruster failure.

Fig.6.3.1. Buoyancy units

6.4. Cameras

For our visual systems, we use four KPC-VSN700PHB analog cameras (Figure 6.4.1). Located symmetrically inside of the front side pressure hull are two of our cameras, with two additional cameras placed on the vehicle’s sides in order to achieve maximum field of vision of 270°.

There are two cameras installed in the cameras’ pressure hull. The first camera can perform observation and sends video feed to the main screen. The second camera is used to implement video capture algorithms (determining the ship dimensions, stitching a panorama, counting zebra mussels). For these tasks, we used camera lens with a small angle of view 63° to avoid aberrations. There is a servo drive inside of the hull that allows rotating the cameras along the horizontal axis. Rotating range is 180° (from -90° to +90°).

Each ‘front’ camera has the angle of view of 90°, because they are specifically for navigation.

Fig.6.4.1. Analog camera KPC-VSN700PHB

6.5. Pressure hulls

AKVATOR Jellyfish has a module structure. There are several hermetic cases with different purposes installed onboard.

Electronics hull (Fig. 6.5.1) is made of a transparent Plexiglas tube, 180 mm diameter that is closed on both sides by aluminum covers, manufactured using CNC milling machines. The cables are connected to the hull using industrial-grade waterproof connectors with IP68 degree of protection that are fully dismountable, reliable and affordable. Electronics case contains all printed-circuit boards of the vehicle: connection controller, thrusters' drivers, tools controller etc.

Cameras' hull was specially designed for AKVATOR Jellyfish and also made of transparent Plexiglas (Fig. 6.5.2). It has a diameter of 100mm and thickness of 4 mm. There are two waterproof connectors in the hull. It is closed from both sides with covers made from ABS plastic using molding into silicone forms.

There are rubber O-rings on the covers' perimeters to provide to make them watertight. To disassemble the hull you only need to pull out a case from the slot in the vehicle's frame and pull out its covers. This feature greatly simplifies maintenance and reparability of the vehicle.

There are also several hulls for different elements of the system, which were placed outside of the main two hulls for different reasons. Among them are two hulls for the side video cameras and a case for the orientation sensor which was manufactured using 3D-printing (Fig. 6.5.3). Orientation sensor case consists of a base that the sensor is attached to and a cover that presses it down. This case waterproofs the sensor and provides it with mechanical protection.

All hulls can withstand pressure up to 10^6 Pascal that approximately corresponds to 100 meters depth. All calculations were performed in Solid Works software and obtained results completely satisfied our needs.

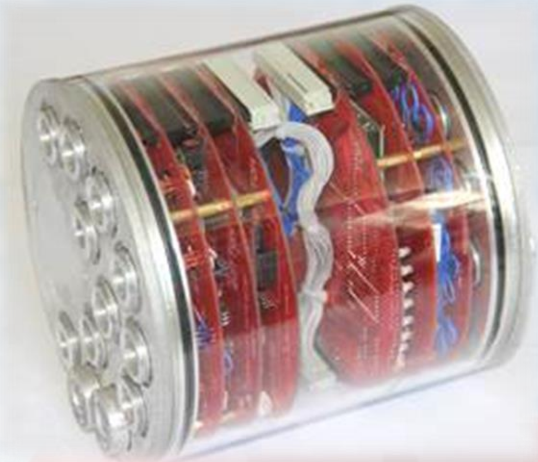

Fig. 6.5.1. Electronics case

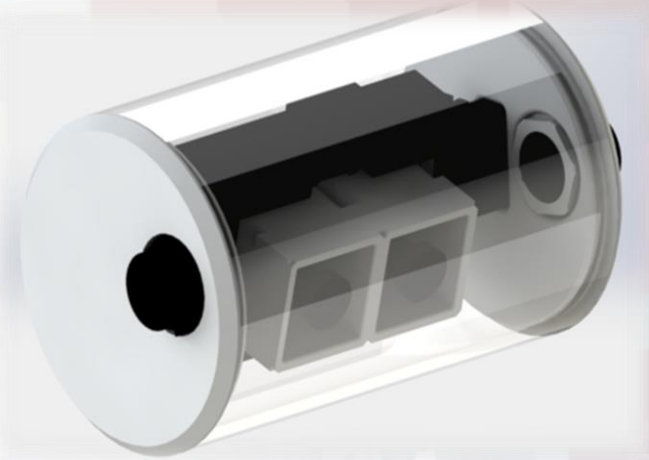

Fig.6.5.2. Frontal cameras' case

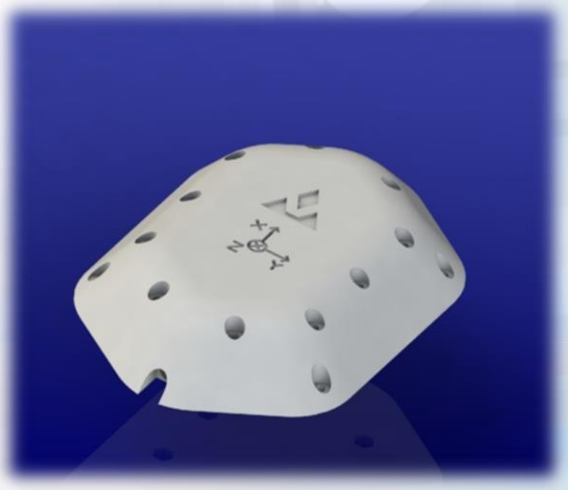

Fig. 6.5.3. Strong case of the orientation sensor VectorNav

Safety comes first!

Transparency of the pressure hulls allows us to easily see if there is a leakage in the hull. We also can observe LEDs inside the electronics hull that can indicate possible failures..

6.6. Propulsion System

Eight in-house designed thrusters make up the propulsion system. They are designed to be as simple as possible: brushed MAXON motor of the RE 40 series with 150W power is placed in aluminum waterproof case and rotates double-bladed 80mm diameter propeller using an elongated shaft. Shaft sealing is provided by two reinforced aluminum cups and rubber O-rings with silicone lubricant. Propellers are placed in special fairings, made on a 3D-printer, that decrease loss of water flow on blade edges and increase the thrust.

Fig.6.6.1. Thruster

Our thrusters (Figure 6.6.1) produce up to 2kg of thrust. This construction showed good results on the previous competitions, and we decided to reuse them. However, we have added a couple of minor improvements regarding sealing mechanism.

There are 4 thrusters that provide horizontal motion and another 4 provide vertical motion, i.e. vectored arrangement. This thruster arrangement allows the vehicle to maneuver in all directions; also it allows minimizing mutual interference between stabilization systems (yaw, pitch, roll angles and depth stabilization).

Fig.6.6.2. Arrangement of the thrusters

Safety comes first!

Our thrusters are covered with metal gratings, which prevent any objects from touching the propellers thus preventing possible injuries.

6.7. Lighting

Our vehicle uses four 20W LED lamps for lighting (Fig. 6.7.1). Two of them are directed forward, another two are directed to the sides. To provide with better heat dissipation the lamps' cases were filled with biodegradable mineral oil. Lenticular shaped glass of the lamps disperses the light from LEDs that provide excellent working zone illumination.

Fig.6.7.1. LED Lamp

6.8. ROV Control Station

Our company designed a mobile control station for the ROV (Figure 6.8.1) which ensures quick and easy deployment of the whole system.

It contains:

1) Shockproof equipment box
2) 30” wide display
3) Saitek X50 joysticks for ROV controlling
4) 2kW power supply unit for all ROV complex
5) Small informational screen for real-time indication of ROV sensors values
6) Analog video converter
7) Mini-PC for connecting peripheral devices to the ROV

Fig.6.8.1. ROV Control Stations

User interface.

User interface is shown on an additional screen, which is located on the control panel (Fig.6.8.2.).

It indicates the state of the vehicle’s equipment and the sensors’ readings. Orientation of the ROV is shown using GUI elements, drawn as aviation instruments: gyro horizon and compass. This indication is very descriptive and convenient for the pilot. This GUI was designed by company programmer, **Vadim Kilimnichenko**.

In the center of the screen there is a simplified drawing of the vehicle, which shows directions of thrust of each thruster. There is a color indication of current values in each motor. When current value becomes higher than the critical limit, the thruster picture starts to blink with red color, which means that something prevents motor from rotating.

On the left and right side of the central vehicle drawing there are two additional panels. Right panel indicates depth sensor readings and also shows numerical values of yaw and pitch angles. Left panel indicates a special service (debugging) user interface. Debugging interface provides the possibility to vary stabilization systems parameters. Thus, it is possible to calibrate stabilization system without reprogramming the main controller of the ROV.

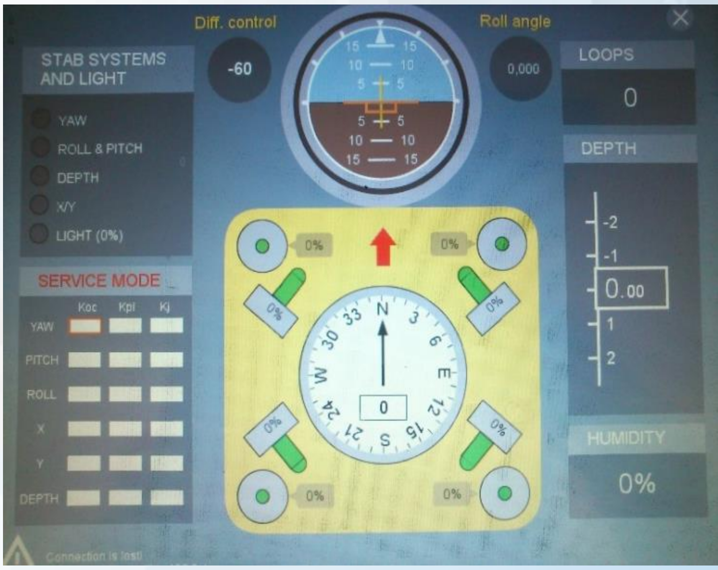

Fig. 6.8.2. GUI

7. Payload for the Mission

7.1. Lift Bag

This device (Fig.7.1.1.) was specifically designed by our company's payload specialist **Vyacheslav Tsoi** for the task of retrieving the 3.6 kg Danforth Anchor from the bottom of the pool.

The original design had a lot of flexible junctions (ropes and rubber bands), because it was the most lightweight and compact arrangement. Unfortunately, handling the device was very inconvenient for the pilot: the ropes were always in front of the cameras, obscuring the pilot's vision. There was also a safety issue, because the ropes could foul the thrusters, and potentially cause lasting damage.

The next proposed design was a solid structure permanently connected to the frame of the ROV. While it eliminated the disadvantages of the initial design, it resulted in a decrease of maneuverability and weight capacity of the vehicle.

We have managed to find a compromise. The design consists of 4 magnets (each has a pull strength of 22 kg), two inflatable rubber containers (made from motorbike inner tubes), weight bearing structure, and a manual air pump. The frame is a vertical pole made from a PVC pipe. There is an X-shaped frame on top of it (also made from PVC pipes), that is holding the rubber containers, which are connected by a hose to the air pump on the surface. The pneumatics interconnection diagram is shown in fig. 7.1.2.

The principle of operation is very simple: once the frame with magnets is installed using the vehicle's grippers, a team member on the surface starts pumping air below the surface of the water. The lift bag then pulls the anchor to the surface.

Advantages of this design:

- Fast and durable grip on the anchor
- No flexible elements that can foul the thrusters
- Convenience for the pilot who can easily install the vertical frame on the target
- The device doesn't obstruct field of view when held in the gripper.

Limitations:

- The lift bag's dimensions are large, in relation to the size of the ROV
- Uneven deformations of the inner tubes when inflated.

Fig.7.1.1. Lift Bag

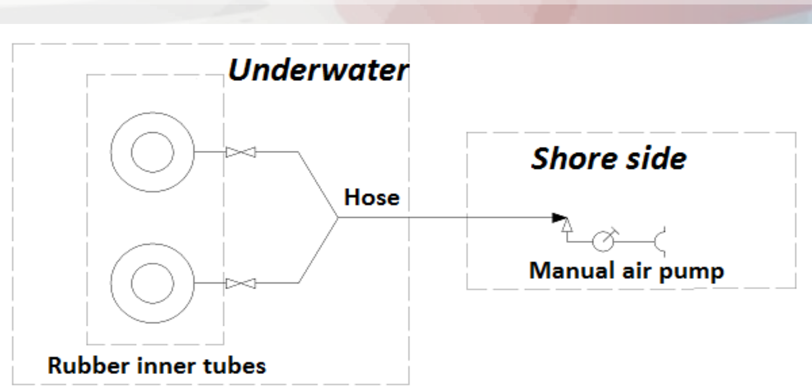

Fig.7.1.2. Pneumatics interconnections diagram

7.2. Conductivity Meter

Developed by **Andrey Vasilchikov**, this conductivity meter was designed specifically for the job of measuring venting groundwater. The board is connected to the measuring cell (two graphite electrodes). Controller on the board sends a square wave voltage to a couple of operational amplifiers that serve as current sources and produce a square wave current through the water. Then the voltage between electrodes is measured, that is proportionate to the water conductivity. Resulting signals are then sent through a low-pass filter, to the ADC of the microcontroller, which sends resulting calculated values to the receiver on the shore. The conductivity meter also includes a temperature sensor (thermal resistor) for compensating the readings bias, caused by temperature change.

The structure of the conductivity meter is shown in Fig. 7.2.1.

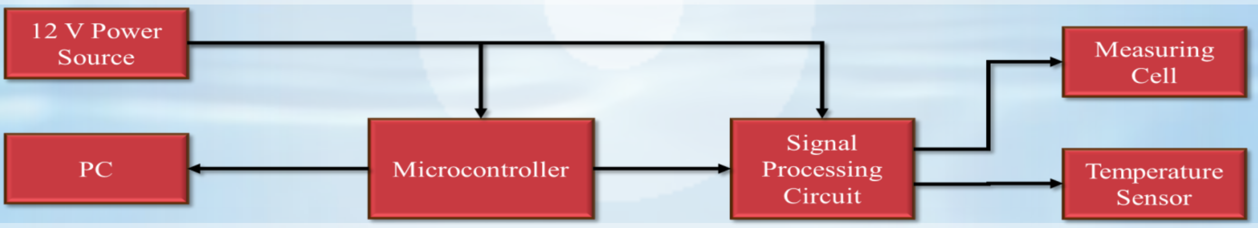

Fig.7.2.1. The structure of the conductivity meter

7.3. Goo Sucker

Goo Sucker is a device designed by our payload specialist **Olga Kiryukhina**, for the task of collecting microbial samples from the site of the shipwreck (*Fig.7.3.1.)*. The sample, delivered to the surface, is a plastic cylinder filled with agar obtained from the microbial mat.

At first we wanted to use a pump for collecting and holding the agar sample. However, we have come to a much simpler solution.

The Goo Sucker consists of:

- A plastic tube with a cap on top with small hole in the middle and a rubber straw through it
- A clamp for the tube
- A stand
- A mounting mechanism

Implanted into the palm of the manipulator is a rubber straw, designed for pumping water through it. When the tube is pressed down on the surface of the microbial mat, it cuts a cylinder into the agar, which extrudes the water from the tube through the rubber straw. After the tube is filled, the straw is then clamped by the gripper preventing the water from leaking in or out of the Goo Sucker. The Goo Sucker is removed safely, with the agar held inside the tube by external water pressure.

The Goo Sucker is mounted on the ROV's frame with a quickly detachable mechanism, which was based on a rifle scope ring. This arrangement allows for easy installation and removal of the device between vehicle submersions.

Other parts of the device (the tube clamp and the stand) were fabricated from polypropylene, as well as the framework of the ROV.

Fig.7.3.1. The Goo Sucker

7.4. Manipulators

The AKVATOR Jellyfish ROV is equipped with two electromechanical manipulators.

One was a Seabotix manipulator, which was then modified by the company engineer **Anatoly Strelnitsky**. (Fig. 7.4.1).

One of the modifications made, was that the ball screw actuator was reduced in size, decreasing the size of the entire manipulator by 60%. Three corrugated fingers allow the manipulator to handle small objects. This gripper has a modular design that allows it to be used and attached to other vehicles, which was designed by the Bauman GidroNAV company.

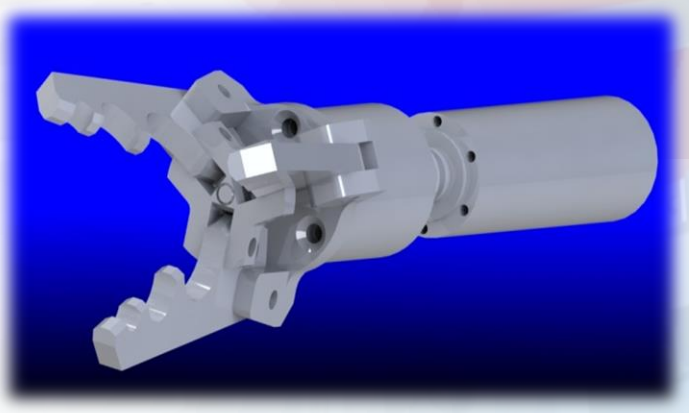

Fig.7.4.1. Manipulator №1

The other manipulator on the AKVATOR Jellyfish was bought from a Russian manufacturer (Fig. 7.4.2). It has the same principle of operation, but it has a longer housing, which allows for a larger range of manipulation. The manipulator also has the ability of holding larger objects, at the expense of dexterity.

Both manipulators are powered by 48 volt motors. The manipulators are needed for performing mission tasks as a multi-functional device. They are used for obtaining pieces of the debris, a sensor string, and other mission props. They are also necessary for the operation of the Goo Sucker.

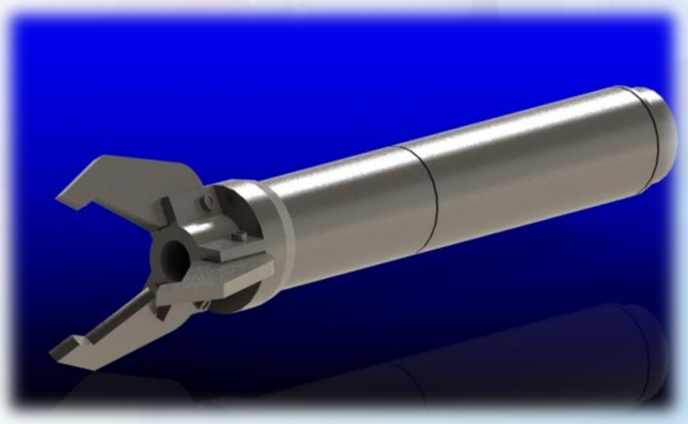

Fig.7.4.2. Manipulator №2

Safety comes first!

Manipulators' drivers have built-in current sensors. This allows us to monitor the strength of a grip to prevent jamming or trapping someone's finger!

8. ROV Testing

AKVATOR Jellyfish ROV was designed to operate at depths up to 100 meters. The durability of the framework and the pressure hulls was calculated and modeled using Solidworks CAD. The ROV itself has been successfully tested at 20 meters.

Because safety is what matters the most at our company, the ROV was subjected to a number of tests before first launching. The tests included but were not limited to: tests for loss of connection and tests of insulation. After that, it was launched in our lab's pool (Fig. 8.1). The pool is 3x2 meters and it is 2 meters deep. Instructions about potential safety issues were given to all team members before the ROV could launch (Appendix B).

For the first test, the vehicle was brought to the pool bottom for 10 minutes. Unfortunately, a leak in the Electronics Unit occurred due to faulty sealed connector. The issue was addressed, and at the next two tests the vehicle stayed 2 meters underwater in intervals of 30 minutes and 1 hour respectively.

First testing of the vehicle movement demonstrated its unsatisfactory maneuverability. We decided to change the arrangement of thrusters to prevent undesirable interactions of the water currents.

The test for weight capacity showed that AKVATOR Jellyfish can lift a load up to 2.5 kg.

To prepare ourselves for the mission, we have constructed equipment for the pool training (Fig. 8.2). We used it to test the vehicle mobility and image processing software and stabilization systems (Fig. 8.3).

Fig.8.1. Preparing the ROV for testing

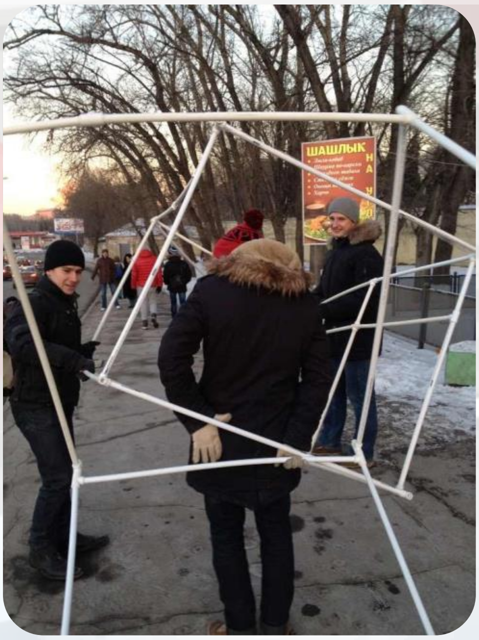

Fig.8.2. Carrying pool training equipment

Fig.8.3. Testing image processing systems

9. Challenges

9.1. Technical Challenges

1) Buoyancy.
During the first launch of the ROV we discovered that it has negative buoyancy, meaning that our initial calculations were not accurate enough. We decided to add additional buoyancy elements on the bottom of the ROV. After that the vehicle showed good stability and maneuverability.

2) Control of a quad video splitter
We have decoded communication protocol between quad video splitter and it's remote in order to pair splitter control system with the vehicle's main controller for simultaneous switching of a camera view when moving sideways.

3) Strength of construction
This year we decided to use casting of plastic instead of sintering in order to increase the strength of plastic parts and to minimize their size. We also strengthened the thrusters mounting using steel clamps.

9.2. Non-technical Challenges

The main non-technical issue of the project this year was fundraising. Due to administrative problems it was very difficult to obtain more than minimal funding from the university. It looked like we were on our own but luckily we have found out about the "All-Russian Student's Forum" exhibition. In included a competition of students' projects in the field of high tech. We presented our ROV AKVATOR 3D, developed by the company in 2013 and won a grant. This allowed us to keep working on the project and implement every feature we planned.

Significant in solving the financial problem was the contribution, made by FabLab77, a Moscow Institute of Steel and Alloys fabrication laboratory. FabLab77 donated the use of their machinery for the manufacture of our ROV framework free of charge.

10. Future improvements

Company CTO **Anatoly Strelnitsky** is currently working on a new thruster. It uses external engagement gear with propeller blades inside of it; allowing for an increase in thruster efficiency and also preventing fouling of flexible components of the ROV such as ropes and cables.

The thruster consists of:

- A plastic casing manufactured using plastic molding into silicone forms.
- Reduction gear to increase torque on the propeller. Comparing this thruster with the previous model, this one ensures that the electrical motor is operating at optimum conditions.
- A propeller made of a plastic ring, manufactured using plastic molding, with specially designed propeller blades inside and a gear teeth on the outside. Ball bearings made from fluoropolymer are supporting the propeller.

This new thruster is only in the development stage. Design of the thruster is shown in Fig. 10.1. The propeller is shown in Fig. 10.2.

We are also planning to improve other elements of the vehicle and add new ones:

1) Development of a detachable structure with additional tools, which is connected to ROV controller using I2C bus. This structue will have standard mountings for different kinds of equipment.
2) Changing the electronics of the vehicle. We plan to use a single-board computer to control all systems of the vehicle instead of several microcontrollers.
3) Adding a stereoscopic image system based on two analog video cameras.

Fig.10.1. Design of the thruster

Fig.10.2. The propeller

11. Reflections and Lessons Learned

While working on the project, we have obtained and improved upon a variety of skills in mechanics engineering, electronics and programming. Teamwork provides an invaluable experience that could not be taught in class.

Projects of this scale require not just enthusiasm, but efficient managing of the workflow and planning. For example, company designer **Daria Igumnova** compiled an overview of the mission tasks that was put on the wall in the lab, so the company members didn't have to look them up in the mission manual (Fig. 11.1).

One of the achievements, this year, was that we decided not to use 3D-printing for the most important parts of the vehicle and used CNC milling of polypropylene instead. This is how we made the framework of the ROV and mounting mechanisms for manipulators and payload.

These are the reflections that company members wanted to share:

Vyacheslav Tsoi, Payload Specialist:

"I learned how to apply my skills as a mechanical engineer and how to perform troubleshooting in a complex system. I also improved my knowledge of electronics. Working with the team taught me how to find unusual solutions to engineering problems, how to discuss and analyze them and to find a compromise."

Sergei Kuznetsov, Embedded Systems Programmer:

"Working on the project, I learned to properly distribute my efforts when performing several tasks. I also learned how to approach creatively to any task, such as programming and electronics design."

Last year most of the company members that participated in MATE ROV competition 2013 have graduated, so now Bauman GidroNAV company consists mostly of newcomers. But we still keep in touch with our predecessors and have asked one of them to share his thoughts:

Felix Palta, Team Supervisor:

"When I worked in the company as a team member, I received invaluable experience in the development of embedded electronics systems. It was this project and not just a degree that made me an actual engineer. Now being a team supervisor I can improve my skills in project managing, risk planning, conflict resolving, in other words, my 'soft skills'. I believe this experience will come in handy when managing my own company."

Fig.11.1. Overview of the mission tasks

12. Acknowledgements

MARINE ADVANCED TECHNOLOGY EDUCATION CENTER

We want to thank MATE Center for an amazing opportunity to take part in this competition. Thanks to you, we receive a new challenge every year and learn how to approach that challenge creatively.

We also want to thank:

BAUMAN MOSCOW STATE TECHNICAL UNIVERSITY (BMSTU)

For financial and administrative support, as well as the provided laboratory and a pool for testing our vehicles.

UNDERWATER ROBOTS AND VEHICLES DEPARTMENT OF BMSTU

For the knowledge and skills they gave us.

FAB LAB "FABLAB77" OF MOSCOW INSTITUTE OF STEEL AND ALLOYS

For the free of charge manufacturing of vehicle's framework and other parts.

SHIRSHOV INSTITUTE OF OCEANOLOGY

For their help in ordering and delivery of motor parts for the manipulators

These people have also been invaluable to the project success:

Valeryi Ippolitov
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Vladimir Kuznetsov
Felix Palta
Ekaterina Lyamina
Andrey Kozinov
Natalia Petrova
Pavel Ikomasov
Dmitriy Kovalevich
Dmitriy Novikov

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2) Steve McConnell, "Code complete", 1998
3) G. Volovich, «Design of analog and digital-analog electronics», 2005
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5) http://www.chipdip.ru
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14. Appendix A. Project Budget Layout

Reporting period: 01.09.2013 – 20.05.2014
School name: Bauman Moscow State Technical University
Mentor: Stanislav Severov
Funds: BMSTU, Fablab

№	*Element*	*Number of*	*Price, US dollars per item*	*Cost, US dollars*
	Re-used			
2	Box for the mobile control station	1	462	462
7	120 Hz 30” display	1	677	677
8	Car display	1	357	357
9	20W LED lamps	4	24	97
10	Camera rotating servos	1	22	22
11	In-house designed neutrally buoyant tether	30	6	183
	Total			1797
	Purchased			
1	Arduino platforms	4	73	294
2	DC/DC converters	1	484	484
3	Sealed connectors	16	25	400
4	Strain gauge pressure sensor	1	103	103
5	Orientation sensor VectorNAV VN-100	1	1018	1018
6	In-house designed conductivity meter	1	171	171
7	MAXON motors	8	357	2857
8	Analog video cameras	4	100	400
9	Electronics pressure hull	1	734	734
10	Seabotix manipulator	2	527	1055
11	GNOM manipulator	1	800	800
12	3D-printed thrusters fairings	16	25	400
13	Electronics parts	1	246	246
	Total			8963
	Donated			
1	Manipulator mounting mechanism, polypropylene cutting *	1	37	37
2	ROV framework, polypropylene cutting*	1	1143	1143
3	3D printing of cameras mounting frame**	1	20	20
	Total			1200
	TOTAL COST of the AKVATOR Jellyfish ROV			11960

Donated by:
* Fablab
** Andrey Vasilchikov

15. Appendix B. Safety Checklist

Before the launching the ROV in the water:

1) Check if all cables are securely fastened to the frame
2) Check if all sealed connectors are inserted correctly. Use markings of the electronics unit cover as a reference.
3) Check insulation of all cables.
4) Check if all thrusters have their protective gratings installed.
5) Check if fuse is installed in the positive power line.
6) Check if the ROV control station is properly grounded.
7) Power up the ROV control station and measure voltage on metallic parts relative to the ground. The voltage should be zero volts.
8) Check if 48V DC voltage source used for powering the ROV is isolated.
9) Before powering up the ROV all joysticks should be in the neutral position.
10) Make sure, that the ROV control station is not too close to the water. It should be at least two meters away to avoid damaging its electronics by splashing water.
11) Make sure that manipulator is not in one of extreme positions, which can cause jamming.
12) Make sure, that no one is touching moving parts of the ROV.
13) Power up the ROV and measure voltage on aluminum covers of pressure hulls and thrusters relative to negative power line of the DC voltage source. The voltage should be zero volts.

Before retrieving the ROV from the water:

1) Power off the ROV to avoid electric shocking in case of leaking hulls.
2) Retrieving the vehicle should be performed by at least two people or using a lifting mechanism.

After retrieving the ROV from the water:

1) Check transparent pressure hulls for signs of leakage and cracks.
2) Check if payload of the vehicle is intact.
3) Check if thrusters' propellers are secured on the shaft and are not slipping.