Far-Eastern Federal University

2011 MATE International ROV Competition

Primorye Coast's Project:

Junior 2011

(Explorer class)

Team Primorye Coast (FEFU)

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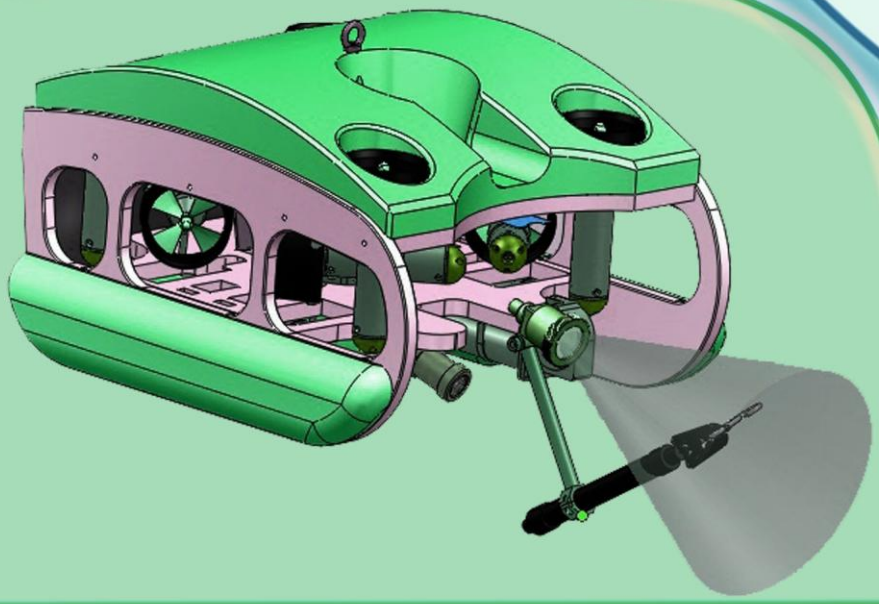

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TABLE OF CONTENTS

ABSTRACT 3

DESIGN RATIONALE 4

- Structural Frame, buoyancy 4
- Propulsion Systems and steering 5
- Camera's location 5
- Design rationale – tasks 6

VEHICLE SYSTEMS 6

- Control System 6
- Electronics 8
- Manipulation system 10
- Sensors 10

CHALLENGES 11

TROUBLESHOOTING TECHNIQUES 11

FUTURE IMPROVEMENTS 11

LESSONS LEARNED 12

TEAMWORK 12

REFLECTIONS ON THE EXPERIENCE 14

ACKNOWLEDGMENTS 14

BUDGET 14

REFERENCES 16

APPENDIX 1. Electrical schematic 16

APPENDIX 2. Control scheme 18

ABSTRACT

Our company "Primorye coast" specializes in development of remotely operated vehicles and specialized tools. The company employees are students of the lead university of the Russian Far East. Our vehicles and equipment are designed to perform underwater work in the offshore oil and gas industry. Also, our company performs underwater operations itself. We specialize in the work related to prevention of underwater industrial accidents, such as the explosion at The Deepwater Horizon in the Gulf of Mexico.

Last year success of the "Primorye coast" team has proven, that Junior 2 design is successful. But we took advice from Luice Carrol: *"... it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"*. We took some solutions form Junior 2 design, but came up with many new ideas: oxidized housings, new frame (which was modeled in SolidWorks), new program for operator, thrusters fairings, firmware upgrade, payload tools (sampler and stopper).

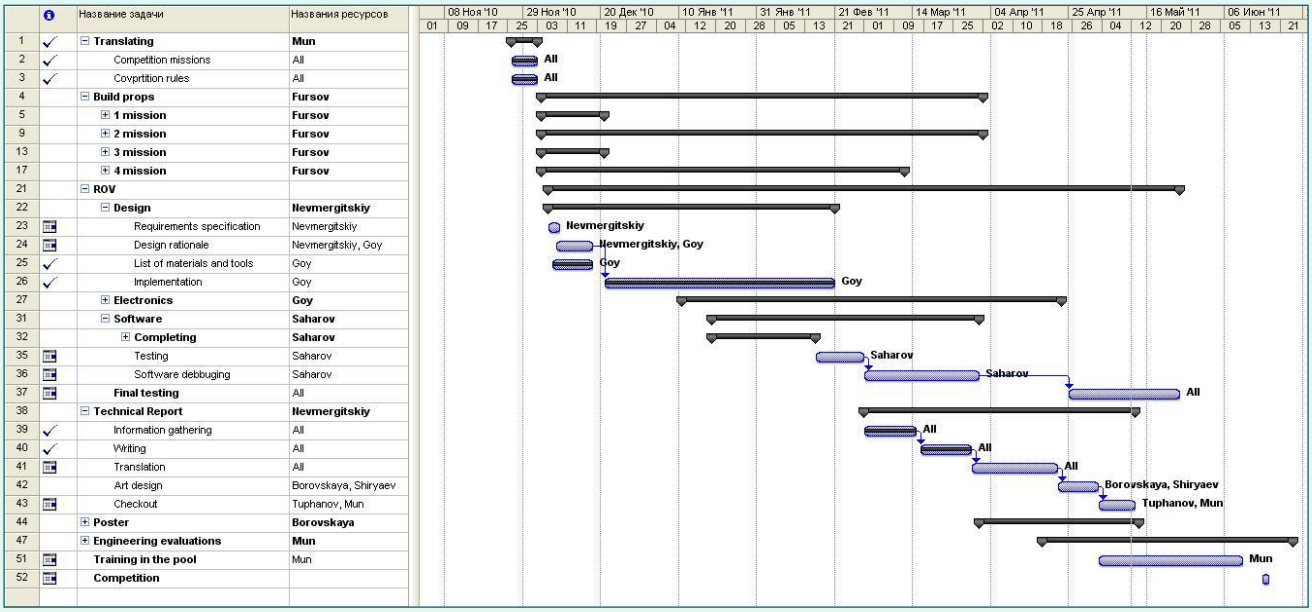
"Primorye Coast" company

DESIGN RATIONALE

In this section we consider the design of our ROV by sections.

Our team learned an important lesson from the competitions of the previous years. We have understood how planning is important. And so the first thing we did when started preparing for the competition this year, we thoroughly planned out our work.

Gantt chart



Structural Frame, buoyancy

ROVs base is a polypropylene frame. The frame consists of left part, right part, lower plane and upper plane. We have kept the layout of the frame like the previous year, changing its technological and design cuts. All other vehicle parts, such as thrusters, lights, and cameras were attached to the frame by thin-metal clamps, screws and nuts. In our opinion, a rectangular frame design is contains the equipment compactly. It gives an ergonomics and good maneuverability in the water to the ROV. Polypropylene plates are connected by fixings. We designed the new good fixings instead of the last year ones. The frame is rigidly fastened and can be conveniently mounted and dismounted.

Buoyancy is fixed on the upper plane. This time we have modeled buoyancy with greater volume. The buoyancy is made of polyurethane foam, which was cut by melting, using thin metal spring with a current, flowing through it. Buoyancy was polished with rubber and painted.

We oxidized all aluminum housing parts to protect the vehicle from corrosion. We dismantled and cleaned of oil all parts of electronics housings, and oxidized all new aluminum parts. Our ROV was reassembled after oxidization.

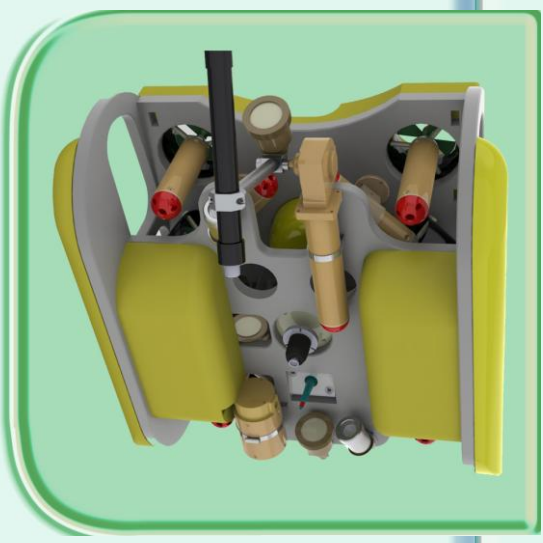
Propulsion Systems and steering

We have kept the excessive propulsion system with eight thrusters. Excessive propulsion system includes a greater number of freedom degrees than the number of vehicle freedom degrees. We can to control by three forward, and two rotary. We have seen that this complex system have provided the best ROVs maneuverability in the last competitions. Four thrusters of eight are arranged vertically and stabilize the vehicle by pitch, four thrusters are arranged horizontally, and stabilize the vehicle by course.

Thruster consists from brush-less direct current (BLDC) motor MAXON EC-max 40, located in pressurized tube of a streamline shape. This composition is kept from the last year design. We have replaced coprolone coupling between the motor's output shaft and propeller's shaft. Also, we added lower fairings to the thruster's construction.

Camera's location

We have used three cameras (rotatable camera VM32HQ-B36 (view angle is 62 °)) for full view. The first camera is installed on a conjunction with the manipulator and provides its capture view. The second camera gives a view of the stopper and the water sampler, which are located in the center of the bottom frame. The third camera gives panoramic view. It is situated at the vehicles rear and looks forward. This design gives head overview. Panoramic camera helps operator to stabilize the vehicle.



Design rationale – tasks

Task 1: Remove the damaged riser pipe

In the first task we need to dismantle damaged pipe section, which was joined by velcro to the wellhead. For this task we use a construction carbine, with a hookup cable. The carbine will be trapped by the manipulator, and will be attached for the U-bolt. Then the manipulator pulls the ring and the velcro releases the pipe. A team member pulls the rope after releasing, dismantling the damaged pipe section.

We set task features on the ROVs frame. There is a stopper with a holder and a sampler for water sampling to perform missions 2 and 3. The overview cameras are placed opposite to the stopper and injector.

Task 2: Cap the oil well

In the second task we need to stop a flow from the pipe. We have made stopper with a conical valve. It is fixed under the ROV's bottom by the holder. The ROV puts the stopper on the pipe by "sitting" on it and turning by 90 degrees. Cameras under the bottom give two views of the pipe and the stopper. Good overview allows us good stopper installation. The holder releases the stopper after the ROV's rotation. The valve closes the pipe hole, and the ROV may go off the pipe. Stopper will be held by frictional forces, and its conical form will cut a water flow. We have designed a special grip for better fixing the stopper on the pipe. The grip rests on the tube, when the stopper is disconnected of the ROV's frame.

Task 3: Measure the depth

In the third task we need to reach the desired depth and sampling a portion of water from the source. Depth sensor is installed on the vehicle. Its measurement accuracy is about 5 centimeters. The sampler is designed to take water portion. It consists of an injector with a plunger, springs and a holder. Plunger is strained by four springs. The injector sucks water automatically after the holder is removed by the manipulator. The injector is located under the ROV's bottom.

Task 4: Collect biological samples

In the fourth task we need to collect biological samples. We collect samples by a manipulator and place them in the bin located at the ROV's top. This method will allow us to collect all samples in one diving.

VEHICLE SYSTEMS

Control System

Development environment

This year all our team programmers are novice in the robotics field. We have decided to create the new control board from scratch, while the last year control board meets all demands and quite applicable for driving new ROV. There are several reasons. First of all, it is our intention to use open source software. The last year control board was created by using deprecated development tools (Borland Builder) and commercial OS (Windows XP). We would like to use the most up-to-date development tools and free operation system (Qt SDK, Ubuntu OS). Our teammates want to achieve new skills in programming field.

Initially we planned to use only free software, but we had to use Windows OS due to absence of applicable driver for USB-RS485 bridge. C++ language with Qt framework are quite reasonable for creating of the ROV operator's control board. Qt is a cross-platform framework, so we can use our software in different operating systems. All our team programmers are skilled in C++ language, so this development kit is suitable.

Graphical User Interface (GUI)

Our GUI consists of several widgets: depth, roll-pitch, joystick, manipulator control, LEDs, cameras and others. Main window periodically calls functions which provide data exchange between ROV and widgets, and allocates data for next processing. Unlike the last year we decided to separate video from the controls and telecast it to the separate monitor.

Programming

Control board modular structure is very convenient for team working. Modularity allows us to vary appearance of the control board and to split the whole programming task in small problems. Each developer has worked out only his own problems to reduce a number of conflicting code changes. It is mean that they could progress simultaneously. Modules integration into the main program is quite easy. Created widgets can be easily used in other projects, both by us and other developers (after all the source code is publicly available). Another advantage is that widgets can be separately used for ROV's systems debugging, before the whole User Interface (UI) is finished.

Widget design was being created simultaneously with it's functionality, and then was applied to the control board with no troubles, thanks to Qt's Cascade Style Sheets (CSS) supporting. The finale result is an easily modifiable and customizable system. The abstraction of objects (making them universal for any implementation of the ROV) allows us to easily modify the software to operate a different ROV. We established conventional coding standard within our team. While debugging, it helped us many times.

Onboard autopilot program has taken insignificant tweaking in comparison with the last year, as it already worked well. We have done refactoring and code optimization. The GUI communicates with the ROV system through the USB-RS485 converter, just as the last year.

Configuration

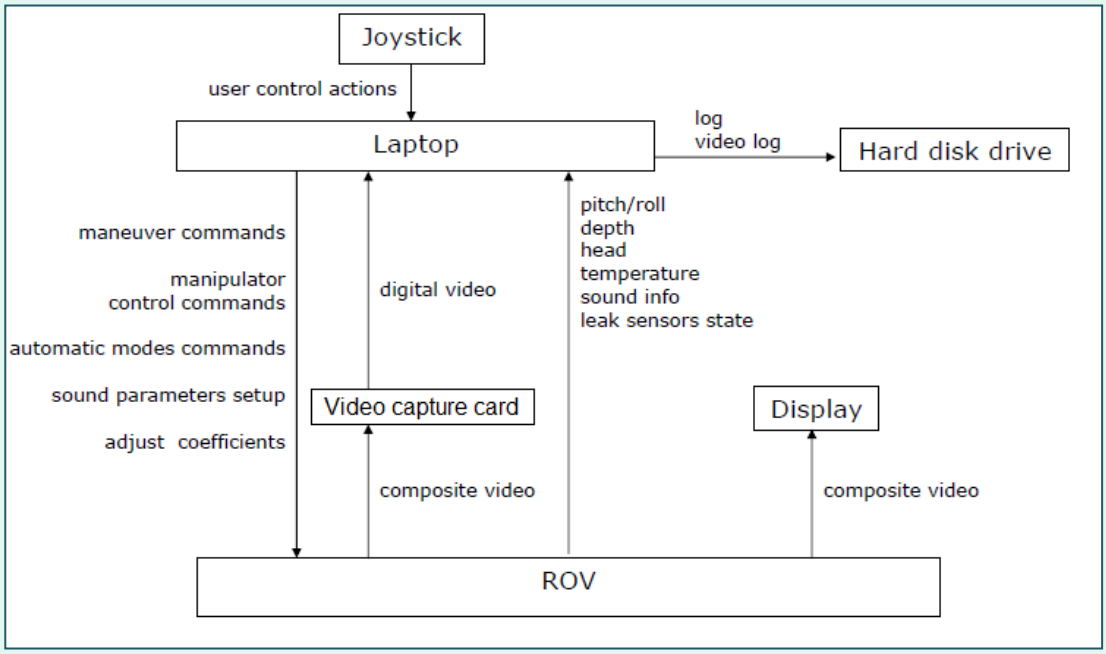
We intend to configure TCUs on the surface. This provides us with the ability to easily change engine parameters without flashing and therefore to save time. In the last year project all settings were stored in INI-files. Now, this approach is deprecated, so all configurations were saved in structured XML-documents. It's quite visually and handy.

Testing and debugging

We debugged our widgets with detached ROV's systems (sensors, cameras, TCUs, manipulator and others) in the process of developing to reduce a debugging time after assembling.

Besides that we always knew where to search for an errors, thanking to widget structure and flexible system of debugging. Our decision to put configurations in XML files has appeared very handy during the debugging, calibrating of sensors and selecting of right coefficients.

Surface data flow



Electronics

Commutation block

Commutation block consists of power supply board, USB-RS485 bridge, video modulator, video capture card and a USB hub.

Power supply block has the AC-DC converter. It converts 110-220V to 48V, maximum loaded current value is 21A. Video modulator converts the high frequency video signal into two analog video signals, one of which goes to the video capture card, and the second one to the operator's console. The video capture card and the USB-RS485 bridge are connected to the laptop through the USB hub.

All circuit boards are designed by students and approved by mentors. Design process is performed in Altium Designer software. Most of circuit boards were designed to be multi-layered (sensor board system and motor controllers board system consist of four-layered boards). This solution provides less size and decreases noises influencing the analog sensors precision. Students couldn't make multilayer boards themselves due to technological complexity of the process, so they were made by "PS-Electro" company in Novosibirsk city. Students made power supply circuit board by themselves. All soldering was also made by students.

Tether

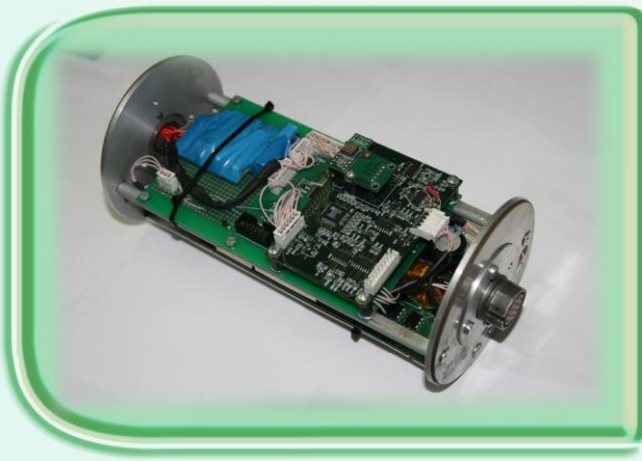
Tether is used to connect vehicle with surface. It is used for power supply and data exchange. Tether also provides mechanical strength of vehicle connection. For the new deeper pool we use a new tether 30 meters length.

It contains the following cables:

- coaxial cable, to transmit video signal to surface
- two wires of 2mm2 for power supply
- two wires of 0.5mm2 for RS-485 interface to control vehicle
- two wires of 0.75 mm2 power autopilot power supply
- one wire of 0.5 mm2 GND RS-485

To fix the tether to the ROV we made a new leakproof tether connector. For quality control cable should not affect the motion of the test stand. Tether should not affect the motion stability in order to perform precise control. That's why we fixed the tether at the center point of the frame. If the tether causes a deviation of the ROV, this effect can be compensated by stabilization thrusters.

Autopilot



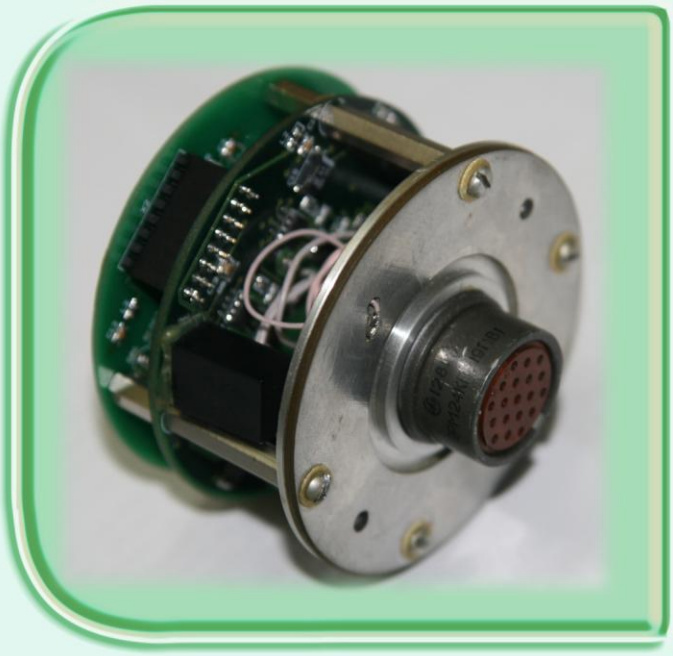
The electronic control system of the ROV is placed in a cylindrical leakproof housing which protects the electronics from water and mechanical damage. Power supply board, board sensors, control board, video modulator and two leak water sensors are placed in the housing. The power supply board had three decoupled grounding (DGND, AGND, VGND) and filters at the input and output of each DC-DC converter. The board gives necessary power supply to all autopilot electronic parts (+24 V, ± 12V, +5 V). The board also contains LED driver, which feeds the direct current 700 mA to the lights.

Microcontroller is placed on the ROVs control board. Also the board includes:

- video multiplexer, which controls switch between three cameras
- RS-485 interface, which ROV uses to communicate with the operator control unit
- CAN interface chip, which helps autopilot to communicate with thruster control units

Sensor board consists of 16-bit Analog-Digital Converters (ADCs) and two angular velocity sensors. One sensor is two axis measuring. It is responsible for roll and pitch stabilization. Second sensor is single axe measuring. It is responsible for ROV's course stabilization. Analog signals from sensors pass to the ADC. After transforming they pass to the control board to be processed by the microcontroller. Also, this board processes depth sensor signals. Video modulator allows to transmit two video signals at high frequencies by one wire. We place water sensors in each electronic housing for leak detecting.

Thruster control units



Thruster control unit consists of two circuits - the logical part and power supply part. Logical part includes a microcontroller and a CAN interface. Power supply part includes ADC, Pulse Width Modulator (PWM) and filter. Each thruster control unit communicates with control board by the CAN interface. Rotor position signals are transmitted from a Hall's sensor to the controller circuit. The signal is processed by the PWM. A thermal sensor watches for circuits overheat.

We decided to keep the thruster control boards in separate housing. There is one thruster control unit for each thruster. Thrusters control circuits are put into four aluminum tubes. One tube contains two thruster control units for two thrusters. The tubes are pressurized and equipped with leak sensors. This solution is reliable at a depth of 30 meters.

Electrical block diagram

Whole system is connected to the ROV's sealed tubes which are filled with an electrically neutral liquid. Electrical schematic is shown in the Appendix 2.

Manipulation system

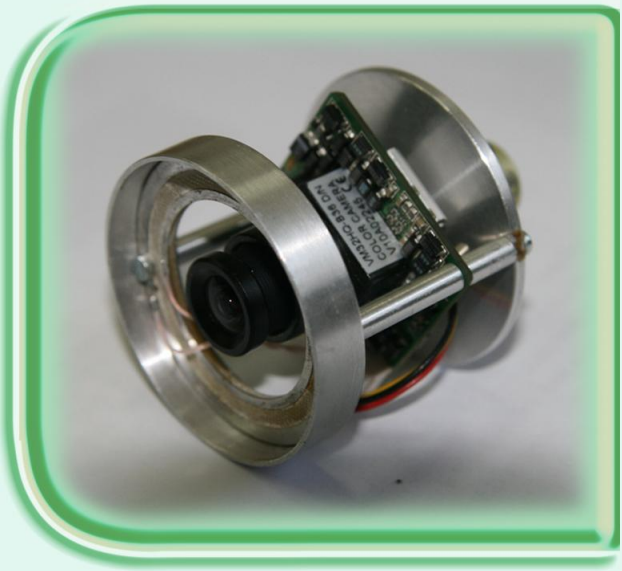
Manipulation system consists of manipulator and reducer. It is used in all tasks. We've used Seabotix TJG300 manipulator, which have one freedom degree. The reducer provides correct manipulators movement in up/down direction. The manipulator control is provided by the control block which is the same that the thruster control block. Manipulation system is mounted at the frames front.

A rotatable camera VM32HQ-B36 (view angle is 62 °) gets information about the manipulators arm. We have designed and built a bracket for the arm and overview camera. Thus, the camera works in conjunction with the manipulator and gives an all actions overview. We place worm reducer with its thruster control units. Worm reducer is available with the reed switch board, which restricts movement of the manipulator in the extreme top and bottom position. Our manipulator works properly to the required depth.

Sensors

Cameras

Our ROV have three color cameras VM32HQ-B36. The first camera is turned on the manipulator arm, the second camera is at the ROV's bottom looking forward. The third camera is set at the ROV's bottom and looks down.



Lighting

The vehicle is deployed by two lights with powerful white LEDs XLD-AC-007WHT. One of them looks on the manipulator working area, and the second camera covers an overview.

Depth sensor

We bought a new sealed pressure sensor DMP 331 110-999 to use in depth measuring. Measurement accuracy is about 5 centimeters on all depths measuring range. We think, it will help to take water samples at required depth.

CHALLENGES

We have designed thruster control boards with thruster housings for small-sized brushless direct current motors (BLDC motors). We planed to use them in all thruster systems and in the manipulator system. The new control board is placed in one housing with the motor. New housings give a compact and leak tightness. This board improves precision of the control and helps to reduce power consumption. Unfortunately, the firm-manufacturer has no time to produce our boards by the deadline, and we had to give up the housings manufacturing too. We decided to mount old motors with thruster control boards in good housing.

We bought new efficient and bright LEDs and designed tight housing for it. We have not manufactured the housings, still we had to go back to the old energy-saving LEDs. Using LEDs helps to reduce power consumption of our ROV.

We made our ROV lightweight in water to achieve better maneuverability. We used lightweight materials (aluminum, polypropylene, fluoroplastic and fiberglass) to ensure a neutral buoyancy of the vehicle. SolidWorks modeling allowed to calculate a mass of all elements up to each diode or a screw. We have determined the mass center of the model and placed all thrusters equidistantly of it. Calculated ROV's weight in the water is balancing by the calculated buoyancy volume. Additionally we balanced the ROV by pieces of foam plastic, according to a tests performed in the pool.

TROUBLESHOOTING TECHNIQUES

ROV's cameras periodically turned off when we performed tests in the pool. The problem was that the synchronous work of thrusters dropped the voltage in the supply line to 32V. DC-DC converter for camera supply operates on 36V. Cameras are disconnected each time the voltage drop. The problem was eliminated by connecting two separate wires to the autopilot. Thus, a possible voltage drop in the supply line does not affect the autopilot board.

At the beginning we faced problems in source code management. Sources were e-mailed or given from hands to hands. That method delayed work. But soon we solved the problem by depositing project files in online repository – GitHub. It allowed us not only to store our sources in the Web, but to establish a source control for any digital documents, and also to presents variety of other interesting and useful features. It allows multiple users to modify the same files at the same time and easily merge them. It also supports file snapshots creating at particular time, which we used to indicate stable code versions.

FUTURE IMPROVEMENTS

We plan to design new LED housings and connect LEDs to the new power circuit. We also plan to obtain thruster control units from the firm-manufacturer and make a compact housing for it.

We have tested a new adaptive robust control system on our autopilot instead of proportional one. The author of this system is Alexander Lebedev – a researcher from Institute of Automatics in FEB RAS. This system can improve roll, pitch, and depth stabilization of the ROV, but it needs further adjustment to work stable.

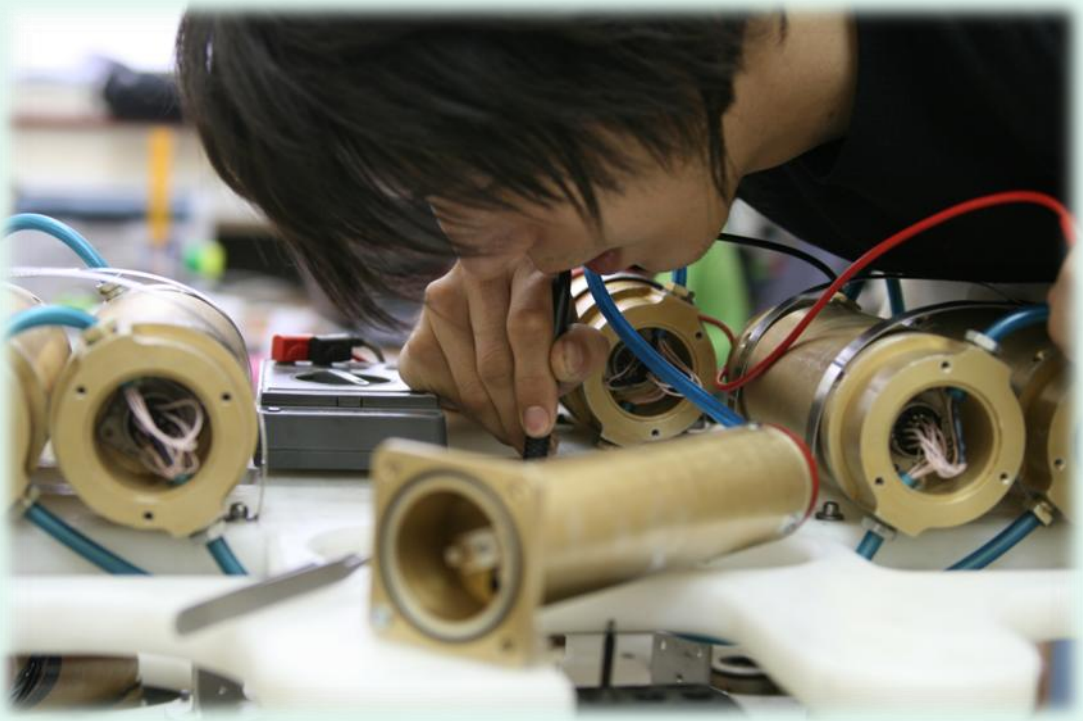
LESSONS LEARNED

Our team have done a considerable work in the field of programming. There are not so many programmers in the team, and each of us has received a lot of experience in development aspects. We have given a special attention to debugging and creation of convenient and functional ROV's system. Except individual tasks there were also tasks for all programmers. Thanks to harmonious working of our designer and programmer groups, we created very convenient and nice interface together.

At the beginning of the project we organized working groups - electricians, designers and programmers. Team members worked independently or in pairs. Everybody was assigned current tasks by the Internet. Through all attempts we understood that all team members should interact for good and effective work. Teamwork joins together all team skills in a common task. Collaboration creates common interest to the project and to each other. The project tasks are solving faster, and the process becomes fun and exciting. We also created team web-site for the design data exchanging and communication.

TEAM AT WORK

Photo parties / Description of roles:



Vladislav is wiring thruster control units

Angelina and Anton is making a new design

Maxim is modeling the ROV construction

REFLECTIONS ON THE EXPERIENCE

Vladislav Goy: I spent quite a lot force on the project management. In fact, it is very difficult to control whole team work, to give a part of time to everyone and to solve a complex problems. I am really pleased that we were able to rally the good working team and to design the perfect ROV.

Anton Shiryaev: I have never participated in that kind of projects. I used to work alone and rely on myself. In this project I have found good friends. These people are interesting for me and I have a great pleasure working with them. They helped me to learn something new.

Maxim Fursov: I was interested in robotics and automotive devices creation from childhood. I literally found myself and learned a lot after joining the team. I hope that this knowledge will be useful in my future professional activities. I learned to work in team and met a lot of good people.

Maxim Nevmerzhitsky: Before joining to the team I was involved in other projects, but only as a subordinate, doing my local tasks. This project allowed me to obtain teamwork and project organizing experience. I learned how to share my experience with other participants, and gained new knowledge from the mentors. My SolidWorks modeling skills has increased significantly over the past six months.

Andrey Sakharov: I learned how the small project is managing. I understood how to organize people and motivate them to work together, if it necessary to have reserve time for unexpectedly appearing problems solving. If a team member have some troubles with problem solving, it is necessary to gather and solve it together.

ACKNOWLEDGMENTS

First of all, we would like to thank MATE Center for such an exiting event, for helping us by competition materials and resources.

We would like to thank our mentors, who shared their great experience and mastership with us through the whole process of vehicle creating.

We want to thank Institute for Marine Technology Problems for providing us with rooms, equipment, materials (buoyancy and a tether)

We want to thank Far-Eastern Federal University for good financial support of our project.

We want to thank companies and personalities, who helped us to transport the materials and part machining.

BUDGET

Expenses

Item	Quantity	Total, $USD
Framework		
Polypropylene Sheets	2	150
Polyurethane Sheet	1	562,5
Clamps	15	24,6
Cutting polypropylene	1	259
Power system		
Current source RSP-1000-48	1	337,5
Tether	30	220,5
Propulsion		
Motor EC-max40	8	2368
Propeller screw	8	480
Control and electrical system		
At90CAN128	2	19,4
ADXRS401EB	2	172,8
IRS2336DM	20	140
AD822ARMZ	9	54
AD592ANZ	9	45
IRF7854	54	64,8
MUR 120 G	36	12,6
KX-KX 16	9	6,3
Pressure sensor DMP 331	1	125
Joystick Saitek Aviator	1	57,5
Manipulation complex		
Grabber Seabotix TJG300,	1	3500
Motor EC-max40	1	296
Optic relay PVG-612	10	131
Information-measurement complex		
VM32HQ-B36 camera	3	390
Light diode cluster XL7090	2	121,6
Coaxial cable PK-50	25	9,75
Traveling expenses		
Visa	7	1485
Air ticket	7	21700
Cost of living	7	5250
Other expenses		
Participation fee	1	50
T-Shirts	15	300
TOTAL		**38332,85**

Donations

Company	Value, $USD
Institute of Marine Technology Problems	904,6
Far-Eastern Federal University	37428,25
TOTAL	**38332,85**

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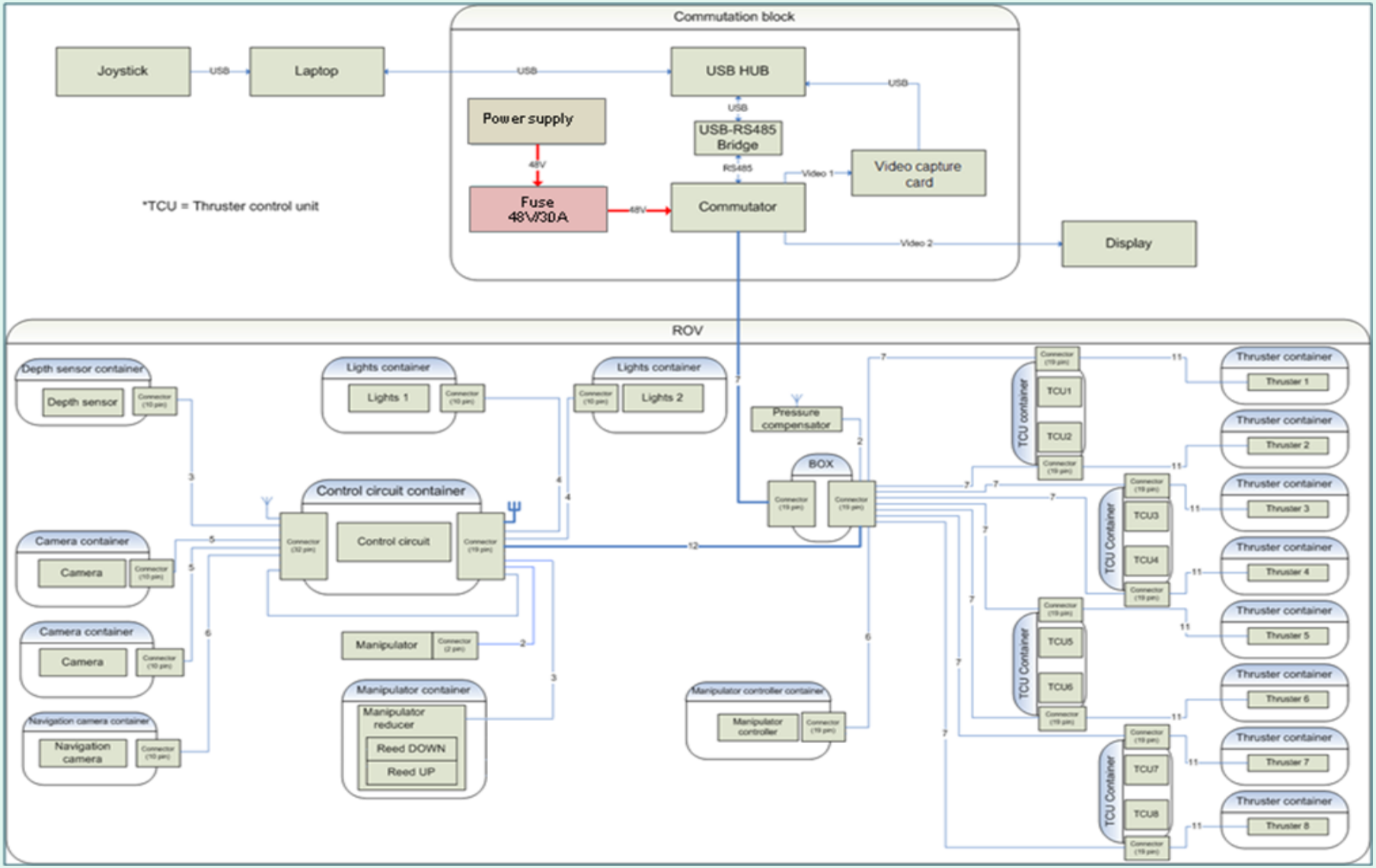
APPENDIX 1. Electrical schematic



APPENDIX 2. Control scheme