Institute for Marine Technology Problems
Far-Eastern National University
Far-Eastern State Technical University

Junior 2

(explorer class)

2010 MATE International ROV Competition
"ROVs in Treacherous Terrain: Science Erupts on Loihi, Hawaii's Undersea Volcano"

Team

Name	**University**	**Age**	**Specialty**
Igor Tuphanov	FENU	21	captain, programming
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Mentors

Name	**Organization**	**Status**
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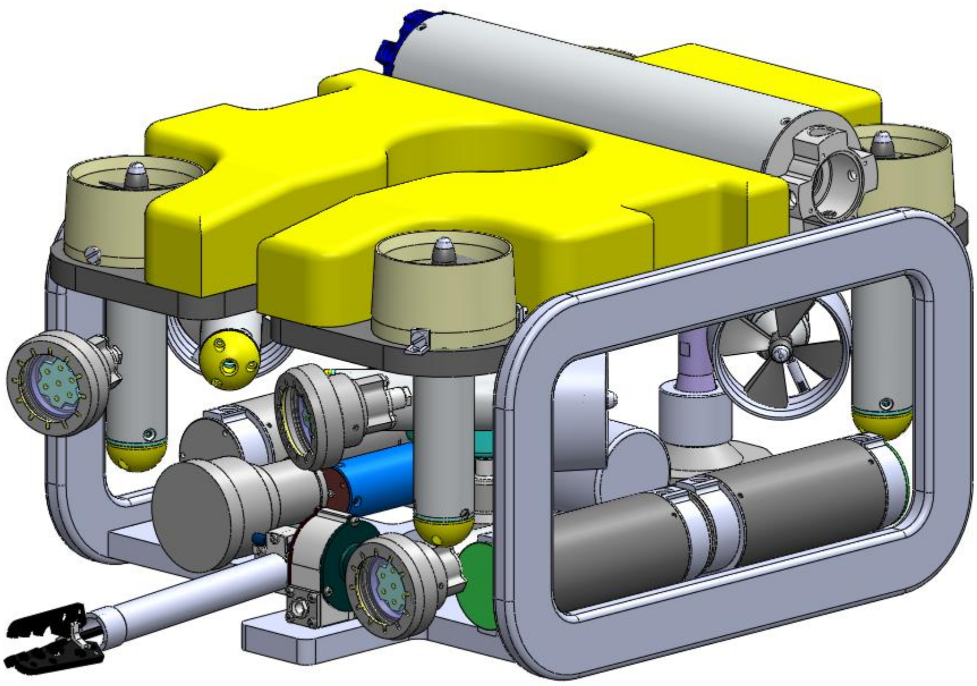
Vladivostok, Russia, 2010

Contents

Abstract

The team of Institute for Marine Technology problems came up to this year contest, organized by MATE Center, with a new vehicle. The vehicle is named "Junior 2". It is designed to accomplish the mission tasks fast and precise. We have the compact polypropylene frame to fit the cave, a hydrophone to catch sound, software for sound processing, generic design to collect samples, video recording software on surface laptop and other features.

The weight of our ROV is 45 kg, and the dimensions are 60 cm long, 51 cm wide, and 40 cm tall.



Junior 2

Design rationale – ROV design

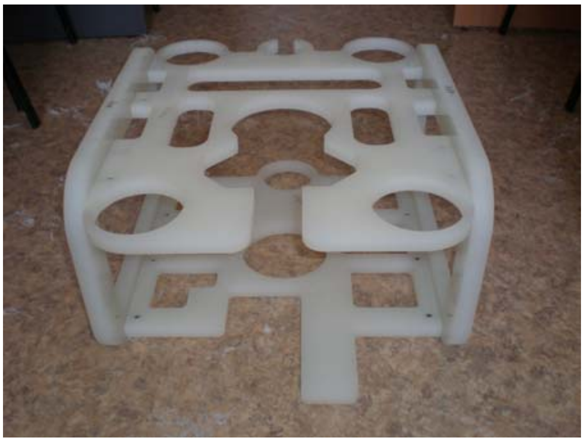
In this section we describe design of our ROV by parts. Complete electrical schematic is introduced in Appendix 2.

Frame

The main part of the vehicle’s body is frame, made of polypropylene. We chose this material because it is quite solid and has density 10% less, then water, providing us additional buoyancy. The frame consists of left part, right part, lower plane and upper plane. Students themselves didn’t cut polypropylene frame, since we have no ability to work on special equipment. Cutting polypropylene by hand would take too much time. Four pieces of frame were joined by couplings, so it can be assembled/disassembled may times.

On the upper plane there is buoyancy. It’s made of a piece of polyurethane foam, which was cut by melting, using thin metal spring with a current, flowing on it. Buoyancy was polished with rubber and painted.

All other parts of vehicle, such as thrusters, lights, and cameras were attached to the frame by thin-metal clamps, screws and nuts.



Polypropylene frame

Electrical system

Electronic control system is situated in pressurized cylindrical metal tube. This tube protects the circuit boards from water pressure, leakage and mechanical destructions. There are circuit boards for power supply, for control, for sensors, and hydrophone circuit board. Video multiplexer, video modulator and inductive compass ID-6 are also located in the tube.

Supply circuit board give 24 V, 12 V, ±12 V, 5 V, ±5 V output from 48 V input, which is necessary to supply electronic system. It also includes current stabilizer, which supplies LED's.

Control circuit board is the heart of control system. It includes microcontroller, which process navigation data and send it to the commutation block. Program, written for this microcontroller provides the main logics of control system. The control system scheme is presented in Appendix 4. Some parts of scheme are real devices, while most part of logics is provided by software. Control decisions are made according to automatic modes (switched by surface laptop). Each automatic mode keeps some value constant. There are automatic modes for

- depth,
- head (yaw),
- pitch.

The control circuit board also contains driver for CAN interface, providing connection between the components of ROV, and driver for RS-485, providing connection between ROV and commutation block.

Sensor circuit board consists of 16 bit ADC, accelerometer and rate gyroscope. ADC provide transformation of analog signals from sensors into digital code. The depth and temperature sensor are situated in individual pressurized tubes. We use the inductive compass ID-6, which is also used in Russian Helicopters, meaning its extreme stability and safety. So we use it with high pride.

Video multiplexer chooses the pair of video signals and then sends them on the video modulator, where they are combined into one signal.

Hydrophone board amplifies signal and filtrates noise. It contains DSP performing Fast Fourier Transform.

Each pressurized tube has one or two leak sensors.

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 and boards for motor controllers are 4-layered). This solution provided less size and decreased noises, which influence on 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 on a factory near Novosibirsk. But students made supply circuit board themselves. All soldering was also made by students.

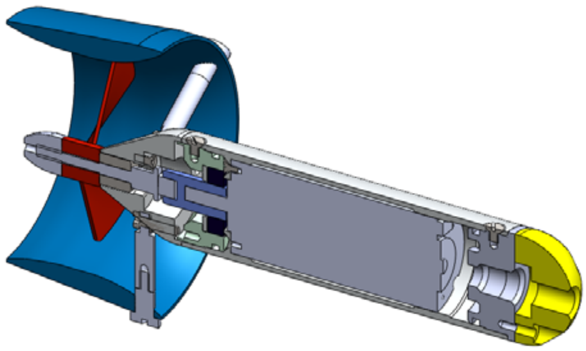
Propulsion and steering

The propulsion and steering complex includes eight thrusters. Four horizontal thrusters provide forward, backward, sideways movements and turning. Four vertical thrusters provide up and down movement and compensation of tether's reaction. The chosen thrusters placement provides high characteristics and gives a possibility to perform mission tasks.

Thruster consists of commutator-free motor MAXON EC-max 40, located in pressurized tube of a streamline shape. At the end of the output shaft there is a screw propeller with the diameter of 95 mm., protected by a nozzle. This nozzle also has a function of a directing water stream. We choose this kind of motor because of requirements for weight (650 g.), required power (120 W) and reliability.

This motor has following characteristics:

- Nominal supply voltage – 48V
- Rated consumption current – 2.19A
- Rated speed – 3770 rpm
- The maximum efficiency – 82%.



Thruster draft

Thruster

Thruster control units

There is one thruster control unit for each thruster. Thuster control unit consists of two circuits: a controller circuit and circuit for driver and power switches.

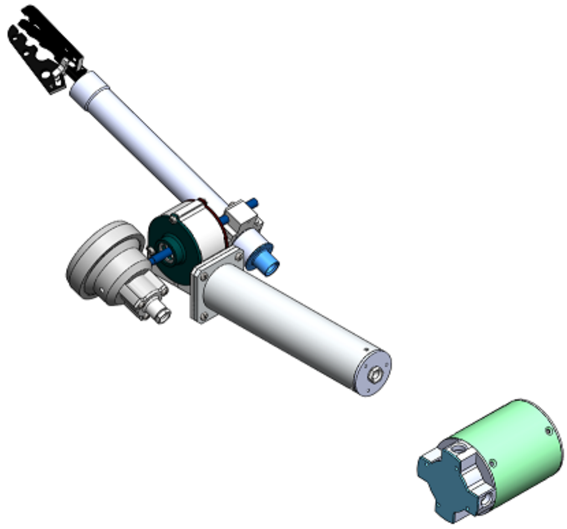
Signal, that contains information about rotor position, is transmitted from Hall's sensor to controller circuit. The signal is processed here by PWM. There is also a chip, providing connection with control circuit board by CAN-interface.

Control signals are created and reinforced on the driver and power switches board. A thermo sensor watches for circuits overheat.

Thrusters control circuits are put into four aluminum tubes. One tube contains circuits for two thrusters. The tubes are pressurized and equipped with leak sensors.

Manipulation system

Manipulation system consists of manipulator and reducer. It is the main part of vehicle, effecting the environment. It is used in all tasks. We've used manipulator Seabotix TJG300, which have 1 degree of freedom. Reducer provides correct movement of manipulator in



Maniplulation system draft

up/down direction. Manipulator control is provided by control block which is like thruster control block.

Manipulator is situated in the front part of vehicle. Such location provides the following advantages:

- it provides convenient view;
- it helps pilot to control manipulator
- it makes possible usage of manipulator to stabilize vehicle.

We have reed switch to catch moment when manipulator came to its edge position.

The major way to get information about manipulator is by using rotatable camera VM32HQ-B36 (view angle is 62˚).

Payload

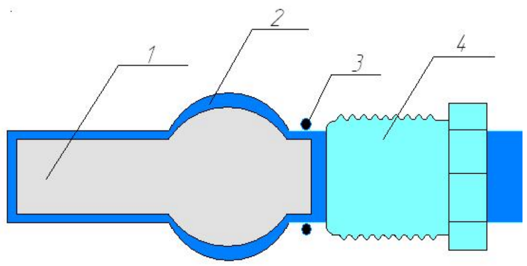
Most of payload is specific for mission tasks, so it is described in next sections. Our vehicle carries the following payload:

- Three cameras. One rotatable camera, one vertical camera (both are VM32HQ-B36) and wide-angle navigation camera (QN-B309). It was located in such a way to provide useful video information.
- Two cluster lights.
- Bucket for samples. It is located in a special hole on buoyancy. Such location helps to put samples in the bucket precisely, using manipulator.
- Hydrophone, which was made with assistance of FENU hydroacoustics laboratory.

Tether

Tether is the only medium, used to connect vehicle with surface. It is used for power supply and data exchange. Tether also provides mechanical strength of vehicle connection. We have used rubber tube 12mm in external diameter. It contains the following cables:

- coaxial cable to transmit video signal to surface;
- to wires with a diameter 2mm for power supply;
- 3 wires with a diameter 0.5mm for RS-485 interface to control vehicle.



Tether connection: (1) compressor, (2) 12mm tube, (3) sealing gum, (4) choke nut.

The construction on picture provides connection of the tether with the electronic blocks.

Surface equipment

ROV control is provided by a laptop, running Windows. We have created a commutation block to connect ROV to a computer.

Commutation block encapsulate power supply (to test our vehicle before the contest), USB-hub, tuner, USB-RS485 bridge, power switching relay, video demodulator, ammeter.

One video signal is transmitted to external display, while the other is digitized with tuner to use it on a laptop.

Data send/receive is done through USB-port, because our team decided, that it is the most easy-to-use interface for external devices at the moment.

We have developed a C++ application for Windows, displaying information received from ROV and sending control commands. This application is capable not only to display ROV parameters and video stream, but also have features for successful mission accomplishment:

- sound parameters displaying;
- a temperature chart;
- leak sensors displaying;
- a timer, counting time before mission ends.

Moreover, we have a log for ROV parameters, including temperature charts. Video stream is also written on hard disk for further analysis. We have used "XviD" open-source codec to compress video. This codec provides good quality and real-time speed.

Joystick is considered as a main control unit. ROV can also be controlled using a keyboard. Redundancy provides better reliability in the case of, for example, any trouble with joystick or control with two pilots. Joystick is handled using Windows API functions.

We have different types of messages, sent to the ROV:

- a message with control commands, waiting for sensor data as answer;
- a message with adjust parameters for better control;
- a request for current sound info (amplitude, frequency);
- a request for the whole FFT chart.

Data flow for surface equipment is presented in Appendix 3.

Design rationale – tasks

In this section we describe design rational specific for each task.

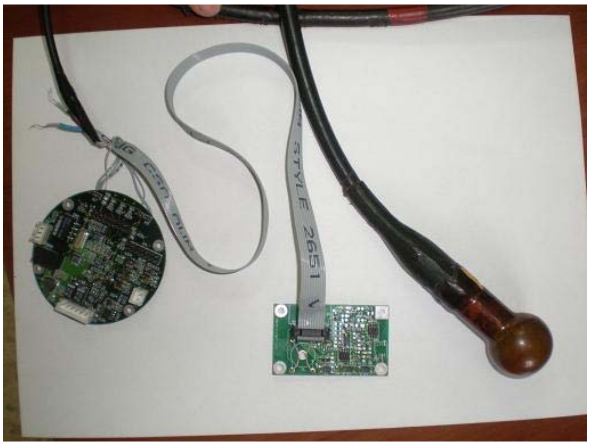
Task 1

According to task 1, we should determine sound source and it's frequency.

We've placed the hydrophone on the board of our vehicle. We decided not to transfer sound signal to our laptop: this would make a tether thicker and would increase noise in the signal. Instead, sound is processed onboard, and then digital information about its amplitude and frequency is sent to the surface.

A signal from hydrophone is transferred to Digital Signal Processor. Then the following algorithm is done:

1. to perform analog-digital transformation;
2. to calculate amplitude (A) of discrete signal;
3. to run Fast Fourier Transform to calculate Fourier Spectrum (see book [1] for FFT details);



Hydrophone

4. to find peak in Fourier Spectrum in frequency range of 1 to 5 kHz, calculate frequency (F), according to the peak;
5. to send A and F to the surface.

In order to determine sound source we choose place where the sound amplitude is maximal.

Task 2

According to task 2, ROV must enter a cave (80 × 80 cm), maneuver to the back wall of the cave, collect up to three samples of crustacean, maneuver out of the cave and return the samples to the surface. We tried to make ROV size as small as possible. We hope, this will allow to perform task, not contacting the walls of the cave.

We have designed buoyancy shape in SolidWorks 3D design software. In the front part of buoyancy there is notch. Due to this notch, manipulator has a wide turning angle (near 300°). We have also installed basket-receiver onboard of our vehicle to collect and transport samples.

For ensuring the maximum viewing angle and directed illuminations we used several cameras and lights:

- The back survey and rotary color camera simplifies the navigation of the

ROV when maneuvering out of the cave.
- The wide-angle photosensitive navigational monochrome camera allows operating in small luminosity conditions of the cave.
- The cluster lights XLD-AC-007WHT are located in lower stern part of frame.

Task 3

The third task is to measure temperature of issuing liquid in three specified locations, to create a graph of temperature versus height, and to take sample.

To perform this task we needed a manipulator to take sample, a bucket to keep sample on the board of the vehicle and a sensor of temperature.

We fastened the temperature sensor on the manipulator so we could watch it by camera. This solution also let us easily move sensor to the proper place under the water.

We use thermal sensor AD592 (Analog Devices). It can measure temperature in range from -25°C to +105°C with precision $\pm$ 0,5°C. Sensor is placed in sealed container made of sheet aluminum, filled with conductive paste. Sensor is attached to manipulator.

Two graphs are plotted by control program on the screen of our laptop. The first graph reflects the dependence of temperature on universal time. This diagram is necessary for identifying the directions of temperature changing. The second graph shows the liquid temperature in specified locations.

When coming to one of the tops, pilot should push the button «begin measurement». When measurement comes to the end, pilot pushes the button «end measurement» (we have separate buttons for each of the three measurements). As the result, we get maximal and minimal temperature between two button pressings. When all three measurements are performed we have two graphs: maximal and minimal. One of them is the answer and the other is close to average water temperature. This was made because we don't know for sure, whether the venting liquid temperature is higher or lower then average value.

A sample collecting will be done by manipulator. Each sample is put in the bucket on the top of our vehicle.

Task 4

The fourth task is taking the samples of bacterial layer from the bottom of the pool.

To accomplish this task we made a sampler, which resembles a syringe. It is composed of base, piston and tube. The vehicle pushes the piston, sucking the bacterial layer into the tube.

To have a tube a proper size we carved on a lathe.

The sampler fastened to vehicle manipulator. It is done because of several factors. First of all, the rotary camera in the manipulator let us watch the process of taking the sample. The other reason is that the manipulator can be moved in such a way, that syringe is situated under the bottom of the vehicle, and that is why it won't bend, and the pressure on the piston will be maximal. And finally, the team member can easily take off full sampler and give it to a jury member, when manipulator is raised.

We are going to accomplish this task first, so after taking the sample we will be able to take off the sampler quickly, because it'll put obstacles during the following missions.

Troubleshooting

Troubleshooting techniques both for programming and electronics are described here.

Programming

IMTP teams already took part in ROV competitions, but this year's vehicle is completely new one. To decrease time of creating ROV, programming of surface laptop should be done while vehicle itself isn't ready. To debug our software without real vehicle, we used test examples. So, while we didn't have cameras, we used usual TV-signal to debug work with video. To troubleshoot work with serial port and commands for vehicle, we used last year electronics.

We also used open-source control version system "GIT" for source code management. Although the number of developers wasn't large, this tool was useful to extract history of source code. Version control also helped to split the whole programming task in small problems.

Electronics

Parts of all circuits were checked separately. When some part of circuit was ready, it was tested first. We had always used power supplies with current limiting to test circuits. This precaution let us to avoid elements burnout or failure.

One of the problems occurred with power circuit. As it was switched on, there were short-circuit and throttles were heated heavily. This happened because of throttles, used to suppress common mode noise. They were made by hand, using lacquered wire wound on ferrite ring. We have found wire insulation damage and realized, that winding were short-circuited on ferrite ring. We solved this problem, using wires with fluoroplastic insulation.

Challenges

We faced challenges in our work. Some of them were about vehicle itself, but some are organizing ones.

Russia is very big, Vladivostok is very far away from the center, and there are some troubles with delivery. So, it took weeks to deliver ordered cameras and video modulator. Some of our circuit boards (which was technically impossible to make by students) where made on the nearest fitting factory in Novosibirsk, which is thousands kilometers away. Due to this situation we reluctantly ordered any parts or equipment and were always tried and found possibility to buy what we needed in our city. Also, we paid more attention to our timing: we were counting what time do we need and what time do we have to accomplish current tasks, drawing time charts.

Another challenge was to create tools to perform task #1. First, we decided to connect hydrophone directly to sound blaster of the laptop. We developed a program for sound processing, performed some experiments and came to the following conclusion. Transfer of sound through 20-meter cable is not reliable due to noises and tether weight. We decided to process sound directly onboard, using DSP, and successfully made it.

Lessons Learned

Among technical skills, that we gained, we would like to highlight the following: construction, digital signal processing, stream video processing, electronic systems troubleshooting.

Apart of our technical skills, we learned creating a device as a whole. This is very different from approach, used in universities. While studying at university, one have to accomplish study tasks, which are mostly just a part of the whole problem. Performing of the whole project gives additional skills to students. It increases the role of troubleshooting and reliability requirements.

Every member of our team has some specialization, but there were tasks (like construction), where we had to work all together as a team. There were also adjacent tasks, which demand working together, like working out the protocol between laptop and ROV. So, this is different form usual university task too: specialists in different fields have to work together to accomplish project.

In the process of our work we understood, that in complex technical system every single element is important. Small omission can influence work of the whole system. This lesson applies to teamwork: every team member is important and the whole success depends on his work.

Reflections and teamwork

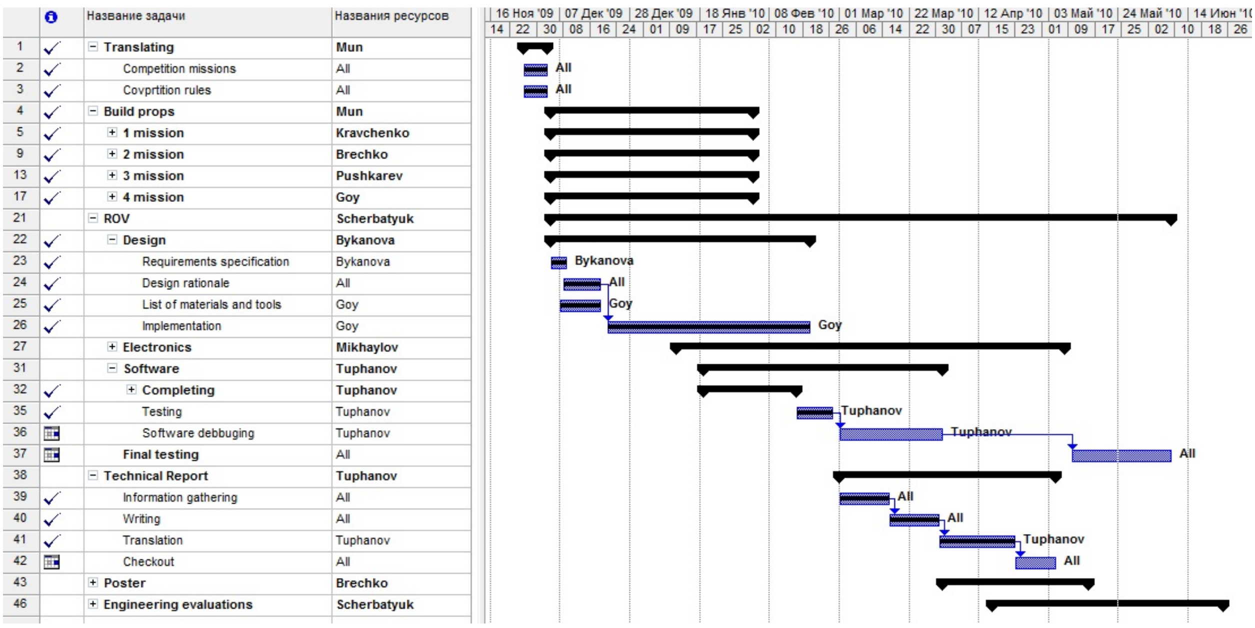
For each of 5 members of our team, this competition gave a chance to gain 4 new friends. We have also enriched our professional toolkits.

Alexey Brechko: "While developing the vehicle, I have strengthened my skills in designing and assembling printed circuit boards. I also gained a great experience in construction and teamwork with specialists in different fields."

Vladislav Goy: "I am a theoretical physicist. However, it turned out that applied work is not less interesting. I had learned to use SolidWorks, improved my skills in using mechanical equipment and construction. Furthermore, it was my first experience in project work."

Evgeny Kravchenko: "During this work, I have learned to be responsible for tasks, assigned to me. I have deepened my knowledge of underwater vehicles. Work with thruster controllers helped me to write my graduation work at university."

Igor Pushkaryov: "By taking part in this competition, I've increased my skills and gained ones in circuitry and circuit boards construction. I've gained experience



Ghantt chart

in underwater vehicles construction, and realized problems of this field. I hope this experience will be useful for my further work."

Igor Tuphanov: "ROV competition gave me an opportunity to increase my professionalism and gain some skills in programming (including embedded programming). I've found a new exciting field for myself, which is creating underwater vehicles. Probably, I will work in this field in future."

To be in time, we maintained Gantt chart with all tasks and persons, responsible for each task. This chart was an instrument to control our timing and to divide the whole process into small tasks.

Future improvement

Present containers for thruster controllers has some disadvantages. They take much room, they are heavy and they influence on hydrodynamic characteristics of our vehicle.

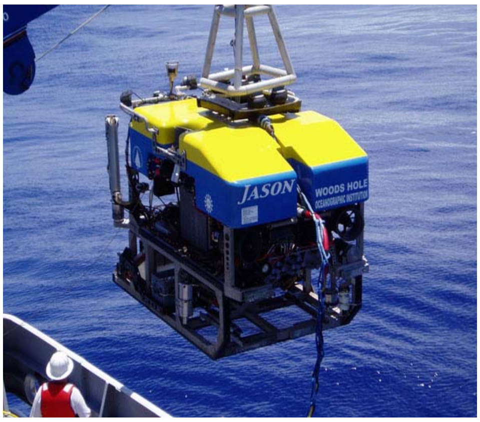
We plan to create thruster controller, embedded in thruster container. Thus we can get rid of five large containers (four for thrusters and one for the manipulator) and decrease the number of electrical connections. This will increase reliability of whole propulsion and steering complex.

At the moment we have developed a model sample of embedded thruster controller. We plan to test it soon. New thruster containers are already designed.

Seamounts and Jasons

«Loud» appearance on the world scientific scene in 1996, the seamount Loihi instantly riveted the attention of many researchers. An important part in these researches had ROVs. From 1996 the study of the seamount Loihi involved such as submersibles Pisces V, Jason2, KAIKO, RCV-150, etc.

We are most inspired by the



ROV Jason

Eruption NW Rota-1

A panorama-view of the front displays in the JASON control van.

expedition involving vehicles Jason (NW Rota-1, 2006-2010) and Jason 2 (Loihi, 2009).

In 2006-2010 an international team of scientists undertook excavations to the existing submarine volcano NW Rota-1, located near the Pacific island of Guam in the deepest area of the world's Mariana Trench. Submarine volcano NW Rota-1 is unique, as it is the only place on the Earth where you can watch the lava eruptions in real time. Scientists were working in constant danger because an eruption in shallow water can cause severe explosions and even a tsunami ([2]). When one of the landslides occurred (March 2010) the team of researchers managed to record unique sounds by using a hydrophone. This record undoubtedly will provide an opportunity to get to know the nature of submarine volcanoes. During the cruises, Jason measured the temperature near the volcano, took samples of water and soil, as well as many others. There is great merit of pilots, who have worked with complex and expensive equipment ([3]).

From 2006 to 2009 a team of researchers carried out 16 ROV dives (Jason 2) to study the microbial mats near the seamount Loihi. Due to these diving scientists were able to test hypotheses on biotic vs. abiotic origin of seafloor ([4]).

We are honored to join the ranks of dedicated submarine volcanoes researchers.

Acknowledgments

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

We want to thank Far-Eastern National University, Far-Eastern State Technical University and Institute for Marine Technology Problems for providing us with rooms and equipment.

We thank Russian Ministry of Youth Affairs and Vladivostok city administration for financial support.

We also would like to thank MATE Center for such an exiting event.

References

[1] T. Cormen, C. Leiserson, R. Rivest, "Introduction to Algorithms", MIT Press, 1990.

[2] http://nwrota2009.blogspot.com/

[3] http://nwrota2010.blogspot.com/

[4] Biogeochemical Cycling of Iron Isotopes at Loihi Seamount, http://www.europolemer.eu/en/biogeochemical-cycling-of-iron-i.php

Team at work

Vladislav, frame assembly

Vladislav, Igor and Evgeny cut bouyancy

Alexey and Igor, programming

Appendix 1. Budget

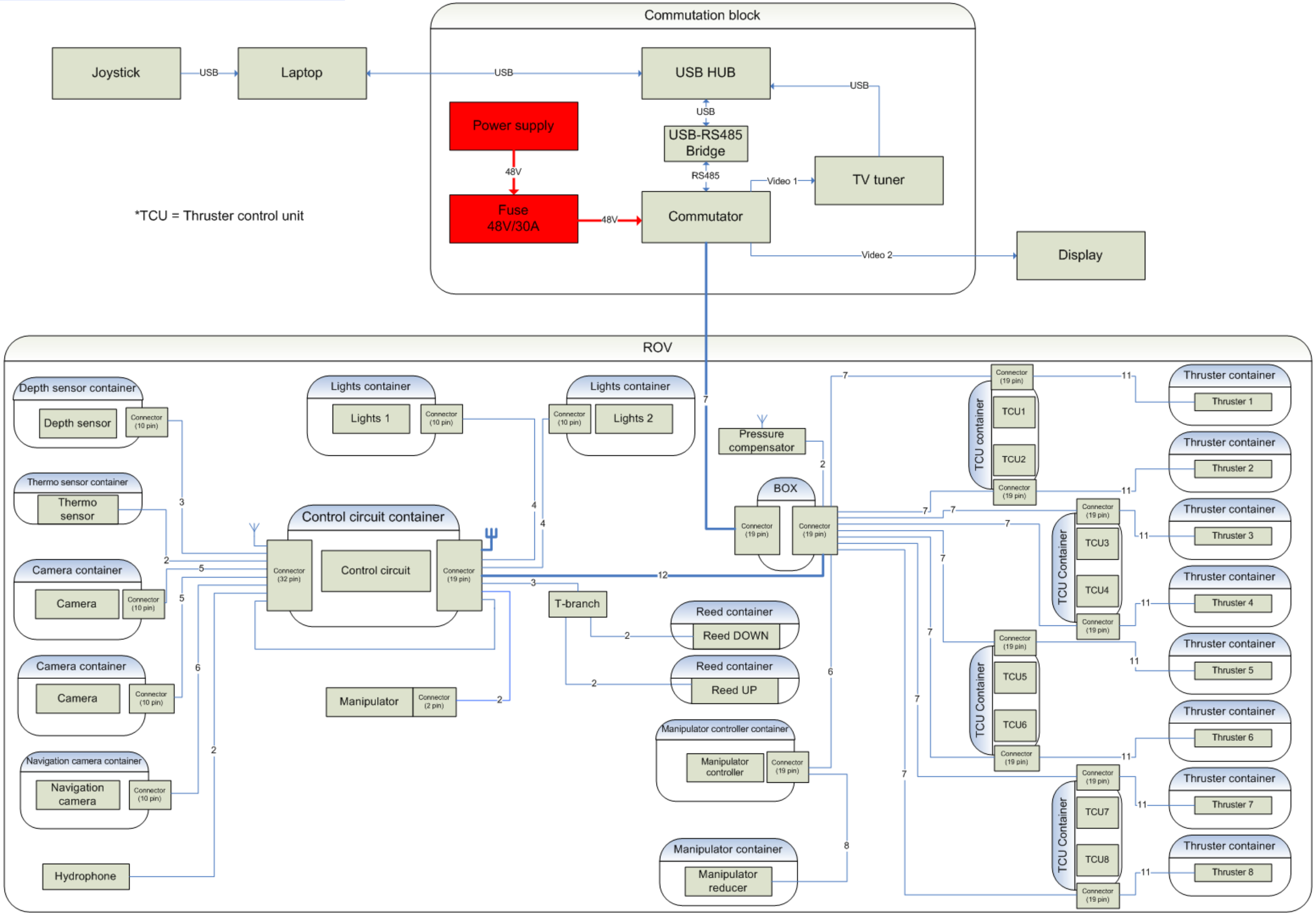
Expenses

Item	Quantity	Price, $USD	Total, $USD
Framework			
Polypropylene Sheets	2	75	150
Clamps	15	1,64	24,6
Power system			
Current source RSP-1000-48	1	337,5	337,5
Cable	50	1,25	62,5
Propulsion			
Electric motor EC-max40	8	296	2368
Propeller screw ◎◎◎	8	60	480
Control and electrical system			
At90CAN128	2	9,7	19,4
ADXRS401EB	2	86,4	172,8
IRS2336DM	20	7	140
AD822ARMZ	9	6	54
AD592ANZ	9	5	45
IRF7854	54	1,2	64,8
MUR 120 G	36	0,35	12,6
KX-KX 16	9	0,7	6,3
Pressure sensor KPT-55	1	125	125
Temperature sensor AD-592	1	5,4	5,4
Joystick Saitek Aviator	1	57,5	57,5
Manipulation complex			
Manipulator Seabotix TJG300,	1	3937,5	3937,5
Electric motor EC-max40	1	296	296
Optic relay PVG-612	10	13,1	131
Information-measurement complex			
VM32HQ-B36 camera	2	130	260
Black-and-white TV camera QN-B309	1	337,75	337,75
Objective Computar 2,6 мм 1:1,0 ½" CS	1	249,7	249,7
Light diode cluster XL7090	2	60,8	121,6
Coaxial cable PK-50	25	0,39	9,75
Traveling expenses			
Visa	9	165	1485
Air ticket	9	1900	17100
Cost of living	9	412	3708
TOTAL	**31761,7**		

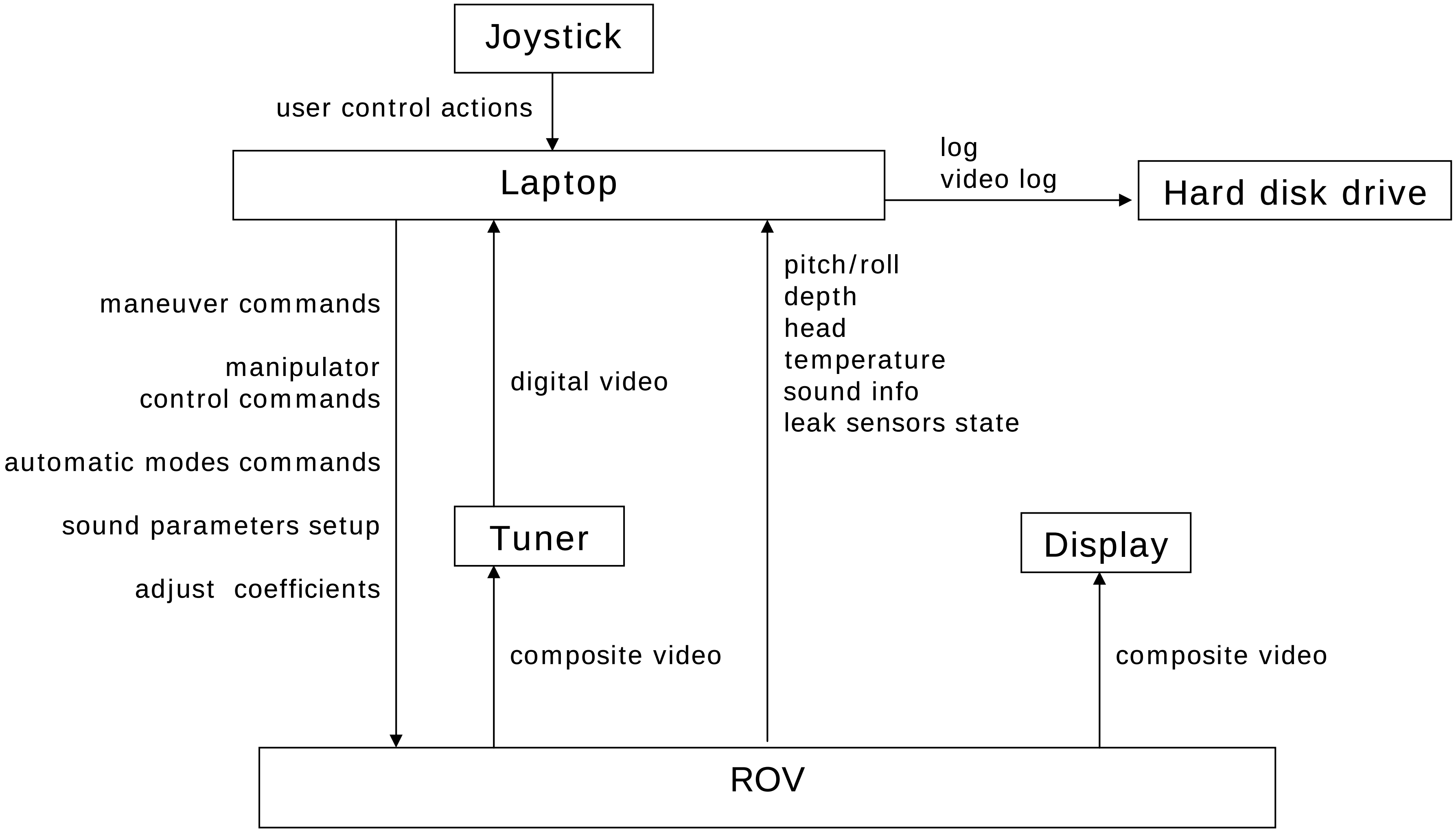
Donation

Company	Value, $USD
Institute of Marine Technology Problems	1 077,7
Far Eastern National Technical University	4 933
Far Eastern National University	11 401
Vladivostok city administration	2 000
Ministry of youth affairs	12 350
TOTAL	**31 761,7**

Appendix 2. Electrical schematic



Appendix 3. Surface data flow



Appendix 4. Control scheme