Institute for Marine Technology Problems presents

The ROV «Junior» from «Primorye Coast» Team

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ABSTRACT

In this work the description of remotely operated vehicle “Junior” is presented. This vehicle was created due to missions that will be conducted on the MATE/MTS ROV Competition in the year of 2008.

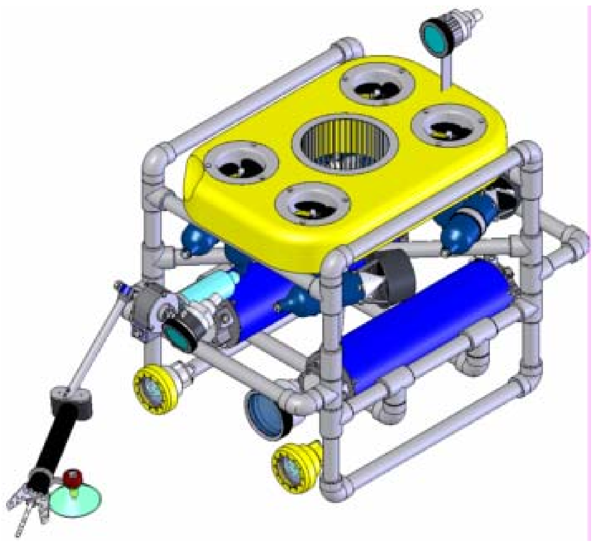
“Junior” has polypropylene framework, propulsion system of 8 thrusters, manipulator providing object capturing up to 40 mm in diameter with the 6,5 kg strength, color camera of top view, wide-angle light-sensitive navigation camera of high resolution and rotary color camera placed on the same axis with manipulator, two clustered lamps, two hermetic containers for electronics, foam buoyancy, sensors of temperature, depth, water flowing and current.

INTRODUCTION

For the last decade in the world interest to development of unmanned underwater vehicles has incomparably grown. This is due to significant technological progress in the sphere of underwater robotics and to essential expansion of a circle of the problems solved by means of underwater vehicles. Many countries that have outputs to the sea put in huge financial resources for creation their own technical developments in this sphere.

The seventh annual international student's competitions should take place in June, 2008 in the class of remotely operated vehicles (ROV) that conduct under the support of international organizations MATE (Marine Advanced Technology Education) and MTS (Marine Technology Society). This arrangement in honor of the year of black smokers is focused on science and engineering features research of these objects that are operating underwater volcanos.

This year our command will participate in these competitions, created on the base of the Institute of Marine Technology Problems of the Far Eastern Branch of Russiam Academy of Science and including 2 students from Lyceum of Far Eastern National Technical University (FENTU), 4 students of FENTU and 2 students of Far Eastern State University (FESU).



1. Design rationale
1.1. Framework

Framework of the ROV should have the minimal weight and dimensions and at the same time it should have heightened strength in a broad band of temperatures (up to 50ºC). As a material of a framework there were selected polypropylene pipes of 1 inch (25,4 mms) and fittings to them. Density of a material of a framework is 980 kg/м^3. The shape of a framework was selected due to optimal placement of all units and systems of the ROV under condition of minimization of overall dimensions. For improvement of floatation the framework is made pressurized. The attachment to a framework of units of ROV is through standard clamps (fig. 1a). In SolidWorks the model of a framework (fig. 1b) with the following characteristics was made: weight - 1,9 kgs, displacement - 2,3 liters.

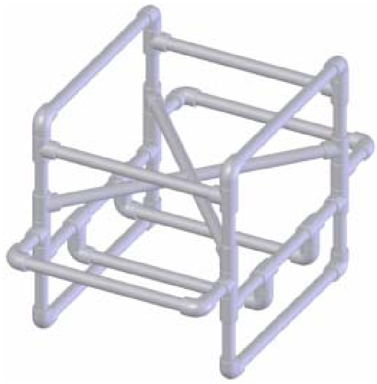


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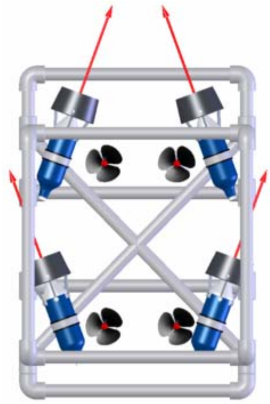
Fig. 1. Elements of the ROV: a – clamps, b - framework

1.2. Thrust-steering system

The thrust-steering system (TSS) of underwater vehicle is based on effective layout of eight (8) thrusters. This number was accepted with purpose of ensuring of execution of mission targets.

Chosen configuration of horizontal thrusters for the creating of forward and lateral movement, as well as yaw control, is shown at fig. 2a. Layout design and scheme of tractive force vectors of vertical thrusters, represented at fig.2b, was chosen with intention to ensure vertical movement of vehicle with trim control and depth stabilization.



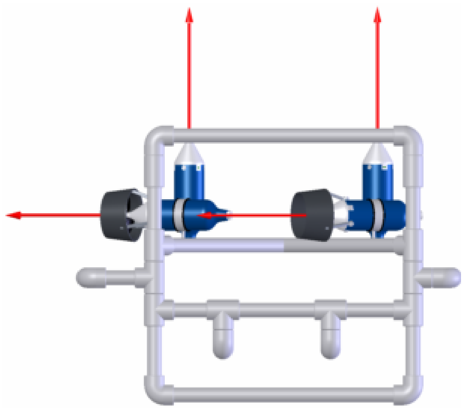


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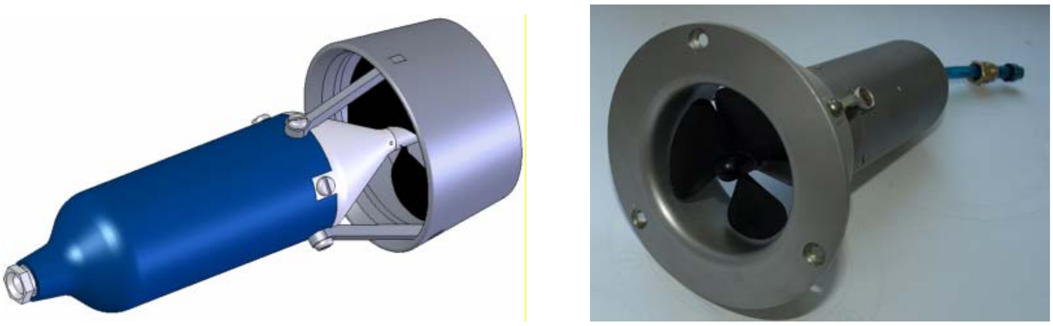
Fig. 2. Scheme of propulsors placement: a – view from above; b– side view

Thruster is brush motor, placed in pressurised volume, with 75 mm diameter screw propeller, protected by nozzle and mounted at the end of output shaft. Screws of the vertical thrusters are arranged in water ducts, placed in foam buoyancy of ROV (fig.7). The model of designed thruster is represented at fig.3a, external appearance photograph is shown at fig. 3b.



a b

Fig. 3. Propulsor: a – model of horizontal propulsor (with nozzle); b – photo of vertical propulsor (with sluice)

1.2. Strong cases

One of the most responsible units in the vehicle are two pressurized containers. Inside the first container the engines power controllers are arranged. The second container comprises control cards by the vehicle units. Both containers have cylindrical shape by a minor diameter of 100 mms and length of 350 mms and are calculated on strength for immersion on depth up to 200 m.

There are also specially projected strong containers, with arranged inside them by the following equipment:

1. Sensor of depth.
2. Lights.
3. Temperature sensor.
4. Uplook color-video camer
5. Black-and-white wide-angle navigational video camera
6. Rotatable color-video camera

All indicated strong containers are calculated on a diving depth up to 200 m.

1.4. Manipulation complex

Collecting of lava ROV can make only if there is a manipulation complex. Here are its main requirements: bearing capacity up to 1 kg in water, collecting of samples into the basket - receiver, capability to collect samples of lava without landing and convenient transport position of the manipulator.

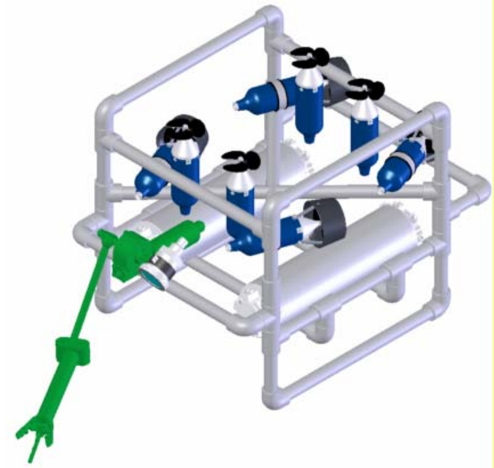
The structure of manipulation complex has:

1. Motor - reduction gearbox and worm reduction gearbox arranged in a pressurized body allow making smoothly varying turn of the manipulator with an angle up to 220^o.

2. Pipe of the grubber magnifies service zone of the manipulator and allows collecting samples of lava without landing.

3. Grubber TJG300 of the corporation SEABOTIX. Allows to make acquisition of object from 1,45 up to 40 mms in diameter, thus the force of compression makes up to 6,5 KGF.

Arrangement of the projected manipulator of the ROV in a mode of collecting of samples is shown in a fig. 4a, in a fig. 4b the transport position of the manipulator is shown.



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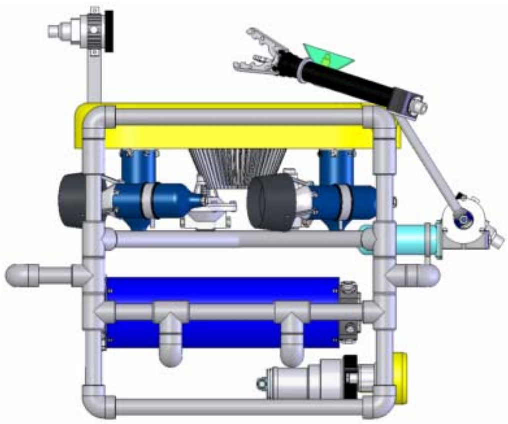

b

c

Fig. 4. Manipulator: a - position in common layout of the vehicle; b - transport position, position of samples reset into the basket; c – mechanical gribber

1.5.Video system

In process of construction of underwater vehicle the special attention was paid to designing of it's video system. There are following components in composition of video system:

1. Lighting fittings (two pieces) (the light source is cluster XLD-AC-007WHT, consisting of 7 high-brightness white LEDs (light emitting diodes) XL7090 with brightness belonging to the range of 56,8…62,0 lm (current consumption is 350 mA).

2.Wide-angle navigational video camera QNB209 (110^0, 0,003 lux, 570 lines).

3.Uplook video camera and rotatable video camera CTCM-2723 (3.0 lux, resolution of 340 lines, viewing angle is 58°).

The video system's cameras are shown at Fig. 5.

Fig. 5. Video cameras: a) survey and rotatable; b) navigational

Arrangement of the lighting fittings and cameras was designed with purposes of maximal visual angle and directional lighting in working area. Lights are arranged stationary in lower stern-part of frame.

Wide-angle camera makes it possible to enlarge the underwater coverage area from vehicle stem, which helps for operator to perform the controlled moving of vehicle and operations of manipulator. Fig.13 illustrates mutual alignment of lighting fittings flux and viewing angle of stationary wide-angle video camera.

Arrangement of the enumerated elements is shown at Fig. 6.

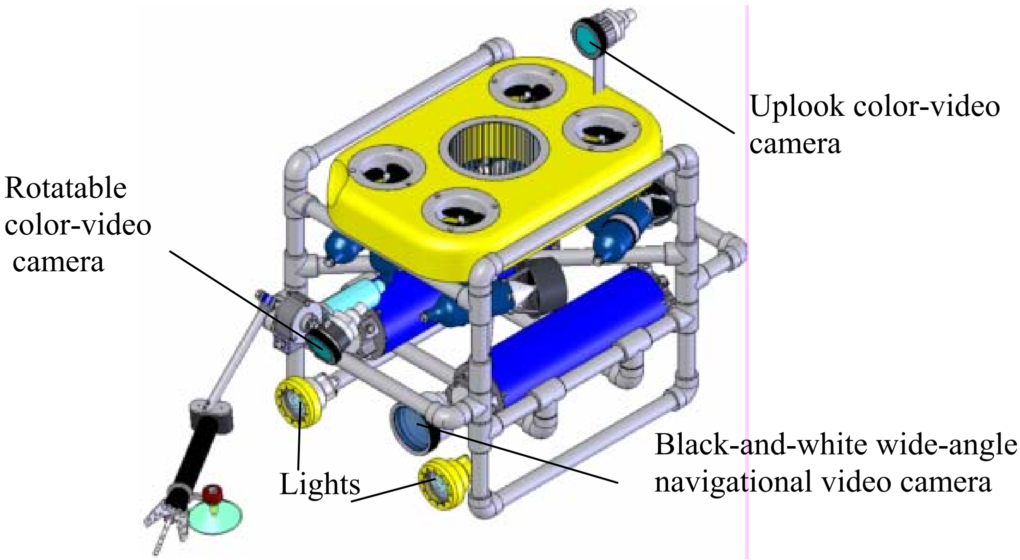

Fig. 6. The model of video system

It is obvious from fig.6, that viewing field of wide-angle video camera may be found insufficient for execution of samples collection, and for this purpose rotatable video camera is used, arranged in-line with manipulator, that allows to track at any time the behavior of manipulator's gripper and its position relatively underwater objects (in limited viewing field).

Uplook video camera makes it possible to implement the view upwards, facilitating the navigation and supplementary view of mission.

1.6. Foam buoyancy

The program of automated designing SolidWorks enables to perform not only configurating of vehicle's systems, but makes it possible to carry out the calculation their mass characteristic. It allows of estimating the mass and displacement of designed vehicle. On basis of this data ROV's buoyancy was analyzed and computed subject to use requirement of negligible positive resultant vehicle's buoyancy. The model of foam buoyancy is shown at fig.7a. It is made of foam plastic solid plate of 75 mm thickness and 150 kg/m3 density. Water ducts are attached to the foam buoyancy by means of flanges, and thrusters are fitted in water ducts. Attachment of the water ducts to the foam buoyancy is shown at fig.7b. Attachment of the thruster to water duct is shown at fig.7c. And also the fig 7b represents the coupling of thruster and water duct.

a b c

Fig. 7. Foam buoyancy: a) the model of buoyancy;
b) water duct (plan view); c) attachment of the thruster to water duct

1.7. Sensors

1.7.1.Depth sensor

The pressure sensor KPT5-33, ensuring the pressure measurement at the depth of 40 m with the accuracy of ±1% , is used as the depth sensor. It is according to the operation range of measuring submergence depths of 40±0.4 m. Analog signal from the sensor is received by the control unit. Depth sensor appearance and placement on the ROV are shown at the fig. 8.

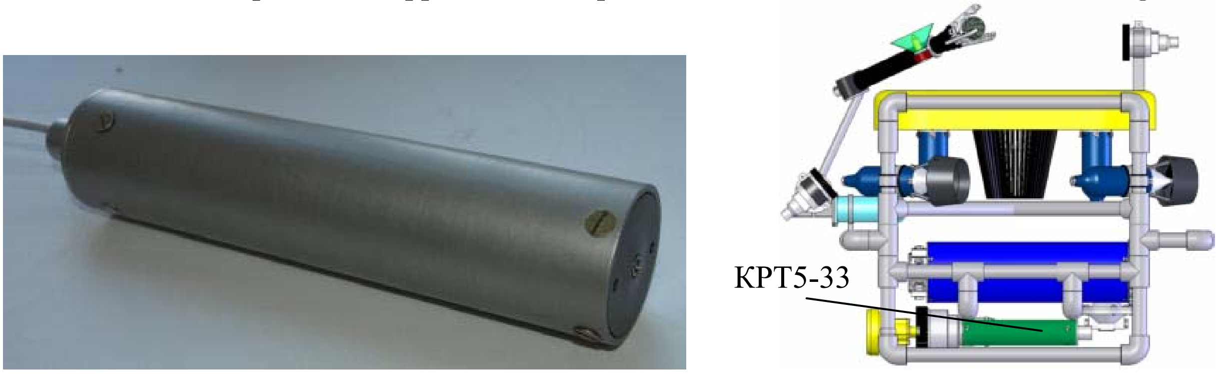

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Fig. 8. The depth sensor: a) photograph; b) placement on the ROV

1.7.2.Temperature sensor

The temperature sensor AD592 of Analog Devices company makes it possible to measure the temperature within the range from -25° to $+105^\circ C$ with the accuracy of $\pm 0,5^\circ C$ and possesses the analog output. Sensor is placed within the aluminium sheet hermetic enclosure, filled by heat-conducting paste. The assembled sensor is attached to the manipulator grubber. Appearance and placement of the temperature sensor are shown at the fig. 9.

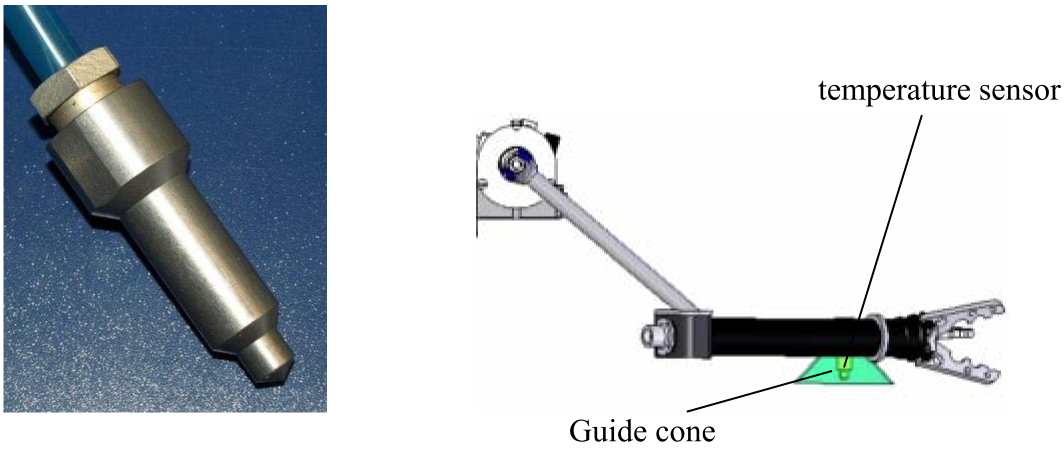

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Fig. 9. The temperature sensor: a) photograph; b) placement on the manipulator

1.7.3. Sensors of water flowing into ROV’s container

Sensor of water flowing is the copper conductor, isolated from container hull. The conductor pose with respect to the hull may be seen at the fig. 10. The conductor is the copper foil, placed on the glass fiber plastic substrate. Gap between conductor and hull is 1 mm. When water flowing into this gap the short circuit occurs between the plate and container, and appropriate comparator of electronic circuit is actuated.

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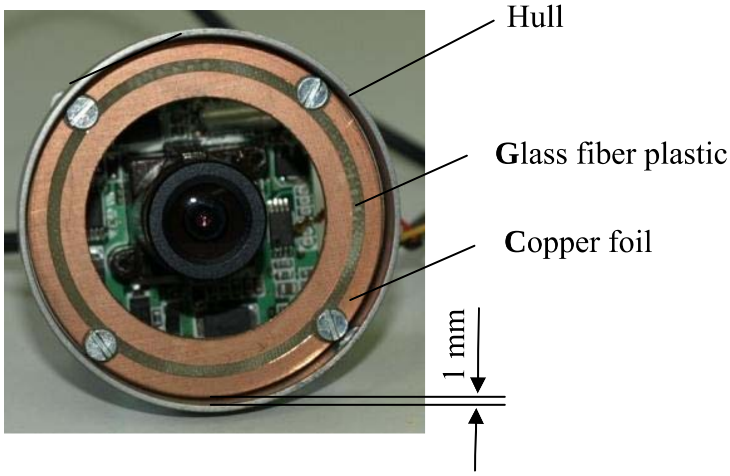

Fig. 10. Sensor of water flowing into video cameras container

2. Control system

The management system "Junior" consists of units arranged in the ROV operator complex:
- Joystick (specifying body),
- Notebook (operator console),

And onboard the vehicle:
- Controller of the autopilot and controller of a power module
- Sensors

The functional diagram of a management system is in the Appendix A.
In a fig. 11 the operator complex of the ROV "Junior" is shown.

Fig. 11. Ship complex of the ROV «Junior»

2.1. Joystick

As a specifying body in remotely-operated vehicle “Junior" the joystick Saitek Aviator AV8R-01 is selected. Fulfillment of missions needs 9 buttons: acquisition of the manipulator (1), switching of video cameras (1), on/off lamps (2), motion of the manipulator upwards/downwards (2), mode of auto course (1), auto trim difference (1) and auto depth (1); and 4 axes: course forwards/back, to the right/to the left, change a course and depths. The joystick, selected by us, has necessary quantity of buttons and axes. For activity with the joystick the functions Windows API and structure Windows were used. Frequency of the reference to the joystick is 10 Hz.

2.2. Notebook

Notebook functions consist of data exchange between the vehicle and operator complex, and also giving the operator full information about all the systems of "Junior" (management system, thrusters system, video system, etc.) As the vehicle transmits the video data only by one video channel, the functions of the monitor are also executed by notebook display. Due to such solution, our system became more compact, and control of the vehicle became more convenient. So, the operator now does not need looking at the screen of the monitor and watching sensors indications on the screen of the notebook at the same time.

For processing and mapping of pilot signal from joystick, videodata and indications of sensors on the notebook, the program "Junior’s Control Panel, written on C ++ Builder 6 with usage of libraries and files DirectX and WinAPI is used.

The program is written so that as much as possible to facilitate activity of the operator, majority of components (mapping of depth, course, roll and different) are outwardly approximate to substantial devices. In a fig. 12 the interface of the program is shown. It allows easily enough receiving the required information during fulfillment of mission. The control can be executed both by joystick, and with the help of mouse. Such reduplication allows two operators working in difficult situation, and also safeguards the system from loss of a specifying body in case of incapacitation of the joystick.

The program has two main modes and one optional. The main operational modes are: mode of guidance of the vehicle on the purpose («on devices») and full-screen mode, for more fine control. As targeting is an important operation in fulfillment of missions, in this mode there are shown indications of all sensors, full information of different malfunctions both on board, and "overhead". In a full-screen mode there are only data that can be necessary for measurement of temperature, correct activity with the manipulator and precise positioning.

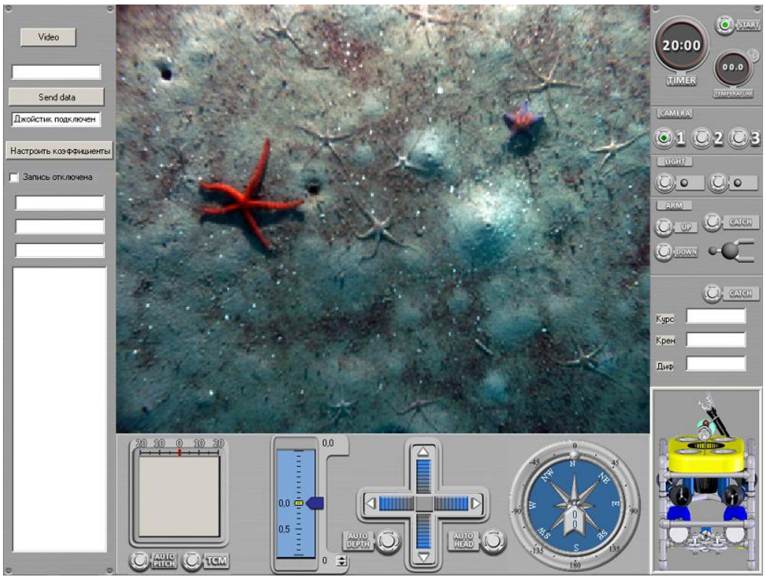

Fig. 12. Interfaces of time schedule control by the vehicle Junior

The optional mode is mode of testing and saving of data, working on a principle "of a black box". In this mode the operator can look at change of main specifications (course, roll, different, depth, etc.) in real time, as on-line, and as after data saving. The operator also can draw necessary charts, reveal reasons of malfunctions, and also test stabilization systems work.

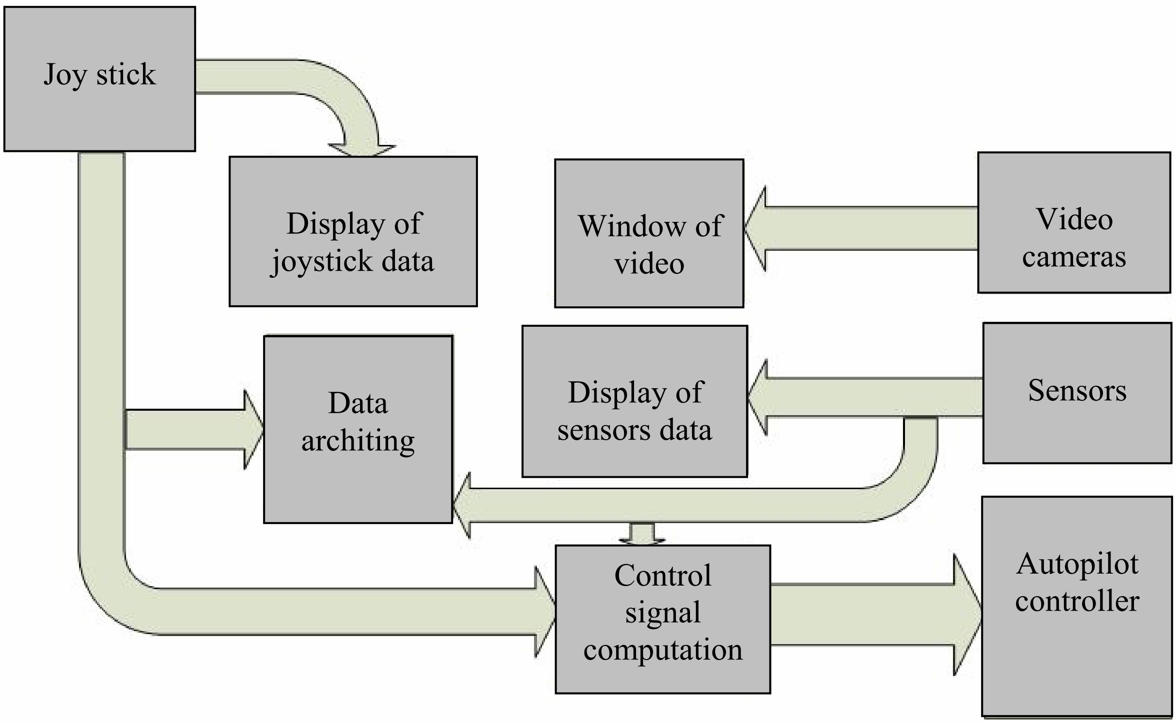

Fig. 13. Information process diagram

2.3. Electronic control means

Electronic control means are divided into switching unit, control block container and power container.

2.3.1. Switching unit

Switching unit is intended for separation of wires of ROV cable on power supply voltage, management interface and video signal. Switching unit also provides protection against current overload (more 20A), indication of consumed current, turning the power on and off of the vehicle, PC connection through USB-port and video transmission on TV tuner.

Through the terminals of accumulator battery supply voltage comes to the safety device, designed for 20A of current and fulfilling the current protection, following which power is supplying to the switching unit through the slot. Observation of current is performing by ammeter, incorporated into the switching unit.

Control signals come to the switching unit from PC through the USB-port. The switching unit by the use of USB – RS-485 bridge changes the interface of data transmission from USB to RS-485 , which possesses better noise stability and requires only three lines for the data transmission. Then the signals through the slot RS-485 are propagated via the interface by cable to the container of control unit. The data from the sensors are transmitted backwards via the same interface.

2.3.2. The container of control unit

The contents of the control unit is shown in the fig. 14.

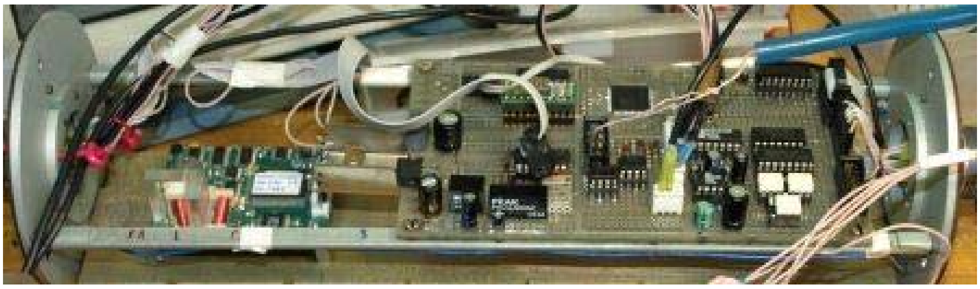

Fig. 14. The contents of the control unit

There are the autopilot card, digital compass TCM2 and two sensors of water flowing in the hermetic container of control unit.

The autopilot card receives the commands incoming via the interface RS-485, analog signals from sensors of temperature, pressure, angular velocity, water (5 pieces), compensator, three video signals from video cameras and signal of digital compass TCM2 incoming via the interface RS-232.

The information processing device from the autopilot is made on basis of microcontroller (MC) AT90CAN128. It is energy-efficient 8-bits CMOS MC with AVR RISC architecture. Data input and output are fulfilled via the USART and CAN interface.

After the scaling by operational amplifiers the analog signals enter the 8-ports 10-bits analog-digital converter, embedded in microcontroller AT90CAN128, where their digitization and further data transfer to the control console are accomplished.

The processing of the analog signals from water sensors is performed by analog comparators, from which the logic signals are enter the port of microcontroller for the following sending to the control console.

Microcontroller turns on optorelay-assisted power supply of selected by operator video camera and commutates the appropriate video signal via the video multiplexer. Video signal from the video multiplexer is transmitted to the switching unit through the video amplifier.

The button is embedded in compensator. In case of decapsulation of the oil system the spring, creating the excess pressure, disconnects the button and logic null is arrived at the entrance of microcontroller.

The digital compass TCM2 measures the course relative to the direction of the magnetic North, roll and trim difference and transmits the data to the autopilot board. This data ensure the feedback for automatic maintenance of cource and trim difference.

2.3.3. Power container

The contents of the power container is shown at the fig. 15.

Fig. 15. The contents of the power container

There are controller board of the motor control units (MCU), the board of the secondary power supply, six MCUs and two water sensors.

The MCU controller board receives the signals of motors, manipulator and lights control, coming from the interface CAN, analog signals from the four water sensors, compensator signal and signals of MCU guard functioning.

The device of data processing of MCU controller is made on basis of MC AT90CAN128. Microcontroller data input and output are fulfilled via the CAN interface.

MC generates the signals of motors actuation, PDM-signals of direction and rotary speed of each motor, turn-on signals of lights and manipulator control signals.

Lights and manipulator management is realized using the optorelay.

The processing of signals from water sensors and compensator is performed similarly to the autopilot board.

3. The autopilot microcontroller program

The autopilot microcontroller receives the control commands from joystick of the control board (running, lateral motion, course turn, vertical movement) and discrete signals of control modes, inquires the feedback sensors, computes the control commands for each motor and transmits via the CAN-interface to the controller of motors control unit.

The commands from the control board are sent 10 times per second; the sensors, connected to ADC (tensometric sensor of depth, vibratory gyroscope of yawing rate, sensor of temperature) are inquired hundred times per second.

Comprehensive measuring instrument of magnetic cource TCM-2 sends its readings about 12 times per second. After updating this data the calculation of stabilization errors in course, pitch and depth channels is fulfilled. Each 10 ms the computation of control commands for motors of TSS (thrust-steering system) is performed, and then this values are transmitted from the autopilot controller to the controller of motor control units. Here the generation of PDM- voltages of propulsion electric drive control is executed.

In addition to the computation of commands for motors the autopilot controller controls the switching of three video cameras and processes the indications of emergency system sensors (flowing into the durable box and leakage from the unloading system of outboard setup).

3.1. The vertical thrusters group control (fig.16)

Vertical group, consisting of the four thrusters, ensures the ability of semiautomatic control of the device immersion depth and stabilization of null pitch angle. The tensometric sensor of pressure KPT-33-5 and pendulous inclinometer of the magnetic compass TCM-2 are used as feedback sensors. In the online mode of depth stabilization “AUTODEPTH” the deviation of the slide of the joystick vertical movement corresponds to selected depth. When the pressure sensor data about actual depth are acquired, microcontroller computes the error and multiplies it by the corresponding factor with further distribution between the vertical thrusters.

If the mode of depth stabilization is off-line, the slide of the joystick vertical movement immediately generates the control impact for vertical thrusters. With on-line stabilization of null pitch angle “AUTOPITCH” the controller receives the signal from pendulous inclinometer, scales it and distributes between the vertical thrusters with allowance for the predetermined commands from the depth channel. Then the calculated commands of vertical thrusters control are subjected to the amplitude restriction and transmitted to the controller of movement control unit for the realization.

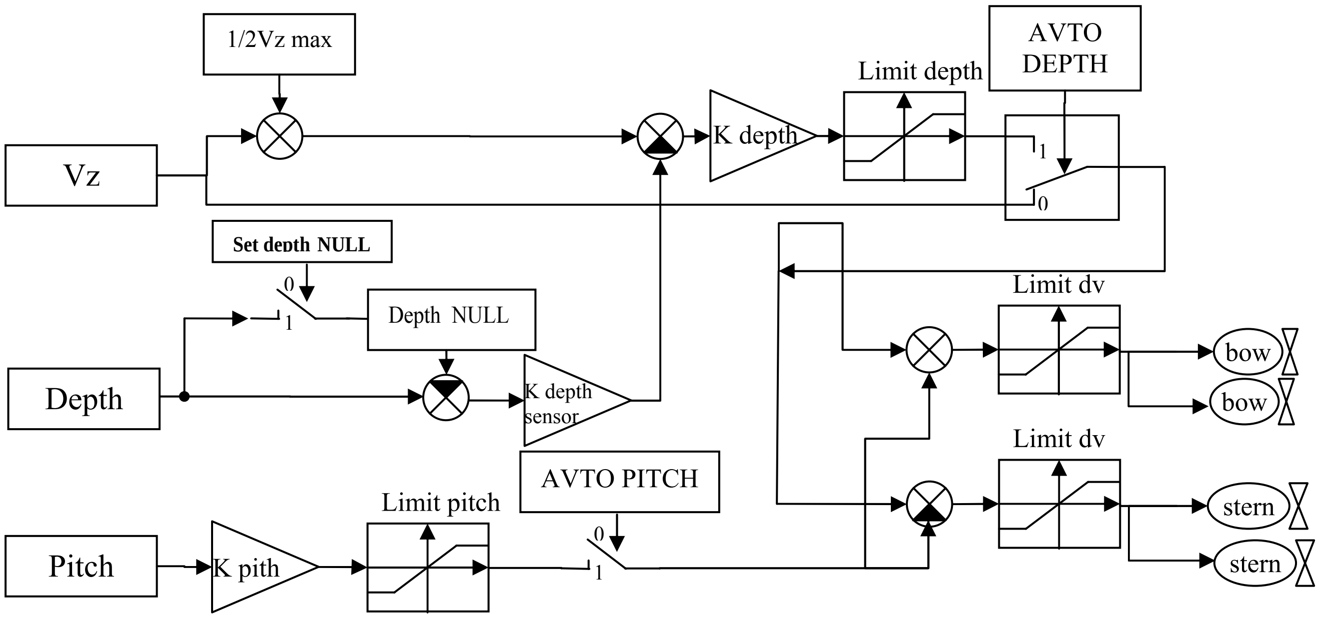

Fig. 16. Scheme of the vertical thrusters group control

3.2. The horizontal thrusters group control (fig.17-18)

Horizontal group, consisting of the four thrusters, ensures the ability of semiautomatic control of the device course, as well as manual control of running and lateral movement. Each of the horizontal thrusters takes part in forming of the control impacts for all of three mobility degrees. ROV is equipped by the induction sensor of magnetic course (TCM-2) and gyroscopic sensor of angular speed (ADXRS402EB). With online mode of course stabilization “AUTOHEAD” and null position of course setter the magnetic course is stabilized, which corresponding the last nulling of setter. In this case the data of magnetic compass TCM-2 is used as well as data of angular speed sensor (ASS). If the course setter moves aside the system switch to the mode of angular speed control with only ASS feedback. Besides the course feedback from TCM-2 is switched off. Also the ability of compulsory switching off the magnetic compass stabilization by additional command «TCM-OFF». This mode was introduced for the ability of maneuvering near the objects, distorting the natural magnetic field of Earth (ferrous and magnetized objects). The joystick commands of longitudinal and lateral motion control are distributed between the horizontal group thrusters taking account of predetermined commands from the course channel. The algorithm of distribution realizes the independence of intermodulation channels control. Then the computed commands of horizontal motors control are subjected to the amplitude restriction and transmitted to the controller of movement control unit for the realization.

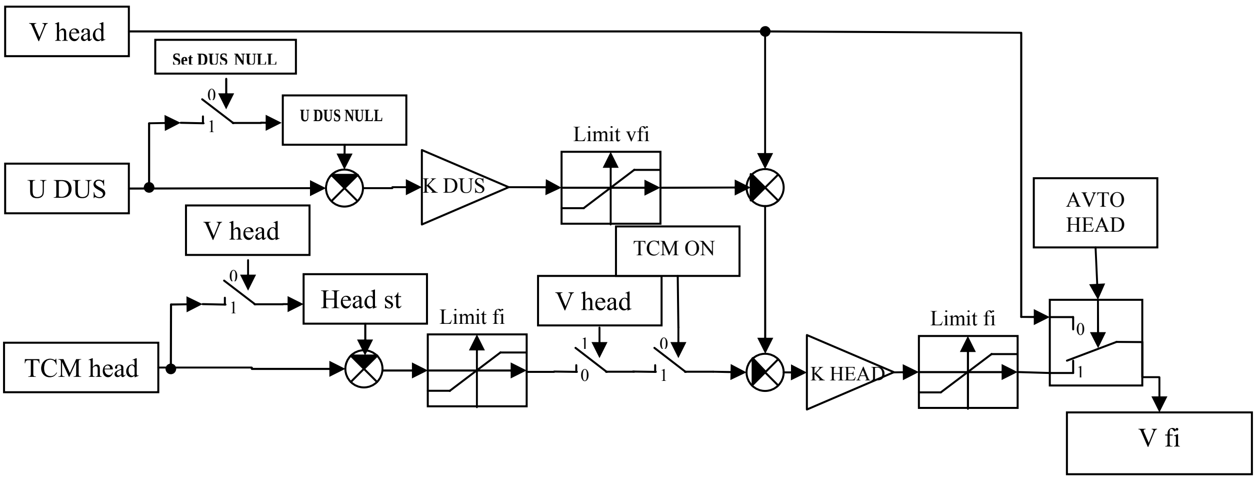

Fig. 17. Computation of the yaw control (V fi)

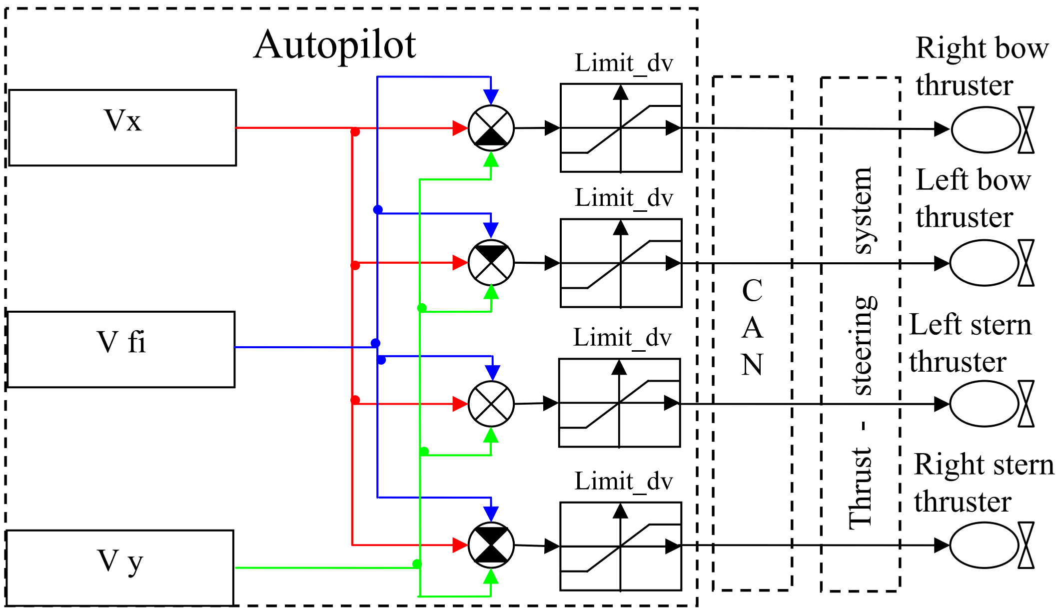

Fig. 18. Scheme of the horizontal thrusters group control

3.3. The checkout control commands

Besides the core command autopilot receives the checkout control commands. There are the factors of control laws for the regulators of depth, pitch and course here. The ability of null setting for depth and angular speed sensors has introduced, allowing to compensate the temperature drift of this sensors. This commands are used by operator at the stage of adjustment of the ROV's moving control system.

4. Budget report

Product	Quantity	Price, $USD	Total,$USD
Framework			
Polypropylene pipe, m 23	10	0.95	9.50
Clamp,	6	1.55	9.30
Clamp,	9	1.7	15.30
Accessory power system			
Current source,	1	1015	1015
Cable, m	50	1.25	62.50
PVC pipe, kg	2	0.25	0.5
Movement-steering complex			
Electric motor ДП-40-430-3-24,	8	67.00	536.00
Propeller screw ∅75,	8	50	400.00
Management sysem			
Board	2	12.50	25.00
Chip At90CAN128,	2	9.7	19.40
Chip ADXRS401EB,	1	86.40	86.40
Chip ADXL203EB,	1	51.80	51.80
Complex sensor TCM-2	1	833.40	833.4
Preassure sensor KPT-55,	1	125.00	125.00
Temperature sensor AD-592,	1	5.40	5.40
Joy stick Saitek Aviator,	1	57.50	57.50
Roverbook	1	1500	1500
Manipulation complex			
Manipulator Seabotix TJG300,	1	3 937.50	3937.50
Electric motor MC-146,	1	311.25	311.25
Optic relay PVG-612,	10	13.10	131.00
Information-measurement complex			
Module CDD FARB of CTCM-2723 camera,	1	468.20	468.20
Black-and-white TV camera QN-B309,	1	337.75	337.75
Objective Computar 2.6 мм 1:1.0 ½" CS,	1	249.70	249.70
Light diode cluster XL7090,	2	60.80	121.60
Coaxial cable PK-50, m	25	0.39	9.75
Pressurized volumes			
Control blocks container	2	100	200
Compensator	2	100	200
Container of lights	2	100	200
Container of camera	3	100	300
TOTAL	**11218.50**		

5. Gained experience and its application

During the work at the apparatus we have learned to work in a team, expanded the mental outlook in area of underwater robotics and received practical experience in creating TV navigated apparatus (TVNA). Each member of the team was given a certain part of the development of ROV, in which he was able to express himself and acquire new knowledge. With this distribution, we covered all major technical areas related to the establishment of apparatus. In doing so, each of the creators in addition to its part of the project worked in related fields.
Experience we can use gained for creating another underwater robotics team, which will include the members "Primorye Coast". Besides, we plan to continue to enhance our skills in the area of ROV, so that in future to take part in competitions already as instructors.

6. The problem and its solution

Initially, when designing the remote operator program, we make only one mode of operation, in which the application was a kind of interface board of aircraft with all major navigation and additional components, as video window. During the test team found that the composition of the elements of the interface designed is not good. In fulfilling the mission of collecting samples of lava, the operator is enough quite distracted by bright devices such as compass, alarm system, depthometer etc. To solve this problem we added additional mode of work – pointing mode in an annet. In this mode, the video window takes practically the entire screen, but for performance information and sensors data there is only a narrow strip at the top of the screen. This change enabled to decide the problem without changing the program finished.

7. Potential use of the ROV

Our universities and IMTP are cooperating with the Institute of Marine Biology, which makes marine aquatic studies. These works are performed as divers as well as underwater vehicles. In doing so, underwater devices perform a very large range of work in conditions dangerous to divers, for example, in toxic hazardous areas, at great depths, and, of course, in places of the thermal flows. We exept our group to provide valuable assistance to the Institute of Marine Biuology in its esearches.

8. Modernization

In reduced visibility under the water when working near black smokers, the proposed video system is not sufficiently effective.
Addition, we can suggest to install sonar on the underwater vehicle.
It is necessary to add degree of freedom into the manipulator in oder to expand coverage.
It is necessary to make the cross-transmission of video signals.

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Application A. Functional scheme of the "Junior" system