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DEVELOPMENT OF A GROUP OF MOBILE ROBOTS FOR CONDUCTING COMPREHENSIVE RESEARCH OF DANGEROUS WAVE CHARACTERISTICS IN COASTAL ZONES

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ABSTRACT

New methods and approaches for carrying out comprehensive measurements of hazardous waves (tsunami, storm surges) and background wave climate with telemetrically related group of ground, surface and underwater based robots are discussed. The design and equipment list of the ground robot are considered. It includes three various types of movers, an add-on for the installation of devices on the mobile platform and the hardware part. Ground robot was tested in 2016 on the coast of Sakhalin Island, cape Svobodny. Based on test results there were made conclusions on the possibility of increasing mobility of the ground robot and expanding its use. Specially designed underwater robot collects data using a video inspection system and a hydrostatic wave recorder with a string sensor. It has the ability to adjust the position of the center of gravity to increase stability when driving on steep slopes of the seabed. The surface robot was designed for conducting detailed bathymetry measurements of investigated water areas by means of a multi-beam echo sounder. Underwater and surface-based robots were tested in July 2017 on Sakhalin Island. Both robotic systems were merged into the united local network. The results of their operation were obtained to verify the data from measuring systems of the ground robot. In 2018, it is planned to conduct a series of tests involving the three robots and merging them into a local network to manage and process data in real-time.

***Keywords**: coastal monitoring, marine hazards, Okhotsk Sea, Sakhalin Island, autonomous mobile robot*

1. INTRODUCTION

Tsunami waves, storm surges, wind wave, hurricane waves are very danger in the coastal zone of many states of Pacific. Several networks of buoys are developed in Pacific (DART, JMA, JAMSTEC, DONET, etc) to register large-amplitude waves in the open ocean and coastal zone; they are active used for forecasting of marine natural hazards having wave origin. Long-term prediction of hazardous waves should be based on knowledge on background characteristics of the wave climate in the same frequency range and variable bathymetry and topography in near-shore zone. The use of mobile robot systems that can significantly improve the efficiency of measurements. There are several ways of coastal monitoring, which are briefly described in [1].One of them is determination of the current situation in coastal areas by using satellites. However, satellite images have a lower resolution in comparison with the results of aerial photography and cannot be obtained with strong cloud cover. The possibilities of coastal zones characteristics researching by means of aircrafts are limited by the conditions of loading capacity and flight safety. Therefore, vehicles that move along the bottom of coastal areas are also used to research the characteristics of the coastal zone. Modern designs of such research systems are given in the papers [2, 3].

Currently, promising techniques of inspection of coastal zones are methods of remote sensing. Such methods are based on the use of sensors that provide information about the distance to an object based on scanning devices of the radio-waves range [4] or laser wave range [5, 6]. Laser methods allow obtaining high-resolution data, but the range is limited to several tens of meters. Radar stations allow capturing much larger area (several kilometers), so their application seems more perspective.

However, they have some disadvantages. The size of such stations is usually a few meters. They need a high-power source and installation on the mast. In addition, compared to laser devices that give information to an object in meters, the radar stations give only the value of the reflected signal intensity and require on-site calibration. Data in absolute values in any point getting to a scanning zone of radar station are necessary for calibration. Knowing absolute wave amplitude and signal strength in one point, it is possible to recalculate intensity into the wave height for a zone in which measurements are taken with the help of scanning devices.

For calibration of wave characteristics there can be used bottom pressure sensors of cable or autonomous types (Fig. 1). The device is made in stainless steel cases and have cylindrical shape. Quartz resonators are used as primary converters of physical quantities. The piezo-resonator elements have a low temperature dependence and high accuracy. There is pressure measuring range (immersion depth) up to 100 m; pressure accuracy 0.06%, temperature accuracy ± 0.3; ± 0.1 or ± 0.05 °C; operating temperature range from -4 to 40 Celsius degrees (°C). Autonomy of devices is about 6 months. Measurement resolution is 1 sec. This sensor was successfully used during our experiment in 2016 [7]. Nevertheless, the use of such sensors has some of disadvantages. Their installation requires the boat. To fix them to the bottom a holding weight is required. Autonomous sensors cannot be used in real-time mode, because the necessary information is only available after raising the sensors, and cable sensors require cabling to coast using the boat. When changing the place of the experiment, it takes a long time to move the sensor.

Fig. 1. Bottom pressure sensor

For express assessments of wave activity in the region through analytical and numerical mathematical models, in addition to the registration of the wave amplitude, detailed bathymetry of the researched water area is necessary. Such bathymetry can be obtained by scanning the water area with an echo sounder from a boat in the immediate measurement area. These factors reduce mobility of research, limit the number of experiments and require significant human and temporal resources.

Methods based on the use of mobile robots are devoid of many disadvantages and have proved themselves in experimental research in single robot configuration [8 – 10] and multi-robot configuration [11] as well. In this article, we propose a new methods and approaches for carrying out a complex measurement of wave climate based on a telemetrically group of ground, surface and underwater-based robots. A possible scheme of conducting experiments and the scheme of interaction of mobile robots are shown in Fig. 2.

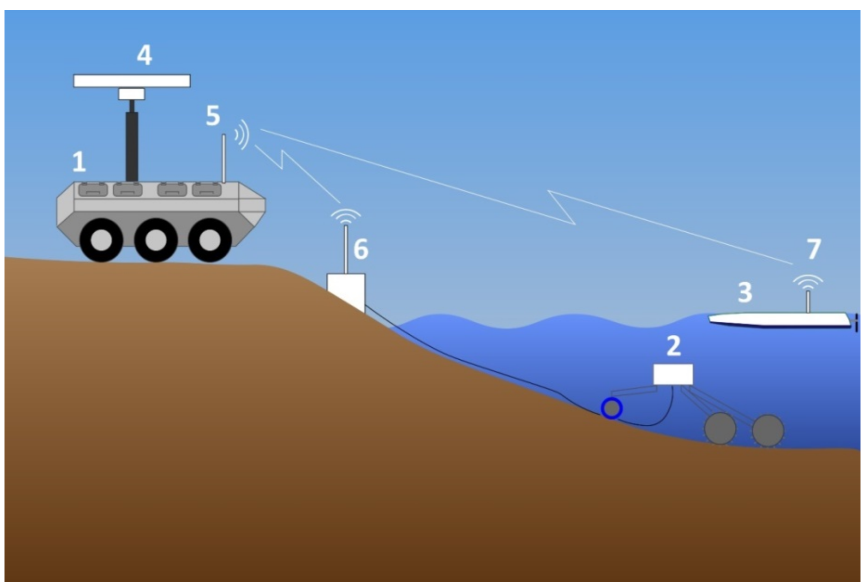


Fig. 2. Scheme of mobile robots interaction

The scheme of the experiment includes the use of three types of robots: ground (1), underwater (2) and surface (3). The robots can be controlled remotely or in autopilot mode. The ground robot has radar (4) for remote wave activity measurement and Wi-Fi transceiver (5). The robot collects information about the height of waves in a certain area by using the radar. The obtained data correspond to the intensity of the reflected signal.The underwater robot (2) is immersed to water and moves along the bottom. It is controlled by the cable connected to the base station (6) that also has Wi-Fi transceiver. The base stations of the underwater and the ground robots are connected to the local network. The task of the underwater robot is to find the wave height at one point in absolute values (meters) using a string sensor. The received data are sent via Wi-Fi to the onboard computer of the ground robot in real-time and after that the calibration of the radar is carried out. It is possible to translate the obtained data from the conventional values of signal intensity into absolute values in meters.

The surface robot (3) is also connected to the local network of the ground robot (1) via the Wi-Fi transceiver (7) and transmits the bathymetry data of the investigated zone. The onboard computer of the ground robot (1) carries out processing and binding data then sends it to the command center or to the operator's laptop. Let us consider details of the implementation of each robot and its description are discussed below.

2. GROUND ROBOT

Ground robots with a variety of equipment are widely used in environment measurement tasks [12-14] due to their ability to perform measurements in autonomous or semi-autonomous mode in hazardous and non-friendly environment. The autonomous mobile robotic system (AMRS) [15, 16] can conduct monitoring in all coastal conditions due to three various types of movers, Fig. 3. Wheeled mover is designed for using on solid ground bases, as well as dry and wet soils. Tracked type of the mover allows increasing the efficiency of the complex operation when driving in difficult areas, such as sandy terrain, wet soils, snow, etc. Rotor-screw mover can be used for work in conditions of wetlands, swamps, flooded areas of the terrain.

Fig. 3. General view of AMRS

The chassis is equipped with a 165 kW internal combustion engine, an automatic gear-box and a mechanical transmission. The general view of AMRS is shown in Fig. 3. The technical characteristics of AMRS are presented in Table 1. Also, the structure of the developed AMRS includes an add-on for the installation of devices on the mobile platform and the hardware part, Fig. 4.

Table 1. Technical characteristics of AMRC

Characteristics	Value
Mass, kg	1500
Engine power, kW	165
Maximum speed, km / h	45 – Wheeled mover 35 – Track mover
Fuel consumption l/100km	18
Dimensions	
Length, mm	3800
Width, mm	2100
Height, mm	1200
Ground clearance, mm	300
Angles of overhang (front and rear), degrees.	45
Model of tires	33x12,5 R15

The hardware consists of the following components: the radar station Mikran River MRS-1000, the weather station Vaisala WXT520, the light detection system LIDAR Sick LMS291Pro, the video camera AXIS Q6045-E, the high-precision mobile GPS/GLONASS receiver (OS-103). For controlling the measuring equipment, collecting, accumulating and processing data on AMRS, the on-board computer Adlink MXE-5400 is installed. Notebook Panasonic Toughbook CF-31WEUAHM9 is used for remote connection to the AMRS on-board computer via Wi-Fi, for viewing data and status of measuring equipment, sending commands to control measuring equipment. To control the movement of the AMRS there is used actuators controlled from the lower level controller based on a single-board computer Raspberry Pi 2.

The robotic system has two control interfaces. There is Tablet TOREX PAD 4G for remote movement control of the complex and the operator's laptop that allows transferring commands to start of the measuring equipment and to display conditions of the system operation. The AMRS passed successfully tests in July 2016 on Sakhalin Island. Test results showed that the approach of using various types of movers allows increasing mobility of the robotic system and expanding the area of its territorial using. Tests of chassis were conducted to check the design of the robot and research its mobility. Tests of functioning hardware, installed on board of the AMRS, were carried out.

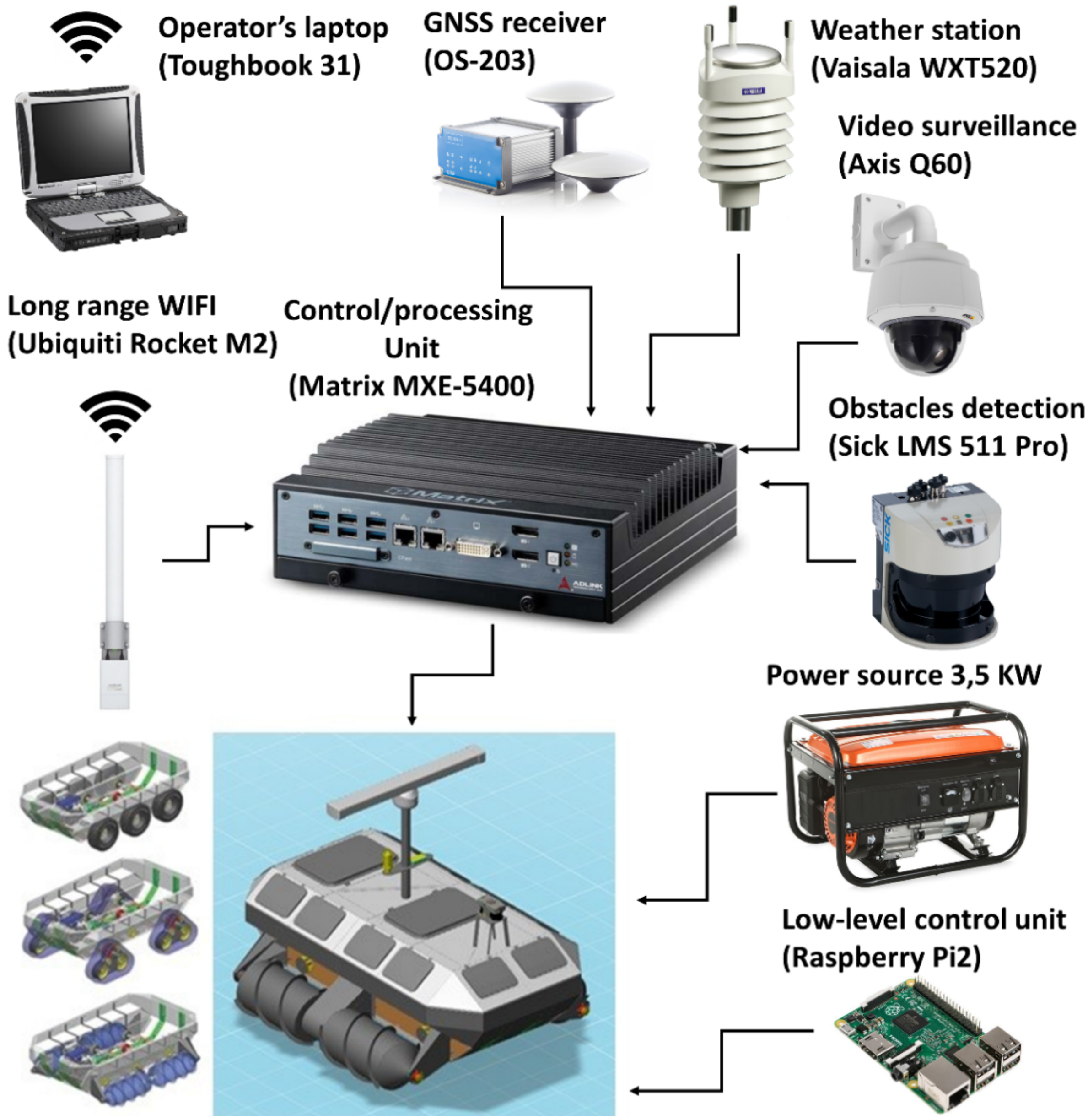
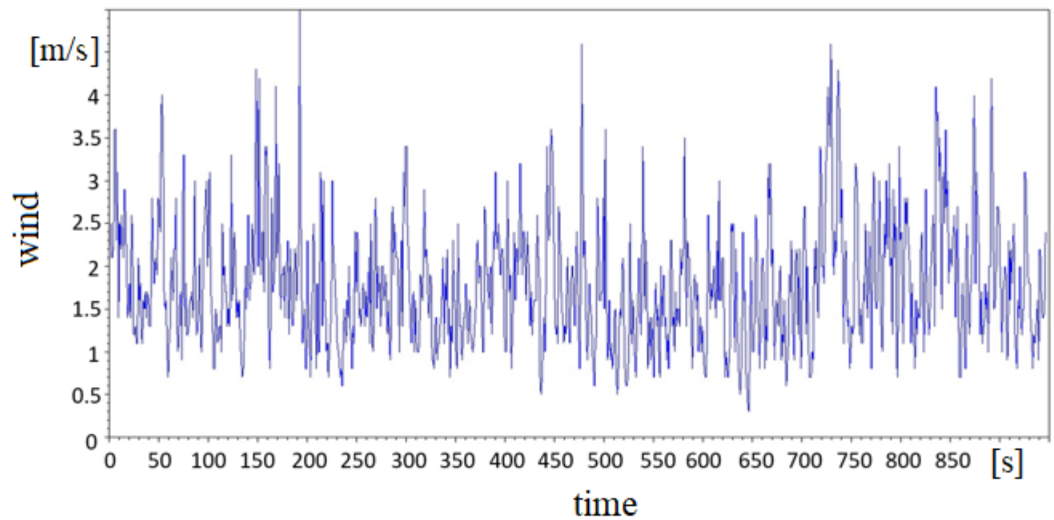
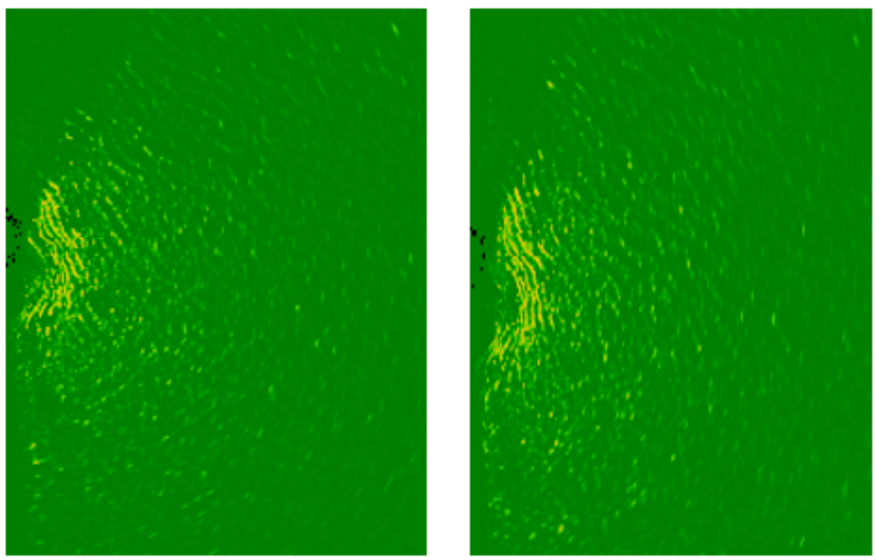


Fig. 4. Equipment of AMRS

Consider an example of processing experimental data obtained from the measuring equipment. Weather station Vaisala WXT520 is used for obtaining meteorological data, such as atmospheric pressure, relative humidity, precipitation, temperature, wind speed and direction. This equipment is resistant to flooding, priming and loss by evaporation during the measurement of precipitation. The meteorological complex is installed on the side part of AMRS with the possibility of fixing at different heights. It connects to the on-board computer via the serial port by the RS-485 interface and is configured for data transfer using the NMEA-0183 protocol.



a)



b)

Fig. 5. Graph of changing in the average wind speed during the measurements (*a*) and the screenshots of the radar (*b*)

The determination of wave parameters using the radar station Mikran "River" MRS-1000 is based on the dependence between the intensity of the reflected signal and the wave height. The power of the reflected echo signal from the sea surface is different depending on force and type of sea waves. Screenshots of the software complex's operation for recording the intensity of sea waves and an example of the meteorological data are shown in Fig. 5.

The robotic system is equipped with the AXIS Q6044-E camera and receives a video stream synchronized with the radar. An example of video, recorded during the test, is shown in Fig. 6.

Fig. 6. Video from camera during the tests

3. UNDERWATER ROBOT

Underwater robots are essential equipment for in situ measurements due to difficulty of accessing the environment by researches. However, their configuration may significantly depend on the task. Typical tasks for this class of robots are surveying, inspection, in situ measurements of water samples. Most commonly used configurations are represented by floating in the water robots [17-19]. For our task we propose bottom robot since typical target depth for this robot is 1-3 meters and bottom robot provide better stability in coastal areas with intensive water fluctuations.

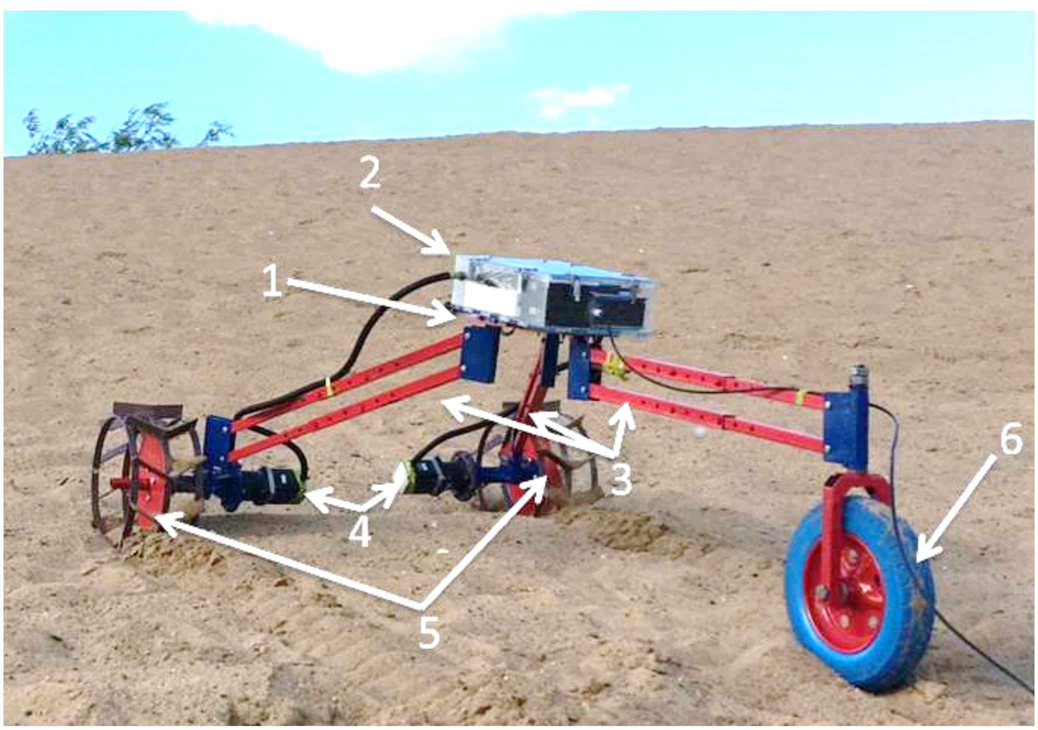
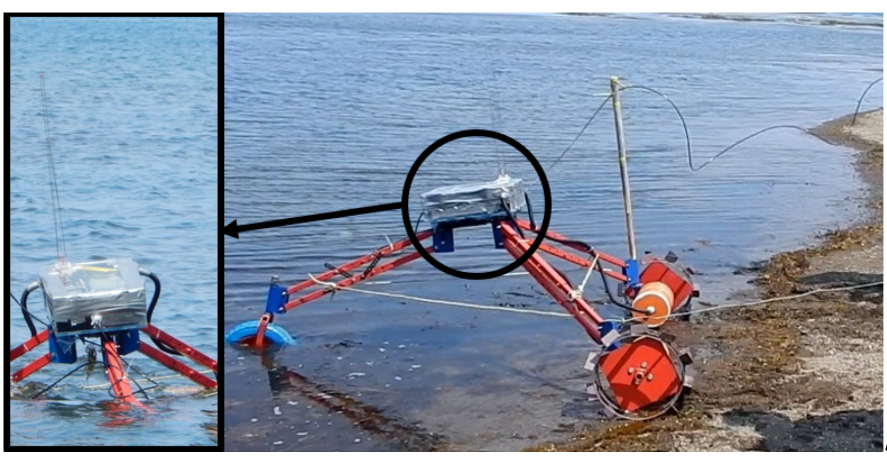


Fig. 7. General view of AMV

Amphibious mobile vehicle (AMV) is consisted of several main components, Fig.7: 1 - supporting platform, 2 - sealed container with measuring equipment, 3 - adjustable levers, 4 - stepper motors, 5 - driving wheels, 6 - support wheel. The AMV collects data using a video inspection system (Fig. 8a) and a hydrostatic wave recorder with a string sensor (Fig. 8b) fixed on the body of the vehicle. The operation of the string sensor is the work of the capacitor plates between the dielectric. Conductors are water and copper wire.

a)



b)

Fig. 8. *a* – fragments of the video inspection system operation at the entrance to water; *b* – string sensor for research conducting

AMV has the ability to adjust the position of the center of gravity to increase stability when driving on steep slopes of the seabed and with significant hydrodynamic effects. Adjustment in the vertical plane is done by reducing or increasing the lengths of each lever, Fig. 9. The maximum length of the arm is 920 mm, the minimum is 770 mm. The adjustment in horizontal plane is done by changing the angle between the levers of drive wheels, Fig. 10. The minimum angle is 39°, the maximum angle is 119°. The axes of motion of the driving wheels are diverged when the positions of the mass center in the two planes are changed. This leads to a mismatch in the direction of the action of traction forces, increasing force of resistance to movement and loss of controllability of the AMV. An adjustment node is used to correct this problem. It allows changing the position of the direction of the motion axes of the driving wheels and turning them in parallel with an accuracy of ± 1 degree.

At this stage, the change in the position of the center of gravity of underwater robot occurs manually. Before the tests, the operator changes the parameters of the robot arms depending on the angle of the bottom of the shore, obtained from the results of bathymetry using a remote-controlled research boat. The use of this type of construction increases the patency of the complex and allows you to do the task set by the operator. In the future, it is planned to use servos for remotely change the geometric parameters of the robot according to the tilt sensor data to keep a position of the container with the measuring equipment close to horizontal and vertical positioning of the string sensor at AMV moving. Electronics of AMV consists of control and power parts. The control part is including a single-board computer Raspberry Pi2. Other sensors are connected to Raspberry Pi 2: a tilt sensor based on a gyroscope MPU-6050, a string sensor for recording the wave height, a Logitech C920 video camera, and a power supply Energizer PB. Controlling is carried out remotely via Ethernet cable from the coastal or through Wi-Fi if the cable is connected to a buoy floating on water surface. The power section consists of two stepped motors with reducers (1:10) and drivers of stepper motors OMD-88. Power supply is lithium battery 48V 10Ah. This power supply is enough for 4 hours of continuous movement that allows conducting the several experiments on immersion. The motors are controlled via the Step/Dir interface, Fig. 11.

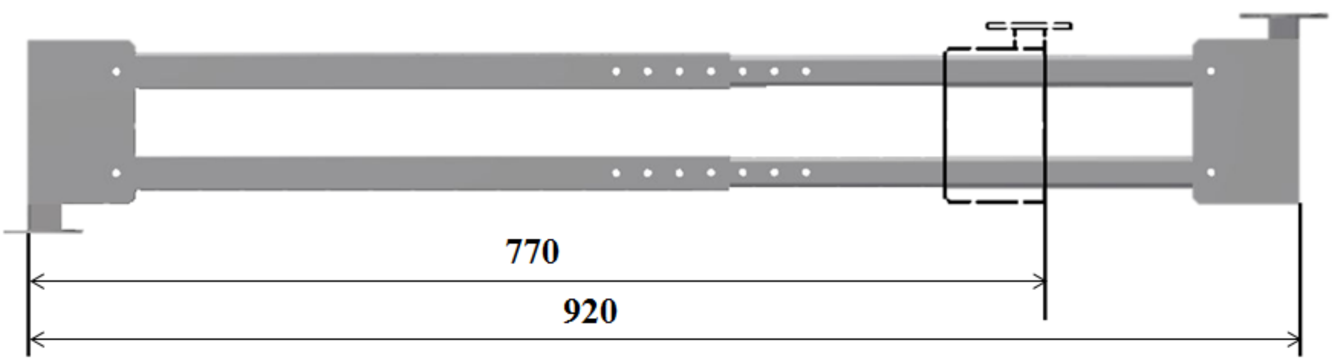


Fig. 9. Adjusting the position of the center of gravity in vertical plane

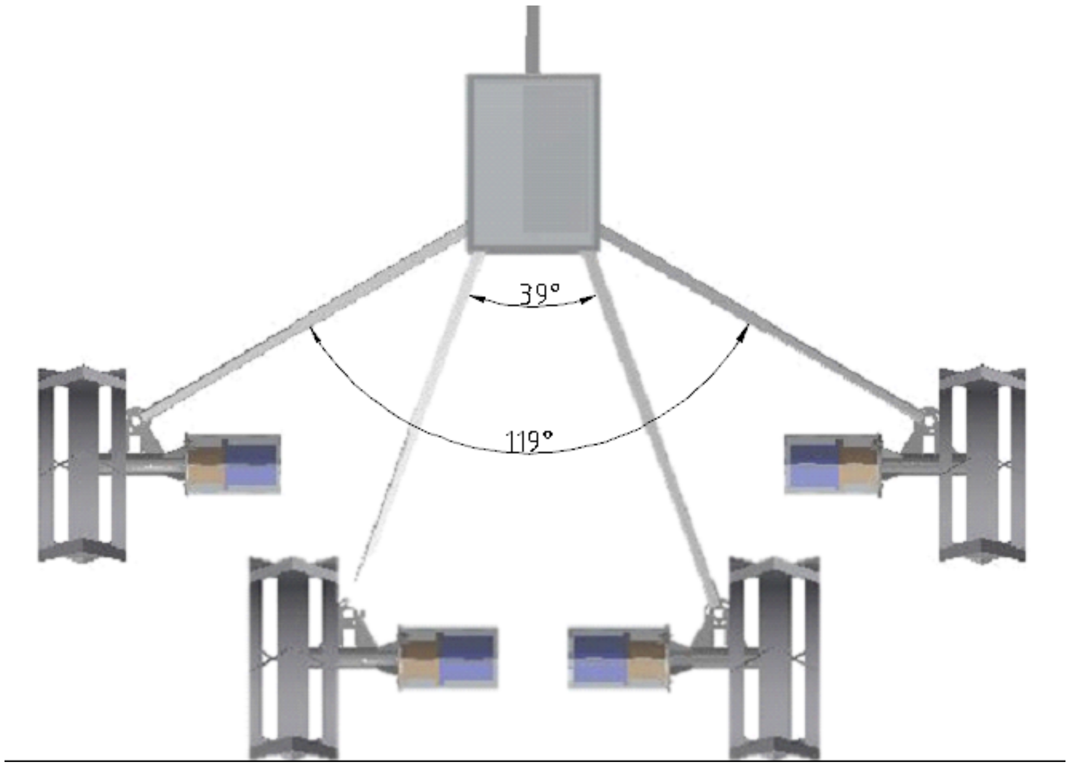


Fig. 10. Adjusting the center of gravity in horizontal plane

As mentioned above, AMV is controlled by a cable connected to the base station, located on the coast and containing a Wi-Fi transceiver that sends control signals from the AMRS and receives data on the value of the wave height (in meters). This data is necessary to recalculate the relative values of signal intensity obtained from radar in absolute values.

During the experiments, it was revealed that winding underwater vegetation takes place on the propeller and AMV design elements. There was an entanglement of the control cable when the chassis landed on the shore. In addition, it was fixed winding the cable on the propeller and its breakage. Therefore, it was decided to use a buoy equipped with a Wi-Fi transmitter instead of laying the underwater cable.

4. SURFACE-BASED ROBOT

Remote-controlled research boat (RCRB) is designed for conducting detailed bathymetry measurements of the investigated water area. This type of robots is very efficient for ocean exploration using on board sensors [20-21] like bathymetry recording [22]. It allows building a depth map quickly with a multi-beam echo sounder. The robot is shown in Fig. 12.

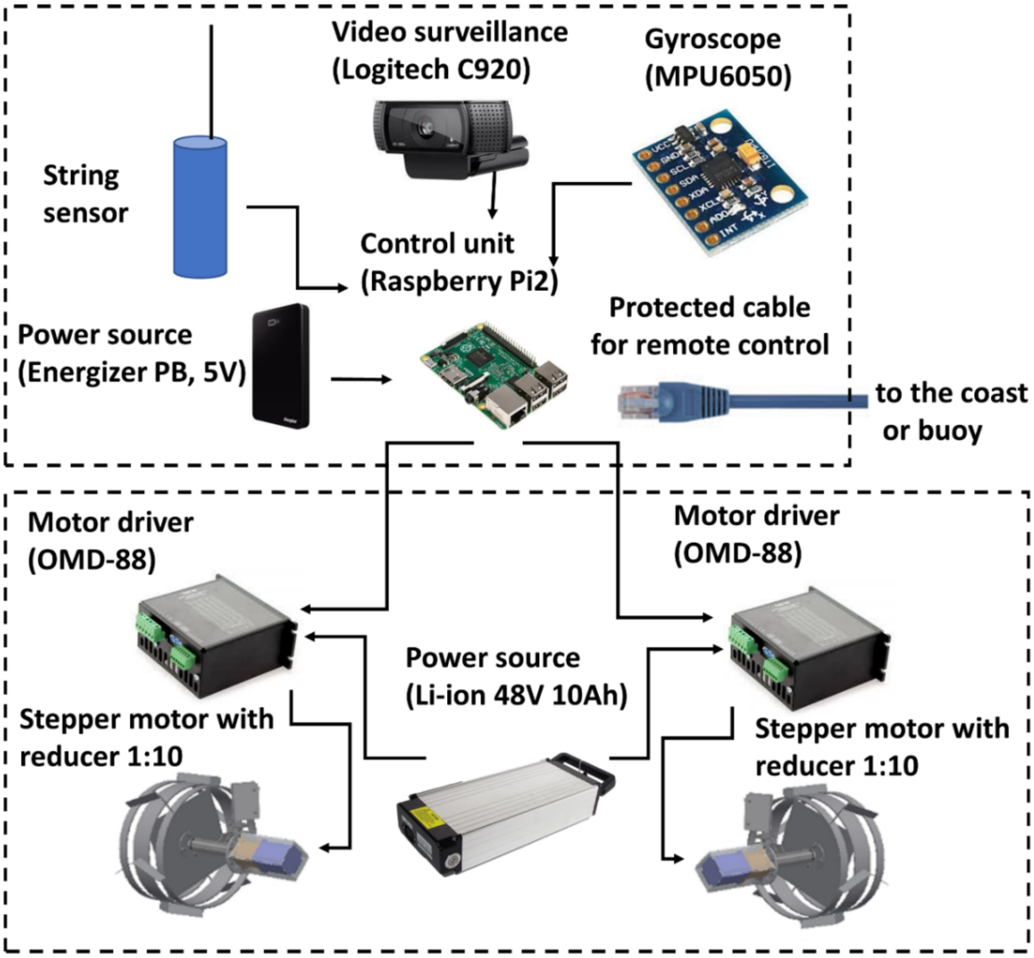


Fig. 11. Equipment of AMV

Fig. 12. Remote-controlled research boat

The development of the remote-controlled research boat was carried out by specialists of the Special Design Bureau for Automation of Marine Research, Far Eastern Branch of the Russian Academy of Sciences. They have extensive experience in creating research systems and conducting scientific research in the field of oceanology, hydro-acoustic research, hydro-physical and hydrodynamic processes, the interaction of atmosphere and ocean, dangerous marine phenomena and safety of seafaring. Equipment installed on board of the robot is shown in Fig. 13. The developed robot conducts amplitude and phase scanning of the bottom. The echo sounder software allows you to build a depth map of the seabed. This card is sent to the ground robot for further analysis.

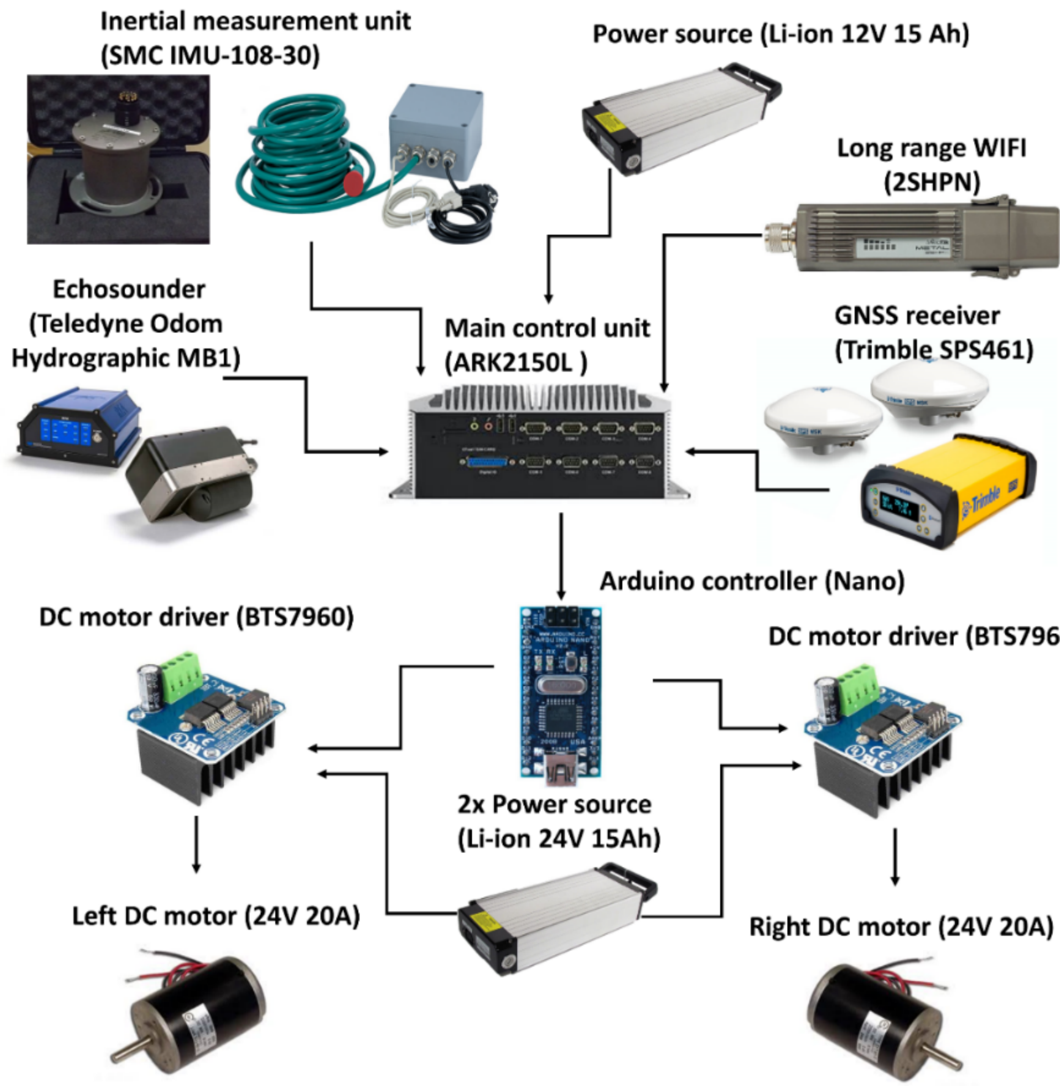


Fig. 13. Equipment of RCRB

The trimble SPS461 GNSS receiver is used for positioning of the robot. The IMC-108-30 SMC is used to find the robot's tilt parameters. The bathymetry data is collected by the Teledyne MB1 multi-beam echo sounder. Data processing and robot control are carried out by the protected computer ARK2105L with a separate power source 12V 15Ah. The power section is based on two direct current motors. The BTS7960 and arduino nano drivers are used as the driver controller. The RCRB control is carried out remotely. Maneuvering is performed by changing the speed of rotation of the right and left motors. Communication with the robot is provided with the help of the Wi-Fi module of the increased range of action on the basis of the access point MikroTik 2SHPN.

5. EXPERIMENT

In July 2017 there were conducted experiments AMV and RCRB functioning. Three expeditions were conducted in coastal zones of the Sea of Okhotsk on Sakhalin Island: at Cape Svobodny, Fig. 14.

Fig. 14. Place of experiments conducting (red point – cape Svobodny)

The terrain is characterized by the small depth of 2-4 meters for several hundred meters away from the coast. The AMV was immersed in water by remote control for a distance of about 50 meters from the coast and a depth of about 2 meters, Fig. 15.

At the same time, bathymetry data was collected using by the surface robot that controlled by a remote operator. An access point Ubiquiti was installed on the coast and the AMV control cable was connected to it, Fig. 15. Thus, both robotic devices were joined into the united local network.

Fig. 15. Immersion of AMV

The wave height data was collected for 60 minutes and displayed in real time on the operator's laptop. Also, the recording of wave height data was duplicated on the on-board computer of the AMV, Fig. 16.

The AMV can be used to verify data received from a radar station installed on a large-scale research chassis for working in a group of mobile ground-based and surface-based robots necessary for comprehensive research of wave dynamics.

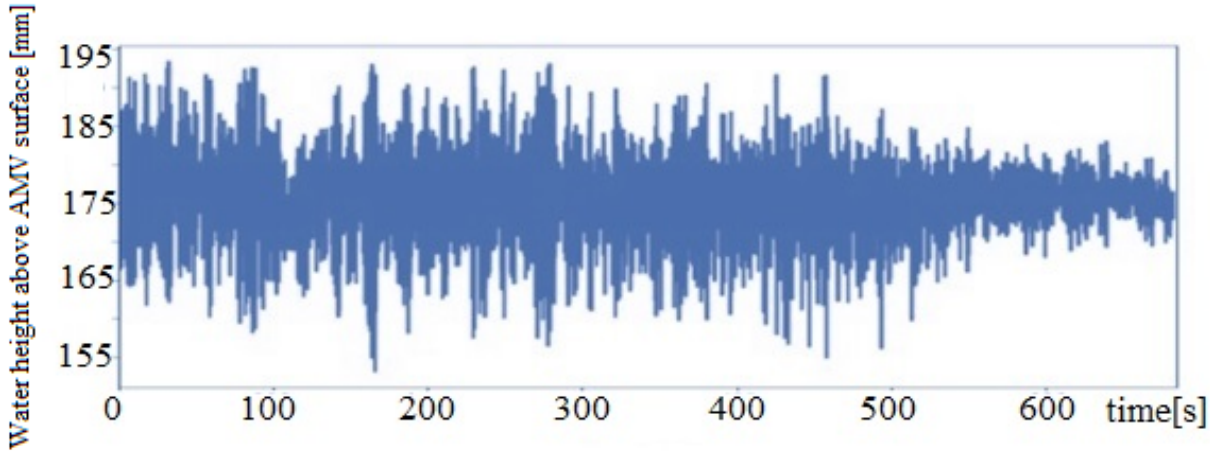


Figure 16. Data obtained by the string sensor of AMV

5. CONCLUSIONS

For registration of the hazardous waves (tsunami, storm surges, wind waves) and background wave climate, several robot system are developed. Also we examine the risk factors for carrying out monitoring of coastal zone. Disadvantages of existing methods have been identified and ways of their solutions have been determined. New perspective methods and approaches have been proposed for effective measurement in coastal zones using a group of mobile ground, underwater and surface-based robots. We present here results of some tests in natural conditions on Sakhalin Island in the Okhotsk Sea.

The registration of waves by different types of sensors simultaneously allows us to overcome these disadvantages of separate measuring instruments. The use of mobile robots, worked in different environments, allows achieving high mobility and efficiency of conducting experimental researches and surveying long coastal areas in a short time that is necessary for instance for post-tsunami surveys.

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