Coastal Remote Sensing using unmanned ground vehicles

ANDREY KURKIN, EFIM PELINOVSKY, DMITRY TYUGIN, OXANA KURKINA, VLADIMIR BELYAKOV, VLADIMIR MAKAROV, DENIS ZEZIULIN
Laboratory of Modeling of Natural and Anthropogenic Disasters
Nizhny Novgorod State Technical University n.a. R.E. Alekseev
603950 Nizhny Novgorod, Minin St., 24
RUSSIAN FEDERATION
aakurkin@gmail.com http://www.nntu.ru

Abstract: Determination of optimal conditions for monitoring coastal zones, especially for locations poorly provided by observations, is one of the most important tasks of the forecast of marine natural disasters. The project covers the development of a technology for monitoring and forecasting the state of the coastal zone environment using radar equipment transported by unmanned ground vehicles (UGV). Sought-after areas of application are the eastern and northern coasts of Russia, where continuous collection of information on topographic changes of the coastal zone and carrying out hydrodynamic measurements and determination of speed and sizes of drifting ice in inaccessible to human environment, are required. This paper presents a new developed UGV for coastal monitoring designed at NNSTU n.a. R.E. Alekseev. For operating in various climatic and landscape conditions there has been chosen the special modular structure with the possibility of re-equipping by different types of movers (wheeled, tracked, rotary-screw). Preliminary evaluation of the functional effectiveness of the technology has been made and the feasibility of developing UGV for coastal remote sensing has been proved.

Key-Words: hydrodynamic measurements, coastal monitoring, unmanned ground vehicles

1 Introduction

Ensuring the safety of people and the preservation of industrial infrastructures, located on the coast and the ocean shelf, are closely related to the study of hydrological and seismic hazards of the area. Environmental monitoring in coastal areas is needed for detecting the risk factor that directly affects people's health and safety. As it is known, to undertake extensive investigations of the situation in the coastal zone is rather difficult due to restrictions related to big length of the coastline, as well as the limited ability of implementation of permanent reliable control. This paper contributes to the discussion of new methodologies for the survey of coastal zones features, helping to provide engineers and managers with clearer understanding the dynamic environment of coastal zones.

Currently, ground vehicles (including unmanned) are used more and more for topographical 3D-survey, simultaneous video survey of features of support surfaces and vegetation of coastal zones, monitoring the level of erosion in coastal areas, definition of parameters of maximum runup of waves and flooded zones, investigations of traces of storms with a resolution of up to several centimeters [1-8]. Examples of such technical systems are presented in the Fig.1-4.

Fig.1. Reigl LMS Q560 airborne lidar system and AEROcontrol GPS/IMU system mounted on the 4x4 vehicle [4]

2 Problem Formulation

The problem of conducting long-term panoramic monitoring of coastal zones is relevant to the Russian Federation. Evaluation of potential hazards is very important in providing oil and gas production in the coastal and offshore fields.

Russia has the longest sea boundaries and, accordingly, the sea shelf. Almost all Russian shelfs is located in seas of the Arctic Ocean and Okhotsk

Sea. Its length from the coast of Russia is 21% of the length of the World Ocean shelf.

Fig.2. Geomobil (Institut Cartografic de Catalunya) with Riegl LMS Z-210 laser scanner, capable of collecting up to 10000 points/per second, and positioning system belongs to Applanix (POS LV 420) [5]

Fig.3. ARGO vehicle with laser scanner (Leica HDS6200), INS (iXSea LandINS) and GNSS receiver (Ashtech Magellan Proflex 500) [6]

Fig.4. StreetMapper [7]: Inertial system TERRAControl, Up to 4 Riegl LMS – Q120 laser scanners for a 3600 field of scan, Video cameras for a better data interpretation

About 70% of its area is promising in terms of minerals, especially oil and gas. The shelf contains a quarter of Russian oil and half of the gas reserves. The development of oil and gas resources of the Russian shelf is characterized by high degree of risk, associated with impact of waves and drifting ice on technical facilities.

A promising method of hydrodynamic measurements, drifting ice analyzing and assessment of hazards in the coastal zone is radar remote sensing.

The project covers the development of technology monitoring and forecasting the state of coastal environment by using radar measuring instruments transported unmanned ground vehicles.

These systems are ideal for long-term deployment, because they provide an opportunity to continuous data acquisition covering several hundred meters from a shoreline. They make possible the implementation of measurements at different temporal and spatial scales.

However, it is necessary to cope with some difficulties associated with the transportation of the radar in severe conditions of coastal zones.

The above-described mobile laser scanning systems, installed on wheeled vehicles, are not applicable for wide operating conditions.

The approach to the creation of mobile systems for monitoring of coastal zones, based on retrofitting of existing transportation and technological complexes and mass-produced ground vehicles with mounted measuring equipment, is significantly inferior to the development of the special multi-purpose chassis on which a particular version of control systems, information systems and special equipment are installed.

3 Problem Solution

One of the possible solutions to this problem is the development and creation of a vehicle with improved performance characteristics. This can be achieved by developing a modular chassis design with the ability to install different types of movers (wheeled, tracked, rotary-screw).

Within the project an experimental prototype of UGV for coastal monitoring and forecasting marine natural disasters has been constructed (Fig.5-7).

The approach to the creation of the technology, its main advantages and limitations were discussed in [9, 10].

The structure of the robotic system includes a chassis with the ability to install different types of drivelines, replacement movers, add-on for installing actuators of control system of the mobile platform; hardware. The composition of the hardware includes the following components: Omni Directional Radar MRS-1000 (space velocity from 12 to 24 rpm, the range of operating frequencies in the range from 9300 to 9500 MHz, the transmitter power adjustment range 28 dB, the degree of protection IP65); workstation for primary data; workstation for remote monitoring; workstation for analysis; Industrial high radio modem (data transfer rate 19.2 Kbps); industrial GPRS / EDGE / UMTS / HSPA + / 4G LTE router, differential GNSS Receiver (positioning error is not more than 30 cm in the driving mode); system of light detection LIDAR LMS511-10100.

Fig.5. Unmanned ground vehicle for coastal monitoring: wheeled version in the measurement process

Within the project there was developed a methodology of carrying out comprehensive studies of hazards of a specific shelf zone with UGV. Let us briefly consider the main provisions of the procedure. The list of hazards, requiring further clarification, is determined after the preliminary examination of this region with the use of analytical approaches based on available data on geophysical parameters. Hydrodynamic data for further use in theoretical and numerical models for generation and transformation of surface waves are collected and analyzed. Additional data on hazards are requested in Geophysical Survey RAS and Federal Service for Hydrometeorology and Environmental Monitoring of Russia. The next step is to conduct detailed numerical modeling using fully nonlinear models. On the basis of the data the most dangerous areas in the region are highlighted, the parameters for field studies are specified. After that, field experiments with UGV are conducted. The research can take a long time and cover a vast territory.

Fig.6. Unmanned ground vehicle for coastal monitoring: tracked version in transportation mode

Fig.7. Unmanned ground vehicle for coastal monitoring: setting of the rotary-screw mover

The intensity of the reflection of waves, received by radar surveillance, is directly related to the height of the waves. Mathematical models and algorithms for processing experimental data (signal selection, spectral analysis, wavelet analysis), recalculation of landwash from data on heights of waves far from the shore, determination of the threshold values of heights of waves far from the shore have been developed. There has been developed the program complex for functioning of the experimental prototype of the UGV, comprising the following modules (Fig.8): data loading module, reporting module, module of georeferencing, data analysis module, monitoring module, hardware control module, graphical user interface (Fig.9).

The key functions of the program complex are the following: loading data coming from measuring equipment; saving data to files and database; data analysis by means of mathematical models, providing relevant information on the status of the measuring equipment; displaying data coming from the measuring equipment in a structured and graphic form through the user interface (Fig.9); control and adjustment of the measuring equipment.

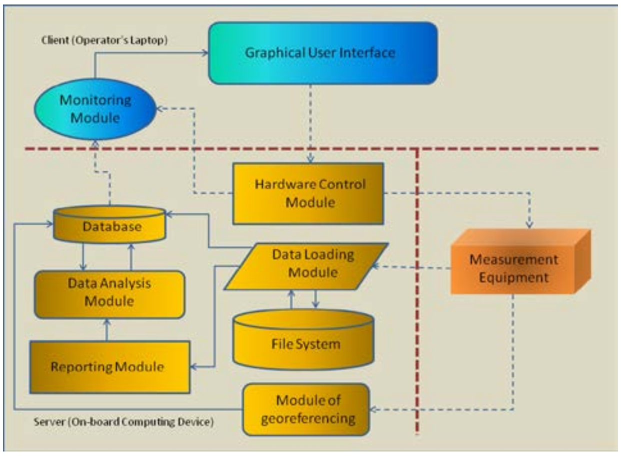

Fig.8. Logical structure of the program complex

Program complex was developed for the client-server architecture and consists of server and client parts. The server part runs on the onboard computing device and implements the interaction with the measuring equipment, loading, analysis and storage of data.

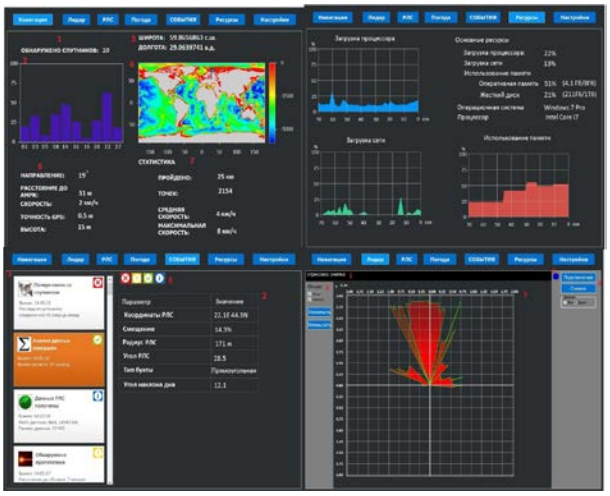
Fig.9. GUI of measuring equipment

The client part runs on a computing device of operator's control panel (laptop). The client part is remotely connected to the server part via TCP / IP connections, implementing conditions for monitoring of the measuring equipment, sending commands for changing settings and displaying the incoming data.

Processing of the input data set is implemented by algorithm for processing experimental data (signal selection, spectral analysis, wavelet analysis), algorithm of recalculation of landwash from data on heights of waves far from the shore, algorithm of determination of the threshold values of heights of waves far from the shore.

These algorithms allow calculating the wave parameters representing the potential hazard considering the bottom topography of the measured area.

Algorithm for dynamic processing of experimental data, using information received from meteorological stations, radar stations and geographic positioning system, calculates waviness fields, meteorological environmental parameters and carries out their typical spectral processing by means of statistical and wavelet analysis.

The algorithm for determining the thresholds of wave heights away from the shore allows to obtain the characteristics of waves for further evaluation of its danger for the coastal zone. The inputs to the algorithm are the wave period and the distance from the waves to the shore. Data of runup height on the shore, at which the wave is considered to be potentially hazardous, must be included on the basis of evaluation of the height of facilities of the coastal zone. Output data of algorithm are the values of wave heights at a distance from the shore. Thus, the algorithm makes it possible to calculate the wave parameters representing a potential hazard considering the bottom topography of the measured area.

Algorithm of recalculation of wave runup on the base wave heights far from the shore, using the information on the amplitude, frequency, wavelength, distance from the waves to the shore, the geographical coordinates of the measurement area, the bathymetry of the selected area and terrain parameters, calculates the height and velocity of monochromatic wave runup on the shore. The algorithm of recalculation of wave runup on the base of the wave heights in the distance from the shore includes the following auxiliary algorithms (subalgorithms):depths averaging algorithm along the bay (the segment passing through the center points of the two sides of the rectangle describing the measured water area in the direction from the shore to the maximum measuring point distance from the coast); algorithm for calculating the angle of the bottom; algorithm for calculating the height and speed of waves runup on shore for a particular relief.

The design parameters of the vehicle have been chosen with reference to the real conditions of coastlines. For preliminary design of the chassis the geomorphology of the territory on the Coast of Sakhalin Island was analyzed by the group of performers, as an area with great prospects.

The group of authors of the project in cooperation with Special Research Bureau for Automation of Marine Researches (Sakhalin Region, Yuzhno-Sakhalinsk, Russian Federation) have an experience in collecting data on wave dynamics on the coast of Sakhalin Island (Fig.10) by means of standard measurement methods.

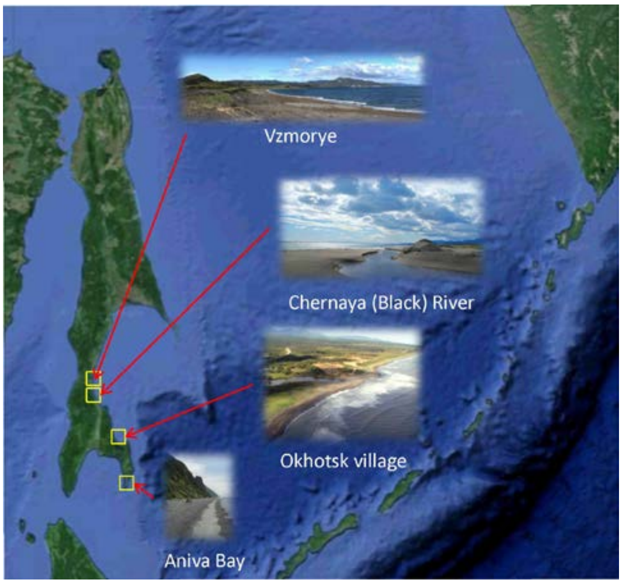

Fig.10. Locations of research

The harsh climate, lack of development and sometimes complete lack of infrastructure significantly complicate carrying out of any in-situ measurements on the shelf of Sakhalin Island.

Within the project it is planned to develop the robotic system that will be to cover the entire route of the Sakhalin Island coastline and perform the remote study of wave dynamics in this area. The measurement data that was received during earlier researches by using of standard methods will be used for validation and verification of experimental data obtained by new methods.

To confirm the performance of the developed UGV there were carried out experimental studies of wave dynamics in the Okhotsk Sea (Sakhalin Island, Cape Svobodny) (Fig. 11).

4 Conclusion

The paper reflects the approach to the creation of a new type of unmanned ground vehicles for monitoring coastal zones. A fundamentally new chassis design and an experimental prototype of the UGV to meet specific operating conditions have been developed.

Fig.11. Venue of measurements on the coast of Sakhalin Island (Cape Svobodny)

The methodology of reducing the consequences of marine natural disasters and improving the efficiency of technical solutions to ensure the reliability and safety of hydraulic structures in coastal zones by monitoring and forecasting environment with UGV has been developed (Fig.12).

The descriptions of algorithm of experimental data processing, algorithm of recalculation of wave runup on the base of the wave heights far from the shore; algorithm of determining the thresholds of wave heights away from the shore have been represented. The program complex for functioning the experimental prototype of UGV has been created.

Preliminary assessment of the effectiveness of using the experimental prototype of the UGV in terms of the ranges of obtained data has been performed.

Preliminary testing of operation of the UGV experimental prototype allows speaking about the effectiveness of the developed technology.

Acknowledgements

The presented results were obtained in Nizhny Novgorod State Technical University n.a. R.E. Alekseev with financial support of applied scientific research of the Ministry of Education and Science of the Russian Federation (agreement № 14.574.21.0089 (unique identifier of agreement - RFMEFI57414X0089)).

References:

[1] Bio A., Bastos L., Granja H., Pinho J.L.S., Gonçalves J.A., Henriques R., Madeira S., Magalhães A., Rodrigues D., Methods for coastal monitoring and erosion risk assessment: two Portuguese case studies, *Journal of Integrated Coastal Zone Management*; Vol. 15. No. 1. 2015, pp. 47-63.

[2] Didier D., Bernatchez P., Boucher-Brossard G., Lambert A., Fraser C., Barnett R.L., Van-Wierts S., Coastal Flood Assessment Based on Field Debris Measurements and Wave Runup Empirical Model, *J. Mar. Sci. Eng*., Vol. 3, 2015, pp. 560-590.

[3] Wübbold F., Hentschel M., Vousdoukas M., Wagner B., Application of an autonomous robot for the collection of nearshore topographic and hydrodynamic measurements, *Coastal Engineering Proceedings*, Vol.1(33), 2012, management.53. doi:10.9753/icce.v33. management.53.

[4] Barber D.M., Mills J.P., Vehicle based waveform laser scanning in a coastal environment, *The 5th International Symposium on Mobile Mapping Technology*, Pradua, Italy, May 29-31, 2007.

[5] Serra A., Baron A., Bosch E., Alamus A., Kornus W., Ruiz A., Talaya J., GEOMOBIL: Integration y experiencias de Lidar Terrestre en LB-MMS, *Setmana Geomatica*, Barcelona, Spain, 2005.

[6] Incoul A., Nuttens T., De Maeyer P., Seube N., Stal C., Touzé T., De Wulf A., Mobile laser scanning of intertidal zones of beaches using an amphibious vehicle, *INGEO 2014*: *6th international conference on engineering surveying*, Prague, Czech Republic, 3-4 April 2014, 2014, pp. 87-92.

[7] Kramer J., Hunter G. Performance of the StreetMapper Mobile LiDAR Mapping System in “Real World” Projects, *Photogrammetric Week* ’07, 2007, pp. 215-225.

[8] Ussyshkin V., Mobile Laser Scanning Technology for Surveying Applications: From Data Collection to End-Products, In *Proceedings of FIG Working Group*, Eilat, Israel, 3–8 May 2009, 2009.

[9] Kurkin A., Pelinovsky E., Tyugin D., Giniyatullin A., Kurkina O., Belyakov V., Makarov V., Zeziulin D., Kuznetsov K., Autonomous Robotic System for Coastal Monitoring, *Proceedings of the 12th International Conference on the Mediterranean Coastal Environment, MEDCOAST 2015*, Vol. 2, 2015, pp. 933-944.

[10] Makarov V., Kurkin A., Zeziulin D., Belyakov V., Development of chassis of robotic system for coastal monitoring, *Proceedings of the 13th European Conference of the International Society for Terrain-Vehicle Systems*, Rome, Italy, 2015, pp. 524-529.

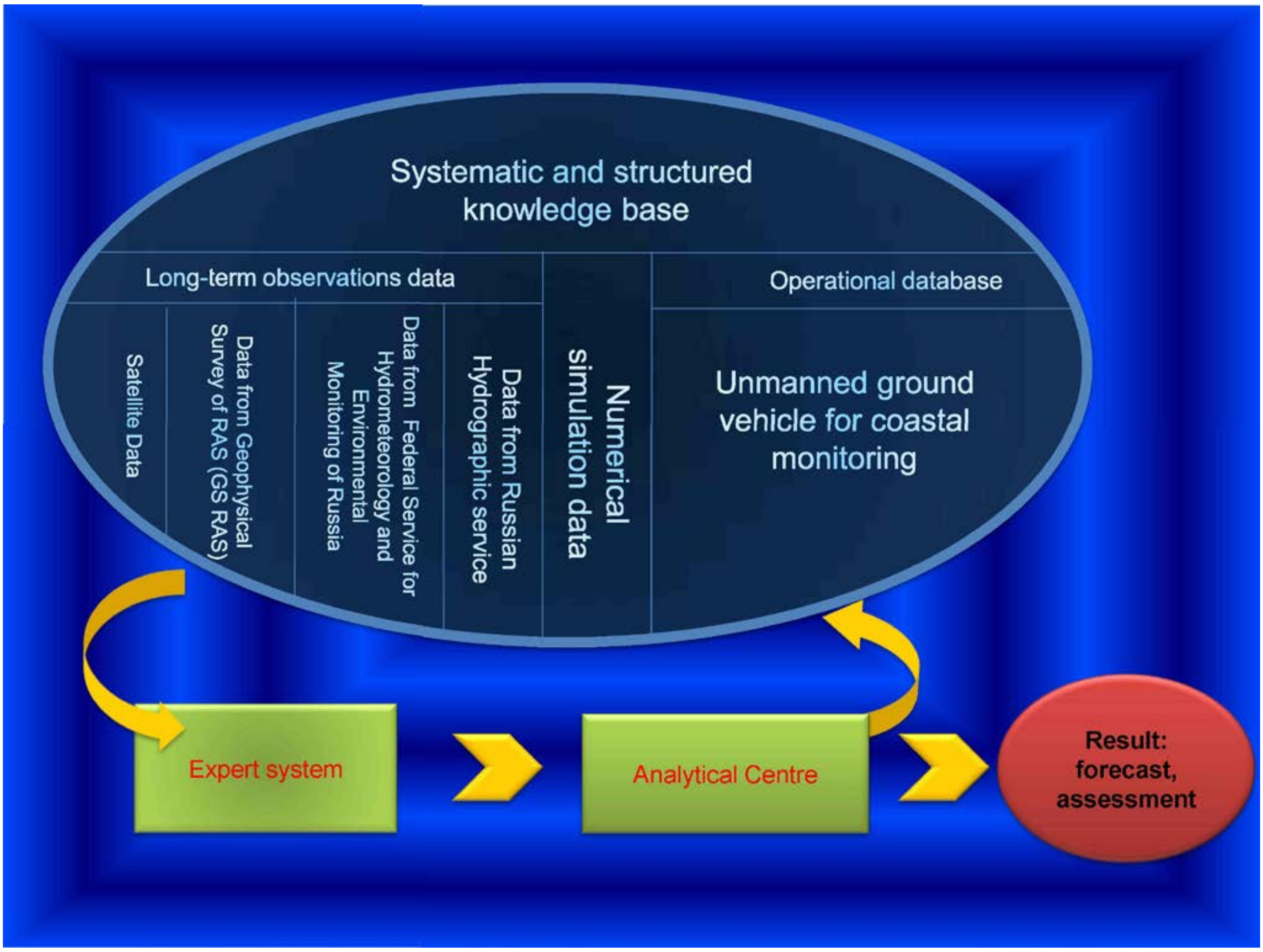

Fig.12. Scheme of using autonomous vehicles for investigations of hazards of specific offshore zone