Water environment monitoring with an autonomous unmanned surface vessel

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Abstract. The paper discusses the use of catamaran-type ultra-small unmanned vessels for studying lakes, rivers and different offshore areas. The key features of a surface vessel designed in Irkutsk Technical University are presented. The article describes major systems of the vessel and concepts of autonomous functioning and remote control. The apparatus can fulfil automatically mapping, searching of sunken objects, hydroacoustic scanning of bottom relief and underwater video recording without the use of additional boats. It is capable to inspect 100 linear kilometers (~15 km²) of the water area per one day. The use of solar panels and Li-ion batteries charged during a single sunny day allows it to work for several days without use of any external sources of energy for recharging. All systems have been checked and debugged in the laboratory and the designed vessel was tested in Irkutsk reservoir. The field testing showed that the error of coordinates determining was within 2 meters. The planned and actual routes almost coincided with an accuracy better than 3 meters.

1. Introduction

Marine unmanned automated systems are increasingly used in the scientific and defense fields [1]. Remote-controlled self-propelled targets have been used for over 30 years. Currently, in the USA, the main directions of development indicated in the USV Master Plan [2] are: anti-mine mapping, organization of communications and navigation support, patrolling aquatic areas, environmental monitoring. In the commercial field, Rolls Royce is one of leaders of developing the idea of crewless maritime transport [3]. The main factor is the high economic efficiency of replacing the crew with an automated ship control system [4, 5]. Engineering services include inspection of bridges, dams, pipelines. The field of engineering services is just beginning developing.

L3 ASV company has developed devices that can work in several directions at once. For example, the C-Worker 8 unmanned vehicle is capable of performing work on positioning underwater vehicles, surveying robots and environmental monitoring. Various payloads can be additionally integrated into the apparatus: hydrophysical and hydrochemical sensors, flow sensors, etc. In addition to commercial use the C-Worker 8 can be used for military purposes as a patrol vessel [6]. A similar remote-controlled vessel designed in Russia is described in the paper [7].

In 2019 a wind-powered saildrone “SD 1020” became the first unmanned surface vehicle (USV) that traveled around the world in Antarctica [8]. The device was equipped with a set of sensors for studying...
the climate. Similar studies had not been conducted in the Antarctic region before. The data obtained with the help of saildrone gave new conceptions of the ocean and climate processes.

All these numerous factors led to reconsideration of the methodology of expeditionary underwater research and observations technologies. One of the promising directions that increase the efficiency of expeditionary work is the use of multichannel universal information-measuring systems based on autonomous robotic platforms.

Today there are a large number of poorly studied reservoirs all over the world. The main reason for this is the high cost of equipment delivery due to lack of infrastructure. Delivery of equipment by air or on foot requires using lightweight and compact size devices. One of types of unmanned vehicles which meet these criteria is catamaran-type ultra-small vessels.

This article presents an autonomous surface vessel designed in Irkutsk National Research Technical University (INRTU). The uniqueness of the apparatus is the use of several measurement instruments at once on the same platform. The main purpose is the studying of different water bodies such as lakes, rivers and offshore areas of the seas.

2. Construction features
The device is equipped with a mandatory and optional payload. The mandatory components include autonomous operating systems, a weather station, video surveillance, and actuators. The optional payload is various. It can be a side-scan sonar, a remotely operated underwater vehicle (ROV) or an autonomous underwater vehicles (AUV), an integrated water quality sensor (CTD sonde) for complex measurements of temperature, pressure (depth) and conductivity (salinity) of water. The hoisting device is equipped with a universal cable and a pressurized connector which allow to change the payload quickly. The vessel can fulfil mapping, sunken objects search operations and underwater video recording without the use of additional boats.

In order to reach the autonomous functionality, the vessel has a control, diagnostic, navigation, communication, power supply, and data acquisition (DAQ) systems. A block-diagram of the systems interaction is shown in Figure 1. Additional modules and systems can be included if necessary. Such modular design allows changing the configuration depending on the task. Data exchange between systems occurs via network protocols such as TCP / IP and MQTT. Data from all systems goes through a router to the internal server of the catamaran. The control computer converts the data into the required formats; some systems can take essential information directly from the sensors. We use two Raspberry Pi boards as a server and a control system computer.

Figure 1. Block-diagram of the surface vessel systems interaction in stand-alone mode of operation.
The control system manipulates the vessel motors according to the current course which is defined with the inertial navigation system (INS) readings and coordinates from the satellite navigation system (SNS). At the same time, these systems are independent and transmit all data over a wireless Wi-Fi network. The diagnostic system collects and analyzes data from all sensors and other systems of the device. It watches all readings are within the prescribed limits. The power supply system is equipped with accumulator batteries, battery management system (BMS) controller and solar panels.

The navigation system [9] processes data from navigation modules and sensors of obstacles. It calculates the coordinates of the vessel and dangerous objects and add all this data to a digital map. The navigation system allows positioning with reference to geographical coordinates with an accuracy of one meter. This accuracy of the coordinates binding is carried out by the use of two Long-band frequency ranges L1, L2 and two global satellite navigation systems GPS and GLONASS. The DAQ system [10] maintains interconnection with additional equipment, primary processing and data recording on the device.

The communication unit is in the center of all vessel systems as it coordinates all inner data exchange. Besides that, it transmits video stream and brief information about the current state to an operator and allows receiving remote control commands back in case of emergency. The maximum radius of data transmission to the operator via Wi-Fi is 2 km. In the case if the vessel works at greater distances (up to 15 km), the operator receives only diagnostic data transmitted through ultra-high frequency (UHF) radio channel at 433 MHz and 915 MHz carriers. In addition, the vessel has 2G / 3G / 4G modules onboard. So if mapping works occur in areas covered with cellular communication networks, any distance limits are removed.

Figure 2. An autonomous unmanned surface vessel designed in the Department of information-measuring systems, INRTU.
The operator plans a mission, deploys a control post, and sends to the device launch commands of moving along the set route. The computer first display shows images from the PTZ camera mounted on the catamaran, the readings of the navigation system, weather station, and information on energy consumption. On the second display the operator monitors the readings of the information-measuring data acquisition system. Echosounding and depth tracking indicators help to be sure that navigation is safe. Also the sonar data allow one to search different underwater objects on the bottom as well as in the water column.

The vessel is capable to inspect 100 linear kilometers per one day, which is about 15-km² area according to the requirements of the measurement standard [11]. During a sunny day, the vessel can move by the energy generated with solar panels only. This allows it to work for several days without use of any external sources of energy for recharging. To top it all the operator station also can be equipped with solar panels and lightweight Li-ion batteries. It is necessary when the targets of mapping are distant rivers and lakes located in hard-to-reach places or there are no infrastructure objects nearby.

3. Field testing

In the process of catamaran constructing, each system was tested and debugged in laboratory. Installation of systems was performed one-by-one in order to track the influence one on another. Long-term measurements were taken to assess possible failures caused by accumulation of inertial navigation system errors. The system response was evaluated in conditions of rapid sensors’ position changes.

Field tests of the vessel were carried out at the Irkutsk reservoir. Figure 3 shows water area (the Pike bay) and configuration of a trial route. The size of the bay is about 1.0 × 0.5 km. At the first stage, the operator’s remote control functions were checked. After evaluation of the dynamics in direction of movement of changes, correction coefficients of the electric motors differential control system were adjusted.

At the next stage, the autopilot functions were tested. In the mode of following a given route, the navigation system calculated the course. According to the data presented in Figure 3-b the planned and actual routes coincide with an accuracy of one cell. In this experiment the cell size was defined by the size of the catamaran (2 meters). So the positioning accuracy was also approximately equal to this order. Such accuracy was ensured by rebuilding the route every 100 ms and updating navigation data at the same speed. This result was obtained under almost ideal conditions when the water surface was completely calm and the wind speed was less than 2 m/s.

![Figure 3. Field testing of the designed vessel: a – trial route in Irkutsk reservoir; b – fragment of built digital track map.](image-url)
4. Conclusion
The designed autonomous unmanned surface vessel demonstrated proper functioning of the systems on board. The error of coordinates determining via the satellite navigation system was within 2 meters. So following the route was provided with an accuracy better than 3 meters. This accuracy can be increased if an additional coastal relay station is used. The station should receive differential corrections of satellite navigation and transmit them to the vessel.

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