Development of Towed Radio Buoy for AUV

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Abstract. One way to extend the functionality of autonomous underwater vehicle is to use a surface buoy-repeater that provides a high-speed data exchange channel between the operator station and AUV in real time. Also, the data of the receiver of the satellite navigation system of the buoy make it possible to correct errors accumulated by the on-board navigation system of the device without using hydroacoustic navigation devices. The report presents the design stages of the towed radio buoy, its composition and functional diagram, structural appearance and some results of field tests.

1. Introduction

Collaboration of autonomous underwater vehicle (AUV) with towed radio buoy (TRB) makes it possible to quickly transfer large amounts of information from the underwater vehicle to the operator's post [1-3,7-10]. Also, according to the receiver of the satellite navigation system installed on the buoy, it is possible to specify the geographical coordinates of the AUV [4-7,11]. The effectiveness of TRB application is particularly evident in the survey of extended bottom facilities (e.g. underwater pipelines and cable routes). At that, coordinates of AUV relative to buoy are determined by solution of the equation of flexible non-extensible wire in stationary flow taking into account buoyancy margin and hydrodynamic resistance of TRB [11, 14].

The purpose of the work is the development of TRB, which provides a stable and high-speed information exchange between AUV and the operator's post during the movement of the device in a given range of speeds and depths of immersion.

The terms of reference for the design of BRP were formulated based on its purpose, safety requirements during operation, convenience during transportation and storage. The main requirements of the technical specification for the design of the device are as follows.

1. The shape of the device shall provide minimum hydrodynamic resistance during towing.
2. The attachment point of the towing cable shall provide height adjustment.
3. The composition of the buoy equipment should provide Wi-Fi communication, radio communication, cellular communication GPRS and 4G.
4. Buoy equipment shall be located in waterproof containers with guaranteed protection against water ingress at a depth of up to 1 m.
5. The buoyancy margin shall ensure elevation of antenna system base above water surface not less than 200 mm at maximum towing speed (1 m/s).
6. The cable attachment point to the buoy shall provide height adjustment to minimize disturbances torque from towing.
The prototype of the developed device is the towed float-repeater "Radio BOA" (idRobotica, Switzerland). It is a vertical wing with minimal hydrodynamic resistance to towing and high stability due to the use of a keel. GPS device and transmitting antennas are located above the water and provide continuous communication with the operator's post. Figure 1 shows a photograph of the prototype.

![Figure 1. Towed buoy “Radio BOA”](image)

2. Stages of device development

2.1. Determination of the model of use of radio buoy

The main purpose of TRB is the information exchange of AUV with the operator's post, which can be located on board the supporting vessel or on the coastal base [13]. The design distance between the operator's post and AUV does not exceed 10 km. At the same time, at distances up to 300 m, the main radio communication channel will be Wi-Fi, and at distances from 300 m to 10 km, radio communication using Lo-Ra technologies will be used. The length of the towing communication cable between TRB and AUV should not only provide stable exchange via the Ethernet interface, but also minimize mechanical impacts on the buoy during towing within the specified stock of floatage and stability. During the maximum length of the communication cable determining, the following parameters of the vehicle movement were taken into account: maximum speed - no more than 1 m/s, diving depth - no more than 10 m. According to the initial data, the optimum cable length is 20 m [14]. The principle of the buoy is shown in Figure 2.

![Figure 2. Work conception of towed radio buoy.](image)
2.2. Determination of TRB equipment composition

Analysis of the technical specification and existing devices of analogues [2-11, 14] shows that they consist of the following main systems:

- communication system between buoy and AUV,
- communication system between buoy and operator post,
- global position system (GPS/GLONASS),
- data processing system,
- autonomous power supply system.

Most of these systems devices are arranged in sealed housing of radio module. The module includes: battery charge indicator boards, satellite navigation system receiver, GSM/GPRS module, antenna radio modems, radio module microcontroller and beacon. The selected light and radio transparent cover of the module allows receiving signals of the satellite positioning system, transmitting beacon’s light and monitoring the readings of the battery charge indicator.

As a result, the following main composition of the buoy was determined: power unit, radio module, frame, antennas, sealed connector for charging the power unit, buoyancy, switch for switching on and off the buoy, device for connecting the AUV cable to the buoy. Figure 3 shows the functional diagram of TRB.

![Figure 3. Functional scheme of the TRB.](image)

2.3. Power unit development

It consisted of the tasks of designing a strong waterproof container and chassis with accumulators located in it, charge control boards, protection devices (from battery overrun, recharging battery above normal, short circuit and leaks). The battery is made on the basis of rechargeable Li-Ion cells of the Sanyo type NCR18650GA

2.4. Layout of components

The design is based on the principle of obtaining the shape of a buoy with minimal hydrodynamic resistance to movement. To ensure stable operation of antennas, their location is chosen at a distance of at least 300 mm above the water level. Battery module is located in waterproof container. Stability of the buoy is due to the presence of ballast. Calculated value of ballast weight (4 kg) and its position on remote rods provided metacentric height of 130 mm. Figure 4 shows overall dimensions, position
of center of mass and center of volume of the device. Figure 5 shows the structural appearance of the designed towed radio buoy.

2.5. Determination of residual buoyancy value
In the main mode of movement, the buoys are towed at the buried position of the underwater vehicle. At the same time, a force deepening the buoy occurs from the side of the communication cable. Design value of deepening force from towing at buoy movement at speed of 1 m/s is 50 N. Based on this, it was decided to select 60 N buoyancy reserve [11, 14].

3. Results

3.1. Appearance
As a result of theoretical development and adjustment of the design, after preliminary tests, the final appearance of the towed radio buoy was determined. Fragments of field tests are shown in Figures 6 and 7.

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3.2. Technical characteristics of radio buoy
The design and fabrication resulted in a device with the characteristics shown in Table 1.

Table 1. Towed radio buoy characteristics.

| Characteristics                             | Value              |
|--------------------------------------------|--------------------|
| Mass, kg                                   | 15.6               |
| Size (LxHxW), mm                           | 537x1232x150       |
| Reserve buoyancy, H                        | 60                 |
| Autonomy (with GPS and Wi-Fi), h           | 11                 |
| Maximum battery discharge current, A       | 10                 |
| Maximum transfer rate (Wi-Fi at a distance of up to 300 m), Mbit/c | 150               |
| Minimum transfer rate GSM/GPRS, kbit/c     | 85.6               |
| Lo-Ra minimum transfer rate, kbit/c        | 150                |
| Maximum range of connection (Lo-Ra), km    | 10                 |
| Length of communication cable, m           | 20                 |

3.3. Radio Module Characteristics
Main characteristics of devices of radio module are given in Table 2.

Table 2. Radio module component characteristics.

| Item of Equipment          | Parameter                          | Value                           |
|----------------------------|------------------------------------|---------------------------------|
| GPS receiver NEO-6Mn       | number of receiver signals         | 50                              |
|                            | sensitivity (tracking/navigation mode), dBm | -161                           |
|                            | navigation accuracy, m             | 2.5                             |
|                            | update frequency, Hz               | 5                               |
| Radio modem EBYTE Lo-Ra E22-900TBH | maximum range of connection, km | 10                              |
|                            | maximum bit rate, kbit/c           | 300                             |
|                            | operating frequency, MHz           | 900                             |
|                            | sensitivity, dBm                   | -150                            |
| GSM/GPRS modem SIM800C     | working frequencies GSM, MHz       | 850,900,1800,1900               |
| Wi-Fi Mikrotik RB Metal 9HPn | maximum transfer rate GPRS,        | 85.6                            |
|                            | communication range                | restricted to the network operator|
| Radio module printed circuit board | signal transmission range, m     | 300                             |
|                            | operating frequency, MHz           | 2400                            |
|                            | data transmission rate, Mbit/c     | 150                             |
|                            | microcontroller type               | STM32F407                       |
|                            | type of Ethernet network switchboard| KSZ8863M                       |
|                            | number of Ethernet network channels| 2                              |
|                            | number of RS-232 channels          | 3                               |
3.4. Results of buoy virtual blowdown
The efficiency of the obtained shape of the buoy was confirmed by modeling its streamlining in water at a speed of 1 m/s. As a result of the calculation by Cosmos Flow Works, the drag force of the buoy $R_x = 8.4 \text{ H}$ and its hydrodynamic resistance coefficient $Cx = 0.23$ were determined.

4. Conclusion
As a result of the development, a buoy design was obtained with a shape that provides small hydrodynamic movement during towing and the ability to transmit signals from the AUV to the operator's post with a range of up to 10 km and a speed of at least 85.6 kBit/s. At the same time, at a range of up to 300 m, a data transfer rate of 150 MBit/s is provided, which is confirmed by experimental work in August 2020 (Patroclus Bay of the Japan Sea).

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