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Original article

Control System for a Moored Autonomous Underwater Profiler

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Abstract

Purpose. This work presents the design and implementation of a modern control system for an autonomous underwater profiler intended to conduct a large series of measurements of vertical profiles of aquatic environmental parameters in an automatic mode at a moored station, and to provide wireless data transmission in quasi-real time and remote control.

Methods and Results. The following components of the tethered control system were considered: electronics, embedded software, software and hardware for data transmission and remote control, as well as end-user application software. The hardware technical characteristics were presented. The structure, functional features, and implementation details of the software components were described in detail. A specialized communication protocol providing reliable transmission of large volumes of data via cellular networks was proposed.

Conclusions. A control system for an underwater profiling probe implementing automatic modes of operation, data transmission, and user interaction has been developed. This system served as a basis for constructing an autonomous robotic platform for oceanographic sensors with a built-in winch called "Winchi". It is designed for regular measurements of vertical profiles of aquatic environmental parameters from the bottom to the water-air interface in shelf sea areas, lakes, and reservoirs. Special software and hardware tools for navigation and robust communication have been developed as part of the probe-profiler control system. For the first time in domestic practice, this made it possible to solve the problem both of remote reconfiguration of the water-column monitoring mode, including adjustment of the measurement time and depth, and modification of the composition of the information transmitted by the device depending on weather and other conditions.

Keywords: operational oceanography, measurement automation, control of an autonomous underwater system, instrumentation electronics, embedded software, data transmission, remote control

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Introduction

Modern oceanographic moored profilers are sophisticated technical tools; by using them, researchers obtain qualitatively new information on the temporal variability of vertical distributions of hydrophysical, bio-oceanological, and hydrochemical characteristics [1]. Autonomous underwater vehicles of this class are deployed for extended periods, sometimes up to several months, at key geographical points in water areas. An important advantage of these instruments is the synchronicity of multi-parameter measurements. The greatest effect is achieved when studying small-scale processes and the fine structure of the vertical stratification of the water column, especially in the upper active layer of the ocean. The application of profilers capable of transmitting measurement data to the user in near-real-time mode enables detailed observation of the evolution and dynamics of oceanic processes in real time at high temporal resolution.

In the process of creating the control system for the profiler, developers need to solve several tasks, namely:

– optimization to increase operational autonomy with a limited-capacity battery;

– ensuring functional stability in specified modes throughout the entire deployment period under the influence of sea currents, surface and internal waves;

– maintaining communication with the operator for the exchange of telemetry information, measurement data, and the receipt of commands for remote diagnostics of the device state and modification of the sounding mode;

– system integration of several measurement channels for heterogeneous oceanographic sensors from different manufacturers, with the requirement that the recording subsystem provide sufficient throughput to work with sensors possessing a sampling frequency on the order of 10 Hz;

– implementation of wireless access to the control system, particularly for debugging, programming, and monitoring purposes.

In this regard, the task of creating the control system for the profiler probe must be solved comprehensively, taking into account the interaction of all subsystems, including external ones, integrated at the software level.

The primary purpose of the profiler control system is to execute an autonomous mission, which consists of a sequence of dives and ascents of the vehicle to specific horizons, from the uppermost to the lowermost and back, at predetermined time points. Measurements of the parameters of the aquatic environment of interest are carried out during movement, and the collected measurement data must be transmitted to a remote operator upon each ascent to the water surface. The volume and composition of the transmitted information can be altered by operator commands received during communication sessions when the vehicle is on the surface. During autonomous underwater operation, the profiler control system performs actions to achieve the programmed mission parameters, which may also be adjusted remotely when the vehicle surfaces.

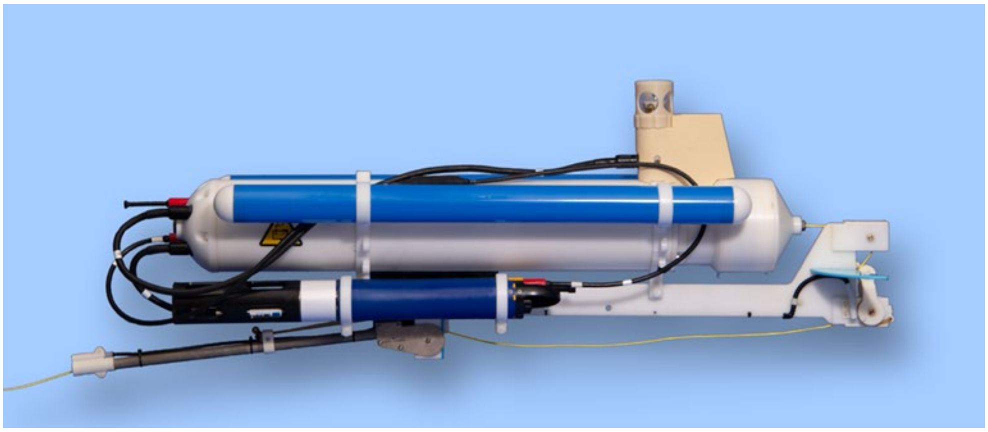
The movement of profiling probes can be implemented in different ways, for example, by altering their own buoyancy [1] or by means of a winch [2]. The latter method seems preferable, as it allows for more precise control of the vehicle's underwater position.

The purpose of the present work is to create a set of convenient, state-of-the-art software tools for the effective and reliable control of long-term autonomous missions of an automatic profiling probe. The developed system consists of three main software components: embedded software, application software, as well as software for communication with the probe, data transmission and storage, monitoring of its state during mission execution, and remote control.

The Winchi profiler

The first winch-type automatic profiling probe at Shirshov Institute of Oceanology, Russian Academy of Sciences, was the vehicle named Winchi [2, 3], which is already being successfully used for scientific research in shelf sea waters [2, 4] and inland water bodies [5]. Winchi possesses positive buoyancy and therefore maintains tension in the cable extending from the underwater winch, the lower end of which is secured to a subsea support or bottom anchor.

Structurally, the profiling probe is built according to a trimaran configuration (Fig. 1). It consists of three cylindrical housings, mounts, and a suspension system. Brackets are attached to the main instrumentation housing and support the side float housings. The two smaller-diameter side floats are spaced apart from the central housing and are slightly elevated. The main housing is divided into two compartments: a dry compartment for the battery pack, electric drive, control system electronics, and oceanographic sensors; and a flooded compartment for the winch drum with cable.



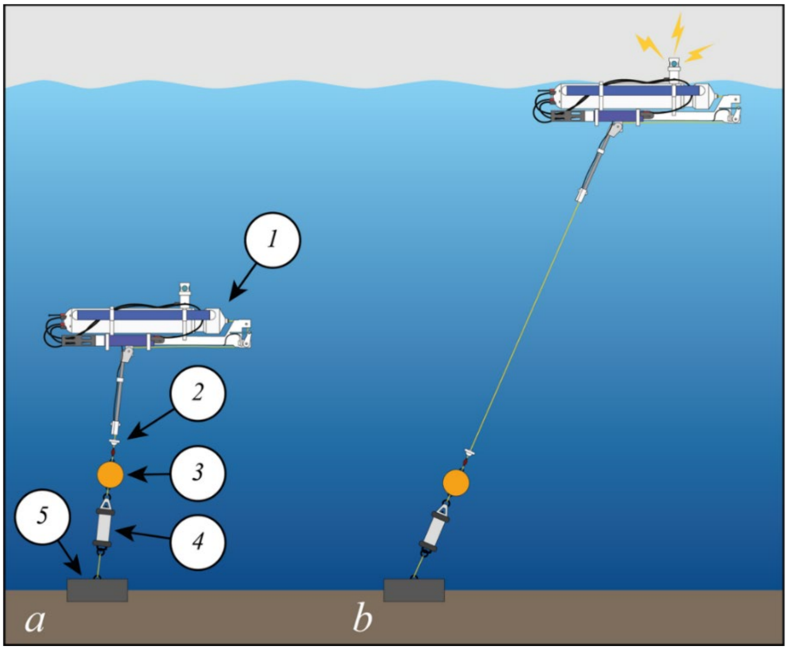
F i g. 1. Exterior view of the Winchi profiler

[1] Mauritzen, A. and Lilleøkdal, F., 2024. *System and Method for Transmitting Subsea Parameters*. US Patent US20240124099A1.

[2] Kawahara, H., Nakamura, T. and Ohta, J., 2014. *Underwater Rising/Falling Device*. US Patent US9102390B2.

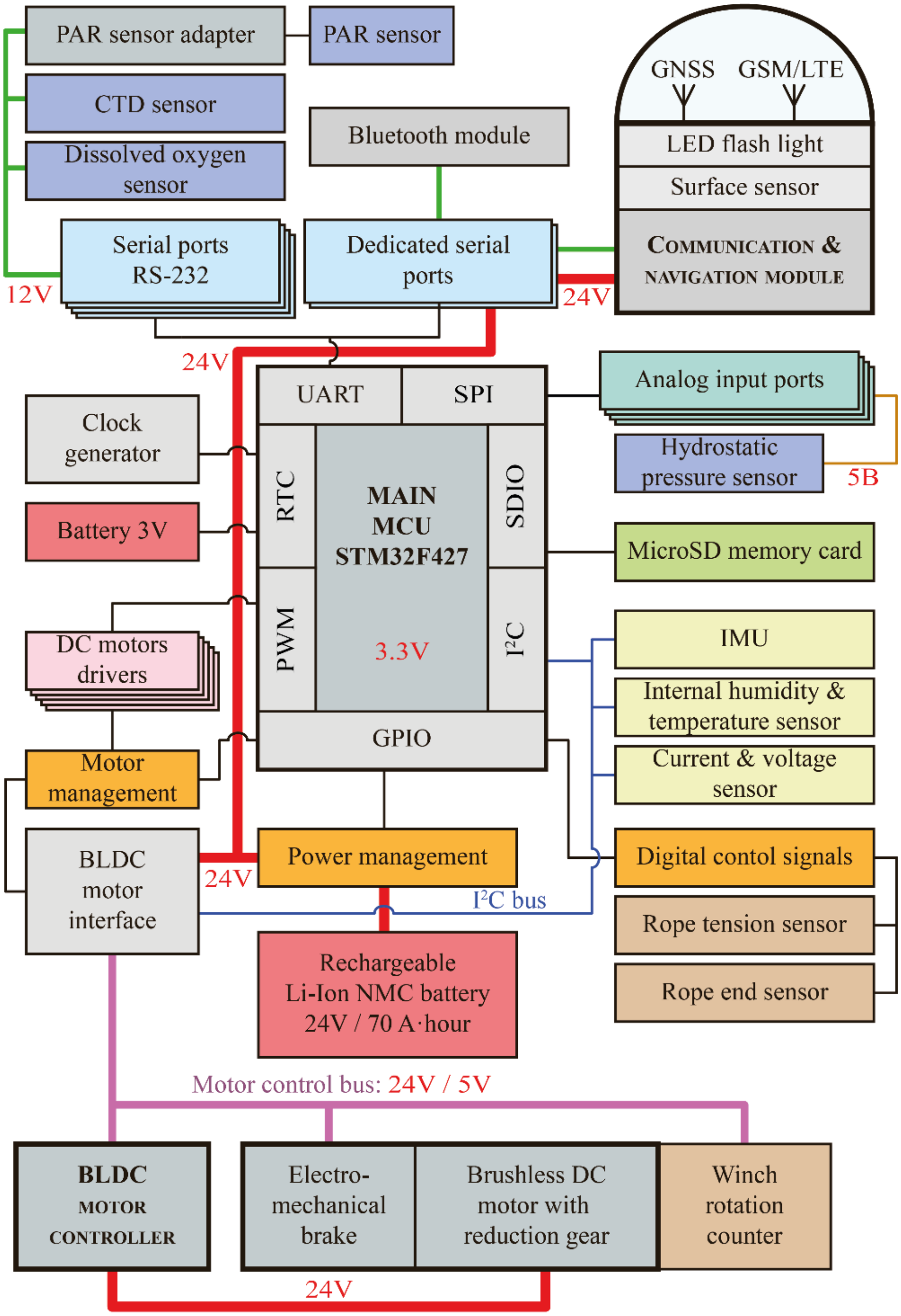
Measuring sensors are mounted on fixtures below the central housing, while a communication and navigation module is installed on top. Underwater, the vehicle maintains a horizontal orientation due to a specially designed suspension system (a frame with rollers through which the cable is run) and a cable guide tube located below on a hinge approximately under the vehicle's center of gravity.

The Winchi deployment scheme with an acoustic release is shown in Fig. 2. The typical deployment depth is determined by the cable length and is 30–40 m. The results of multiple tests in freshwater bodies and marine environments demonstrate that the capacity of the onboard battery pack is sufficient for 400–500 profiling cycles, depending on factors such as deployment depth, current velocity, and water density.



F i g. 2. Deployment scheme of the Winchi profiler: *a* – parking position; *b* – data transmission at the sea surface; *1* – the Winchi profiler, *2* – rope-end magnetic sensor; *3* – underwater float; *4* – hydroacoustic release; *5* – weight

Winchi has a positive buoyancy of approximately 30 N and, in order to ascend from depth to the water surface, must unwind the cable from the winch drum. The side float housings provide the vehicle with additional stability on the surface, ensuring that the communication antennas are raised above the water. Upon completion of a communication session, Winchi proceeds to dive; for this purpose, the winch winds the cable onto the drum until it receives a signal from the magnetic end-of-cable sensor installed above the bottom part of the station. Diving is the most energy-intensive phase of the vehicle's movement. In the parking position near the bottom, Winchi enters a low-power standby mode until it receives an activation signal from the built-in real-time clock.



F i g. 3. Functional scheme of the Winchi profiler hardware

The sequence of actions “dive – sleep – ascent – data transmission” is referred to as a working cycle, and each action is considered a phase of the working cycle. During movement through the water column, the vehicle performs measurements of various parameters of the aquatic environment. The set of measured parameters is determined by the installed sensors.

The control system described below was developed specifically for the Winchi profiler. The development is based on an original unified hardware-software platform for the control system of autonomous underwater profiling vehicles [6]. Since the publication of that work, both the hardware and software have been adapted specifically for the control of the autonomous underwater profiler Winchi [6], as described below.

The profiler hardware

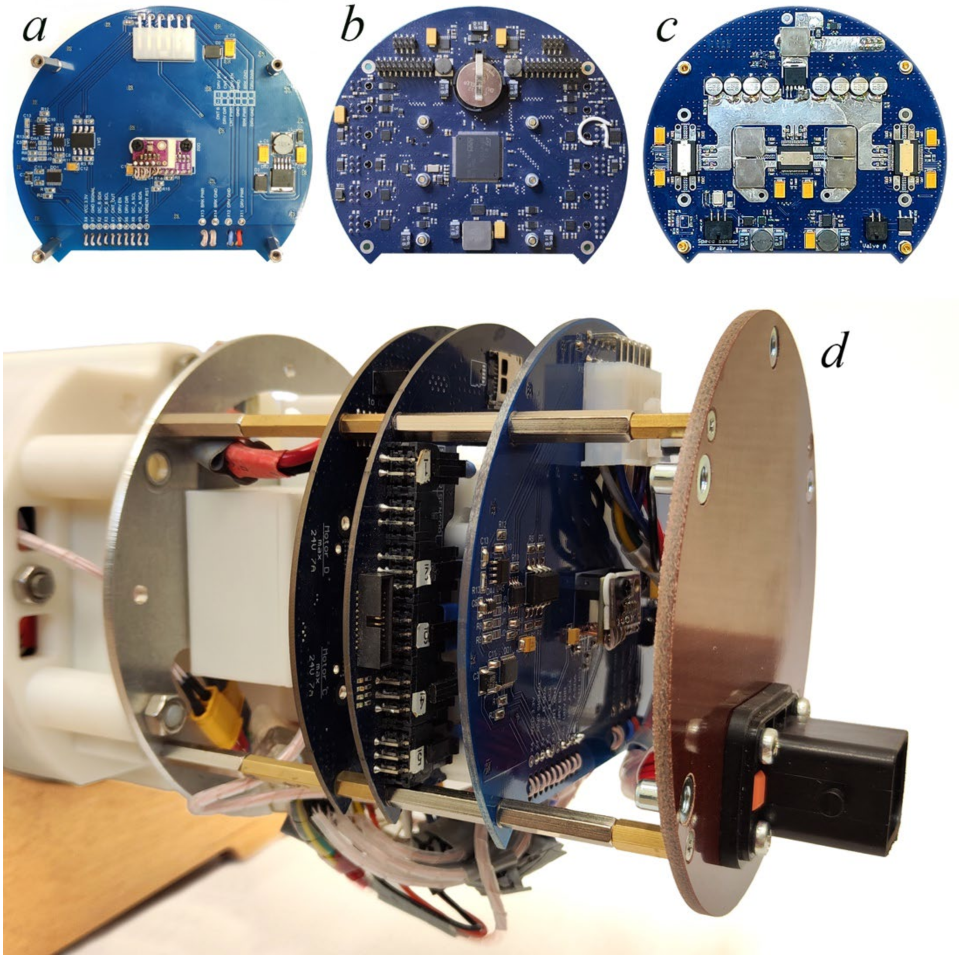
The foundation of the hardware-software platform of the Winchi profiler is a set of control electronics. It consists of two modules: the Main Processor Module (MPM), which is housed inside the main sealed enclosure of the instrument, and the Communication and Navigation Module (CNM), which is mounted in a separate small sealed enclosure externally and connected to the MPM via a cable. The printed circuit boards of the control electronics were initially designed specifically for use in automatic profiling probes of IO RAS [6]. The technical capabilities of this device are sufficient to create a variety of devices based on it, including ocean gliders.

The latest, fourth version of the hardware set was created in 2025. It has performed reliably both in terms of ease of installation and operation. The functional diagram of the hardware is shown in Fig. 3.

Main processor module. It consists of two printed circuit boards: a power board and a processor board. In addition, a third board providing supplementary interfaces is included. All boards are combined into a single assembly (Fig. 4), which is then placed in a protective plastic casing with openings for access to the quick-release microSD data storage device and the debug port.

A general-purpose STM32F427ZITx microcontroller is used as the central processor. This is a high-performance 32-bit ARM processor with a large amount of RAM and flash memory, supporting various peripheral devices and interfaces.

For controlling the underwater vehicle, the MPM provides the capability to connect up to six DC motors, four analog sensors, four external measuring instruments via RS-232 ports, and two I^2C device chains. A Bluetooth wireless module is provided for near-field communication with the instrument; for long-range communication, the external Communication and Navigation Module is used, which can provide access to the GSM/LTE network or to a VHF LoRaWAN radio channel. A removable microSD memory card serves as the data storage medium and supports FAT32 and ExFAT file systems. Digital input/output lines are also available for additional devices and sensors. The MPM requires a power source with a nominal voltage of 24 V.

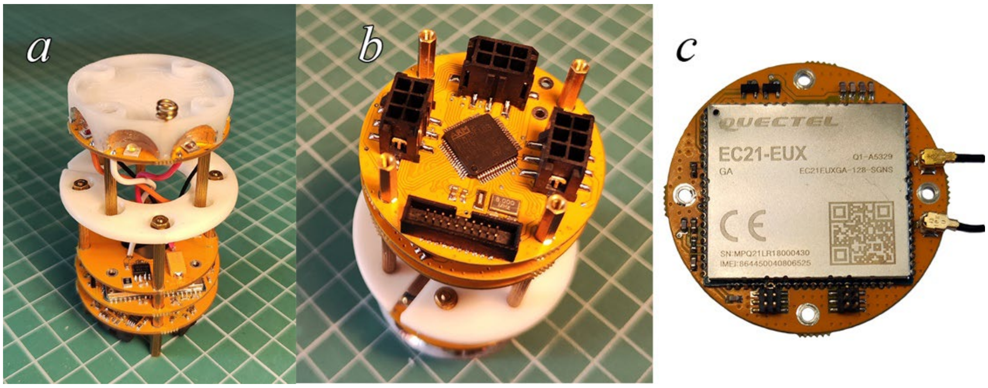


F i g. 4. Main processor module (MPM) assembly and printed circuit boards (PCBs): *a* – interface PCB; *b* – processor PCB, *c* – power PCB, *d* – MPM assembly

A valuable feature of the MPM is the capability for flexible power management of peripheral devices. Each energy consumer in the system can be independently switched on or off. This allows for effective management of power consumption, making it possible to create optimal configurations for various modes. For instance, when the instrument is at depth, the use of wireless communication systems is impossible, so they are completely de-energized. Other power consumers, even low-power ones, can also be disconnected if necessary. Owing to this, a sleep mode is implemented, wherein the current consumed by the equipment drops to less than 2 mA.

Communication and navigation module. This small-sized electronic module plays a crucial role in the operation of the profiling probe. Its primary function is long-range communication for transmitting data obtained during the instrument's operation and receiving control commands from a remote operator. The capability for regular data transmission allows the obtained measurements and telemetry to be reviewed in quasi-real time, while two-way communication enables control of the vehicle's behavior in near-real-time operation, including, when necessary, modification of the parameters of the automatic operation program embedded in the probe.

The module is equipped with its own STM32F103RETx microcontroller, that has enough resources to operate the Quectel-EC21 GSM/LTE modem and manage other peripheral devices efficiently (Fig. 5).



F i g. 5. Communication and navigation module (CNM) electronics: *a* – module assembly; *b* – processor PCB; *c* – modem PCB

In addition to communication systems, the module contains a conductivity sensor, which allows determination of the moment when the antennas rise above the water surface during ascent. The module is also equipped with a GNSS receiver, thanks to which the geographical coordinates of the vehicle in its surface position can be determined. This information is transmitted as part of the telemetry and is used for automatic notification if the distance from the deployment point to the current location of the vehicle exceeds a specified threshold value.

To facilitate visual search during recovery operations, the module has a built-in LED flashing beacon with white and red emitters, located in the upper part of the module under a transparent protective cap.

Structure of the Winchi profiler control system

The development of an effective control system for the Winchi profiler included four basic blocks, which were determined by the instrument's purpose, and their content was modified based on the results of field tests. We consider them the four foundations of the control system:
– kernel architecture;
– behavior;
– communication;
– user interfaces.

Kernel architecture refers to the structure of the embedded software that is executed by the microprocessors of the control electronics set and fully determines the vehicle's behavior in automatic mode.

The vehicle behavior refers to the set of action algorithms that it performs to achieve the goals of each phase of the working cycle.

Communication includes the definition of the data transmission protocol and a set of server software that provides functions for data reception, storage, and access to the obtained data, as well as the generation and transmission of remote control commands.

User interfaces are the application software for user devices, such as a PC or smartphone, used for maintenance, diagnostics, and programming of the vehicle before deployment, as well as for monitoring the progress of automatic operation and remote control.

Architecture of the control system kernel. Building a reliable and robust architecture of the control system kernel is a key development stage. It was planned from the outset to create on its basis various profiling probes differing in design, principles of movement, and logic of behavior. Our decision was to create a universal embedded software that reduces the cost of adapting to a specific vehicle type. Such an architecture has a two-level structure. The lower level is formed by software functional modules, each of which solves its own limited task and is either very loosely coupled to other modules or has no such connections at all. At the upper level is the Main Logic Module (MLM), which coordinates the operation of the functional modules and contains logic and functionality specific to a particular type of product.

The set of functional modules is universal, i.e., suitable for supporting the operation of any profiling probe that can be built on the basis of this control system kernel. It includes the following modules:

– configuration module;
– state module;
– motion module;
– logging module;
– schedule module;
– communication module;
– external sensors module;
– power management module.

Let us briefly consider the purpose of each module.

Configuration module – provides storage of configuration parameters in non-volatile memory, updates their values, and grants access to them.

State module – carries out regular polling of a set of built-in sensors, such as the current-consumption and battery-voltage sensors, external pressure, vehicle orientation, and others. The module converts measured values into units convenient for operation, filters and smooths the data, provides access to the results, and forms data packets for a comprehensive description of the vehicle's state for the log file and for transmission to the user application.

Motion module – ensures operation of the motors and control of the vehicle's movement in space. For a profiling probe, this is primarily movement in the vertical plane. Therefore, the basic function of the module is the execution of command "go to a specified depth." The module determines which motors should be engaged and in what mode. Then it determines the moment when the movement should be stopped.

Logging module – covers the entire spectrum of operations with the built-in data storage: from opening a file and writing or reading data to formatting the storage medium.

Schedule module – serves as a scheduler that determines the sequence of phases and sub-phases of the working cycle and the frequency of cycle execution.

Communication module – includes all communication operations both in the near field and at long range, the definition of data transmission protocols, validation of control commands, and their transfer to the upper level of the system, namely to the MLM, for execution. The embedded software of the Communication and Navigation Module is also defined within the framework of the external communications module.

External sensors module – contains a set of drivers for external measuring instruments and their configuration. The main tasks of the module are power-on, initialization, data acquisition and transfer to the logging module, as well as power-off and de-energizing of the measuring instruments upon completion of a measurement session.

Power management module – allows peripheral devices to be powered on and off upon request.

All embedded software of the control system kernel is written in the C++ programming language. This object-oriented language provides mechanisms for extending and modifying the functionality of the control system kernel; therefore, adapting the embedded software to the design features and behavioral logic of the vehicle under development does not entail the need to rewrite significant volumes of program code. In fact, the kernel represents a so-called framework, in which low-level operations common to the platform are hidden from the developer by a software interface layer.

The described structure of software modules has proven to be successful and has not undergone substantial changes over the entire duration of the project development.

Motion control. The functioning of an automatic profiling probe implies safe, trouble-free underwater movement in a fully automatic mode. For this purpose, the control system must monitor the current position of the vehicle in space, the state of the winch electric drive, the length of cable on the winch drum, and also take into account the wave height at the sea surface. The control system analyzes the corresponding data and makes decisions on the actions necessary to achieve the goal of the current phase of the working cycle, using the algorithms embedded within it. Composing and debugging such algorithms is a critical task. The experience of developing the profiling probe has shown that for functional stability, information on parameters influencing the vehicle's movement, provided by specialized sensors of various subsystems, primarily the winch and its electric drive, is critically important. Two critical points in the operational cycle can be distinguished at which the likelihood of an emergency event or contingency resulting in the cessation of automatic functioning is highest. These are the points where the control system must make a decision to stop, i.e., the moments of reaching the water surface during ascent and the parking position during diving. On the water surface, the critically important parameter is the cable tension. If it slackens or disappears entirely, the force that pulls the free cable out of the winch drum also disappears. Continuing to unwind in this case inevitably leads to the formation of loops on the cable and subsequently to cable override on the drum. After this, the cable will begin to wind onto the drum, despite the motor rotating in the unwinding direction. At the initial stage of sea trials, failures of this kind occurred most frequently. This happened due to incorrect detection of the water-air boundary based on the readings of a special conductivity sensor when the vehicle reached the sea surface. To ensure that the water-air boundary is determined reliably under dynamically changing conditions, an adaptive algorithm for assessing the conductivity of the medium was developed, which uses data from the external pressure sensor built into the instrument to determine the “in-water” state when the instrument is submerged to a depth of 2.5–5 m. The conductivity measured in this position is taken as the reference, and the transition to the “in-air” state is assessed relative to this value.

For trouble-free operation under conditions of slackening of the winch cable, a tension sensor was developed. It consists of a swinging, spring-loaded lever with a roller for the cable, a magnet, and a Hall effect sensor. When the cable tension decreases, the spring moves the lever with the magnet away from the sensor, and the control system stops the rotation of the winch drum electric drive.

The second critical point of the working cycle is the stop in the parking position. During the first tests of the vehicle prototypes, this decision was made based on the readings of the winch drum revolution counter. Considering the fact that the specified cable stretch coefficient is 1%, counting the number of revolutions should provide a good estimate of the length of the unwound cable. However, in practice, it turned out that, firstly, due to different tension under conditions of varying current, the density of the cable winding on the drum could differ significantly, leading to a different number of revolutions when the cable is fully wound. Secondly, the measurement error of the unwound cable length accumulated over a large number of winch drum revolutions. As a result, during automatic operation, the vehicle most often did not reach the point of maximum achievable depth, which reduced the working range of the profiling probe.

To solve the problem of stopping in the parking position, a magnetic end-of-cable sensor was created and integrated into the Winchi design. It consists of a polyurethane-potted magnet in a plastic housing, which is attached to the very end of the cable, and a Hall effect sensor located at the end of the cable guide tube under the vehicle housing. When the end of the cable is reached, the magnet approaches the sensor, and the control system receives a signal upon which it immediately stops winding. The use of the end-of-cable sensor made it possible to skip stopping upon the revolution counter reaching a preset limit value and to ensure descent to the maximum possible depth in every cycle.

Data transmission. The issue of selecting a communication channel for data exchange with a surfaced profiling probe will most likely lose its current relevance in the near future, and the use of satellite communication operating through terminals comparable to modern cellular-network terminals will become the most rational solution. However, at the present moment, a choice must be made between three available options: local radio communication such as LoRaWAN, the GSM/LTE network, and satellite communication, for example, Iridium or Gonets. To make a justified choice, it is necessary to briefly review the features of the data transmitted by the Winchi profiler. A typical profile measured by the probe contains about 100 Kb of data. Log files and telemetry are added to these data. As a result, the total volume of data that the vehicle can transmit in each cycle amounts to approximately 500 Kb. To save energy and traffic, compression is applied, resulting in a complete data packet containing about 300 Kb. This is a large volume for transmission from an automatic device. Existing solutions for satellite communication, such as Iridium SBD, are designed for infrequent transmission of messages with a maximum length of up to 300 bytes, and the cost of such communication is high. Although the LoRa-type radio channel is attractive for its reliability, the achievable transmission speed is also quite low, about 200–300 bytes/s. Moreover, a local radio channel implies the need to deploy infrastructure at the work site for receiving messages from the probe such as a mast with an antenna, a receiver, a server, and an uninterruptible power supply system. Data transmission over the GSM/LTE cellular network, even in the relatively slow 3G mode, can be carried out at a speed on the order of 10 Kb/s, the cost of traffic is low, and the network of one operator or another is available almost everywhere where people permanently reside.

At this stage, cellular communication was chosen for data transmission from Winchi, and this determined the components of the data transmission subsystem hardware. Its basis was the Quectel-EC21 modem, which has a built-in TCP/IP protocol stack and rich functionality for communication with remote devices over the Internet. This significantly facilitates the task of using the modem under the control of microcontrollers, the resources of which are quite limited compared to conventional personal computers. The most valuable feature of this modem for our tasks was the presence of the so-called transparent data-transmission mode. This mode is activated after establishing a connection with a remote server, and the modem sends to the server the entire data stream arriving from the microcontroller of the communication module. All data received in response from the server is, conversely, transmitted to the microcontroller without any processing. In this way, it is possible to maximize the throughput, although there is a limitation on the speed of the serial port through which the modem is connected. Additionally, the Quectel-EC21 has a built-in GNSS signal receiver, which is used for tracking the location of the vehicle.

The next issue that had to be resolved when creating the data transmission subsystem for Winchi was the selection of means to ensure uninterrupted, 24/7 reception of messages from a multitude of these probes. A suitable solution proved to be a virtual dedicated server operating in a commercial data center. At low cost, over the entire period of testing with data transmission, such a virtual machine demonstrated excellent reliability, never once being the cause of failures. Nevertheless, due to increasing requirements for the volume of stored data, the launch of a separate physical dedicated server at the IO RAS server facility is planned. The server operates under Linux OS.

The most complex problem solved within the framework of the data transmission subsystem of the Winchi device was the development of a specialized application-layer protocol (according to the OSI model [7]) that ensures efficient operation under unstable communication channel conditions. The use of cellular communication in marine conditions on an autonomous underwater vehicle that does not possess a high mast for antenna placement but operates effectively from the water surface differs significantly from conventional use in urban environments. A typical situation in this case is temporary antenna submergence by a wave, as a result of which communication is disrupted. Sometimes, if the base station of the cellular network is located far away, even rain or fog can significantly degrade communication quality. Therefore, it is important to transmit data in such a way that constant connection interruptions do not lead to the necessity of repeating the transmission from the beginning. Furthermore, since the modem uses its own built-in TCP/IP protocol stack, the external control system does not have the ability to control the processes occurring at the transport layer. For this reason, it is not possible to use the delivery-control mechanism built into the TCP transport protocol. This means that sending data to the modem does not guarantee delivery of this data to the server, and therefore, a separate mechanism for confirming the delivery of each sent packet is needed.

Based on these considerations, a data transmission protocol named WPro was developed, in which all files sent by the probe are divided into fragments. Each fragment contains a header with metadata uniquely identifying which portion of which file this fragment belongs to. In this way, the server gains the ability to assemble incoming files piece by piece and track which fragments are still missing. Upon receiving a fragment, the server sends an acknowledgment to the device, and the device, in turn, proceeds to transmit the next fragment only after receiving confirmation from the server. Under normal communication conditions, this protocol creates a minimal additional load on the channel capacity, but under conditions of an unstable connection, it allows retransmissions to be minimized while guaranteeing complete data delivery.

F i g. 6. Screenshot of the Winchi Operator Application

Another feature of the protocol is the use of an observation made during tests: if the device is able to establish a connection with the server, in most cases, it manages to transmit about 2–3 Kb of data before the connection is interrupted. Accordingly, immediately upon establishing a connection, Winchi transmits the most essential information: telemetry data and low-resolution measurement results. If the connection is interrupted after this, the remaining data are placed in a queue and transmitted when more favorable conditions arise.

Transmission of control commands to the probe works in a similar manner: the server repeats sending the command until it receives an acknowledgment from the device. This guarantees that each command will be delivered.

The necessity of using a specialized protocol determined the composition of the server software. The main component is a network service written in C++ that accepts incoming connections, performs authentication of the connected device, and interacts with it according to the WPro protocol. Special utilities have been created for unpacking and converting the received files, as well as for generating commands.

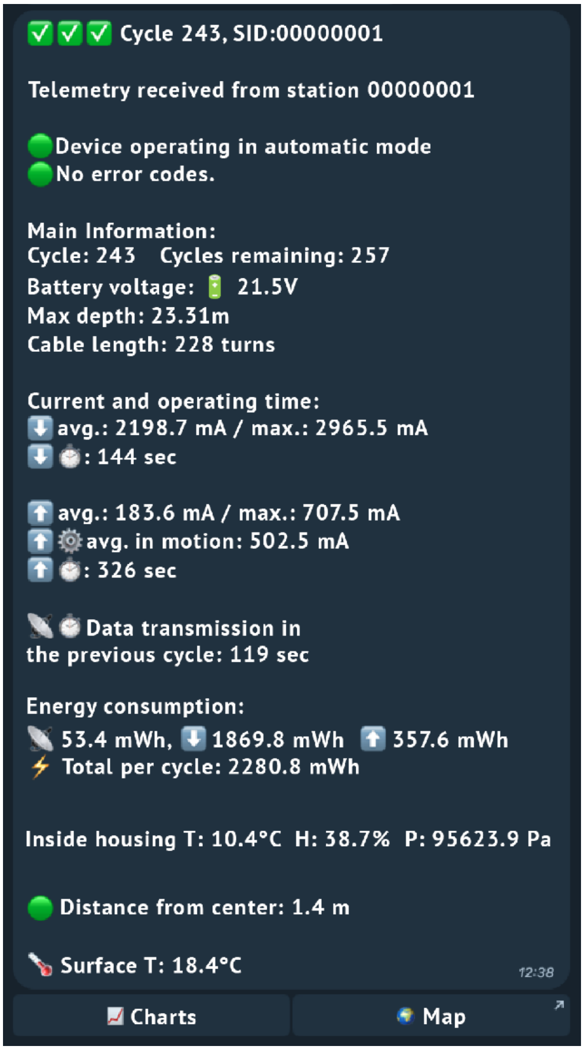
User interfaces. User interaction with the profiling probe occurs both in maintenance mode and during automatic operation. Different software tools are required for this purpose.

Software has been developed for diagnostics, test execution, and servicing of the instrument, as well as for programming the automatic operation mode – the operator application. This is a Java application for a personal computer with a graphical user interface. The Java language allows the application to be cross-platform and to run without recompilation on all the most common operating systems: Windows, Linux, and MacOS.

The main screen of the application contains indicators for displaying the status of all subsystems of the probe (Fig. 6).

The second software tool serves for interaction with the instrument during automatic operation. During the development of the Winchi profiler, this tool evolved from a specialized website into a so-called Telegram bot. It turned out that the service provided by the Telegram messenger is well suited for operational notification of events, such as communication sessions with the instrument after it has surfaced (Fig. 7).

Formatting and emoji icons can be used in messages delivered by the bot program, facilitating the perception of telemetry information. In addition to telemetry, the Winchi bot can generate images of graphs with incoming low-resolution data. This is sufficient for operational monitoring of the instrument's operation, but a feedback function is also available. Users included in the list of system administrators can issue control commands for the probe directly within the Telegram messenger interface. The bot program is written in Python and runs on the same server that receives incoming data from the device.



F i g. 7. Screenshot of Telegram bot displaying the Winchi telemetry report

For comprehensive access to operationally acquired data – including detailed log files and full-resolution measurement outputs – the system employs an SFTP service featuring strong authentication and encryption. Data are downloaded to the researcher's personal computer, where they are processed with convenient tools, such as MATLAB or Octave. Decoded files are stored in CSV format, which makes their processing possible in virtually any data-analysis environment.

Testing of the Winchi profiler control system

During the development of the Winchi profiler, starting from 2017, several prototypes of the device were created from scratch. The main driving force behind the development was field testing. Each new prototype was first tested in freshwater bodies, such as Lake Glubokoe at the biological station of the A.N. Severtsov Institute of Ecology and Evolution of the Russian Academy of Sciences [5].

The conditions of the lake, which were as close as possible to those in a pool but still allowed the instrument to be deployed at a depth of about 30 m, provided an opportunity to test various ideas and solutions pertaining to both the design and the control system.

Sea trials were conducted during the annual Black Sea expeditions of IO RAS on the shelf in two areas – near Gelendzhik Bay and near Cape Utrish [3]. As a result, through the efforts of a small development team, a fully functional Winchi profiler and a basic hardware-software platform of the control system were created.

Since 2024, the Winchi profiling probe has been successfully operating in Vityaz Bay in the Sea of Japan at the Cape Shults Marine Experimental Station of the V.I. Il'ichev Pacific Oceanological Institute of the Far Eastern Branch of the Russian Academy of Sciences [4].

Conclusion

An original underwater system for moored monitoring on the continental shelf has been created at IO RAS, and it is beginning to be applied to operational oceanography tasks.

The control system ensures reliable automatic operation of the vehicle and provides convenient software tools for the full spectrum of operations associated with it: diagnostics, maintenance, mission-execution monitoring, remote control, as well as near-real-time work with measurement results.

The operational experience gained with the instrument defines the direction of further development of the control system, primarily in terms of improving user interfaces, expanding device control commands, and supporting new external measuring sensors. Immediate plans include developing a mobile application for smartphones and tablets and expanding the Telegram bot functionality.

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All authors conceived, planned, and performed testing of the Winchi profiler, and discussed the results.

The authors have read and approved the final manuscript.
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