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A Wireless Sensor Network and Communication System of an Autonomous Unmanned Vessel

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ABSTRACT

Studying the bottom of lakes using hydroacoustic methods allows to obtain valuable information about the evolution of organisms, geological structures, make bathymetric maps, and also search for various objects. However, research near the shore or in shallow water is difficult due to the fact that the research vessel must be small. One of the modern approaches is the use of robotic unmanned vessels. In such devices, the most important element is the communication system, which completely determines their functionality and flexibility. The aim of the work is to design a communication system of an unmanned vessel based on the use of modern wireless networks protocols and IoT technologies. The main systems and sensors are described in details. The use of NodeMCU microcontrollers with ESP8266 Wi-Fi modules allowed to integrate all sensors with various protocols into a flexible wireless network. A local server based on Raspberry Pi mini PC implemented quick data acquisition via MQTT protocol. The vessel is also equipped with LoRa UHF transmitter for transition of main systems' parameters to an operator's post if it is located farther than 2 km form the research area. Work of the robotic vessel was tested during an expedition to Lake Baikal. The paper demonstrates results of bathymetric measurements of the nearshore area nearby Baikal Gigaton Volume Detector. The field testing showed stability of automatic movement along the specified route. The minimal detected depth has been about 1 m, which makes the autonomous vessel a unique instrument for measurements including shallow water.

1. Introduction.

Modern wireless networks allow to crate multifunctional, multi-module high-speed systems for various purposes. For instance, a sensor equipped with a Wi-Fi module significantly extends functionality of complicated devices making it more reliable, efficient and inexpensive. A communication system for data exchanges between lots of sensors is highly required for different autonomous robotic devices (Caccia et al., 2007). Unmanned vessels can be related to a group of such complex apparatuses that demand increased data exchange reliability.

The major application of unmanned vessels is found in scientific activities for studying bottom relief of lakes, seas and oceans. In the department of information-measuring systems of INRTU underwater studies of the bottom sediment stratification, hydrophysical and hydrochemical properties of the aquatic environment of the Baikal (Gubin, Grigorev, Poletaev & Chensky, 2021) and other freshwater lakes are carried out. From this purpose, an unmanned vessel is a unified platform that is capable to carry any hydroacoustic instrument like side-scanning sonar, echosounder, profilograph, underwater vehicles. All these features allow to use it as a whole autonomous mobile research laboratory that can be applied for studying of even shallow reservoirs.

Working on the water has a number of difficulties that are involved with extra high humidity, varying widely air temperature, large wind loads and rolling of the vessel. For operating in such conditions modern hardware and control techniques are required. The most important for a robotic platform is the main systems monitoring and guidance control.

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Lots of sensors are located throughout the vessel. In the diagnostic system they help to organize continuous monitoring of the vessel's state and allow to detect faults and potentially inoperative modules in proper time. Sensors of the power supply system are placed inside different hulls and check current consumption and batteries charge. The meteorological data acquisition system is located at a height of more than 4 meters, while the navigation system is installed in the center of mass of the vessel.

All these systems must exchange data with each other and transmit them to the operator's control post. Moreover, in order to improve reliability some sensors should be reserved which means using additional switches. Connecting with wires seriously complicates the design and does not provide an opportunity for further adding or replacement of modules with other ones. Thus, the main goal is to make a communication system based on wireless sensor networks. The use of modern Internet of things (IoT) concept is the best choice here.

2. Materials and methods.

2.1. Main systems and sensors.

All sensors and systems can be divided into several functional groups: inner components diagnostics, meteorological and environment monitoring, navigation and positioning, machine vision and obstacles detection (Chensky et al, 2021).

Meteorological sensors include ds18b20 temperature modules with 1-wire digital protocol, SHT10 humidity sensors with I2C digital protocol, anemometer with analog output, a weather vane with analog output, pyrometer MLX90614ESF with I2C bus, an accelerometer and gyroscope for pitching and rolling checking. There are also I2C methane, carbon, oxygen, hydrogen gas sensors. Besides that, the vessel is equipped with a complex sensor SMP37ODO for the basic water environment parameters measurements like conductivity, temperature, pressure, oxygen saturation. This device interacts via a serial port.

Diagnostic sensors monitor operational parameters of all systems of the vessel. For instance, in the power supply system it is necessary to measure the operating voltages and currents in order to calculate the residual capacity of the batteries. ACS758 current sensors are installed on batteries and work continuously using an analog protocol even when other equipment is turned off. Additional sensors are installed on the charge controller that operates charging with solar panels. Batteries and motors' voltages are measured with 12-bit analogue-to-digital converters (ADC). Though each controller checks local temperature and humidity using DHT 10 modules, there are several ultra sound sensors for leakage detection in the hull. Movers' rotational velocity is checked with Hall sensors.

Navigation sensors include global navigation satellite system (GNSS) modules U-blox C099-F9P-103, inertial sensors Xsens MTi-1 IMU for measuring vessel's lurch, trim and course. In addition, there are Wi-Fi video cameras providing it with machine vision, radio locators, acoustic and optic rangefinders in the obstacle detection system.

2.2. Network configuration.

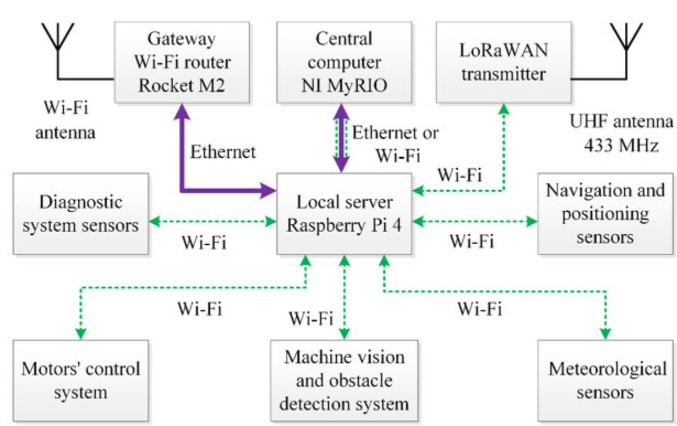
The most optimal way for providing with interaction over wireless communication protocols is the connection of all electronic devices to a Wi-Fi network. For this purpose, all sensors which do not have own Wi-Fi interface are connected to a microcontroller. At the same times the microcontroller must implement communication with the use of various protocols like MQTT, LoRaWAN, and digital (I2C, SPI, RS232) or analog interfaces. It is rational to use here ESP32 or NodeMCU Lua V3 with ESP8266 Wi-Fi modules. The combination of the ESP microcontroller and sensors forms a transceiver module.

The inner communication in the vessel is based on the use of Raspberry Pi 4 single board computer which works as a local MQTT server and the wireless access point device airCube. The MQTT protocol transmits short messages and does not load the network, stable in the harsh environment conditions and therefore it is ideal for IoT systems and fully suitable for autonomous robotic devices. The Fig. 1 shows the network structure.

Microcontrollers fetch the readings of the systems' sensors and publish them on the MQTT server. The data can be processed directly on Raspberry Pi 4 or this function is implemented with NI MyRio single board computer. In addition, the vessel system data can be transmitted to a remote control and observation post. An operator's computer is also on this subnet via Wi-Fi connection and can receive data from the MQTT server as a client.

If the vessel works at a distance of no more than 2 km, then the operator is connected to the network via a 2.4 GHz Wi-Fi bridge with the use of Rocket M2 router and AirMax Omni 2G13 antennas providing with 13 dBi gain. In the case of working at a greater distance, data transmission to the control post is implemented using the LoRaWAN protocol at 433 MHz frequency. The network operates in an unlicensed frequency band, has a high communication range and low power consumption (Tselishchev & Kopisov, 2019).

Figure 1: Architecture of a network of wireless sensors and systems.



Source: Authors.

The LoRA transmitter is connected to the ESP microcontroller which reads all topics on the MQTT server, filters data through the threshold values, writes to the flash card and sends it to the operator. If a sensor value is out of the specified by the threshold range a failure signal is sent to the operator and its parameters are not taken into account. In case of the use of research instruments like, for instance, echosounder, this is insufficient and it is necessary to periodically review the instrument's sampling data. For this purpose, a short-time data example is periodically recorded, compressed and transmitted to the operator for check of settings correctness.

The control post LoRa receiver reads and receives the data, checks for errors by the parity bits and transmits it to the operator's computer via the UART protocol. The operator's client software is implemented with LabVIEW programming media. The software allows to view the current data from each sensor and plot graphs. This system can be quickly reconfigured and allows any device to work with any data. For example, data from inertial sensors is needed not only for movement, but also for an echo sounder and sonar.

3. Results.

The communication system of the unmanned vessel has been checked in laboratory conditions, as well as during research work on the study of the bottom surface relief in the area of the southern basin of Lake Baikal. The research area is located near Baikal Gigaton Volume Detector (Baikal-GVD) (Antipin et al., 2007). The object of interest is coastal bottom slope (104.413414 N, 51.797119 E). The device was equipped with a single-beam echo sounder of our own design. The echo sounder operated with chirp signals at a frequency of 50-60 kHz.

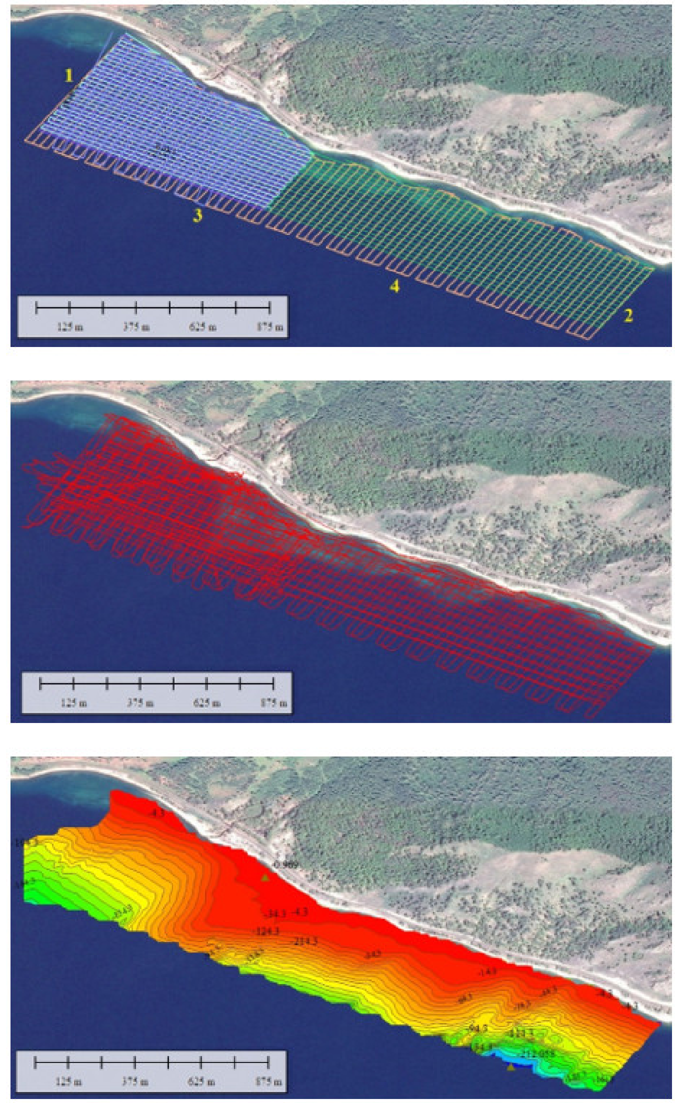
The expedition lasted 7 days. The Fig. 2 shows the results of testing. The vessel followed the specified route in the daytime and it moored the shore to charge the battery at night. First, the device followed the tacks which are parallel to the coast (Fig. 2a, tracks 1 and 2), then perpendicularly to it (tracks 3 and 4). The path deviation errors were varying from 2 to 10 meters (see Fig. 2b). They were caused by a set of factors like choppy wind and rough water, non-ideal motors' control, GPS and other sensors' errors.

As a result, the vessel followed 91 linear kilometers and covered the survey area of 0.54 km^2. The Fig. 2c demonstrates a bathymetric map reconstructed with the echo sounder data. As it can be seen, the costal bottom slope is gentle. The depths vary from 0.97 to 212 meters.

4. Discussion.

The results obtained during the expedition are in good agreement with the general patterns of the bottom topography near the Baikal Gigaton Volume Detector (Safronov, 2021). The use of a light and small vessel made it possible to perform measurements in close proximity to the shore at depths of about 1 m. The information-measuring system developed on the basis of wireless sensor network technology has shown its full functionality. Course deviation due to various destabilizing factors did not affect the results of constructing a bathymetric map due to multiple measurements at the study area.

Figure 2: Field testing of the autonomous unmanned vessel designed in INRTU: a - designated route, b - actual track, c - measured bathymetric map.



Source: Authors.

Conclusions.

Integrating modern IoS technologies into an autonomous vessel allowed getting a flexible system's architecture. The use of local MQTT server makes it possible to reconfigure quickly the vessel systems. The designed wireless network of distributed sensors has shown its operability. The field testing demonstrated stability of movement along the specified route. In the future, it is planned to equip the vessel with additional hydroacoustic instruments to carry out complex measurements.

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