Audio recording system for underwater monitoring with fast notification for detected sound anomaly

Nikolai Georgiev[1], Aleksandar Kolarov[1], Ilian Iliev[2]
[1] Bulgarian Academy of Sciences - Institute of metal science, equipment and technologies with Hidroaerodynamics centre "Acad. Angel Balevski", e-mails: niki0611@abv.bg, aleksandar_kolarov@abv.bg
[2] Naval Academy "N. Vaptsarov", Varna, Bulgaria e-mail: i.iliev@nvna.eu

Abstract: *To enforce the Republic of Bulgaria's "Maritime Spaces, Inland Waterways and Ports Act" and EC Decision 2010/477/EU is a need for an underwater monitoring system in the national maritime spaces. As an element of such a system, a prototype of a bottom-positioned modular system has been developed at IMS-BAS, designed for reading and recording and transmission of hydro physical, hydro chemical, biological and ecological data for the marine environment, sounds from biological sources and anthropogenic noises, registration and classification of a sound anomaly, a fragment of it is overwritten wirelessly in an autonomous radio beacon, which quickly floats and transmits the information to a base station on a radio channel, and then acts as a radio marker. One of the radio buoys is connected to the central airtight body by a rope wound on a spool. Its purpose is in case of technical problems or pre-programmed to float and signal on a radio channel. After lifting the station to the surface, the recorded information is taken off and maintained.*

Keywords*: SEL, SLP, underwater monitoring, anthropogenic noise, sound anomalies, radio buoy.*

1. Introduction

As a result of human activities in the marine environment, various types of fields are excited such as sound, light, electromagnetic, thermal, hydrodynamic, etc. Of all these fields, the sound field is distributed over the longest distances from the source. That is why great attention is paid to the assessment of the energy impact of sound waves on marine species. A harmful underwater sound field is one in which exposure causes temporary or permanent damage to the fauna of the marine ecosystem. In theory, when such a field is created as a result of human activity, it is referred to as harmful anthropogenic noise. Anthropogenic noise is recognized as a serious stress factor for most marine mammals, many marine fish, crustaceans and other marine organisms. The degree of noise impact depends onthe sound exposure level, which is abbreviated as .It is calculated according to the formula [1]:

$$SEL = 10 \left(\int_0^T \frac{p^2(t)}{p_o^2} dt \right) \ (\mathrm{dB/\mu Pa^2 s}), \quad (1)$$

where $p(t)$ the instantaneous value of the sound pressure in (μPa); p_o - relative pressure equal to 1 (μPa).

The degree of impact of anthropogenicyat noise on marine animals depends on its type. Two types of anthropogenic noise, pulsed (emission of pulsed sonar, explosions at seismic studies, etc.) and continuous (for example, noise from shipping, dredging and underwater power plants, etc.). To assess the impact of anthropogenic pulsed and low-frequency continuous sounds in the marine environment, as required by EC Decision 2010/477 / EC and the "Guide to the monitoring of underwater noise in European seas" under the Marine Strategy Framework Directive (RDMS) 2008/56 / EC, a "noise" register should be established, which will describe all human activities that generate pulsed and continuous noise in marine areas, which are carried out under regulated conditions and are licensed, as well as specialized research and military operations (if permissible). Noise emissions from ships will be included in the noise register. The creation of a "noise register" will help to determine the overall spatial and temporal scale of the spread of anthropogenic noise sources, as well as to establish the initial levels (baseline values) of the current state of the measured environment and trends in its change relative to these levels. The noise register will provide not only monitoring data, but also data for planning measures to reduce / prevent negative impacts on the marine environment [2,3,4].

2. Assumptions and ways to solve the problem

The planned measures in the Program of Measures to the Marine Strategy for Environmental Protection in the Sea Waters of the Republic of Bulgaria envisage the monitoring under indicator D11C1.1 in fulfillment of the requirements of the RDMS to be performed on the basis of the analysis of data and information to be collected in the national "noise" register. The register will describe all human activities that generate impulse sounds in the sea area of the Republic of Bulgaria. Data on noise emissions from different types of ships will be collected from ship manufacturers / owners or specialized information systems (eg national AIS system, etc.), as well as from measurements by underwater noise monitoring stations. Data and information on anthropogenic activities will be collected continuously throughout the year and the noise register will be periodically updated. The monitoring under indicator D11C2.1 will cover the coastal and shelf zone (up to 100 m depth), for which purpose 4 stationary autonomous hydrophone systems for underwater noise measurement will be used, located in areas of high and low intensity of navigation, and areas of Nature 2000, which cover the most probable habitats of marine animal species. Due to the small number of hydrophone systems, their location will change monthly (subject to the above conditions) to cover the whole assessment area. Measurements of the noise level in the marine environment will be performed continuously throughout the year. Seasonal measurements will also be performed with a mobile hydrophone system. In parallel with the acoustic observations, the hydrological parameters of the aquatic environment will be measured: temperature, salinity and speed of sound [14]. In addition to legally regulated activities that create anthropogenic noise in marine areas, short-term sound anomalies are possible, such as the sound of leaking gas in the event of a pipeline breach, or an uncharacteristic level of anthropogenic noise in protected or prohibited areas and water activities, noise from the use of bottom trawls for fishing, etc., which may cause significant harmful effects. Their timely registration and response to the authorities authorized by law can significantly reduce the harmful consequences.

3. Solution to the studied problem

As an element of an underwater monitoring system in the national marine areas, IMS-BAS has developed a prototype of "Audio recording system for underwater monitoring with rapid notification of detected sound anomaly" /ARSUM/, designed for recording, classification and recording of sounds from biological sources (marine mammals, fish, shrimp, etc.), anthropogenic noise - pulsed (as a result of seismic surveys, laying pylons for wind farms and platforms on the seabed, use of pulsed sonar, underwater communications, underwater explosions, etc.) or long-term (caused by shipping, dredging, leaks in underwater gas and oil pipelines, actions of power plants, acoustic signals from artificial radiation, etc.) [5,6]. The main elements of the system are shown in Fig. 1:

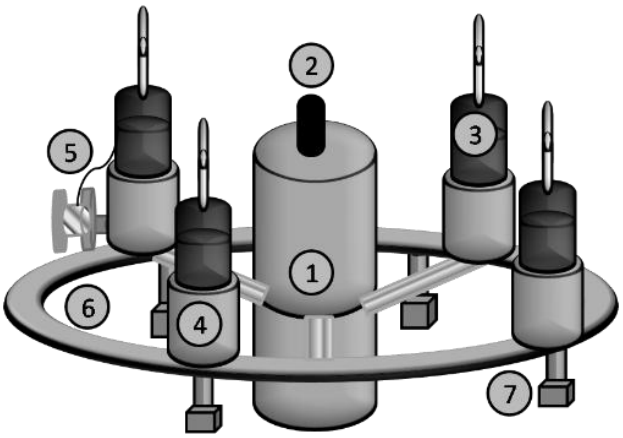

Fig.1 *Basic elements of ARSUM*

where: 1 - The central airtight body;
2 - Receiving hydrophone;
3 - Radio buoy with positive buoyancy;
4 - Socket for radio beacon with electromagnetic locks;
5 - Reel with rope attached to the emergency beacon;
6 - Hermetic ring for the cable connection between the sockets and the central body;
7 - Legs of the supporting structure for stable positioning of the bottom.

When detecting, recording and classifying a sound anomaly (eg sound of a leaking gas in the event of a pipeline breakage, noise from the use of bottom trawls for fishing or an uncharacteristic level of anthropogenic noise in protected or prohibited areas and for certain activities in the water area and etc.) a fragment of the information is recorded, with a duration sufficient for the classification of the event [7]. This fragment is transmitted wirelessly in an autonomous beacon from the device kit, where it is overwritten. Upon completion of the information transfer process, the radio beacon floats and transmits the critical information via radio to a shore, ship or air base station acting as an operations center. It is then used as a radio beacon to indicate the location of the event. One of the radio buoys is connected by a rope wound on a spool to the supporting structure. Its purpose is for technical problems related to breach of the seal, depletion of battery capacity and more. programmed to float and signal on a radio channel for the occurrence of the undesirable event in the base station. After lifting the station to the surface, the information stored in it is taken off and maintained [8].

4. Results and discussion

The main electronic modules in the composition of ARSUM perform the following functions:

• Reception and digitalization of underwater acoustic broadband signal and determination of the sea noise level;

• General detection of underwater acoustic broadband signal above the threshold level and production of control signals;

• Classification of the signal after the general detection and production of control signals;

• Recording at general detection of underwater acoustic broadband signal;

• Transmission / reception of data for a signal representing a sound anomaly after classification of the detected underwater acoustic broadband signal.

The functional diagram of the ARSUM hydroacoustic channel for detection and classification of objects according to their own noise with possibilities for recording the noises from the general detection and classification of SD cards and transmitting the file for the classified purpose by radio channel in analysis center is shown in Fig. 2.

Arduino microprocessor platform was chosen for the implementation of the channel, whose modules and software are available, while providing the minimum requirements in terms of speed and own noise [9].

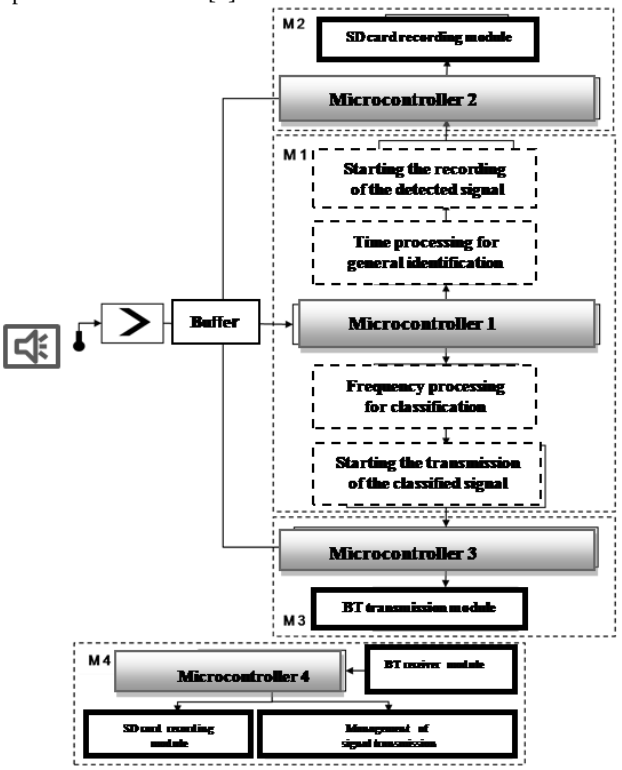

Fig.2 *The functional diagram of a prototype of the hydro acoustic channel of ARSUM*

The microcontrollers of this series operate with a frequency of up to 84 MHz, allowing the input of an analog signal with LSB up to 0.8 (mV) and a sampling rate of up to 70 kHz, which is sufficient for processing acoustic signals with a frequency spectrum up to 35 kHz. In addition to the analog inputs, the microcontrollers have a built-in analog output, programmable digital inputs/outputs and support the communication standards USB, SPI, CAN and I2C (TWI), as well as the network Ethernet standard. These characteristics of the platform allowed on its basis to realize an acoustic reception channel with cyclic signal input and processing through a built-in software DSP processor.

The diagram shows the functional connection between the individual modules of the hydroacoustic channel and the operations performed by them on the received signal. The buffer circuit is used to match the output of the amplifier with the ADC inputs of microcontrollers 1, 2 and 3, as well as to disconnect the three inputs.

The M1 module is designed to receive and process a broadband hydro acoustic signal with the ability to control external devices. It is designed to detect and classify a broadband hydro acoustic signal in the frequency band from 100 Hz to 8 kHz. The analog part of the module includes a hydrophone with a frequency band of reception in the specified range and a preamplifier with a band pass filter. The digital part of the module is realized on microcontroller 1, where after digitization of the analog hydro acoustic signal signal processing is performed in the time and frequency domains. The processing in the time domain is performed by the method of broadband detection and after fixing the moment of detection the process of recording the detected signal is started. The signal is digitized at a frequency of up to 70 kHz with a resolution of 12 bit. The detection is performed by averaging the signal strength in a crawling window and comparing the obtained values with a dynamically changing threshold [10,11]. The dynamic threshold is obtained on the basis of previous statistics of the instantaneous values of the signal power, their averaging in the window of selected length and their multiplication by a factor taking into account the level of false alarm. Detection is fixed when the signal level in the current window exceeds the dynamic threshold level.

The end of the recording is determined by the average time the target stays in the observation area of the sensor. The classification of the broadband hydroacoustic signal is performed in the frequency band from 100 Hz to 8 kHz on open discrete frequencies of special interest. To solve this problem in microcontroller 1, the signal is transformed into the frequency domain by FFT [12,13]. The signal is digitized at a frequency of up to 80 kHz with a resolution of 12 bit, and its conversion in the frequency range is performed by 256-point window FFT. The selected ADC and FFT conversion parameters allow narrowband signal processing in 156 Hz bandwidths. After fixing the presence of a certain discrete component in the broadband signal, the module starts the module for transmitting the signal via VT to the module for recording and transmission to the Analysis Center.

The module 2 is designed to record the hydroacoustic noise signal detected during broadband detection. For this purpose, a second microcontroller is used, which digitizes and records the data in audio format. The recording is started and stopped by a command from microcontroller 1. The sampling frequency for recording is 18 kHz with a resolution of 12 bit. The information for each detected signal is recorded in consecutive files.

Module 3 serves to transmit the classified hydroacoustic signal via BT. It includes a microcontroller 3, which digitizes the signal and controls the transmission of data over a built-in VT network, and a unit for transmission via VT. The VT circuit is programmed to work in "Master" mode, which ensures the construction of a VT network. The start and stop of the transmission is performed by a command from microcontroller 1 after classification. The sampling frequency of the transmitted classification signal is 18 kHz with a resolution of 12 bit.

The module 4 is designed to receive the classified signal on VT. Includes microcontroller 4, BT reception circuit operating in slave mode and SD card recording circuit. The reception and recording of the data is performed automatically after the data starts to be transmitted by the module 3. In addition to the control functions of the connection and recording circuits, the microcontroller 4 controls the floating processes and the radio transmission of the data to the analysis center.

The technical implementation of the main elements of ARSUM is shown in the following figures:

- Radio beacon (Fig 3):

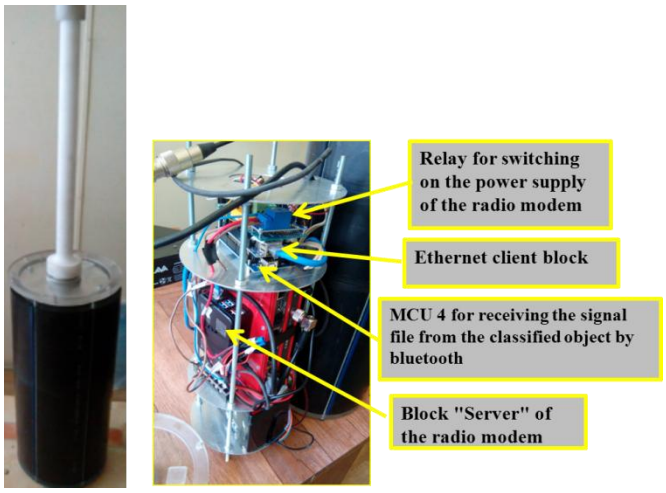

Fig. 3 *Construction of an experimental sample of a radio beacon.*

The buoy bottom made of transparent material provides an opportunity for BT communication and for activating the light relay for connecting the power to the radio modem and the server to it, MCU 4, GPS and the SD card recording scheme.

- Central airtight body (Fig 4):

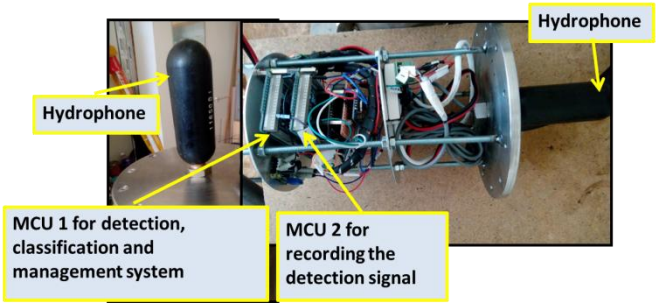

Fig. 4 *Construction of an experimental sample of the central hermetic body*

- Radio buoy socket with electromagnetic locks (Fig. 5):

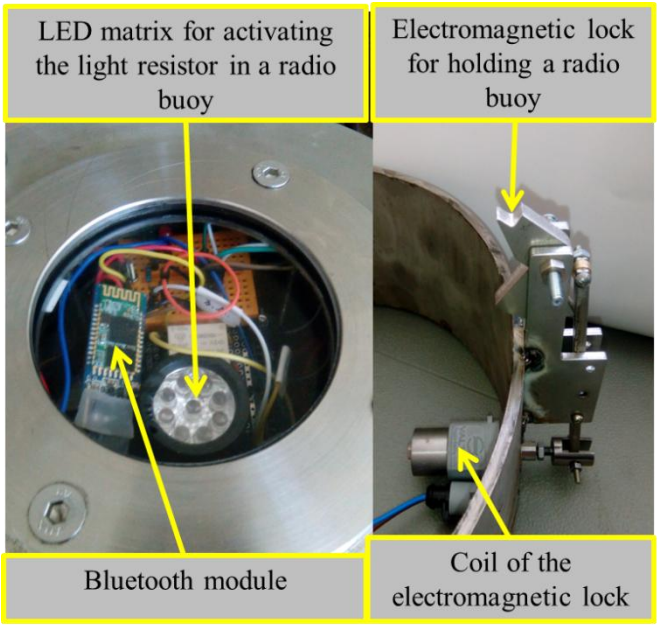

Fig. *5* *Construction of the radio beacon socket*

- General configuration of ARSUM (Fig. 6):

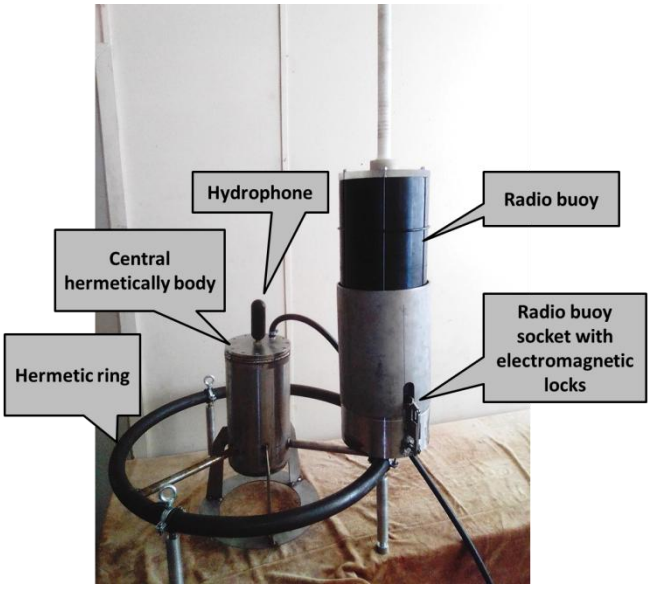

Fig. 6 *General configuration of an experimental sample of ARSUM*

In Fig. 7 and Fig. 8, the amplitude and spectrum, respectively, show the correspondence between the signal before broadcasting via Bluetooth channel (in black) and there after (in blue):

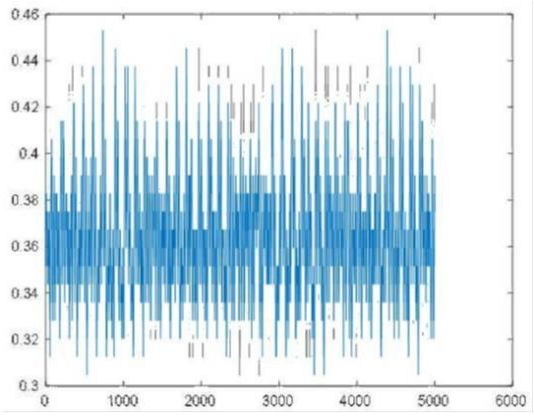

Fig. 7. *The correspondence between the amplitudes of the audio signal before and after translation*

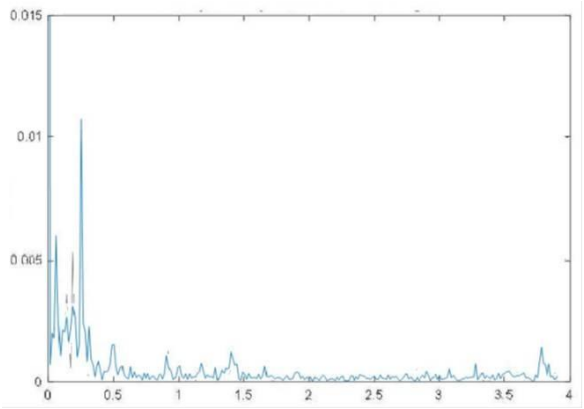

Fig. 8 *The correspondence between the spectrum of the audio signal before and after translation*

It can seen that the correspondence between the signals before and after the translation by Bluetooth channel in amplitude was 97% ÷ 98%, on the distribution of the frequency spectrum than 99%. This means that the attenuation and distortionof the signal is up to 3%, which is practically negligible.

5. Conclusion

The prototype developed at the institute is "Audio recording system for underwater monitoring with rapid notification of detected sound anomaly" /ARSUM/, provides registration, classification and recording of sounds from biological sources (marine mammals, fish, shrimp, etc.), anthropogenic noise - pulsed (as a result of seismic underwater phenomena, seismic surveys, laying of pylons for wind farms and seabed platforms, pulsed sonar or communication means, explosions, etc.) or long-term (caused by shipping, dredging, leaks in underwater gas and oil pipelines, actions of power installations, acoustic signals from artificial radiating means, etc.) of ARSUM allow the full provision of information on all human activities that generate pulsed and continuous noise in marine areas, which are carried out under regulated conditions and are licensed, as well as specialized research and military operations (if permissible), as well as noise emissions from ships for the establishment of a "noise register", in accordance with the requirements of EC Decision 2010/477 / EC and "Guidelines for monitoring underwater noise in European seas according to the RDMS". In addition, upon detection, registration and classification of sound anomaly or uncharacteristic level of anthropogenic noise in protected or prohibited for navigation and for certain activities areas of the water area, a recorded fragment of information wirelessly in an autonomous radio beacon is transmitted to the Analysis Center, which responds in an appropriate manner.

6. Acknowledgements:

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