Digital Signal Processing for Hydroacoustic System in Biomimetic Underwater Vehicle

Hidroakustični sustav procesuiranja digitalnoga signala u biomimetičkomu podvodnom vozilu

Pawel Piskur
Institute of Electrical Engineering and Automatics
Polish Naval Academy
Gdynia, Poland
e-mail: p.piskur@amw.gdynia.pl

Marek Gasiorowski
Institute of Electrical Engineering and Automatics
Polish Naval Academy
Gdynia, Poland
e-mail: m.gasiorowski@amw.gdynia.pl

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Summary

Signal processing in hydroacoustic system will be presented in this paper. The research results, depicted in this article, were achieved during realization one of the stages of the project for the development of an biomimetic underwater vehicle (BUV). The hydroacoustic system is installed inside Biomimetic Underwater Vehicle no. 2 (BUV2) and is designed for passive obstacle detection system. The passive measurement system was based on two hydrophones mounted on the upper part of the BUV2. The results of the hydroacoustic module testing were made in a real environment. The signals from the hydrophones were converted from analog to digital form and then filtered and analyzed by using algorithms implemented in the Texas Instruments C2000 series microcontroller.

KEY WORDS

digital signal processing,
hydrophone
passive detection of obstacles
Biomimetic Underwater Vehicle

Sažetak

U ovome će se članku prikazati procesuiranje hidroakustičnoga signala. Rezultati istraživanja opisani u ovome članku postignuti su tijekom realizacije jedne od faza projekta za razvoj biomimetičkoga podvodnoga vozila (BUV). Hidroakustički sustav instalira se unutar biomimetičkoga podvodnoga vozila broj 2 (BUV2) i predviđen je za sustav detekcije pasivne prepreke. Sustav pasivne izmjene temeljen je na dva hidrofona postavljena na gornji dio BUV". Rezultati hidroakustičnog modula testiranja napravljeni su u stvarnom okruženju. Signali s hidrofona konvertirani su iz analognoga u digitalni format i potom filtrirani i analizirani korištenjem algoritama koji su implementirani u mikrokontrolni instrument serije Texas C2000.

KLJUČNE RIJEČI

digitalno procesuiranje
hidrofon
pasivna detekcija prepreke
biomimetičko podvodno vozilo

1. INTRODUCTION / *Uvod*

The rapid development of unmanned and autonomous vehicles has been observed during recent years. Among many types of unmanned vehicle there is a group that operates in the underwater environment. Many scientific teams realize various approaches for imitation of underwater living organisms. Some of the results, after more than ten years of BUV [1] development in the Polish Naval Academy, are presented in the papers [2][8][16]. The first BUVs were driven by undulating propulsion consisting of two side fins and one tail fin. In the BUV2 the one tail fin was replaced by two tail fins simulating the seal movement. The propulsion system is supported by a ballast tank for changing buoyancy. In the BUV as well as in the BUV2, there is a wide variety of sensors implemented for communication [7], navigation, investigation [6] or exploration purposes [12].

The BUV2 was built within European Defense Agency project category B called SABUVIS. The project of the BUV is carried out by a consortium consisting of nine scientific and industrial partners with Polish Naval Academy AMW as the leader.

Here, the part of the system designed for obstacles detection system was developed [11]. The passive detection of obstacles [13] is carried out using two hydrophones (marked as red cycles in Figure 1 and the microcontroller unit (Figure 2) placed inside BUV2.

Analog to digital conversion (ADC) is a critical element in hydroacoustic systems where high sampling frequency of signals is required. The speed of sound in water is four times higher than in the air, that is why the signal sampling frequency must be high enough. What is more, adequate space of memory is needed for gathering the desired time series of measured signals. That is why, the memory space in the microcontroller unit (MCU) is an additional restriction which has to be taken under consideration when choosing the appropriate device.

The microcontrollers (MCUs) needed for algorithm verification can be programmed using C, C++, and/or assembly language. Moreover, integrated development environment Code Composer Studio can be used for convenient work on the MCUs [3]. However, during this research the more convenient technique was chosen. Matlab-Simulink with toolbox Embedded Coded Support Package for Texas Instruments C2000 processors and Digital Signal Processing for filter design and signal filtration were adopted. The embedded code

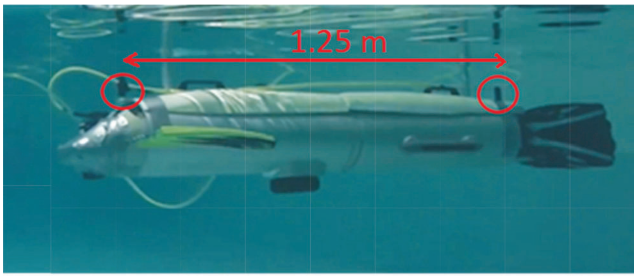

Figure 1 The BUV2 picture made under water surface
Slika 1. Fotografija BUV2 ispod vodene površine

procedure from Matlab toolboxes to the microcontroller unit allows us to use block libraries for on-board peripherals such as ADC, automated build and execution code, real-time parameter tuning and logging using external mode and ability to perform processor-in-the-loop tests [4].

This paper is organized as follows. Section 2 describes the test stand and signal processing algorithm for passive obstacle detection. Section 3 discusses the results of measurements in real condition and the filtration process. Section 4 provides discussion on the future research. Finally, conclusions are presented in Section 5.

2. TEST STAND FOR PASSIVE OBSTACLE DETECTION / *Pokusni test detektiranja pasivne prepreke*

The HTI-96-MIN hydrophones have omnidirectional characteristics and sensitivity -165 dB re: 1 V/uPa. The hydrophones are situated in the upper part of the BUV2 with 1.25 meter distance between each other (Figure 1).

The Texas Instrument LaunchPad C2000 series with digital signal processor (DSP) TMS320F28379D was chosen as the microcontroller. The C2000 devices are 32-bit microcontrollers with high performance integrated peripherals designed for real-time control applications. The main advantages of the C2000 microcontrollers are up to 200 MHz sampling frequency in both ADC channels mutually, the memory space available to gather data vectors needed for filtration and the implementation of the moving obstacles' algorithm detection. Due to the limited space inside the BUV2, the most significant advantage of the TMS320F28379D is its dimensions. Figure 2 shows the open BUV2 with the C2000 MCU visibly mounted inside. The analog signals from the hydrophones are converted to a digital format with a 12-bit resolution. More information about the technical specifications of the MCU can be found in [3].

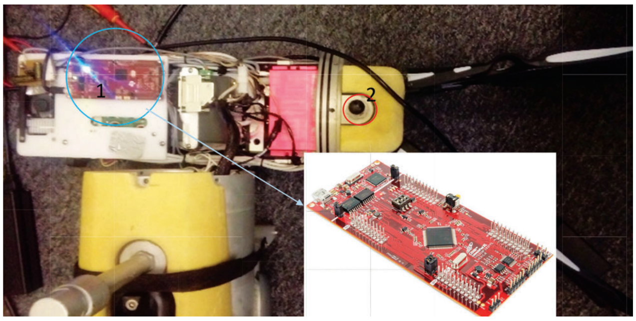

Figure 2 The interior part of the BUV2: 1- the microcontroller unit, 2 – the rear hydrophone
Slika 2. Unutarnji dio BUV2.-1- mikrokontrolna jedinica, 2 – stražnji hidrofon

The measurements were carried out in an up to six meters depth lake. There were two sources of sound: the underwater sound speaker and the propeller (Figure 3). At the beginning, the underwater sound speaker was used for verification of the measurement algorithm. The signal frequency was set to the known value and used for checking the accuracy of the test stand. After the test stand calibration process, the measurements were done with propeller as a source of sound with different angle and rotation speed.

The sampling frequency in both channels of the ADC's was set to 10 kHz. Assuming that the source of sound is along the axial symmetry of the BUV, and that the speed of sound in water is approximately equal to 1450 meters per second, an acoustic wave needs 0.86 millisecond to move the distance between the two hydrophones. The above assumption depends on the temperature of the water and will be used for future cross correlation algorithms for obstacle detection. The analysis of different methods for obstacle detection performed by the Authors is included in [10].

To compute distinct dominant frequencies, the Fast Fourier Transformation (FFT) was implemented. Then, the filter parameters were selected to distinguish the spectrum of signals needed for the detection of a moving obstacle. The whole algorithm of digital signal processing for passive detection of the moving obstacle detection system is presented in Figure 4.

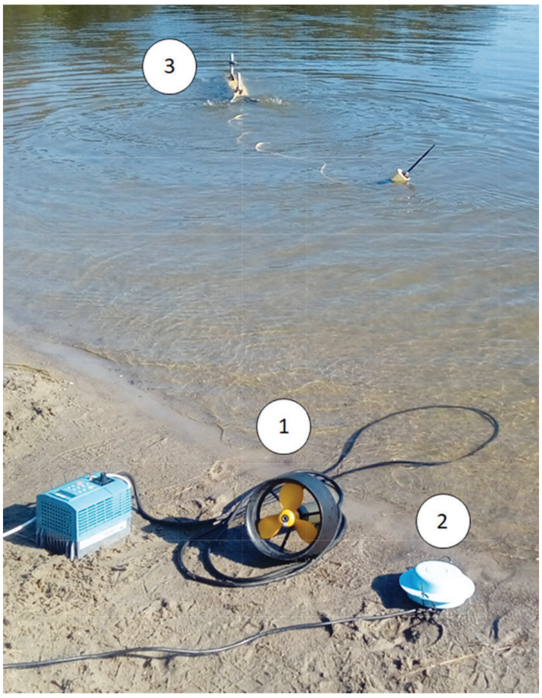

Figure 3 Test stand on the shore of the lake: 1 – propeller, 2 – underwater sound speaker, 3 – BUV2
Slika 3. Pokusni test na obali jezera: 1 – propeler, 2 – podvodni zvučnik, 3 – BUV2

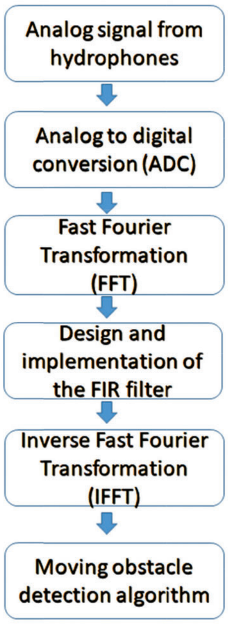

Figure 4 Signal processing algorithm for passive detection of the moving obstacle

Slika 4. Algoritam procesuiranja signala pasivne detekcije pokretne prepreke

3. RESULTS OF RESEARCH / *Rezultati istraživanja*

In Figure 5, the signals from both hydrophones are presented with the BUV2 set at different angles to the source of sound. Each signal is depicted as a function of time. The red signal (H1) is from the hydrophone situated in front of the vehicle and the green one (H2) is from the hydrophone situated on the stern of the vehicle.

Having done the measurements, a sequence of recorded data was decomposed using Fast Fourier Transformation. The Fourier series is an effective technique for handling periodic functions such as acoustic waves generated by a vessel propeller. Both signals after the FFT were presented in Figure 6. The differences between both signals, especially in the frequency range from 0 up to 1500 [Hz], are mainly caused by the different distances between the hydrophones and the side and tail fins. Signals were measured during the undulating propeller activity and this turbulences need to be suppressed for further analysis to take place. Additional noise mainly comes from the acoustic wave reflection from the lake bottom and from the upper water surface.

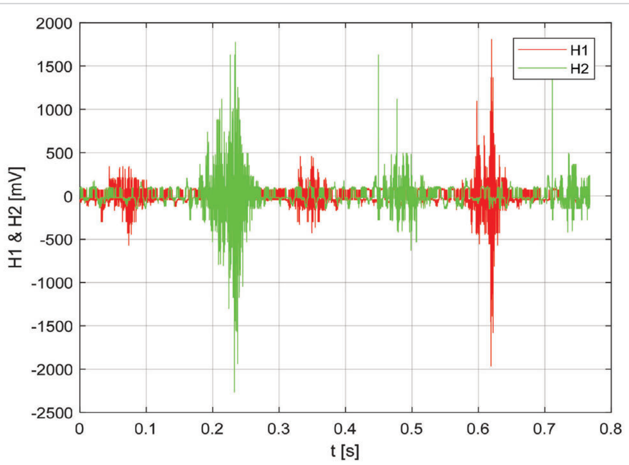

Figure 5 Two signals measured by the hydrophones as a function of time

Slika 5. Dva signala izmjerena hidrofonom kao vremenske funkcije

Due to the disturbances the dominant frequency was selected and the filter was used to correct the interference. In Figure 6, two data points are depicted with the highest absolute value of signal from each hydrophone.

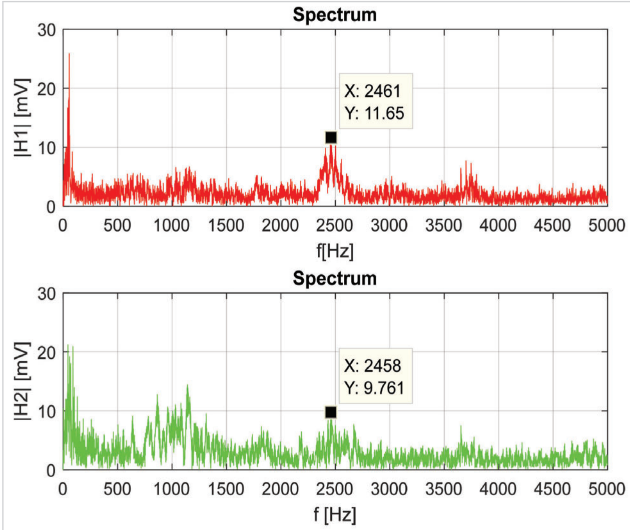

Figure 6 The spectrum of signal from the both hydrophones

Slika 6. Spektar signala za oba hidrofona

The second-order digital peaking filter was used for filtration. The peak was located at 2450 Hz, and the bandwidth was set to 500 Hz. The spectrum of the signals H1 and H2 after signal filtration was presented in Figure 7. The estimated frequency corresponds to the characteristics of a hydroacoustic wave source.

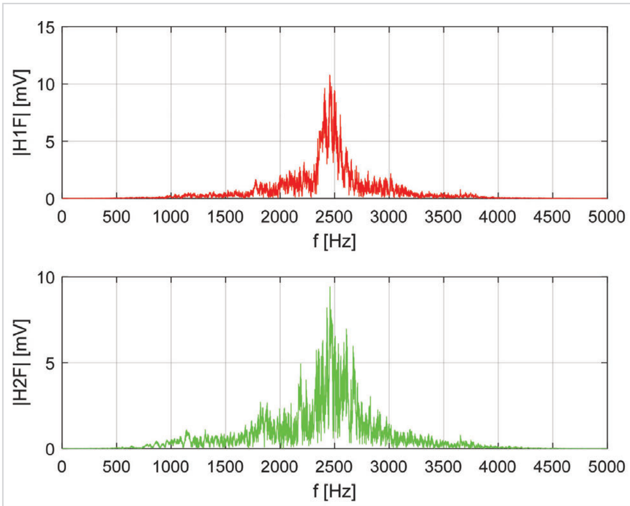

Figure 7 The spectrum of the signal from the front hydrophone (H1) and the rear hydrophone (H2) after filtering process (H1F and H2F respectively)

Slika 7. Spektar signala s prednjega hidrofona (H1) i stražnjega hidrofona (H2) nakon procesa filtriranja (H1F i H2F navedenim redoslijedom)

The signals before and after noise suppresion were compared and presented in Figure 8. The Finite Impulse Response (FIR) filter was used with moving average parameters.

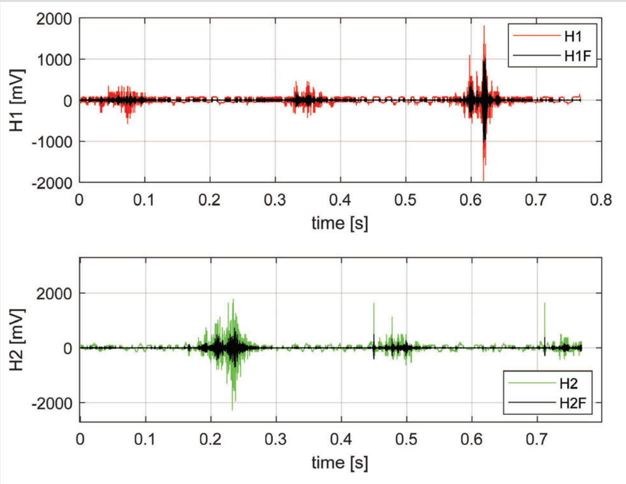

Figure 8 The example of the signals from the both hydrophones before (H1, H2) and after filtering process (H1F, H2F)
Slika 8. Primjer signala s oba hidrofona prije (H1, H2) i nakon procesa filtriranja (H1F, H2F)

The filter parameters depend on the frequency of the signal source, that is why they have to be identified and constantly updated. The filtered signal is needed for the correct determination of a bearing on the moving obstacle with cross correlation function. In Figure 9, the signals after the filtration process with enlarged fragment are presented. The small phase shift between signals can be observed.

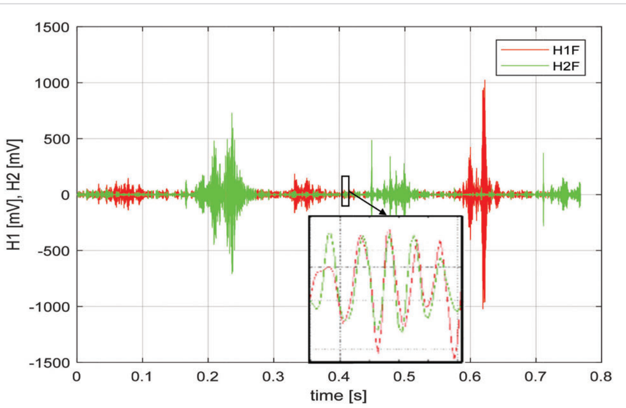

Figure 9 The signals from the both hydrophones represented in the time domain after filtering process
Slika 9. Signali s oba hidrofona prikazani u vremenskoj domeni nakon procesa filtriranja

The principle of measuring the offset between two signals is the main condition for estimating a course. That is why, the zero-phase filter was used to keep the phase of both signals undisturbed. As a results of filtration process the signals have zero phase distortion and the amplitude of signals seems to be high enough for the phase delayed calculation.

4. SCHEDULE OF THE FUTURE RESEARCH / *Raspored budućih istraživanja*

Future tests will be taken in a deeper water reservoir, where the noise from reflected acoustic waves should be smaller.

If there is a moving obstacle detected, then the BUV2 has to change its course until the obstacle dissapers from the collision course. In an emergency situation such us the BUV2 being placed in a crowded zone, the bouyoncy can be changed by the ballast tank and the BUV2 can avoid collision by submerging. Another challenge the authors have to face, is to modify the algorithm to detect the arrival direction of multiple targets simultaneously. This will be achieved by implementing one of the algorithms on the microcontroller platform, for example: beamscan [5], Minimum Variance Distortionless Response (MVDR) [9] or Multiple Signal Classification (MUSIC) [14][15]. Beamscan calculates the direction of arrival of a specified number of signals by locating peaks of the spectrum. MVDR is similar to beamscan but uses a minimum variation distortionless response beam. Multiple signal classification (MUSIC) is a subspace method that provides high resolution directly out of arrival estimates (DOA). For all three methods, the peaks of the output spatial spectrum indicate the DOAs of the received signals.

After the comparison of algorithms effectiveness the most robust algorithm will be chosen.

5. CONCLUSION / *Zaključak*

The hydrophone signals conversion was realized despite restrictions from a wide range of sampling rates. After the preliminary test was carried out in the lake, it can be shown that measurement test stand is calibrated with adequate precision and sampling frequency which is sufficient for future obstacle detection calculations. The filter is designated properly, but efforts are going to be made to enable more robust algorithms to detect even more obstacles, each with an individual frequency.

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