Building a Computer Model of an Acoustic Signal Recognition Device

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Abstract. The system of acoustic detection of UAVs is based on the recognition of the noise of the apparatus on the background of acoustic noise. To protect small objects from illegal surveys, simpler acoustic detection systems are required that can be integrated into existing security systems. It can be built in the same way as glass break detectors. The paper concentrates on modeling at the level of the functional circuit of the security acoustic detector using MATLAB. The development of a computer model of a security acoustic detector is carried out using a recognition algorithm based on two-channel processing. In one channel, low-frequency sound vibrations in the range from 1 to 200 Hz are analyzed. In another channel, the high-frequency components of the sound of breaking glass are analyzed. The simulation results coincide with the technical characteristics of the prototype detector, which confirms the adequacy of the constructed model. The developed model makes it possible to evaluate the reliability of separation by the security detector of signals from the intruder and signals from interference, to determine the parameters of the signals that create cases of false alarms. The developed model allows evaluating the quality of signal processing using the algorithm of this detector. It is a tool for choosing the optimal detector design parameters. The developed model makes it possible to assess the ability of the detector to separate the useful signal and interference.

Keywords: UAV, acoustic detectors, system modeling.

1 Introduction

The use of unmanned aerial vehicles (UAVs) is increasing. At the same time, the growing threat of using them for illegal purposes is becoming increasingly significant [1]. Detection of UAVs becomes the first step in protecting against them. The detection system is built on the use of various equipment: radar systems, acoustic sensors, radio detectors, video and heat cameras with various technical and performance characteristics. Acoustic detection equipment for UAVs is easy to install and operate. The sound characteristics (signature) of the UAVs are transmitted from the acoustic sensor to the server, where they are compared with the signatures of all the UAVs arranged in a special database. If it matches the corresponding signature (identifying the object as a UAV), an executive command is issued to turn on the notification device.

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To protect small civilian objects (cottages, etc.) from illegal surveys, simpler acoustic detection systems are required that can be integrated into existing security systems [2]. It can be built in the same way as glass break detectors, the task of which is to distinguish between the sound of glass breaking on the background of other noise interferences. At the same time, it is most important to develop a correct and simple recognition algorithm so that its hardware implementation is easy.

The development of algorithms for the recognition of acoustic signals using computer simulation is the most common approach. Simulation of systems at the level of functional schemes is widely used in the practice of design [3].

In this research, the simulation is carried out at the level of a functionally scheme by means of a MATLAB security acoustic detector. Such detectors are widely used in alarm systems. The security acoustic remote detector is designed to protect the premises from unauthorized entry through a window by breaking glass. The acoustic detector should remotely perceive sounds in a protected room, analyze them and automatically make decision about glass breaking or not. in this case, it may be possible to not detect the target (if the sound is too low) or a false alarm (if triggered, for example, to the sound of broken dishes).

The purpose of the development of the model is to obtain the capabilities of a theoretical study of the effect of signal processing parameters in the detector on the effectiveness of its detection of an intruder in acoustic noise.

2 Literature Analysis and Problem Statement

The development of a computer model of a security acoustic detector is carried out according to the method presented in [4, 5], in the process of performing the following stages:

1. The choice of the detector prototype.
2. Construction and analysis of the block diagram of the prototype detector and signal processing in the structural units of this scheme.
3. Building a functional model of the detector based on its structural scheme.
4. Construction of a mathematical model of signal processing in the detector.
5. Compilation and debugging of a computer program in a selected programming language.
6. Testing the program.

3 Development of Computer Model

Analyze the implementation of the main stages.

Stage 1. The acoustic security detectors have the general structure shown in Fig. 1.

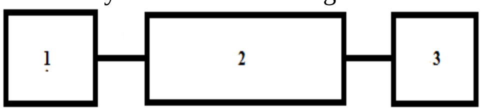

Fig. 1. Acoustic security detector: 1. Microphone. 2. Processing and recognition node. 3. Shaper output signal.

The microphone converts acoustic oscillations into electrical ones. The electric information signal after the conversion goes to the processing and recognition node, which implements one or another recognition algorithm. The output driver synthesizes the output signal in the format of communication with the control unit.

As a rule, in modern acoustic detectors, the recognition algorithm is based on two-channel processing [2]. In one channel low-frequency sound vibrations are analyzed in the range from units to hundreds of Hz. In another channel, the high-frequency components of the glass breaking sound are analyzed.

In [2], it is argued that with the correct formation of the set of features of the useful signal and the criteria for their analysis, two main frequency ranges are sufficient.

However, neither the signs, nor the criteria, nor the detailed structural scheme is given either in [2] or in other modern literature. Therefore, the signs and criteria were chosen based on the crash tests conducted by the author and their analysis [6].

Stage 2. The developed structural diagram is shown in Fig. 2.

The operation of the detector, built according to the above scheme, is as follows.

A microphone with an amplifier (1) converts the sound waves into an electrical signal and amplifies it to the level necessary for the operation of the linear detector and threshold devices. The signal is simultaneously fed to a low-pass filter (2) and a band-pass filter (3), which organize two frequency channels: low-frequency and high-frequency. The signals in each channel are detected by linear envelope detectors with smoothing (4). The smoothed signals of both channels are compared with thresholds in threshold devices – comparators (5). At the output of threshold devices, pulses of a fixed amplitude and duration equal to the time interval in which the envelope level is greater than the thresholds are formed (the thresholds are different in the low-frequency and high-frequency channels). The output pulses of the threshold devices fall on the coincidence circuit (6), which produces a pulse of a fixed amplitude and a duration equal to the time interval in which the envelope level is greater than the thresholds simultaneously in the low-frequency and high-frequency channels.

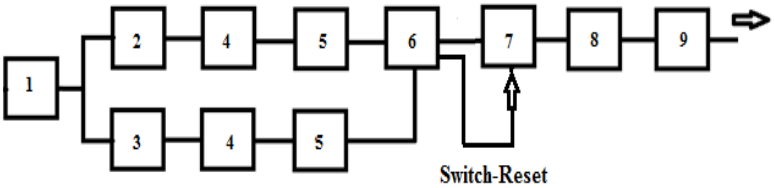

Fig. 2. Block diagram of the acoustic detector glass break: 1. Microphone with amplifier. 2. LPF. 3. BF. 4. Envelope detector. 5. Threshold device. 6. Matching scheme. 7. Integrator. 8. Threshold device. 9. Key scheme with relay.

The transition of the coincidence circuit to a high output level includes the integrator. At the same time, the pulse of the coincidence circuit is fed to the input of the integrator, at the output of which a slowly increasing voltage is formed, proportional to the duration of the integration time. The output voltage of the integrator is fed to the threshold circuit (8). When the threshold at the output of the threshold circuit is exceeded, a high voltage appears, which includes the key circuit (9), which initiates the relay with self-blocking. The relay contacts are included in the alarm loop. The detector switches the “Alarm” state.

After the termination of the coincidence circuit pulse, a low voltage level appears at its output, which the integrator resets. If the pulse duration is short, then the integrator output voltage is not enough to trigger the threshold circuit (8). The key circuit does not turn on, the relay is not initiated. The detector switches the “On Duty” state.

Thus, the criterion by which the detector makes a decision about the fact of breaking glass is the simultaneous excess of the threshold in terms of the intensity of the sound wave in both frequency channels, while the simultaneous excess of thresholds should be a significant part of the breaking time of the glass sheet (without breaking the fragments) - 0.1 second.

As regards the choice of intensity thresholds, it is carried out during detector tuning at the testing stage, usually by changing the gain of the amplifier.

Stage 3. Simulation of the processing of the acoustic signal converted into digital form was carried out using the MATLAB program. Therefore, the functional model of the detector presented in Fig. 3 was consistent with the capabilities of this package. At this stage of modeling, models of all nodes of the structural scheme are specified: a microphone with an amplifier (1). filters (2,3), envelope detectors (4), threshold devices (5), coincidence circuits (6), integrator (7), output stage (8).

The functional diagram of the detector model is shown in Fig.3.

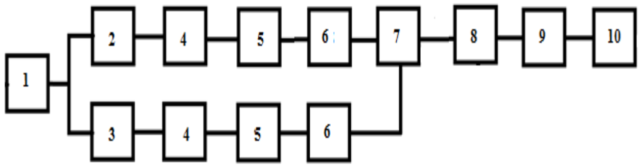

Fig. 3. Functional model of the detector.

Stage 4. Modeling according to the scheme shown in Fig. 4. Let's consider the functional purpous of model blocks.

Block 1. Reading a sample of glass breaking sound in a Wav-file form from the database and converting it into a MATLAB matrix format.

Block 2. Simulation of a low-pass filter with a Butterworth 4 order and a cut-off frequency of 500 Hz by MATLAB operators.

Block 3. Simulation of the BF by Butterworth filter 4 orders of magnitude and bandwidth 3 ... 11 kHz by MATLAB operators.

Block 4. Nonlinear conversion of the full-wave detection of the filtered signal: calculation of the absolute value of the input signal for block 4 by the MATLAB operator.

Block 5. Simulation of a low-pass filter with a Butterworth 4 order and a cut-off frequency of 10 Hz by MATLAB operators. Thus, at the output of blocks 5, the envelopes of the signals of the frequency channels are calculated.

Block 6. In the comparison block, the envelopes of the frequency channels are compared with the thresholds specified in the source data and a single amplitude pulse is produced and the duration is in the time interval when the envelope exceeded the threshold.

Block 7. In the coincidence block, a single amplitude pulse is produced and a duration in the time interval when the envelopes of both frequency channels exceed the specified thresholds.

Block 8. In the integrator block, the coincidence block pulse is integrated and a voltage proportional to the duration of the input pulse is obtained at the output.

Block 9. The voltage proportional to the duration of the input pulse is compared with the threshold set in the initial data. When the threshold is exceeded it is considered that the fact of breaking the glass is fixed. If the threshold is not exceeded, it is considered that the sound signal has a different origin.

Block 10. In this block the program solution is displayed. If the sound of glass breaking is fixed, the words “ALARM” are displayed. In the opposite case, the word ON DUTY" is displayed.

Stage 5. This program, compiled in MATLAB codes, debugged and tested to adequately reflect the characteristics of the real device 4.

Stage 6. When testing the program, the sounds of breaking real windows [6] recorded in the database as wav-files were taken as input. These files were then converted to the MATLAB package format. So samples of sound breaking glass № 1-10 were obtained. An example of recording the input information signal is shown in Fig.4 below.

At the debugging stage, the cut-off frequency was experimentally selected in the envelope detector of the frequency channels. The simulation of the envelope detector in the low-frequency channel about the cutoff frequency of low-pass filters of 50 Hz and 10 Hz was carried out. The simulation results led to the conclusion that the first option does not smooth out the signal spikes and cannot guarantee the reliable operation of the frequency channel envelope analysis units [7-9].

During logical processing of envelopes using the comparison and coincidence blocks, the Low Frequency Channel Comparison Unit generates a pulse “3” at the P1 = 0.1 threshold, the High Frequency Channel Comparison Unit generates a pulse “4” at the P2=0.25 threshold, and the Coincidence Unit produces a pulse “5”. All of them are shown in Fig. 5.

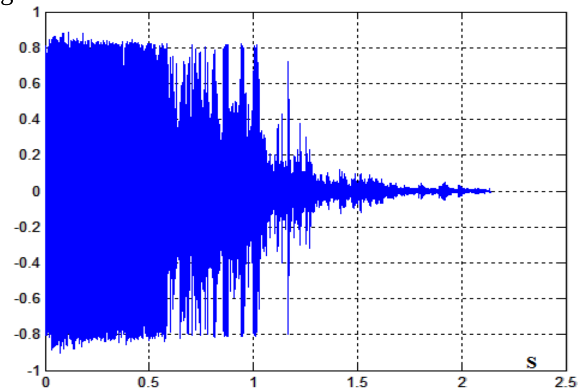

Fig. 4. Sample recording sound breaking glass.

When integrating pulse 5 by the Integrator, the voltage will be generated at its output:

$$U=0.1436 \text{ V}.$$

Since it is greater than the threshold P3 = 0.1, the message appears on the display: “ALARM”.

4 Acoustic Detector Model Study

Using the developed computer model, the sounds of breaking real windows were analyzed (10 samples). The results of the analysis are shown in Table 1 in columns 1-10 for various threshold values. In addition, the glass breaking sounds reproduced by the glass break tester VITRON, (three samples) were analyzed. The results of the analysis are shown in Table 1 in columns 11-13 for different threshold values [8-11].

Table 1 uses the following conventions:

– correct detection of glass breaking - (+);

– non-detection of glass breaking - (N);

– the correct failure to detect the sound of the tester - (-).

Table 1 in the first column shows the numbers of options that differ thresholds. Option 1: P1 = 0.1; P2 = 0.1; P3 = 0.1. Option 2: P1 = 0.05; P2 = 0.1; P3 = 0.05.

Fig. 5. The results of the numerical study of the sample sound break glass: 1. The signal envelope at the output of the low-frequency channel. 2. The envelope of the signal at the output of the high-frequency channel. 3. Pulse of the low-frequency channel comparison unit. 4. Pulse of the high-frequency channel comparison unit. 5. Impulse block matches.

The results of the analysis show that overestimated values of the thresholds lead to an unacceptably high frequency of the intruder’s pass (the upper line). But even at moderate thresholds (bottom line), the violator’s omission takes place – for samples 5 and 10.

Table 1. Results of the analysis of breaking glass

№	1	2	3	4	5	6	7	8	9	10	11	12	13
1	+	+	N	N	N	N	+	N	N	N	-	-	-
2	+	+	+	+	N	+	+	+	+	N	-	-	-

Fig. 6-7 shows the output signals of the frequency channels and the reasons for the non-target detection. On it, lines 1 and 2 show envelopes of the LF and HF channels, respectively.

It can be seen that in sample 5 there is a low level of the LF signal and a small duration of the sound of glass breaking. This happens when breaking a small glass area, for example, the vents.

Sample 10 is characterized by an overall low signal level, which occurs when the microphone is too far from breaking glass.

Both of these cases are recorded in the technical documentation for glass break detectors. Glasses of small area, located further than the maximum distance, are not blocked.

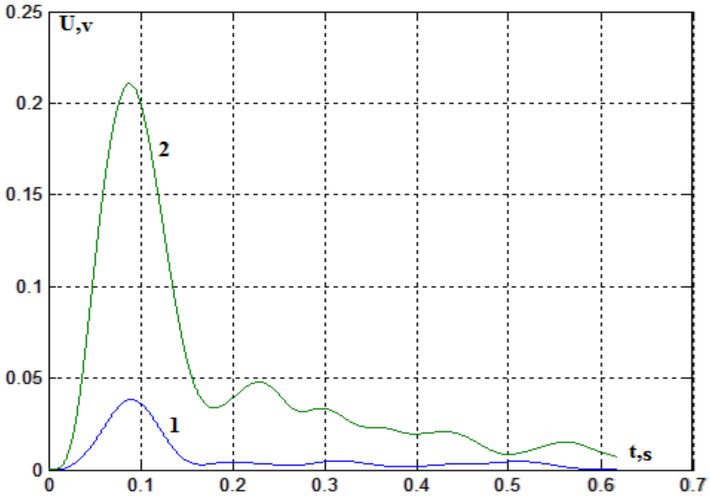

Fig. 6. Analysis of sample 5.

The results of the analysis also show that the dual-frequency glass break detector is adequately protected from false alarms. It does not work on the sounds of the glass break tester VITRON, made for testing single-frequency detectors. Fig. 8 shows the reasons for the absence of a false alarm: the tester does not reproduce the low-frequency component of the glass break sound [11-14].

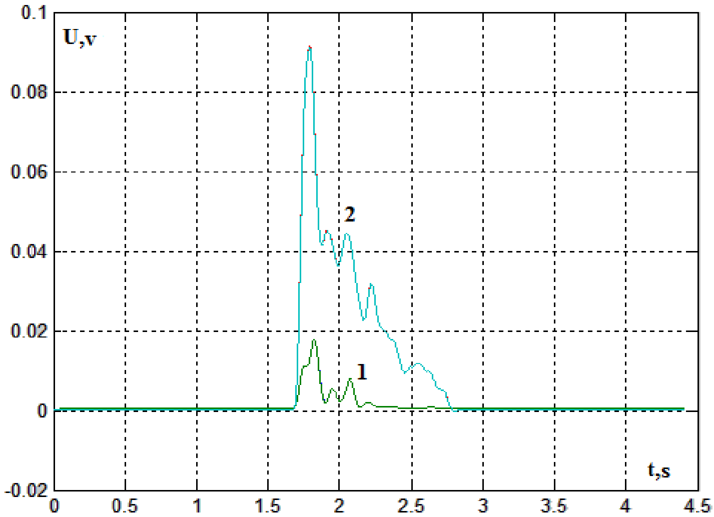

Fig. 7. Analysis of sample 10.

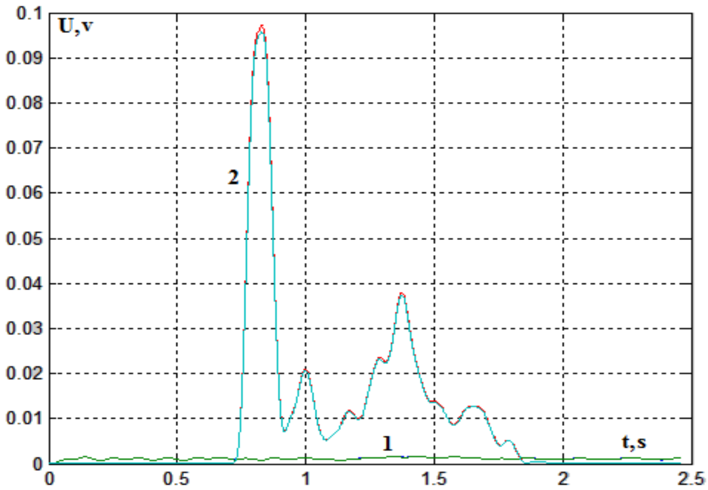

Fig. 8. Analysis of sample 11.

5 Conclusions

The simulation results coincide with the technical characteristics of the prototype detector, which confirms the adequacy of the constructed model. The developed model makes it possible to evaluate the reliability of the separation by a security detector of signals from an intruder and signals from interference [14-18], to determine the parameters of signals that create cases of false alarms.

The developed model allows to evaluate the quality of signal processing using the algorithm of this detector. It is a tool for selecting the optimal parameters of the detector design.

The model can be useful both to developers of security acoustic detectors when improving processing algorithms, and to students when studying the principles of operation of radio electronic security systems.

The model building method can be used to test the recognition algorithms of acoustic signals of a UAV.

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