Detection and Analysis of Moving Objects

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Abstract: - In many ecological applications, e. g., for aerospace remote sensing of earth surfaces for the purpose of prevention of dangerous natural, ecological, and industrial catastrophes, it is necessary to perform the efficient detection of new moving objects, which could appear as a result of natural or other disasters. The method of detection and estimation of the objects' motion as well as understanding of scenes on the basis of performance of the operation of segmentation of dynamical images is considered. The motion cue is used as a segmentation attribute of the object of interest. This method makes it possible to determine the motion trajectory, distance passed by a stealth object and its velocity as well as solve the problem of the reliable and trustworthy detection of the object of interest on the background of spatial interference. The article considers the possibility of the segmentation with the help of noise-correcting coding and of the expansion of the image signals in the basis of the Hadamard orthonormalized rectangular functions. The coding is performed on the basis of the use of finite cyclic group arithmetic and the concept of dyadic shift as an information parameter of a moving object. The main application of the method lies in the field of strong noise, real-time mode and limitations on computing and energy resources of observation. Under these conditions, the method allows to minimize time, computational, energy costs and detection errors in comparison with deep learning approaches. The algorithm can be used in the image classification process, for automation of identification of the objects on the shots obtained by sounding the earth surface on surveillance equipment such as small unmanned aerial vehicles.

Key-Words: - Rademacher function, dyadic shift, segmentation, orthonormalised function, object of interest, interference.

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1 Introduction

The aerospace remote sensing (RS) of the earth surface is commonly used in the up-to-date Industry 4.0 technology, [1], [2]. With the development of modern electronic systems with high computing performance, it has become possible to consider the motion as an additional feature, which can be used in the image processing to solve problems of recognizing the objects and understanding the scenes. Solving the problems of segmentation of dynamical objects is referred to the section of scientific researches in the field of theory and practice of digital image processing and intelligent vision. The solution of the segmentation problem is especially relevant in medical imaging, since it is an important step before describing, recognizing or classifying a disease. Reliable evaluation of the observed and studied dynamic image of biological material, for example, for cytological diagnostics of soft tissue tumors, contributes to improving the quality of the final diagnostic solution, understanding the problem, and planning the treatment.

The analysis of the motion fields on the image sequence is provided in monographs and scientific articles, [3], [4], [5], [6], [7], [8], [9]. Various approaches relate to performing the segmentation of dynamical objects and understanding of the scene are known. A number of main segmentation methods based on different image models described in the spatiotemporal domain have been developed and are used. They include: the background subtraction method, differential geometrical method, [10] correlation method [11], least squares method, computationally expensive method of description of the spatiotemporal image structure using the eigenvalue analysis, [12].

The practical implementation of the method under consideration can be based on the use of deep learning and convolutional neural networks. However, the application of deep learning methods has a limitation associated with the low ratio signal-to-noise ratio

$q = S/N$ at the output of the data transmission channel, where the average signal power is S, equal to or greater than the average noise power N.
In this case, deep learning becomes ineffective in obtaining an optimal solution. Deep learning cannot solve object detection problems for many special applications. For example, to ensure reliable detection of an object in channels with intentional electromagnetic influence with a ratio

$$q = S/N \ll 1.$$

Deep learning and convolutional neural network methods require significant computational, time and energy costs for channels with low signal-to-noise ratio. This is an obvious drawback of these methods. However, there is a need for less computationally expensive algorithms that do not use neural networks. For example, on small unmanned aerial vehicles equipped with low-power devices with ARM architecture, without parallel computing capabilities such as GPU or neural network processors NPU. Another example of the problem is the detection of objects with small pixel sizes (20×20) in remote sensing images. The use of software implementation of neural network algorithms becomes problematic. The above mentioned costs for real-time signal processing become unacceptable. The paper considers an approach aimed at detecting a moving object in a channel with an input signal-to-noise ratio $q \ll 1$. The selection of a particular method is determined by many factors:

− statistical characteristics of the source, [13];
− specifications of the shooting cameras;
− conditions of shooting in the mode of continuous observation over the object of interest;
− field of application, [14], etc.

For example, the classical correlation method in the spatiotemporal domain may be unacceptable. For the case when slow changes in scenes occur and motion cues are formed rarely, the search for the maximum cross-correlation coefficient in a three-dimensional vector space (x, y, z) with the operation of the inner product of matrices requires:

− significant time and computational costs;
− specialised high-velocity equipment. The German-Indonesian Geographic Information System (GIS) for early tsunami warning may be cited as an example of the time spent for processing image frames, [15]. The main components of such GIS are geostationary and communication satellites, networks of seismological sensors and marine buoys as well as systems for communication and processing of dynamic data (tsunami wave velocity and energy). The system issues a disaster warning 5 minutes after signs of an underwater earthquake appear, [16].

2 Problem Formulation

It is supposed that the object is moving with a constant velocity V. The dynamical data of the digital images $g(x, y, t)$ as sequences of discrete functions of the RS are presented in the form of screen-type patterns in GIS. Here $x, y \in \mathbb{Z}$ − are coordinates of the two-dimensional space and $t \in \mathbb{Z}^{+}$ − is the discrete time. The revealing of the motion may be associated with the orientation in the spatiotemporal images. The $g(x, y, t)$ in the form of spatial (feature) points with respective coordinates forms the object motion trajectory at discrete moments t. Solving the problem of detecting and analysing dynamic processes in channels with a significant level of interference (noise) is computationally expensive and leads leading to an increase of the equipment complexity and processing time.

3 Problem Solution

The today's analysis of the moving objects being present in available images can be based on a statistical approach, [17], when spatial data are represented as random brightness values and as a stochastic process in the case of representation by a temporal series. In this case, more efficient processing and extraction of significant classification features of dynamic objects can be performed using the noise-immune coding, [18] methods and coordinate Fourier-like transformations. Most of these transformations have fast computational algorithms, which provide a significant time gain in signal processing and reduce the hardware costs. The paper considers a method for determining the motion in image sequences using encoding and coordinate transformation based on rapid expansion into discrete Hadamard functions, [19]. A reliable solution to the problem at hand is provided by introducing redundant encoding of the data observed. The coding is performed using the meander Rademacher meander functions. Then, a method for determining the highest energy concentration of the observed encoded signal within a specified time interval of observation is applied. The value of the maximum energy value is used for the best assessment of detection of the object of interest. In this case, it is possible to obtain an arbitrarily small probability of detection error of the observed object in accordance with Shannon's theorem, [20]. Fig. 1 shows a generalized structural diagram of the dynamic object detection system.

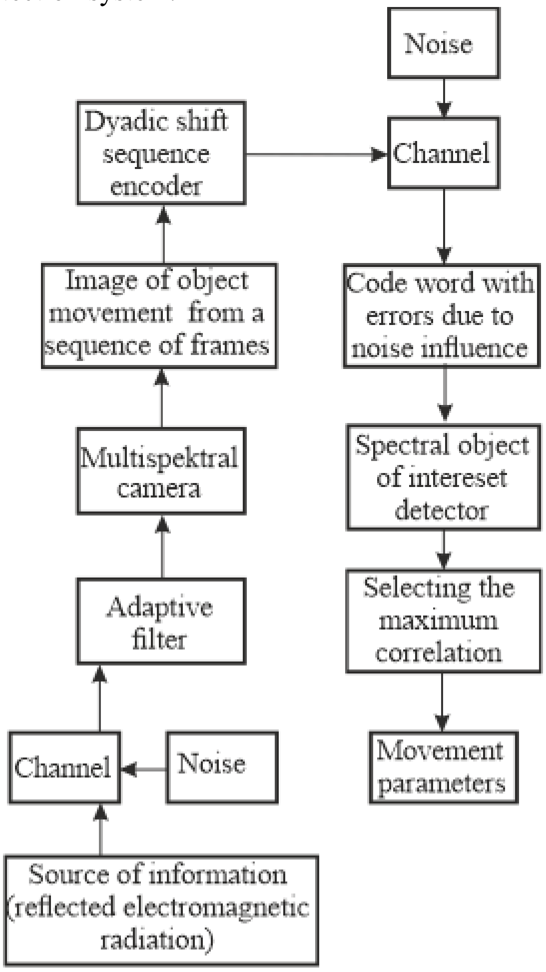

Fig. 1: Generalized structural diagram of the search for an object of interest

4 Theoretical Principles

To increase the reliability and efficiency of processing the dynamical process $g(x, y, t)$, it is proposed to perform the segmentation using the arithmetic of the finite cyclic group G, to be specified on the binary set $\{1, -1\}$, [21]. Such a group is featured by the possibility of formation of a subset $A = \{a(t)\}$ of discrete functions with a specified code distance value [22]

$$d = n/2,$$

where n – is the commonly used designation of the of the code length.

In the theory of algebraic finite groups, the subset of dyadically shifted functions A is defined as a subgroup A of the group G. In this case, the subgroup A can be used for encoding-decoding of samples (pixels) of the image $g(x, y, t)$ in the spatiotemporal domain for the purpose of noise-immune processing of the frames obtained. In this case, it is possible to choose two options for the optimal decoding algorithm.

The first variant can be implemented in the spatiotemporal domain on the basis of the operation of expansion of the group G into adjacent classes with respect to the subgroup A.

The second variant can be implemented using the methods of orthogonal coordinate transformations based on the generalized Fourier series on the finite intervals of the form

$$g(t) = \sum_i c_i \varphi_i(t), \tag{1}$$

where $c_i = \langle \varphi_i(t), g_i(t) \rangle$ is a complex or real number;

$\varphi_i(t)$ is the orthogonal function of the expansion basis.

Based on the a priori knowledge of the channel's transient characteristics, which are described by statistical parameters of interference (error probabilities p) and the selected number of the observation frames B, to be analyzed, the fast decoding option using (1) to calculate the dyadic correlation function may be computationally more effective. To do this, the theorem on computation of the dyadic convolution (correlation) should be applied, [23]. Calculating the value of the shift τ after analyzing and decoding the resulting sequence of images makes it possible to make a decision about detecting the object of interest with the specified (best) confidence. Besides, it is also possible to have estimations of the motion parameters. Performing a dyadic shift operation over $A(t)$ generates relatively easily a set of orthogonal code words with the maximum possible code distance

$$d = n/2 \geq 2t + 1,$$

where t is the commonly used designation of the number of process errors to be corrected in the output channel with spatial noise.

The choice of the code distance d value is carried out taking into account a priori knowledge of the channel characteristics p and the required value of the posterior probability density of object detection.

Since the a priori probabilities of the set $\{A(t)\}$ are the same, the a posteriori probability of detecting an object is equal to

$$P(A(t)|P(A(t)+\theta(t)) = p^{d}(1-p)^{n-d}. \qquad (2)$$

where $\theta(t)$ is the interference component.
If the probability of error in the channel is smaller $p<0,5,$ then from (2) it follows that the probability of error in detecting a moving object decreases with increasing

$$d \geq 2t+1.$$

Moreover, if the probability of error in the channel is smaller $p<0,5,$ then from (2) it follows that the probability of error in detecting a moving object decreases with increasing code length n.
Unlike the discrete Fourier transformation, where the N-th root of unity, i.e.

$$\sqrt[N]{1} = e^{\frac{j2\pi}{N}}$$

or, in another way, complex finite exponents are to be used as a character of a finite cyclic group, the application of the real expansion basis on the binary set $\{1, -1\}$ makes it possible to solve the segmentation problem more effectively, from both the computational and energetic points of view, [23]. The method under consideration involves the performance of the three main computational steps.

At the first preliminary stage of detection and analysis of the motion, the well-known filtering algorithm of subtraction (3) of static objects of the preliminary $g(x_i, y_j, t_l)$ and subsequent $g(x_i, y_j, t_{l+1})$ frames, i.e.

$$g(x_i, y_j, t_l) - g(x_i, y_j, t_{l+1}) = 0. \qquad (3)$$

is implemented.
Operation (3) is illustrated by the space-wise structure x, shown in Fig. 2. By analogy with the structure along the x axis, operation (3) is also performed along the y spatial coordinate of the 2D space. The static and dynamic image regions in the x and y coordinates form vertical and horizontal structures, respectively, as well as regular linear structures in the form of a displacement vector. If the object is moving at a uniform velocity, the trajectory of motion along the orientation of the displacement vector as shown in Fig. 2 is formed after completion of B frames. The values of the tangents of the angles of slope φ_x and φ_y, Fig. 2 of the displacement vectors in the x and y coordinates make it possible to determine the velocity components in the directions of the coordinate axes

$$V = -\begin{pmatrix} \tan\varphi_x \\ \tan\varphi_y \end{pmatrix}.$$

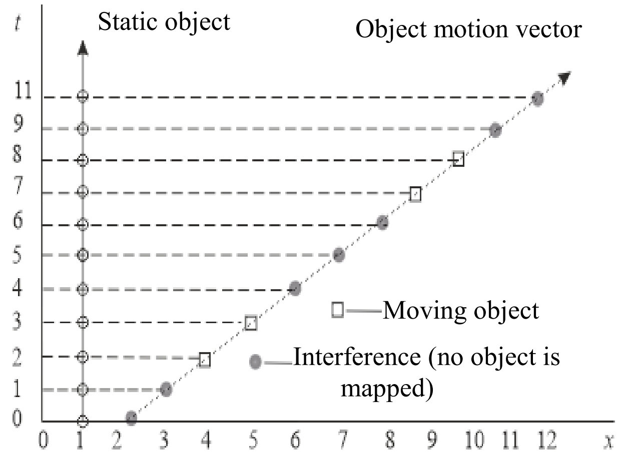

Fig 2: Structure of the spatiotemporal image in the x coordinate.

The non-linear structure of the displacement vector may indicate a change in the trajectory of movement, impact of interference during the formation of the image frames and appearance of other moving objects in the frame.

At the second stage of detection and analysis of the motion, all the dyadically shifted functions (discrete sequences) written in the matrix form $\mathbf{A}$ are constructed. The number of functions is determined by the parameter B. The generating matrix $\mathbf{A}$ in the form of all layers of the dyadically shifted sequences is constructed on the basis of Rademacher functions The continuous Rademacher functions are defined as

$$\mathrm{rad}_k(t) = \mathrm{s}ign(\sin 2^k \pi t),\ t=[0,1),\ k \in \mathbb{Z}^{+}, \qquad (4)$$

where $\mathrm{sign}(\sin 2^k \pi t) = 1,$ if $\sin 2^k \pi t \geq 0;$
$\mathrm{sign}(\sin 2^k \pi t) = -1,$ if $\sin 2^k \pi t < 0;$
index k determines the frequency parameter of the function.
To construct the $A(t)$, the $\mathrm{rad}_k(t)$ with an odd number k should be chosen in (4). The lengths of the sequences $\mathrm{rad}_k(t)$ is equal to $n = 2^k$.
The value of the frequency parameter k of the

Rademacher function is determined by the required length n of the noise-resistant code used in the detection system.

In the presence of a significant noise level (SNR<<1) at the input of the detector of the observed object, the optimal length n of the code is selected from the condition that allows determining the autocorrelation function of the code word. When the signal-to-noise ratio $S/N << 1$, the optimal length n is chosen such that it is sufficient to ensure accurate detection of the observed object. The qualitative characteristics of the detection process for given input signal to noise ratios depend on the observation time of the object and the code length n. In the context under consideration, the n value is equal to the number of frames of observation B. The number of frames B is determined based on the expected speed of movement of the object of interest and the number of images per second. In this case, the number B is calculated taking into account the required $\left(S/N\right)_{out}$ signal/noise value at the detector output to ensure the specified reliability.

The main code sequence $A_0(t) = (a_0(0),\ a_0(1),...,a_0(n-1)$ of the cyclic dyadic subgroup is formed using the majority addition operation in the form:

$$A_0(t) = \mathrm{Maj}(\mathrm{rad}_1(t),\ \mathrm{rad}_2(t),...,\mathrm{rad}_k(t)). \quad (5)$$

According to formula (5), the i^{th} symbol of the sequence $A_0(t)$ is equal to 1, if the sum of i^{th} symbols of the components $\mathrm{rad}_1(t),\ \mathrm{rad}_2(t),...,\mathrm{rad}_k(t)$ is positive. If the sum of i^{th} symbols of the components is negative, the i-th symbol of the sequence $A_0(t)$ is equal to -1. The set of all code words $\{A(t)\}$ is obtained by shifting dyadically the word $A_0(t)$. The space of n-dimensional sequences over the set $\{1,\ -1\}$ can be presented as a matrix

$$\mathbf{A} = \begin{pmatrix} a_0(0),\ ...,\ a_0(n{-}1) \\ a_1(0\oplus\tau_1),\ ...,\ a_1((n{-}1)\oplus\tau_1) \\ \vdots \\ a_l(0\oplus\tau_l),\ ...,\ a_l((n{-}1)\oplus\tau_l) \\ \vdots \\ a_{n-1}(0\oplus\tau_{n-1}),\ ...,\ a_{n-1}((n{-}1)\oplus\tau_{n-1}) \end{pmatrix}, \quad (6)$$

where $a_l(t\oplus\tau_l)-$ is the dyadically shifted code word $a_0(t) = A_0(t)$;

$l \in \{0,\ 1,\ ...,\ n-1\}-$ is the number of the code word;

$\tau_l -$ is the binary representation of the shift value l;

$t -$ is the binary representation of the discrete time;

$\oplus -$ is the addition operation on the set $\{1,\ -1\}$.

The MATLAB code used to generate the reference word is given below.

Program 1. Formation of the reference code word

```
function maj_a=maj(k)
%Formation of the reference code word a
n=2^k;% Word length a
  a=[];
  fori=1:k
    k=n/(2^i);%Rademacher function index
    a_r=[];
    forj=1:2^i
      ifmod(j,2)==1
        a_r=[a_r, ones(1,k)];
      else
        a_r=[a_r,-ones(1,k)];
      end
    end
    a=[a;a_r];
  end
  maj_a=zeros(1,k);
  fori=1:k
    forj=1:k
      maj_a(i)=maj_a(i)+a(j,i);
    end
    ifmaj_a(i)>0
      maj_a(i)=1;
    else
      maj_a(i)=− 1;
    end
  end
```

At the third stage of detection and analysis of the motion, the decoding operation is performed in order to make a decision on detecting a moving object of interest in the channel with spatial interference. To do this, the operation of calculating the dyadic correlation function is performed. The operation is equivalent to the operation of the optimal maximum likelihood technique. If $B = n$, and the number of frames to be analysed is relatively large, the computational complexity with respect to additive operations (in a single coordinate) is

$$n \times (n-1) \approx n^2.$$

Here multiplicative operations are absent since the calculation takes place on the binary set $\{1,\ -1\}$. The structural peculiarities of the matrix $\mathbf{A}$ make it possible to proceed to decoding using the dyadic correlation theorem. The algorithm of fast inverse coordinate transformation in the form

$$\mathbf{R}_x = \tfrac{1}{n}\mathbf{H}(\mathbf{H}\mathbf{A}_x\mathbf{H}\mathbf{A}_0),$$
$$\mathbf{R}_y = \tfrac{1}{n}\mathbf{H}(\mathbf{H}\mathbf{A}_y\mathbf{H}\mathbf{A}_0). \quad (7)$$

is implemented,
where $\mathbf{R}_x -$ is the vector of coefficients of the dyadic correlation function in the x; coordinate;
$\mathbf{R}_y -$ is the vector of coefficients of the dyadic correlation function in the y; coordinate;
$\mathbf{A}_x -$ is the image vector obtained after coding B frames in the x; coordinate;
$\mathbf{A}_y -$ is the image vector obtained after coding B frames in the y; coordinate;
$\mathbf{A}_0 -$ is the vector representation of the sequence $A_0(t)$;
$\mathbf{H} -$ is the kernel of the Hadamard transformation with the dimensions $n \times n$.
Expression (7) makes it possible to reduce significantly the computational complexity of solving the detection problem by using the algorithm of the real fast Hadamard transformation (FHT).

4.1. Computation technique

The proposed algorithm for detecting a moving object of interest and estimating the parameters of its motion in the space and time in the form of a sequence of executable computational procedures will be shown through the example.

Example. Let the observation process take place over a time interval corresponding to the number of image frames equal to $B = 32$. For discrete time, the observation interval during the B frames is defined as $t = [0,\ n-1]$. The $B = 32 = 2^5$ value requires a basis consisting of 5 Rademacher functions. The MATLAB code used to generate dyadic shifted words is shown below.

Program 2. Code generation .

```
function a_word=encoder(k,tau,a)
a_index=0:2^k-1 %Codeword element indexes
z=dec2bin(a_index,k); %Indecec as binary vectors
z=(z-'0')'
tau=dec2bin(tau,k); %Dyadic shift index
tau=(tau-'0')'
a_index_word=[]; %Indices of codeword elements after shift
fori=1:2^k
   z(:,i)=xor(z(:,i),tau);  %Indices of binary vectors after shift
   a_index_word=[a_index_word,bi2de((z(:,i))','left-msb')];
end
z
a_index_word
a_word=[];
fori=1:2^k
a_index_word=[]; %Indices of codeword elements after shift
fori=1:2^k
   z(:,i)=xor(z(:,i),tau);  %Indices of binary vectors after shift
a_index_word=[a_index_word,bi2de((z(:,i))','left-msb')];
end
z
a_index_word
a_word=[];
for i=1:2^k
   a_word=[a_word,a(a_index_word(i)+1)];
end
end
```

By applying (5) and Program 1, we will obtain the structure of the main code sequence. The one-dimensional sequence, represented as two rows of a matrix, has the form

$$a_0(t) = \begin{pmatrix} 1\ 1\ 1\ 1\ 1\ 1\ 1 -1\ 1\ 1\ 1 -1\ 1 -1\ -1\ -1\ 1\ 1\ 1 \\ -1\ 1\ -1\ -1 -1\ 1 -1\ -1 -1\ -1 -1\ -1 -1 \end{pmatrix}.$$

For $a_0(t)$, the dyadic shift $\tau_0 = 0$.
Using (6), we will obtain the generating matrix $\mathbf{A}$ with the dimension 32×32. For example, the code word $a_2(t)$ has the structure of the form

$$a_2(t) = \begin{pmatrix} 1\ 1\ 1\ 1\ 1 -1\ 1\ 1\ 1 -1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ 1\ 1 \\ 1 -1\ -1\ 1\ -1 -1\ -1\ 1\ -1 -1\ -1 -1\ -1 \end{pmatrix}.$$

After performing the preliminary filtration (2), the image structure will be determined by motion pixels and interference in the shooting channel, i.e. the input process of image processing is represented as

$$z(x, y, t) = g(x, y, t) + \theta(x, y, t),$$

where $\theta(x, y, t) -$ is the interference component hiding the object of interest in some moments of time. By calculating the number of the single maximum correlation component $\max R(i)_x$ и $\max R(i)_y$ using formulae (7), the detection is fixed and the shift between the frames and, consequently, the velocity of the object in the spatiotemporal domain is determined. Fig. 3 and Fig. 4 show the computed graphs of the discrete functions $R(t)_x$ for the two extreme cases.

1. *Interference is absent*, i.e. $\theta(x, y, t_l) = 0$. Correlation function $R_{\max}(t)_x = 1$ for $\theta(x, y, t_l) = 0$.

The probability of the detection error is equal to zero.

2. The moving object is invisible (hidden) by interference on 7 frames.
Correlation function $R_{\max}(t)_x = 1$ for SNR$=-3$ dB.
The probability of the detection error is equal to zero.

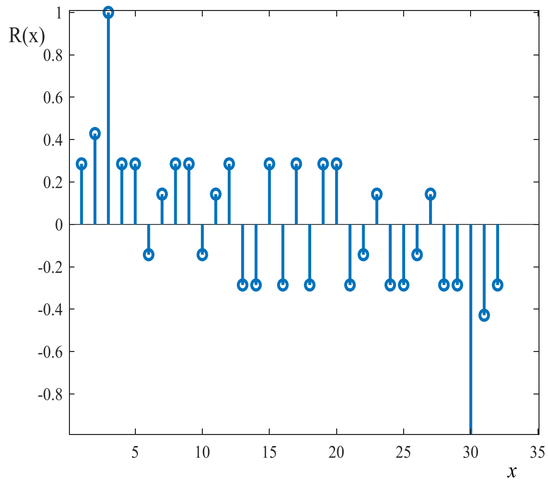

Fig. 3: Correlation function for $\theta(x, y, t_l) = 0$

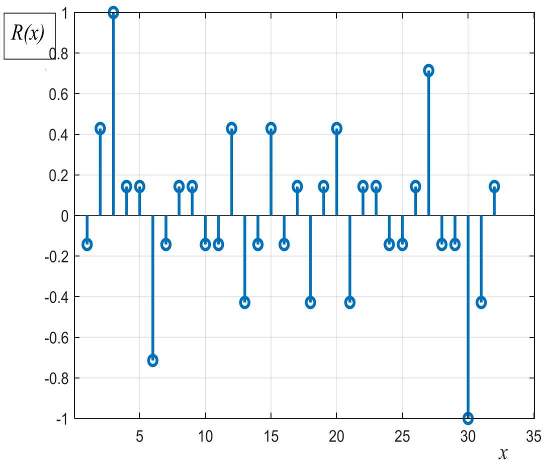

Fig. 3: Correlation function for distorted frames

Let's estimate the volume of calculations for one coordinate required to solve the problem of detecting a dynamic object.
1. As follows from (7), to obtain $\mathbf{R}_x$, it is necessary to perform three Hadamard coordinate transformations.
2. Since the sequence $A_0(t)$ is known a priori, the transformation $\mathbf{HA}_0$ can be calculated in advance. Therefore, these computational costs are excluded from the overall algorithm performance evaluation.
3. As follows from the properties of the dyadically shifted sequences $\{A(t)\}$, the result of every transformation of the sequence $A_i(t)$ using the kernel $\mathbf{H}$ contains $n/2$ non-zero coefficients.
4. As follows from the estimation 3, the element-by-element product $\mathbf{HA}_x \cdot \mathbf{HA}_0$ in (7) does not require n, but requires only $n/2$ operations.
5. It is assumed that each coordinate transformation is implemented using the well-known FHT algorithm. The computational complexity of the FHT is equal to $n\log_2 n$. From two FHTs, we will obtain

$$2n\log_2 n$$

additive operations.
6. As follows from consideration of the graphs shown in Fig. 3 and Fig. 4, the computation of $n/2$ coefficients of the $\mathbf{R}_x$ can be omitted, because

$$\mathbf{R}_x = (R_x(0,\ R_x(1), \ldots, R_x(n-1)),$$

where $R_x(n-1) = R_x(0),\ R_x(n-2) = -R_x(1), \ldots$
$\ldots, R_x(n-n/2) = -R_x(n/2)$.
7. The estimation of the computational complexity of the detection algorithm is equal to

$$(2n\log_2 n) + n/2. \qquad (8)$$

8. Let's estimate the processing gain in comparison with the maximum likelihood method, which consists in computing the correlation coefficients on the basis of the expression

$$\mathbf{R}_x = \mathbf{AA}^T{}_x. \qquad (9)$$

Using (9), it is necessary to compute the number of the maximum component of the vector

$$\mathbf{R}_x = (R_x(0,\ R_x(1), \ldots, R_x(n-1)),$$

for which

$$R_x(i) = \max_i R_x(i).$$

The computational costs over the set $\{1,\ -1\}$ for the expression (9) are equal to

$$n \times (n-1) \approx n^2.$$

The gain in the number of operations as a parameter of the processing efficiency should be determined from the expression

$$C = \frac{n^2}{(2n\log_2 n) + n/2}.$$

Let the shooting of the object under observation contains a sequence consisting of $B = 128$ frames. The value $C \approx 9$. As B increases, the efficiency of detection of the object of interest will increase too.

5 Experimental studies

The experimental studies of the approach under consideration were carried out using the software tools of the MATLAB package. An experimental detection of a low observable object of interest was performed on a sequence of dynamic scenes for the numbers of frames from 8, 32, 128. The images were distorted by additive uncorrelated pulse noise. In the images, such noise looks like random binary dots as motion cues do, Fig. 2. The noise dispersion (density) was evenly distributed throughout the image of each frame. The simulation was carried out with noise of different densities (signal-to-noise ratio). The code constructions (6) with the maximum possible code distance d equal to 4, 16, 64 were used. For these distances and a given signal-to-noise ratio in the channel, estimates of the probability of errors in detecting the observed object were obtained.

In this case, low signal-to-noise ratios were considered, which are critical for deep learning approaches. The work of deep learning algorithms already for ratios $S/N = 1,$ or 0 dB becomes almost impossible to do in real time. For example, so that a special radio-electronic system can produce results within one second.

The simulation was performed for a channel with Gaussian white noise and the BPSK modulation method. In this case, the theoretically possible reliable detection of an object, [24] distorted by interference is implemented provided that the maximum number of distorted frames (error multiplicity) is $t = \lceil (d-1)/2 \rceil = 1,\ 7,\ 31.$ The theoretically computed graphs in Figs 3 and 4 were completely confirmed experimentally (see Figures). As seen from the graph, the detected object corresponds to the displacement vector shown in Fig. 2. Table 1 shows the detection error values as a function of the channel signal-to-noise ratio.

Table 1. Probability of detection error depending on the SNR value and A-code parameters.

Parameters A-code	$n = 8,$ $d = 4$	$n = 32,$ $d = 16$	$n = 128,$ 0 $d = 64$
SNR [dB]	0 −3	0 −3	0 −3
Probability of error P_e	$\approx 4 \cdot 10^{-2}$ $\approx 13 \cdot 10^{-2}$	$\approx 3{,}6 \cdot 10^{-4}$ $\approx 3{,}8 \cdot 10^{-4}$	≈ 0 ≈ 0
Probability of error with out **A** -code	$\approx 7{,}8 \cdot 10^{-2}$ $\approx 15{,}9 \cdot 10^{-2}$		

6 Results and their discussion

1. The experimental results show that the noise-resistant image processing of dynamic objects with a specified probability of correct detection and minimum probability of false alarm and reliable motion analysis, requires the increase of the observation time.
2. As the noise level increases, it is necessary to increase the number of observation scenes in order to identify and describe significant classification features of motion more reliably.
3. The method makes it possible to detect linear continuous and discontinuous trajectories, predict the motion direction and understanding of scenes.
4. The method makes it possible to increase the noise immunity of the detection system for a low-observable object in the presence of interference in the images of natural origin.
5. The method makes it possible to increase the noise immunity of the detection system for a low-observable object in the presence of organized interference with an optimizable structure on image frames.
6. The method implements a simultaneous solution to the problem of detecting and analyzing the parameters of motion of the object of interest

6.1 Conclusion

The paper presents an approach to noise-resistant image processing of dynamic objects, where motion is considered as orientation in the spatiotemporal domain.

1. The approach based on the application of temporal and coordinate (spectral) descriptions of motion on a sequence of images in the 2D space makes it possible to increase the parametric trustworthiness of the object detection estimation.

2. High accuracy in estimating the detection of motion of the object under observation is achieved even with low signal-to-noise ratios.
3. The combined use of the chosen design of noise-resistant codes based on dyadic and cyclic groups and dyad correlation in the motion segmentation problem has made it possible to apply a fast real coordinate transformation.
4. Application of the considered image processing method makes it possible to reduce the volume of additive computations from $\approx n^2$ operations to $\approx (2n\log_2 n) + n/2$ operations for each coordinate.
5. If even partial hard-to-distinguish attributes extracted from an image distorted by interference are obtained, the proposed method of detection and analysis of the motion is effective, reliable and can find application in ecology, medicine, and other fields.
6. The considered method is highly accurate due to the optimal noise-resistant correlation approach.
7. The considered method is effective due to performance of operations on a binary set.
8. The method can be used for applications involving the need for continuous observation of different surface polygons in remote sensing images.
9. The experimental studies of the considered approach confirm the reality of its use in modern radio electronic systems for various purposes.

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