THE MATHEMATICAL MODELING OF COORDINATE DETERMINATION OF ACOUSTIC SIGNALS WITH PRIORITY PLACEMENT OF MICROPHONES

Bohdan Trembach[1], Rostyslav Trembach [2], Mykhailo Mykhailyshyn[3], Volodymyr Savkiv[4], Roman Mykhailyshyn[5]

[1] *Lviv Polytechnic National University, Bandery str 28 a., Lviv, Ukraine; trembach.bogdan@gmail.com*
[2] *Ternopil National Ivan Puluj Technical University, Rus'ka str. 56, 46001, Ternopil, Ukraine; trb@tntu.edu.ua*
[3] *Ternopil National Ivan Puluj Technical University, Rus'ka str. 56, 46001, Ternopil, Ukraine; mms@ukr.net*
[4] *Ternopil National Ivan Puluj Technical University, Rus'ka str. 56, 46001, Ternopil, Ukraine; v.b.savkiv@gmail.com*
5 Ternopil National Ivan Puluj Technical University, Rus'ka str. 56, 46001, Ternopil, Ukraine; mykhailyshyn@tntu.edu.ua

Abstract: The structural model of the spatial identification of sources of acoustic signals in Cartesian coordinates of a two-dimensional Hemming space with the priority placement of microphones as receivers of acoustic signals is proposed. [2] Examples of analytical calculations of the system characteristics of the hardware and time complexity of the correlation system based on a certain number of microphones and the corresponding number of interrelations are presented. The structural solutions of the hardware special processor implementation of such a class of multichannel devices for recognition and identification of types and the spatial location of sources of acoustic signals are developed. It is shown the possibility of using such a class of devices in the field of special military equipment.

Keywords: acoustic signals, correlators, special processors, Hemming space.

1 Introduction

The works [1], set forth the principles and theoretical base of the method of location finding, identification of the spatial angle and angular-position measurement of acoustic signal sources (ASS) based on two acoustic signal receivers (ASR). The method is characterized by finding the angle β between the perpendicular drawn from middle point of the acoustic base, and the line traced between middle point of the acoustic base and the source point (Figure 1) [1], [2]:

$$\sin\beta = \sin(NDO) = \frac{(t_2 - t_1)\times C}{L} = \frac{\Delta t \times C}{L}, \tag{1}$$

where: c - the speed of sound in the atmosphere;
t_1 and t_2 - periods of time at which the acoustic waves cover the distance from the source to the first and second acoustic signal receivers respectively;
Δt - time difference in audio signal registration by first and second sound receivers
L - length of acoustic base.

Multichannel digital correlator (MDC) [2] structure can be improved by means of a special arrangement of ASR beyond the demarcation line when one of ASR is preferentially placed closer to the demarcation line than other ASR, as shown in Figure 2.

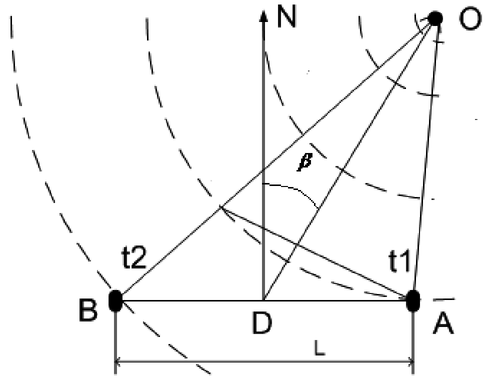

Fig. 1 Acoustic base elements arrangement: A, B - microphones; O - sound source

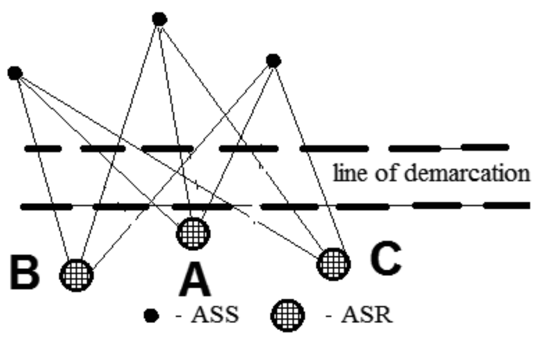

Fig. 2 Examples of priority arrangement of one the ASR beyond the ASR and ASS demarcation line

Figure 2 shows that the length of AS distribution from ASS in this case, is the lowest for ASR A, which makes it possible to reduce the number of necessary correlators in the MDC structure to two. Moreover only priority ASR A correlator will include one block of delay register (BDR), and the number of accumulating memory items is reduced to two. The structure of the optimized MDC is shown in Fig. 7.

As shown in Fig. 3, compared with the principles of the correlation processing of ASS signal at random spatial arrangement of ASR in optimized MDC structure due to given priority spatial positioning of one of ASR, the hardware complexity of microelectronic components can be reduced, which results in:

1) the number of BDR is reduced from three to one;
2) the number of integrators (I) is reduced from the three stages to two, plus one;
3) such MDC structure has a high regularity and many similar utilities that significantly simplifies its design and implementation on PLIC chip .

When processing software and hardware implementation of analytical expression of definition integrated assessment of correlation by expression it has been found that this method is cumbersome and not effective, as multiplicative correlation algorithm requires alignment of signals $x_i(t)$ and $x_j(t)$ as well as performing their multiplication and accumulation taking into account ± signs.

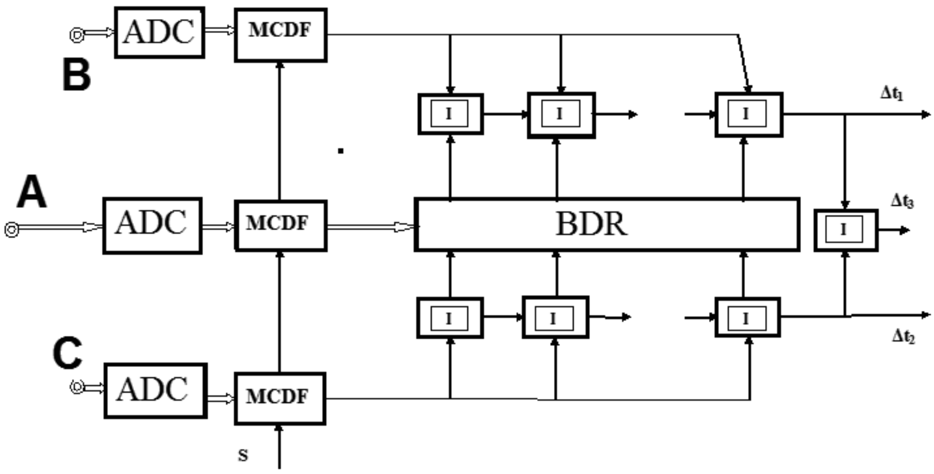

Fig. 3 The structure of the optimized MDC

Multiplicative correction of digitized AS values is characterized by low information content as with the existence of zero values in centered codes x_i and x_j out of *n* – bit sample more than 30 – 40% products are zero, which significantly reduces the information value of multiplicative correlator with respect to, for example, structural and modular ones according to expressions (2) and (3) [3].

$$C_{xx}(j) = \frac{1}{n}\sum_{i=1}^{n}(x_i - x_{i+j})^2 \ ; \tag{2}$$

$$G_{xx}(j) = \frac{1}{n}\sum_{i=1}^{n}| x_i - x_{i+j} | . \tag{3}$$

Analysis of analytical expressions of structural (2) and modular (3) correlation functions shows that the latter is characterized by much simpler algorithm with respect to the expression (3), which determines the feasibility and effectiveness of the module correlation for MDC implementation.

Fig. 4 shows an example of the correlation interaction of two AC timebase deflections according to the module correlation function $C_{xx}(j)$.

Fig. 5 [3] shows the characteristics of the $C_{xx}(j)$ function at discrepancy and concurrence of signal-wave envelopes x_i and x_{i-j} at a certain time, i.e. cross-correlation modular function verges towards "0" when signal-wave envelopes x_i and x_{i-j}, concur at τ moment of time.

The application of module correlation function in the system of ASS monitoring and spatial parameters identification in the event of priority placement of ASR beyond demarcation line requires an additional introduction into MDC structure certain differentiating units (D) between ASR and ADC inputs, as shown in Fig. 6.

The stated analysis of existing systems of recognition and identification of ASS and ASR spatial distribution allows us to ascertain that the use of multiplicative correlation and chaotic spatial distribution of ASS and ASR is not effective enough in the design of PLIC-based software and hardware special processors [3].

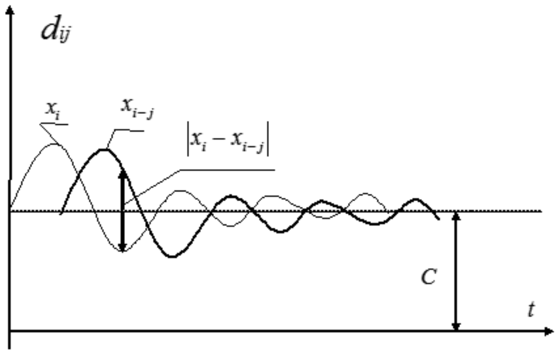

Fig. 4 x_i and x_{i-j} signals timing interaction at calculation of module correlation $C_{xx}(j)$:
C - constant of amplitude signal shift

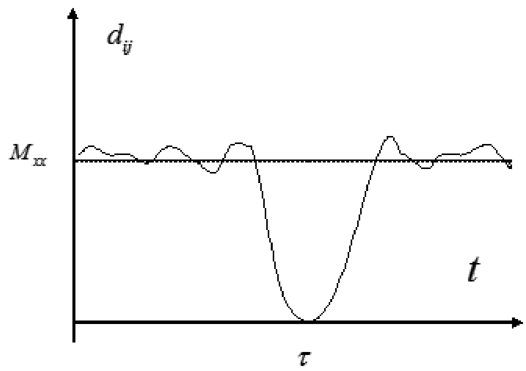

Fig. 5 Timing performance of module function of correlationv

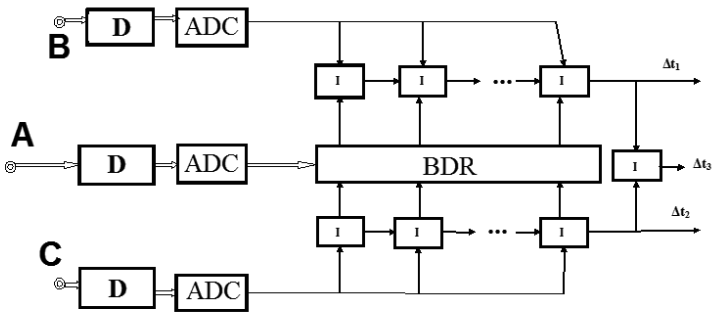

Fig. 6 MDC structure based on integrated calculation of module correlation function *I* and differentiator *D*

The proposed optimized structure of multichannel digital correlator with priority spatial placement of one of ASR microphones beyond the line of demarcation with ASS and application of module correlation function for acoustic signal processing can significantly simplify the calculation algorithm, reduce hardware complexity of correlator and enhance its performance, thus justifying feasibility and effectiveness of these solutions at establishing ASS monitoring system and implementation of PLIC-based special microelectronic processors.

2 Main part

The problem of identifying the spatial location of the DAS belongs to the class of problems in the theory of pattern recognition in the Hamming space.

Pattern recognition information technology in the Hamming space is based on the processing and transformation of signals presented in a discrete form, which include: algebraic, correlational, structural, spectral, geometric, fuzzy sets, statistical, spatially related processes, etc.[5]

The analytics of known methods of pattern recognition are formalized by the following functionals:

$d_{i\,j}$ – estimation of the Euclidean distance between the i and j objects;

$\chi_{i\,\kappa}$ – a discrete value of the κ sign of i object;

$\chi_{j\,\kappa}$ – a discrete value of the κ sign of j object;

υ – the number of features that describe the objects.

According to the provisions of cluster analysis, it is determined that the estimate of the Euclidean distance between objects in the Hamming space for the whole set of features describing classified objects is some value $d_{i\,j}$, which is determined by the expression:

$$d_{ij} = \sum_{k=1}^{k} | x_{ik} - x_{jk} | \tag{4}$$

and satisfies the following axioms:

1) $d_{i\,j} > 0$ (the positivity of the Hamming distance);
2) $d_{i\,j} = d_{ji}$ (symmetry);
3) $d_{i\,j} + d_{ji} > d_{\kappa}$ (triangle inequality);
4) $d_{i\,j} \neq 0$ то $i \neq j$ (non-identical objects);
5) $d_{i\,j} = 0$ то $i = j$ (inseparability of identical objects).

In addition to the linear estimation of the Euclidean distance (4), a quadratic estimate of the species is used:

$$d_{ij} = \sum_{k=1}^{k} (x_{ik} - x_{jk})^2 . \qquad (5)$$

This estimate gives a quadratic increase in information and accuracy of object class boundary recognition. That is equivalent to a estimated value of the Euclidean distance according to the expression

$$d_{ij} = \sum_{k=1}^{k} v_k \left| x_{ik} - x_{jk} \right|,$$

where v_k - estimated function.

An example of a estimated value of the Euclidean distance is Minkowski's step distances, in which some numbers "p" are used

$$d_{ij} = (\sum_{k=1}^{k} v_k \left| x_{ik} - x_{jk} \right|)^{\frac{1}{p}} . \qquad (6)$$

The marginal estimate of such Euclidean distance is the estimate of the "Manhattan distance" when $p \to \infty$, also called dominance or sup-metric and is calculated by the expression

$$d_{ij} = (\sum_{k=1}^{k} v_k \left| x_{ik} - x_{jk} \right|)^{\frac{1}{\infty}} .$$

Fundamentally different from the given Euclidean distance metrics in the Hamming space is the Mahalanobis metric, which is determined by the expression

$$d_{ij} = (X_i - X_j)^T \times S^{-i} (X_i - X_j) ,$$

where X_i and X_j – the corresponding vectors of the columns of the variable attributes of the i-th and j-th objects; the symbol T defines the vector transposition operation, and the symbol S defines the group variance-covariance matrix.

Thus, when the correlations between the variables i - th and j - th objects are equal to zero, the Mahalanobis distance is equivalent to the Euclidean distance.[5]

The analysis of theoretical foundations of pattern recognition based on Euclidean distance estimates in Hemming space allows us to state the following:

1) known methods are highly specialized and problem-oriented and are not characterized by versatility;

2) the most general Hamming distance estimates are based on the calculation of the covariance and statistical characteristics of the features of the i-th and j-th objects;

3) known applications of pattern recognition methods in the Hemming space apply binary values of the vectors of the signs of the i-th and j-th objects of type "0" and "1", which implies the use of correlation analysis on the basis of sign-correlation function:

$$H_{ij} = \frac{1}{n} \sum_{i=1}^{n} sign(\overset{o}{x}_i) \times sign(\overset{o}{x}_j),$$

where $sign(x_i) = \begin{cases} +1, at\ \overset{o}{x}_i \geq 0 \\ -1, at\ \overset{o}{x}_i \langle 0 \end{cases}$; $sign(x_j) = \begin{cases} +1, at\ \overset{o}{x}_j \geq 0 \\ -1, at\ \overset{o}{x}_j \langle 0 \end{cases}$;

$\overset{o}{x}_i = x_i - M_x$; $\overset{o}{x}_j = x_j - M_j$; $M_i = \frac{1}{n}\sum_{i=1}^{n} x_i$; $M_j = \frac{1}{n}\sum_{i=1}^{n} x_j$.

Significant expansion and enhancement of the pattern recognition efficiency in the Hamming space can be achieved by applying different discrete estimates of the character correlation x_i and y_i binary multi-bit Rademacher bases.

A two-dimensional Hamming space given by a lattice with two-dimensional nodes can be represented in Cartesian (Fig. 7) and polar coordinates (Fig. 8).

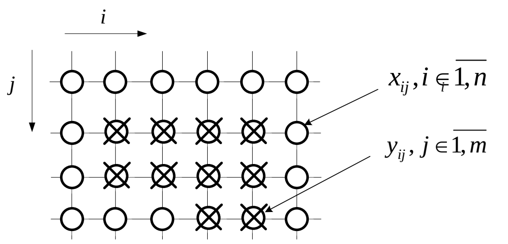

Fig. 7 Information nodes of two-dimensional Hemming space

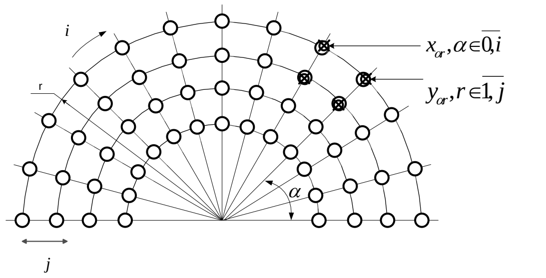

Fig. 8 Two-dimensional Hamming space in polar coordinates

The solution of the problem of pattern recognition in two-dimensional Cartesian Hamming space (see Fig. 7) is performed according to the Euclidean distance estimate

$$d_{ij} = \frac{1}{n \cdot m} \sum_{i=1}^{n} \sum_{j=1}^{m} \left| x_{ij} - y_{ij} \right|,$$

where n, m - the corresponding number of knots of the Hemming space horizontally and vertically.

The solution of the problem of pattern recognition in two-dimensional polar Hamming space is performed according to the expression [5]

$$d_{ij} = \frac{1}{\alpha \cdot r} \sum_{i=0}^{\alpha} \sum_{j=0}^{r} \left| x_{ij} - y_{ij} \right| \cdot$$

These algorithms differ in the wau that in Cartesian coordinates the accuracy of calculations and discretes between nodes of the Hemming space are the same, and in polar coordinates the accuracy of calculations decreases as the radius characteristic () increases.

In pattern recognition, the Hamming distance between the characteristics of the objects according to the Euclidean metric in the linear space according to expression (7) was applied effectively.

$$d_{ij} = \frac{1}{n} \sum_{i=1}^{n} | x_i - y_i |, \qquad (7)$$

where x_i , y_i - digital object feature codes.

The application of such a metric can be performed in code systems of various theoretical and numerical bases, in particular in Unitary, Rademacher and Krestenson, which give rise to code systems of unitary, binary and modular residuals.

The most widely used in our time is the Rademacher basis, which is based on the presented characteristics (in the case under study) of binary acoustic signals *n* – bit codes x_i and y_i , which are formed at a sampling interval over time Δt at the outputs of two ADC.

Formalization of the algorithm for determining the integral is differential result of processing of acoustic signals is realized according to the following sequence of operations on binary codes x_i and y_j :

1) record digital codes x_i and y_i in according *n* – bit memory registers on D–triggers, and direct outputs are formed by direct binary codes x_i and y_i , and inverse outputs are formed on the inverted outputs of the D - triggers of the memory registers $\overline{x_i}$ and $\overline{y_i}$:

$$P_{11} := x_i ,\ P_{12} := \overline{x_i} ,\ P_{21} := y_i ;\ P_{22} := \overline{y_i} ;$$

2) parallel operations of adding the formed lines are performed x_i , y_i and inverse $\overline{x_i}$, $\overline{y_i}$ codes in *n+1* – bit binary adders according to expressions:

$$S_{i1} = x_i + (\overline{y_i} + 1);\ S_{i2} = y_i + (\overline{x_i} + 1),$$

where addition of "1" is performed to ensure the addition operations in adders and S_{i2} above the direct and complementary codes;

3) analysis of transfers on the outputs of adders S_{i1}, S_{i2}, moreover, if there is a transfer of a unit in one of the adders, it indicates the fact of subtracting a smaller number from a larger one:

$$x_i \rangle y_i ;\ (x_i + \overline{y_i}) = Z_i ;$$
$$x_i \langle y_i ;\ (\overline{x_i} + y_i) = \overline{Z}_i ,$$

where Z_i – the result of determining the difference $|x_i - y_i|$ in direct code, $\overline{Z}_i$ – respectively in the complementary binary code;

4) Z_i value obtained from the output of the multiplexer, which performs the following operation:

$$\left.\begin{matrix} S_1 = 1 \\ S_2 = 0 \end{matrix}\right\} S_1 \vee S_2;\ \sum := \sum + Z_i ;$$

where S_1, S_2 – the bits of hyphenation in the higher digits of difference adders, at the outputs of which codes are formed Z_i and $\overline{Z}_i$, $\sum$ – integrating $n + \log_2 k$ – bit binary adder, *k* – the number of accumulations of the sum of difference codes Z_i ;

5) integrative accumulation of the sum of modular differences according to the expression

$$d_{ij} = \sum_{i=1}^{n} Z_i \cdot$$

Implementation of the described algorithm for determining the integral - difference estimation of the Hamming distance between digital values of acoustic signals x_i and y_i in the Rademacher basis is illustrated by the following structural graph, which is shown in Fig. 9.[5]

$$
\left.\begin{array}{l}
x_i \Rightarrow \begin{matrix}1\\0\\\dots\\1\\0\\1\end{matrix} \Rightarrow \overline{x}_i \begin{matrix}0\\1\\\dots\\0\\1\\0\end{matrix} \Rightarrow \begin{matrix} x_i+\overline{y}_i \to S_1 \\ 1+0+\ 0\\ 0+0+\ 0\\ \dots+\dots+\ \dots\\ 1+0+\ 0\\ 0+1+\ 0\\ 1+0+\ 1\end{matrix} \Rightarrow \\
y_i \Rightarrow \begin{matrix}1\\1\\\dots\\1\\0\\1\end{matrix} \Rightarrow \overline{y}_i \begin{matrix}0\\0\\\dots\\0\\1\\0\end{matrix} \Rightarrow \begin{matrix} y_i+\overline{x}_i \to S_2 \\ 1+0+\ 0\\ 1+1+\ 0\\ \dots+\dots+\ \dots\\ 1+0+\ 0\\ 0+1+\ 0\\ 1+0+\ 1\end{matrix} \Rightarrow
\end{array}\right\} Z_i \Rightarrow \sum_{i=1}^{n} Z_i = d_{ij}
$$

Fig. 9 Structural graph of the algorithm for determining the integral - difference code of the Hamming distance Euclid linear metric

When implementing such an algorithm (Fig. 9), the minimum result is obtained d_{ij} (approaching to zero) indicates a high level of AS similarity and a corresponding close to +1 correlation level.

Accordingly, the increase in valuation d_{ij} indicates a low similarity of acoustic signals and close to "0" coefficient of correlation.

3 Results of the investigation

The application of multiple autonomous systems of parallel direction finding of acoustic signal sources with respectively small number of nodes in the Hamming space allows to significantly reduce the accuracy requirements of the digital representation of values $\Delta t_1, \Delta t_2$ and Δt_3 [6].

The required memory for tactical representation of coordinates of the acoustic signal source at $i \in \overline{1,256}$ and $j \in \overline{1,256}$ equals 256 Kbytes.

Generalized chart of acoustic signal processor operation in the Hamming distance based on the modular correlation function is shown on Figure 10.[6]

The input to the simulation is the coordinates of the triangle locations of the sound receivers *A, B, C, v* is the speed of sound constant. Denote $A(X_A, Y_A)$, $B(X_B, Y_B)$, $C(X_C, Y_C)$. There is an acoustic signal source that we will mark $O(X, Y)$. Coordinates $O(X, Y)$ remain unknown and need to be found (Fig. 11).

Let the source of the acoustic signal produce sound that is captured at the observation points. The thing is to capture this sound at the point of observation, which is closest to the signal source. The time at which the sound overcame O to A is unknown. Let's mark it t_A. The next sound-recording observation point will be, for example, point B (or C). Observers can only record the time difference between sound arrival to point A and point B lets mark this difference Δt_{BA}. Therefore, the time for the sound to pass from point O to point B will be $t_A + \Delta t_{BA}$. Similarly, there is a time difference between C and, for example, A – Δt_{CA}. Then the sound will come to point C in time $t_A + \Delta t_{CA}$. Values Δt_{BA} i Δt_{CA} – know, t_A – unknown. We know that the path that will pass the sound in time t equal $v_s \cdot t$.

So $|OA| = v_s t_A;\quad |OB| = v_s(t_A + \Delta t_{BA});\quad |OC| = v_s(t_A + \Delta t_{CA}).$

Finding the distance between two points:

$$(x - x_A)^2 + (y - y_A)^2 = v_s^2 t_A^2;$$
$$(x - x_B)^2 + (y - y_B)^2 = v_s^2(t_A + \Delta t_{BA})^2 = v_s^2(t_A^2 + 2t_A\Delta t_{BA} + \Delta t_{BA}^2);$$
$$(x - x_C)^2 + (y - y_C)^2 = v_s^2(t_A + \Delta t_{CA})^2 = v_s^2(t_A^2 + 2t_A\Delta t_{CA} + \Delta t_{CA}^2).$$

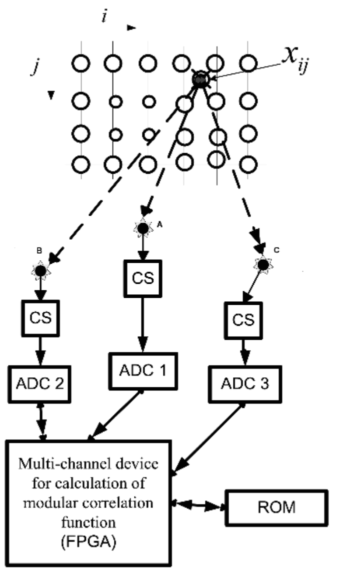

Fig. 10 Basic structure of digital special processor for correlation processing of acoustic signals in the Hamming distancev

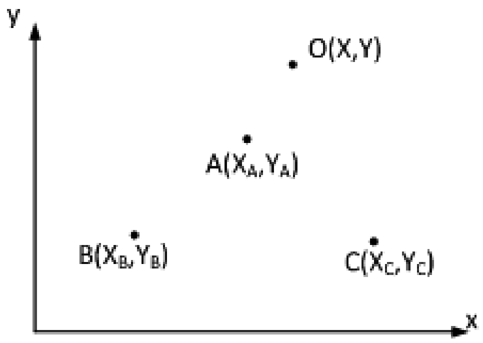

Fig. 11 Coordinates of acoustic signal sources (A, B, C) and acoustic signal receivers O

Denote $X_{AB} = x_A^2 - x_B^2 + y_A^2 - y_B^2 + v_s^2 \cdot \Delta t_{BA}(2t_A + \Delta t_{BA})$,

$$X_{AC} = x_A^2 - x_C^2 + y_A^2 - y_C^2 + v_s^2 \cdot \Delta t_{CA}(2t_A + \Delta t_{CA}),$$

$$\tilde{X}_{AB} = x_A^2 - x_B^2 + y_A^2 - y_B^2 + v_s^2 \cdot \Delta t_{BA} \quad \tilde{X}_{AC} = x_A^2 - x_C^2 + y_A^2 - y_C^2 + v_s^2 \cdot \Delta t_{CA}.$$

Then

$$X_{AB} = \tilde{X}_{AB} + 2v_s^2 \cdot \Delta t_{BA} \cdot t_A, \quad X_{AC} = \tilde{X}_{AC} + 2v_s^2 \cdot \Delta t_{CA} \cdot t_A.$$

Denote $Z_N = 2[(x_A - x_B)(y_A - y_C) - (x_A - x_C)(y_A - y_B)]$.

Then

$$x = \frac{\tilde{X}_{AB}(y_A - y_C) - \tilde{X}_{AC}(y_A - y_B)}{Z_N} + \frac{2v_s^2 \cdot t_A}{Z_N}\left[\Delta t_{BA}(y_A - y_C) - \Delta t_{CA}(y_A - y_B)\right],$$

$$y = \frac{\tilde{X}_{AC}(x_A - x_B) - \tilde{X}_{AB}(x_A - x_C)}{Z_N} + \frac{2v_s^2 \cdot t_A}{Z_N}\left[\Delta t_{CA}(x_A - x_B) - \Delta t_{BA}(x_A - x_C)\right].$$

We introduce the notation:

$$a = \frac{\tilde{X}_{AB}(y_A - y_C) - \tilde{X}_{AC}(y_A - y_B)}{Z_N}; \quad b = \frac{2v_s^2}{Z_N}\left[\Delta t_{BA}(y_A - y_C) - \Delta t_{CA}(y_A - y_B)\right];$$

$$c = \frac{\tilde{X}_{AC}(x_A - x_B) - \tilde{X}_{AB}(x_A - x_C)}{Z_N}; \quad d = \frac{2v_s^2}{Z_N}\left[\Delta t_{CA}(x_A - x_B) - \Delta t_{BA}(x_A - x_C)\right].$$

Then $x = a + b \cdot t_A$; $\quad y = c + d \cdot t_A$.

Substitute this solution into the first equation and obtain the equation for finding t_A

$$t_A = \frac{-[b(a - x_A) + d(c - y_A)]}{b^2 + d^2 - v_s^2} \pm$$

$$\pm \frac{\sqrt{v_s^2[(a - x_A)^2 + (c - y_A)^2] - [b(c - y_A) - d(a - x_A)]^2}}{b^2 + d^2 - v_s^2}.$$

To simulate the algorithm for calculating the coordinates of the sound source, we use MathCAD 15:

ORIGIN:= 0

Coordinates of points (x,y)

$A := (0\ \ 250)$, $B := (-500\ \ 0)$, $C := (500\ \ 0)$

The difference in the timing of signals

$\Delta t\,BA_i := i \cdot 2$, $\Delta t\,CA_j := j \cdot 2$,

$i := 0..33$, $j := 0..33$.

Speed of sound

$V := 333$.

$$X_{AB_i} := X_A^2 - X_B^2 + Y_A^2 - Y_B^2 + V^2 \cdot \left(\Delta t\,BA_i\right)^2$$

$$X_{AC_j} := X_A^2 - X_C^2 + Y_A^2 - Y_C^2 + V^2 \cdot \left(\Delta t\,CA_j\right)^2$$

$$ZH := 2\left[(X_A - X_B)\cdot(Y_A - Y_C) - (X_A - X_C)\cdot(Y_A - Y_B)\right]$$

$$a_{i,j} := \frac{X_{AB_i}\cdot(Y_A - Y_C) - X_{AC_j}\cdot(Y_A - Y_B)}{ZH}$$

$$b_{i,j} := \frac{2\cdot V^2}{ZH}\cdot\left[\Delta t\,BA_i \cdot (Y_A - Y_C) - \Delta t\,CA_j \cdot (Y_A - Y_B)\right]$$

$$c_{i,j} := \frac{X_{AC_i}\cdot(X_A - X_B) - X_{AB_j}\cdot(X_A - X_C)}{ZH}$$

$$d_{i,j} := \frac{2\cdot V^2}{ZH}\cdot\left[\Delta t\,CA_i \cdot (X_A - X_B) - \Delta t\,BA_j \cdot (X_A - X_C)\right]$$

$$t01_{i,j} := \frac{-\left[b_{i,j}\cdot\left(a_{i,j} - X_A\right) + d_{i,j}\cdot\left(c_{i,j} - Y_A\right)\right]}{\left(b_{i,j}\right)^2 + \left(d_{i,j}\right)^2 - V^2};$$

$$t02_{i,j} := \frac{\sqrt{V^2\cdot\left[\left(a_{i,j} - X_A\right)^2 + \left(c_{i,j} - Y_A\right)^2\right] - \left[b_{i,j}\left(c_{i,j} - Y_A\right) - d_{i,j}\left(a_{i,j} - X_A\right)\right]^2}}{\left(b_{i,j}\right)^2 + \left(d_{i,j}\right)^2 - V^2}$$

$$t0_{i,j} := t01_{i,j} + t02_{i,j},\quad X0_{i,j} := a_{i,j} + b_{i,j}\cdot t0_{i,j},\quad Y0_{i,j} := c_{i,j} + d_{i,j}\cdot t0_{i,j}.$$

$$Xp := \left(X_A\ \ X_B\ \ X_C\right)^T,\quad Yp := \left(Y_A\ \ Y_B\ \ Y_C\right)^T.$$

The simulation results are presented in Figure 12.

4 Conclusions

The characteristics of the algorithms for determining the Hamming distance according to existing metrics according to non- estimated and estimated of the quadratic Euclidean distance of the Manhattan dominance, Sup - and Mahalanabis metrics are systematized and investigated.

This method of representing and encoding image characteristics greatly simplifies computational complexity and increases the processing speed of data. The simplest Hamming distance estimation algorithm is implemented according to the linear Euclidean distance by representing the characteristic x_i and y_i in Rademacher bases.

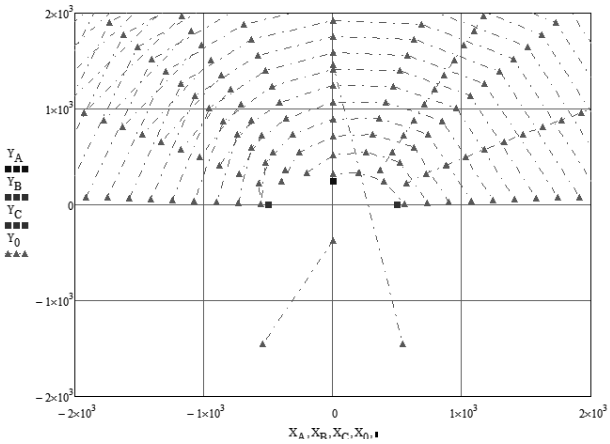

Fig. 12. The simulation results

Formalized structures and arrays of information nodes of one-dimensional and two-dimensional Hamming spaces given in Cartesian and polar coordinates.

The mathematical foundations for the calculation of the coordinate of the acoustic signal source have been developed, which allow to clarify the spatial determination of the location of the acoustic signal source relative to the Cartesian Hemming space node.

References

1. Kochan, R.V., Trembach, B.R. (2016). Approach of distributive automatic sound ranging system based on cellular communication. *Modern information technologies in the sphere of security and defense*, *1*(25), 59 – 63.

2. Trembach, B., Kochan, R., Trembach, R. (2016). Multiplex digital correlator with high priority deployment of one of the acoustic signal receivers, *Scientific Journal of TNTU*, *4*(84), 99-104. Retrieved from http://visnyk.tntu.edu.ua/pdf/84/339.pdf

3. Trembach B., Kochan R., Trembach, R. (2017). Methods of structural design optimization of software hardware problem identification of the spatial parameters of acoustic signals sources, *Scientific Journal of KNU*, *1*(245), 136-139. Retrieved from http://lib.khnu.km.ua/pdf/visnyk_tup/2017/(245)2017-1-t.pdf

4. Trembach, B., Kochan, R., Trembach, R. (2017). The method of correlation investigation of acoustic signals with priority placement of microphones, *Experience of Designing and Application of CAD Systems in Microelectronics*, Proceedings of the 14th International Conference. Polyana, Ukraine.

5. Trembach, B. (2017). Method of spatial identification of acoustic signals source in the two-dimensional Hemming space. *Visnyk Natsionalnoho universytetu "Lvivska politekhnika". Serie: Kompiuterni systemy ta merezhi*. *881*. 166-177. doi: org/10.23939/csn2017.881.166

6. Trembach, B., Kochan, R., Trembach. R. (2018). The method of correlation investigation of acoustic signals with priority placement of microphones. *Advances in Science, Technology and Engineering Systems Journal*, 3(1), 412-417. Retrieved from https://astesj.com/v03/i01/.