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Reliability of the calculation results in the optical-electronic holographic computing systems

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ABSTRACT

The problems of investigation and calculations results reliability (CRR) evaluation in holographic computing systems are considered. The analysis of the existing approaches to estimation of CRR has been overtaken. A new method of CRR is proposed. The evaluation of CRR in the systems with single and coded correlation responses regarding processing of the images and the images Fourier spectrum has been performed. The simulation results are submitted.

Keywords: holographic, system, calculation results reliability, image, identification.

INTRODUCTION

One of the important problems, arising in the optical-electronic holographic computing systems (HCS) investigation is estimation of calculations results reliability, i.e. the probability of correct objects classification and determination of their coordinates.

The analysis shows, that HCS can be divided into two main classes - of invariant and normalised images processing. In the first HCS class the effect of deforming parameters on the image (rotation, change of scale and others) is reduced to equivalent shifts. To such systems belong space-dependent filtration systems [1,2] and some other [3,4]. The reference images are previously aligned, are presented in the special coordinates systems, then the identification is executed. To the second class are to be attributed optical-electronic systems[5], analogical optical processors on the basis of the special holographic filters[3] and others. The main feature of such HCS is that before the stage of the identification the images are normalised and reduced to reference on the parameters of angular orientation, scale, etc.

In this paper the problems of investigation and calculations results reliability evaluation in HCS are considered. The analysis of the existing approaches to estimation of calculations results reliability in optical-electronic holographic systems (section 1) has been overtaken. A new method of calculations results reliability in HCS (section 2) is proposed. The calculations results reliability evaluation in the systems with ordinary and coded correlation responses regarding processing of the images and the images Fourier spectrum (IFS) has been performed. The simulation results and their analysis are submitted (section 3).

The presented materials are based on the results of the theoretical and experimental researches of the images angular orientation influence on the signal and noise distribution in the correlation field of various classes systems, executed by the authors[6], as well as developed models of signal and noise in the correlation field of HCS, analytical evaluation of a signal to noise ratio taking into account the influence of the angular orientation of the reference images, as the used holographic filters[7].

1. THE APPROACHES TO CALCULATION RESULTS RELIABILITY EVALUATION IN THE OPTICAL-ELECTRONIC SYSTEMS

It is knows[8], that the general probability P_c of the correct classification in the system is a mathematical expectation of the objects correct classification probabilities P_i:

$$P_c=\sum_{j=1}^{M}\alpha_i P_j=\alpha_1 P_1+\alpha_2 P_2+\ldots+\alpha_q P_q+\ldots+\alpha_M P_M \tag{1}$$

where α_i - is a prior probability of the i - object occurrence; M - the objects number.

Let $\alpha_i = 1/M$. Then for evaluation of classification reliability P_c, as follows from expression (1), it is necessary previously to define the probability P_i of the objects correct classification.

There are various approaches in evaluation of probabilities P_i. Usually these probabilities are evaluated by the ratio of the correct solutions number to the total of investigated situations for each object. This method may be used when studying the no high quality images processing systems. But such an approach to the reliability classification evaluation in more complicated systems results in an extremely large volume of necessary investigations. For example, for evaluation of the correct classification probability using the method, based on the concept of allowable transformations of reference images, the study of the typewritten marks several tens of thousands was necessary[8].

In conformity with the other approaches[9], a prior knowledge of the noise laws distribution in the realisation of the signal and noise is necessary. However, in optical-electronic holographic computing systems the determination of these laws is a rather difficult problem in connection with the large variety of the processable images and the two-dimensional character of the signal and noise distribution.

The following approach to the probabilities P_i evaluation[10] is simpler, and is based on similarity measures minimum differences calculation as which correlation coefficients are used:

$\min\Delta_{ij}= Q_{ii}-\max Q_{ij}$, where Q_{ii}, Q_{ij} are the measures of identified image similarity of the with and of another standards. Thus, the probability P_i is evaluated as probability that $\min\Delta_{ij}>0$: $P_i=P(\min\Delta_{ij}>0)$.

However, direct application of this method to calculations results reliability evaluation in HCS is also inconvenient. Firstly, the specified degrees of similarity do not take into account the specific character of the systems, built on other principles - the coherent optics and holography, therefore it will be required essential additional systems hardware and increase of processing information time expenditures, caused by the necessity of correlation coefficients calculation. Secondly, the law of measures similarity differences distribution in holographic systems is unknown. And thirdly, the proposed systems are oriented to processing the images of another class and are intended for the resolving of more complicated problems - the object classification of any complexity and determination of their space coordinates.

Thus, the existing approaches to evaluation of calculations results reliability are not appropriate to be used for HCS. In these systems, based on principles of the coherent optical filtration, the unknown image should be referred to one of the standards, each of which is given as in the form of a holographic filter. Therefore, the probabilities of correct classification P_i will be defined basically by the properties of the resulting correlation field (by its signal - noise ratio).

2. A NEW METHOD OF CALCULATION RESULTS RELIABILITY EVALUATION IN THE OPTICAL-ELECTRONIC HOLOGRAPHIC SYSTEMS

The method of minimal similarity measures differences is offered, which permits to evaluate the probabilities of objects correct classification P_i in optical-electronic holographic computing systems. The feature of this method consists in the application of a new measures of similarity, taking into account the specific character of HCS. In a such systems the P_i probability will be defined by the properties of the correlation field, which is analysed by a device for pointing out the maximal intensity.

Let P_D be the detecting threshold power of the device pointing out the maximal intensity. If the power of the light flow, dropping on the photoreceiver of the device is equal to or exceeds the P_D level, the detecting circuit generates an electrical signal of a high level, which will be an feature of the objects identification. Otherwise the object will not be identified.

Thus, the probability of correct classification of an i-object can be determined as probability, that the maximum power of noise $\max\{P_N\}$ in a correlation field will be less that the detecting threshold level:

$$P_i=P(P_D>\max_{\Omega}\{P_N\})=P[P_D-\max_{\Omega}\{P_N\}]>0,$$

where Ω - the correlation field area.

Hence, in optical-electronic holographic systems as a measure of similarity Q_{ii} can be accepted the parameter P_D, which is equal or proportional to a maximum on the correlation field area value of a additive mix of the signal and noise: $\max\{P_{SN}\}$ The significance $P_{SN}=I_{SN}S_{PD}$, where S_{PD} - the area of photoreceiver, I_{SN} - intensity of a additive mix of the signal and noise. As the I_{SN} can depend on angular orientation Θ_o of the analysed image, it is reasonable to consider the general case, i.e. to accept as a degree Q_{ii} of similarity the minimum to the given decorrelated factor the value of P_{SN}:

$$Q_{ii}=\max_{\Omega}\{\min_{\Theta_O}\{P_{SN}\}\}$$

As a unit of similarity Q_{ij} can be accepted the maximum on the correlation field area power of the light flow, containing noise:

$$\max_{j\neq 1} Q_{ij}=\max_{\Omega}\{\max_{i\neq 1}\{P_N\}\}.$$

The difference of the specified degrees of similarity will be equal:

$$\min_{j\neq 1}\Delta'_{ij}=\min_{\Theta_O}\{\min_{j\neq 1}\Delta_{ij}\}=\max_{\Omega}\{\min_{\Theta_O}\{P_{SN}\}\}-\max_{\Omega}\{\max_{j\neq 1}\{P_N\}\}$$

Thus, the proposed measures of similarity take into account the specific character of the optical-electronic holographic computing systems. The probability of the objects correct classification will be defined by the probability, that the difference of the similarity measures will be bigger than zero:

$$P_i=P(\min_{j\neq 1}\Delta'_{ij}>0) \tag{2}$$

For direct estimation of values P_i it is necessary to justify a hypothesis about the distribution law of the $\min\Delta'_{ij}$ value. The distribution laws of the similarity unit $\max\{\max\{P_N\}\}$ and $\max\{\min\{P_{SN}\}\}$ are the compositions of the distribution laws, influenced by errors, caused by the equipment, variations of the position of the correlation maxima comparatively to the photoreceiver, irregularity of the laser beam, which follow the normal distribution law. Therefore the laws of similarity degrees distribution and, hence, the law of the distribution of their differences can approximately be considered as normal.

Taking into account the proposed measures of similarity and distribution law of their difference, the method of the correct classification probabilities evaluation will consist in following.

1. For the case of coordinate filtration is defined maximal on the area of the correlation field and minimum on image angular orientation the power of the light flow, containing signal and noise, that is:

$$\max_{\Omega}\{\min_{\Theta_O}\{P_{SN}\}\}.$$

2. For the case of noncoordinate filtration is defined the maximum under the standards and on the area of the correlation field the power of the light flow, containing only noise:

$$\max_{\Omega}\{\max_{j\neq 1}\{P_N\}\}.$$

3. The minimal difference of the similarity measures is calculated:

$$\min_{\Theta_O}\{\min_{j\neq 1}\Delta_{ij}\}=\max_{\Omega}\{\min_{\Theta_O}\{P_{SN}\}\{-\max_{\Omega}\{\max_{j\neq 1}\{P_N\}\}.$$

4. The mathematical expectation of the value $\min_{\Theta_O}\{\min_{j\neq 1}\Delta_{ij}\}$ is defined under the formula:

$$\Delta'_{ij}=(1/n)\sum_{l=1}^{n}(\min_{\Theta_O}[\min_{j=1}\Delta_{ij}])_l$$

5. The root-mean-square deviation of the value $\min_{\Theta_O}\{\min_{j\neq 1}\Delta_{ij}\}$ is calculated under the formula:

$$\sigma_{ij}=\{(1/n)\sum_{l=1}^{n}[(\min_{\Theta_O}\{\min_{j\neq 1}\Delta_{ij}\})_l-\Delta'_{ij}]^2\}^{1/2}.$$

6. The ratio of the mathematical expectation Δ'_{ij} to the root-mean-square deviation σ_{ij} of value $\min\{\min \Delta_{ij}\}$ is calculated:

$$Z_k = \Delta'_{ij}/\sigma_{ij}.$$

7. The probability P_i of correct classification with application of the probability integral tables[11] is defined:

$$P_i=(1/2\pi)\int_{-\infty}^{Zk} e^{-t/2}dt.$$

The proposed method can be applied not only for evaluation of the correct objects classification probabilities, but also for evaluation of object's coordinates correct probabilities definition.

Thus, a method for evaluation of calculations results reliability in optical-electronic holographic systems, based on applications of degree of similarity, taking into account the specific character of the given systems, and argumentation of the hypothesis about the normal law of the specified similarity measures differences distribution is proposed.

The probabilities P_i, defined on the bases of a this method, will characterise the calculations results reliability in the case of single (ordinary) correlation maxima formation at the stage of holographic filtration. We shall call such computing systems as "systems with a single responses" (SSR). An example of such type of systems is, for example, the single-channel optical-electronic system[4].

In multichannel optical-electronic computing systems[1-3,5] at the stage of objects classification the formation of coded correlation maxima in a kind of binary codes is stipulated. We shall name such systems as "system with coded responses" (SCR). The reliability of the objects classification in these systems will be other than in SSR. Let us evaluate the reliability of classification in the SCR.

3. THE RELIABILITY OF OBJECTS CLASSIFICATION IN THE HOLOGRAPHIC SYSTEMS WITH CODED CORRELATION RESPONSES

In SCR at the stage of classification are using the holographic filters, which form coded correlation responses. At the stage of optical codes reading and their transformation to electrical signals (binary codes) the different errors are possible.

Let us evaluate in advance the calculations results reliability in the systems of invariant processing, and then - in the systems of normalised processing.

Firstly, let us use the concepts of errors of the first and second types. The errors of the first type are such errors, in which an "one", in any digit will be accepted for "zero", or "zero" - for "one". Errors of the second type will be understood as errors, when the digit of a binary word an "one" will be accepted for "zero" and simultaneously in other digit from "zero" will be accepted for "one". The errors may be of any multitude.

Let the binary word consist of N digits and contain K - "ones" and J=N-K - "zeroes". As far as the errors of the first type at their occurrence will be detected at the analysis of holographic results, because of the wrong objects identification can result only errors of the second type. In this connection, for evaluation of objects correct classification probability we shall define at first the probability of occurrence of the second type errors of various multiple b_{ik}, and probability $P_{pi,k}$ of faulty objects classification at the given errors.

Then let as define directly the object correct classification probability at occurrence of various multitude errors with use of the formula of complete probability:

$$P'_i=1-P_{pi,k}=1-\sum_{i=1}^{m} \beta_{i,k}P_{pi},$$

where P_{pi} - general probability of faulty classification of i - object; m - maximum multiple of an error.

Let A be the event, which consists of the fact, that at reading of a binary word the "one" signal will be accepted for "zero" in the digit; B - event, concluded in the fact, that at reading of the same word the "zero" signal is accepted for "one" in an other of its digits; C – the event, then at reading the "one" signal was accepted for "zero" and "zero" for "one" - simultaneously in different digits of the same word, i.e. unitary error of the second type has taken place. As far as at the objects identification, the binary words are reading in parallel and independently under the digits, it's obvious that the events A and B are independent. Then under the theorem about the product of probabilities of the independent events A and B, we have that the probability of the event C, concluded in simultaneous occurrence of events A and B, is equal to P(C)=P(A)P(B). Let us assume, that $P(A) = P(B) = P_{pi}= (1-P_i)$, where P_{pi}, P_i - the probability of faulty and correct classification of the i object in case of reception of an single light response on the identified object.

Then the probability of occurrence of the event C, i.e. P(C) is nothing than a probability of occurrence of an unitary error of the second type at reading of the code of the identified object, i.e. $P(C)= \beta_{1i}$. In such case the probability of a k multiple error occurrence at reading of a code of the i object will be equal: $\beta_{ik}=(1-P_i)^{2k}$.

Let us define the probability of the i - object faulty identification as a result of various multitude errors occurrence at reading a code. Let us define the formula of the faulty identifications probability taking into account the quantitative ratio in a code of "ones" and "zeroes". Because of the wrong objects identification can result only errors of the second type, that's why the probability of the faulty identification of the i object at occurrence of the second type errors of multiple k will be defined as the relation of the undetected errors quantity $Q_{n.k}$ to the general number of possible errors $Q_{o.k}$:

$P_{pi,k} =Q_{n.k}/Q_{o.k}$.

Let us define the number of the undetected errors $Q_{n.k}$ of the second type of multiple k. Let us consider the following case. The length of a word be equal with 8 digits (N=8). We shall record a binary word as follows:

$Z=Z_8,Z_7,Z_6,Z_5,Z_4,Z_3,Z_2,Z_1$

We designate $Z_{n.o}$ - be the faulty acceptance in the n - digit of an "one" signal at reading (i.e. transition $1\rightarrow0$); $Z_{n,1}$- faulty acceptance in the n - digit of a "zero" signal for an "one" (i.e. transition $0\rightarrow1$). Let the number of "ones" in the word be K=5, J=3 – number of "zeroes", and, for example Z=10110101. Then in the word the following combinations of "unitary" errors of the second type are possible:

$Z_{8.0}Z_{7.1};Z_{8.0}Z_{4.1};Z_{8.0}Z_{2.1};Z_{6.0}Z_{7.1};Z_{6.0}Z_{4.1};Z_{6.0}Z_{2.1};Z_{5.0}Z_{7.1};Z_{5.0}Z_{4.1};Z_{5.0}Z_{2.1};Z_{3.0}Z_{7.1};$
$Z_{3.0}Z_{4.1};Z_{3.0}Z_{2.1};Z_{1.0}Z_{7.1};Z_{1.0}Z_{4.1};Z_{1.0}Z_{2.1}$

The general number of such errors is equal to $Q_{n.1}=15$. The analysis shows that $Q_{n.1}=C^1_KC^1_J$, where C^1_K,C^1_J - the number of combinations from K and J one by one.

Similarly it is possible to state, that $Q_{n.2}=C^2_kC^2_J$; $Q_{n.3}=C^3_kC^3_J$; $Q_{n.4}=C^4_kC^4_J$ and etc. That is: in general the number of errors of the second type (of multiple k), which will lead to the wrong objects identification, will be defined as follows:

$$Q_{n.k}=C^k_kC^k_J \tag{3}$$

Taking into account that the second type error of multiple k is a consequence of faulty signals acceptance simultaneously in n=2k digits of the word, the general number of errors can be defined as follows:

$$Q_{o.k}=C^n_N=C^{2k}_N \tag{4}$$

Hence, the probability of the i - objects faulty identification at occurrence of errors of multiple k taking into account the expressions (3), (4) will be equal to:

$$P_{pi,k}=Q_{n.k}/Q_{o.k}=(C^k_KC^k_J)/C^{2k}_N.$$

The general probability of the i - objects faulty identification at occurrence of the second type errors of various multiple will be defined by the following expression:

$$P_{pi}=\sum_{k=1}^{m}\{\beta_{i,k}P_{pi,k}\}=\sum_{k=1}^{m}\{(1-P_i)^{2k}C^k_KC^k_J\}/C^{2k}_N \tag{5}$$

The probability of the correct objects identification at occurrence of various multitude errors will be:

$$P'_i=1-P_{pi}=1-\sum_{k=1}^{m}\{(1-P_i)^{2k}C^k_KC^k_J\}/C^{2k}_N.$$

Then the expression for general probability of the objects correct identification in the systems will be:

$$P_k=\sum_{i=1}^{M}\alpha P'_i=\sum_{k=1}^{m}\{\alpha_i[1-\sum_{k=1}^{m}\{(1-P_i)^{2k}C^k_KC^k_J\}/C^{2k}_N]\} \tag{6}$$

Let us evaluate the classification results reliability in the systems, based on formation and analysis of images Fourier spectra (IFS). In such systems there are possible situations when two or more objects can have similar IFS and as far as the phase information detecting is lost, further operations can result in errors at the identification.

Let, for example, the M_s objects from M have the similar among themselves IFS. At identification of objects from the group with similar IFS there will take place the identification with one of them of all the other objects of this group, i.e. wrong classification will be executed. In this case the objects number, which can be recognised, will be reduced from M to $M' = M-M_s+1$. The general probability of the correct identification thus will be defined by the following expression:

$$P^c_{ko}=\sum_{i=1}^{M'} \alpha_i P'_i = \alpha_1 P'_1+\alpha_2 P'_2+\ldots \alpha_q P'_q+\alpha_{M'} P'_{M'},$$

where $q=M-M_s$ - is the number of the objects images, which have various IFS.

Thus the probability of the correct identification of the M' - object, i.e. $P'_{M'}$ will be equal to the probability of the correct identification of one of the M_s - objects. Let us consider that $P'_{M'}=P'_{q+1}$. The prior probability α_M of objects occurrence will be also equal to the prior probability of the (q+1) object occurrence.

Taking into account this one, the expression for evaluation of the general probability of the correct identification will be equal to:

$$P^c_{ko}= \alpha_1 P'_1+\alpha_2 P'_2+\ldots \alpha_q P'_q+\alpha_{q+1} P'_{q+1}=\sum_{i=1}^{q+1} \alpha_i P'_i$$

Let further that among M analysed images be present r_r groups on M_{sj} , $j=1\div r$, images with similar IFS. In such case the number of objects M', which can be classified, will be defined as: $M'=q+r_r$. The general probability of correct classification will be equal to:

$$P^c_{ko}= \sum_{i=1}^{q} \alpha_i P'_i +\sum_{j=1}^{r_r} \alpha_j P'_j=\sum_{i=1}^{M'}\{\alpha_i[1-\sum_{k=1}^{m}\{(1-P_i)^{2k}C^k_K C^k_J\}/C^{2k}_N]\} \tag{7}$$

On the basis of expressions (6), (7) there have been calculated the probabilities of objects correct classification having the following parameters: number of classified objects $M=10$, probability of the correct identification of each object $P_i=0.95$, number of "ones" and "zeros" in the code $K=J=4$, maximum multitude of errors of the second type $m=4$ and number of objects with similar IFS: $M_s=1\div4$ (at $r_r=1$).

The calculation results analysis shows, that the reliability of objects classification is identical to $M_s=1$ and makes $P=0.998$. With an increase of M_s the reliability of classification in SCR with processing IFS is reduced up to $P=0.699$ (at $M_s=4$), and in SCR of processing of the images does not change. The reliability of classification in the systems with "one" correlation responses changes from $P=0.95$ (at $M_s=1$) up to $P=0.665$ (at $M_s=4$). Thus, the reliability of the objects identification in the systems with coded correlation responses is higher, than in the systems with "one" responses. Besides, at processing of IFS are also more effective, than SSR.

CONCLUSION

There have been proposed a method of calculations results reliability evaluation in holographic computing systems, based on application of similarity measures, taking into account the specific character of this systems, and the hypothesis about the normal law of distribution of similarity measures differences. An analytical evaluation of calculations reliability in holographic computing systems has been performed, which has shown that the probability of faulty decisions in the systems with coded correlation responses is much lower (25 times) than in the systems with single responses. Besides, in HCS, based on processing of the images Fourier spectrum, the reliability of objects classification is lower, than in HCS of images processing.

REFERENCES

1.Perju V.L., Rotari S.L. Organisation of computing processes in optical-electronic holographic systems for images analysis // Semiconductor structures, radioelectronical devices and monitoring system - Kishinev: Stiinta, 1989.

2. Perju V.L. Construction of principles of multichannel optical - electronic computing systems for images processing // Proc. of the conf. "Optical image and recording environments". - Leningrad, 1990. - V.2, p.207-208.

3. Katis G.P., Perju V.L., Rotari S.L. Methods and computing means for images processing. - Kishinev: Stiinta, 1991.

4. Casasent D., Psaltis D. Position, rotation and scale invariant optical correlation. // Appl. Opt. - 1976. - Vol.15. - N7 - P.1799 - 1802.

5.Patent N 972531 (USSR), G06G9/00. An optical-electronic device for optical information processing / Perju.V.L., 1982.

6. Perju V.L. The analysis of the influence of the angular orientation of the image on the distribution of signals and noise in the correlation field of the holographic recognition systems / MOLDNIINTI. - N1226 - M91. - VINITI, N9, 1991.

7. Perju V.L. Distribution of signals and noise in the correlated field of the holographic recognition systems // Radiotechnics. - 1993. - N6.

8. Kovalevski V.A. Methods on optimal decisions in images recognition. - Moscow: Nauka, 1976.

9. Shirman J.D., Manjos V.N. The theory and engineering of processing of the radar-tracking information on a background of noise. - Moscow: Radio & svjaz, 1981.

10. Belobragina L.S., Eliseev V.K. Statistical researches of the recognition algorithm of typewritten characters. // Cybernetics.- 1967. - N5. - C.65-72.

11. Ventsel E.S. The theory of probabilities. - Moscow: Nauka, 1969.