Adaptive Suppression of Geometric Noise on an Irregular Nonstationary Photodetector Matrix Structure

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Abstract

Considering the retina of the eye as an irregular, nonstationary matrix structure, there was presented an alternative to traditional algorithms algorithm of suppression of the "geometric" noise of matrix photodetecting elements, which provides its correction at the maximum possible adaptation mode. It's proposed to use fast controlled two-dimensional low amplitude scan of photodetecting elements matrix regarding the image in order to obtain information on current parameters of photodetecting elements directly in the process of observing the object.

1. Introduction

The problems of suppressing or compensation of noises of multi-item optical transducers are relevant as a result of widespread distribution of such devices in all branches of a man’s activities. Besides under using analogs the problems are solved connected with using of visual system of a man and animals, which regard retina as irregular nonstationary matrix structure.

Creation of matrix image converters with wide specter, big dynamic range, maximal special-time resolution and high sensitivity which can have high metrological qualities is connected with a number of problems. One of the problems is a geometrical noise, which is fixed deviations of output signal value of matrix photosensitive element (PHE), caused by equal input action. The aim of geometric noise correction is obtaining of a signal of one and the same level from each pixel of photosensitive elements on conditions of their uniform illumination.

Traditional procedures of “geometric noise” suppressing based upon previous registration of images, homogeneous as for field test oscillators which further are used for calculating of coefficients and digital correction of photosensitive elements’ sensitivity, do not solve to the full extent the indicated above problem. There can be several causes for that: heterogeneity of irradiation during calibration, changing of parameters’ values during time passed after finishing of the last calibration, instability of photosensitive elements’ parameters, difficulties of making homogeneous as for field test oscillators, variations of spectral distribution and emission intensity of investigated images compared to test ones.

In the papers [3-5] a new approach to suppressing of “geometric” noise was investigated, which insures its correction in the mode of maximal possible adaptation to the conditions of measurements and potentially free from the above mentioned drawbacks. In order to get information about current parameters of photosensitive elements directly in the process of object’s surveying and only according its results it was suggested to use a quick controlled two-dimensional low-amplitude scanning of PHE-matrix with regard to the image of the object under test and corresponding digital processing of registered at the same time sequence of its displaced images.

Such scanning takes place in the process of human eyes’ functioning too, which can be considered as made by nature and unmatched according totality of characteristics biological analog of matrix image converter with ≈10⁸ photosensitive elements, dynamic range ≈ 10¹⁰, maximal sensitivity, limited by quant nature of radiation, with ability of quick adaptation to changing observation conditions.

The number of photosensitive elements in modern matrix runs up to ≈10⁶ - 10⁷, that is why the actual realization of methods of adaptive correction of “ geometric” noises based on usage of low-amplitude two-dimensional scanning needs development of mutually coordinated and efficient algorithms of scanning and digital processing algorithms of sequence of registered images.

In view of the aforesaid the aim of this paper is usage of approaches and principles of solving of the problem of geometric noise’ adaptive suppression.
2. The materials and results of the investigation

Let us state an alternative to traditional algorithm of approximate determination point of functional’s minimum, based on procedures’ hierarchy including local minimization with recursion on the model moving across the matrix, with doubling of its linear spatial scale and corresponding averagings at transition to next level of hierarchy. The algorithm makes it possible to build a row from the highest frequency spatial harmonics of “geometric” noise are restored, as last – the low-frequency ones.

1. For isolated cell of 4 photosensitive elements, with a model \( (h_{ij}, h_{i+1j}, h_{ij+1}, h_{i+1j+1}) \), under the assumption that \( h_{ij} \) is known, with the classic method of MNK we deduce:

\[
h_{i+1j} = h_i + \frac{V_{ij} (\alpha_i + \beta_{ij}) + \alpha_{ij+1}}{\alpha_i + \alpha_{ij} + \beta_{ij}} \]

\[
h_{ij+1} = h_{ij} + \frac{U_{ij} (\beta_{ij} + \alpha_{ij+1}) + \alpha_{ij}}{\alpha_i + \alpha_{ij} + \beta_{ij}} \]

2. Supposing \( i=1 \), \( j=1 \), \( h_{i1} = 0 \) and using (1), we calculate \( h_{12} \) and \( h_{21} \).

3. When \( i=1 \), \( j=2 \) and \( i=2 \), \( j=1 \), using (1), we deduce \( h_{13}, h_{23}, h_{31}, h_{32} \) correspondingly. We suppose \( h_{i1} = (h_{i0} \alpha_i + h_{i+1} \beta_{i})/(\alpha_i + \beta_{i}) \)

4. Using obtained values of \( h_{i1}, h_{i2}, h_{i3} \) (equal to i,3) we deduce the next diagonal series of values etc., up to \( h_{N1} \), as a result we get a matrix of \( b \)-coefficients, to which we give a name \( H1 \).

5. We repeat the procedures similar to (1-4), choosing as initial approximation \( h_{i3} = 0 \), \( h_{i2} = 0 \), \( h_{i1} = 0 \), and correspondingly we get matrices \( H2, H3, H4 \).

We consider the matrix \( [k_{ij}] = 0.25(H1 + H2 + H3 + H4) \) as a zero approximation for \( b \)-coefficients. Let us mark the total of the procedures 1-5 over initial matrix \( [U_{ij}], [V_{ij}], [\alpha_{ij}], [\beta_{ij}] \) with a symbol \( R \):

\[
R([U_{ij}], [V_{ij}], [\alpha_{ij}], [\beta_{ij}]) = [k_{ij}] \]

6. If a correlation of images \( [A_i], [B_i], [C_i], [\ldots] \) is made, using \( [k_{ij}] \):

\[
\tilde{A}_i = A_i - k_{ij}, \quad \tilde{B}_i = B_i - k_{ij}, \quad \tilde{C}_i = C_i - k_{ij}, \quad \tilde{\ldots} \]

and to deduce new difference values \( \tilde{U}_{ij}, \tilde{V}_{ij} \), so we get:

\[
\tilde{U}_{ij}^{(1)} = \tilde{A}_{i1} - \tilde{B}_i = U_{ij}^{(0)} + \{h_{ij}^{(0)} - k_{ij}^{(0)}\}, \quad 1 \leq i \leq N - 1, \quad 1 \leq j \leq N; \quad (3)
\]

\[
\tilde{V}_{ij}^{(1)} = \tilde{A}_{i1} - \tilde{C}_i = V_{ij}^{(0)} + \{h_{ij}^{(0)} - k_{ij}^{(0)}\}, \quad 1 \leq i \leq N, \quad 1 \leq j \leq N - 1.
\]

Using the matrices \( [\tilde{U}_{ij}^{(1)}], [\tilde{V}_{ij}^{(1)}], [\tilde{h}_{ij}^{(0)}], [\tilde{h}_{ij}^{(1)}] \), from (3) we deduce matrices \( [\tilde{U}_{ij}^{(0)}] \) and \( [\tilde{V}_{ij}^{(0)}] \).

7. We consider the photosensitive element matrix with dimensions \( N \times N/2 \), in which a group of four photosensitive elements that of the model of the previous matrix plays the part of new “averaged” photosensitive elements. For the new matrix we calculate averaged difference values \( U_{ij}^{(0)}, V_{ij}^{(0)} \) and corresponding to them weighting coefficients \( \alpha_{ij}^{(1)}, \beta_{ij}^{(1)} \) according formula:

\[
U_{ij}^{(1)} = \sum_{k=1}^{N} \alpha_{2i,2j-k} \alpha_{2i,2j} U_{ij}^{(1)} + \sum_{k=1}^{N} \beta_{2i,2j-k} \beta_{2i,2j} V_{ij}^{(1)}
\]

\[
1 \leq i \leq \frac{N}{2} - 1, 1 \leq j \leq \frac{N}{2} \]

\[
V_{ij}^{(1)} = \sum_{k=1}^{N} \beta_{2i-1,2j-k} \beta_{2i-1,2j} U_{ij}^{(1)} + \sum_{k=1}^{N} \alpha_{2i-1,2j-k} \alpha_{2i-1,2j} V_{ij}^{(1)}
\]

\[
1 \leq i \leq \frac{N}{2} - 1, 1 \leq j \leq \frac{N}{2} - 1.
\]

8. We use the procedure (2) to the matrix we got \( U_{ij}^{(0)}, V_{ij}^{(0)} \), \( \alpha_{ij}^{(0)}, \beta_{ij}^{(0)} \):

\[
R([U_{ij}^{(0)}], [V_{ij}^{(0)}], [\alpha_{ij}^{(0)}], [\beta_{ij}^{(0)}]) = [k_{ij}^{(0)}].
\]

The whole of the procedures (6-8), as a result of which corresponding “averaged” matrices of \( k \)-approximation (together with two-times less basic dimension) are deduced from matrices \( [U_{ij}^{(k-1)}], [V_{ij}^{(k-1)}], [\alpha_{ij}^{(k-1)}], [\beta_{ij}^{(k-1)}], [k_{ij}^{(k-1)}] \) of \( (k-1) \)-approximation corresponding “averaged” matrices of \( k \)-approximation (together with two-times less basic dimension), we mark with \( \tilde{G} \):

\[
\tilde{G}([U_{ij}^{(k-1)}], [V_{ij}^{(k-1)}], [\alpha_{ij}^{(k-1)}], [\beta_{ij}^{(k-1)}], [k_{ij}^{(k-1)}]) = (5)
\]

\[
= [U_{ij}^{(k-1)}], [V_{ij}^{(k-1)}], [\alpha_{ij}^{(k-1)}], [\beta_{ij}^{(k-1)}], [k_{ij}^{(k-1)}].
\]

9. Using the matrix \( [k_{ij}^{(0)}] \) as initial and the procedure (14) in series while \( k = 2, 3, \ldots (M - 1) \), we deduce the matrices \( [k_{ij}^{(2)}], [k_{ij}^{(3)}], \ldots [k_{ij}^{(M-1)}] \) with dimensions \( (N/4 \times N/4), (N/8 \times N/8), \ldots (2 \times 2) \) correspondingly.

10. The restored matrix of \( b \)-coefficients in \( K \)-times approximation is defined as matrix sum:

\[
[k_{ij}^{(K)}] = [k_{ij}^{(0)}] + \tilde{Q}([k_{ij}^{(1)}]) + \tilde{Q}([k_{ij}^{(2)}]) + \ldots + \tilde{Q}^{(K)}([k_{ij}^{(K-1)}]);\]

\[
K = M - 1
\]
where \( \bar{Q} \) is an operator of double increase of square matrix’ dimension \( [x_{ij}] \) with linear interpolation of zero order:

\[
\begin{bmatrix}
y_1 \\
y_2 \\
\end{bmatrix} = \bar{Q}([x_{ij}]); \quad (7)
\]

\( y_{2+2j-1} = y_{2+2j} = y_{2+2j+1} = x_j \).

When \( K = M - 1 \) we get a matrix of \( b \)-coefficients restored with maximal in frames of the given algorithm possible accuracy \( \hat{h}_{ij}^{m-0} \) = \( \hat{h}_{ij} \).

The total of arithmetic operations of algorithm is \( \sim 100N^2 \), i.e. it depends linear upon number of photosensitive elements, which is especially substantial when \( N \) are big. Besides as the results of computer simulation showed the mean square error of \( b \)-coefficients, restored with this algorithm, \( \langle (\hat{h}_i - h_i)^2 \rangle \), is not more than 10 \% higher than an error of restoration according LSM method with iterative solution of set of equations.

The structure of algorithm 1-10 makes it possible for real time systems to carry out in a pipeline mode a parallel processing of the registered images with the use of matrix of processors, the total of which can reach up to \( \sim N^2 \), each of those makes algorithms operations for a certain group of registering devices.

While using the developed algorithm as a basic one, one can develop an algorithm of restoration for different hierarchies of two-dimensional scanning, which makes it possible to make image restoration more accurate and make better characteristics of matrix photosensitive elements.

The results of corresponding experiments are given in figures 1,2.

Fig.1. Examples of test images: 1 – one of the shots made by the photosensitive elements matrix at different shifts; 2 – the image, restored according to developed algorithm from successive shots made with shift; 3 – the matrix of restored characteristics of photosensitive elements (\( h_{ij} \)/coefficient)

Fig.2. Restoration errors of \( h \)-coefficients: 1 – residual noises (errors) od image restoration, obtained as a result of using of two-dimensional scanning on 1 pixel; 2 – scanning on 1 and 8 pixels; 3 – scanning on 1,2,4,6,8,16,32,64 pixels; 4 – matrix of initial (uncorrelated) noises of photosensitive elements; 5 – 8 – their spatial Fourier specters correspondingly

3. Conclusions

The mathematical model of scanning discreet matrix image converter with an adaptive digital correction of additive coefficients of converting photosensitive elements was developed. For their restoration an economic algorithm of solving incorrect over determined system of linear equations of special type with \( N^2 = 2^{2M} \) of the unknown, including \( \sim 100N^2 \) operations, which algorithm makes possible making calculations parallel on \( \sim N^2 \) processors. The efficiency of procedures and algorithms was proved by computer modeling.
Bibliography:

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