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Method and software of automatic resolution evaluating of optic-electronic telescopic land remote sensing system.

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ABSTRACT

This article deals with automatic evaluation of resolution of optic-electronic telescopic system (OETS) for Earth remote sounding during its prolonged operation. Initial information for resolution evaluation is digital arrays of video-data, that is images of Earth surface, saturated with objects in a form of sharp knife-edges(urban blocks, industrial objects, etc.). Results of video-data analysis (evaluating MTF and evaluating level of noise), as well as parameters of path of OETS, including a ground processing complex and video-data visualization are used for pre-distortion of 3-bared mire. Evaluation of resolution is done in iterations with changing of mire size. Resolution is spatial frequency of 3-bared mire for which the probability of detecting the central mark with the background of neighboring spacing by the observer has the required value. Software is developed and experiments are performed with test and real images.

Key words: resolution, 3-bared mire, optic-electronic telescopic system, MTF, knife-edge.

1. INTRODUCTION

One of the actual tasks of metrological control of an OETS system for remote sounding while its prolonged operation is the automation of routine procedure of resolution evaluation by a digital image of the Earth. Procedure of automatic determination of resolution for space optic-electronic observing system with test marked mires on ground surface is examined in work [1]. The basis of procedure [1] of resolution evaluation is recognition of marked mire. Disadvantage of the approach is the necessity of on-Earth location of special test objects along the flight trace. The other work [2] suggests to determine the resolution of system of optical range as the exit point of averaged over Fourier specter image on horizon, corresponding to noise level. But the accuracy of this method is not high because of the accepted assumptions.

We have developed the procedure of automatic evaluation of resolution over the Earth image without test objects on ground. It is realized as a program package.

Resolution is determined as spatial frequency of 3-bared mire for which the the probability of detecting its central mark with the background of neighboring spacing by the observer has the following value:

$$p(\nu_x) \geq P_0,$$

where $p(\nu_x)$ - is the probability of detecting the central mark with the background of neighboring spacing between the bares on the final photo-document, P_0 - the defined value of probability of detecting the mire bare, ν_x - the required spatial frequency.

Probability $p(\nu_x)$ is calculated on the base of MTF and OETS noise level evaluation which are determined experimentally by images of knife-edges while analysis of digital arrays of video-data. Recognition, distinguishing and analysis of the searched knife-edges are done in automatic mode independently on level of the external illumination.

Mathematical apparatus of recognition of knife-edge image is based on structural-probable approach, considers the structure of the recognized object and provides adaptation to changes of the external illumination. Distribution of intensity in direction perpendicular to knife-edge $B(x,y)$ is the realization of boundary curve $U(x)$. A set of realizations of boundary curves is averaged. The result of differentiation of the averaged boundary curve is the Line Spread Function (LSF). MTF is determined as Fourier transformation of LSF. The level of noise is determined as root-mean-square (RMS) and is evaluated over the uniform distances of intensities.

The method is realized as a program package in Borland C++ with library of classes Object Windows Library. Input and visualization of initial arrays of video-data and all results of images transformation while their analysis is provided in this package.

2. THEORY AND ALGORITHMS

Accuracy of MTF determination over the image of knife-edge is linked with value of signal/noise ratio. The latter defines the distinguishing of the heaviest changes of intensity. Recognition of objects with heavy intensity changes is not difficult. The specific feature of the task is to satisfy the condition of invariability concerning the changes of external illumination while recognition of the searched intensity changes. Variable illumination is connected with meteorological conditions, depends on daytime and season. The listed situations bring to different image signals from the same objects or districts. Moreover, algorithm of recognition should satisfy the condition of belonging of intensity sharp change to the structure of knife-edge.

Mathematical apparatus of knife-edge image for the above procedure is based on the structural-probable approach [3]. The structural analysis of the image provides object description on the base of distances and correlation between them. Image of knife-edge is a division line between light and dark continuous objects. We call them indicator(display) lines (fig.1a).

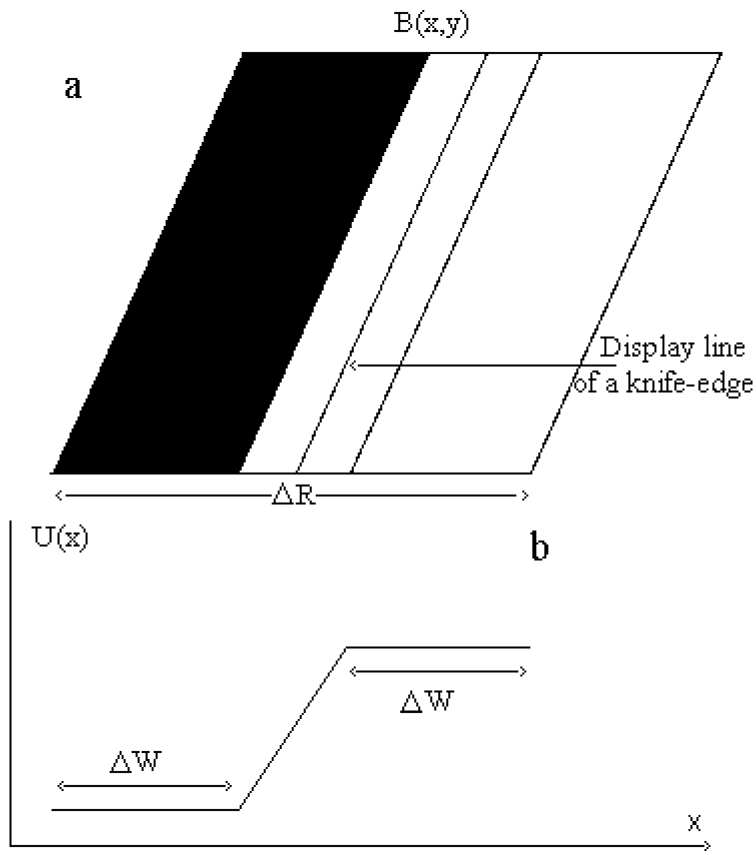

Fig. 1.

Indicator lines are taken away from consideration, if intensity differences (changes) ΔB over area ΔR do not exceed the threshold $\Pi\Delta_B$. The remain set of indicator lines will represent the lines of the required knife-edges. And the graph representation of knife-edges $B(x, y)$ is the intensity distribution of the boundary curve $U(x)$ (fig.1b).

The probability of distinguishing of the most sharp changes of intensity exceeding the threshold $\Pi\Delta_B$ is determined as follows:

$$p = \int_{\Pi\Delta_B}^{\infty} P(z)dz \quad ,$$

where $P(z)$ - density of probability of image intensity differences.

In analyzing the OEST quality by the current digital fragment the reverse task of determination of threshold $\Pi\Delta_B$ by the current distribution $P(z)$ is solved. So, the threshold parameter $\Pi\Delta_B$ used in recognition procedure is adaptive and automatically reconstructed depending on concrete intensity distribution. The threshold parameter $\Pi\Delta_B$ is determined from distribution of probability distribution $P(\Delta B)$ and is linked with it as follows:

$$p\Delta_B = 2 \cdot \int_{\Pi\Delta_B}^{\infty} P(\Delta B)d(\Delta B) \qquad (1)$$

where $P(\Delta B)$ - the probability density of absolute values of intensity differences $\Delta B = |\Delta B|$, $p\Delta_B$ - threshold probability.

One of the approaches for the approximate evaluation of unknown probabilities $p\Delta_B$ over the selected data is learning with teacher [4]. Distributions $P(\Delta B)$ are formed over the selected images (urban blocks, industrial objects, etc.). After that the best (from "teacher's" point of view) values of parameters $\Pi\Delta_B$ are specified, at which knife-edges with the most sharp intensity differences ΔB are distinguished. Threshold probability $p\Delta_B$ is determined by the value of threshold parameter $\Pi\Delta_B$ (1).

After recognition system is taught, the tested images are presented. Evaluated distributions $\acute{P}(\Delta B)$ are constructed over each image and the reverse task of determination of parameter $\acute{\Pi}\Delta_B$ by threshold probability $p\Delta_B$ is solved . Further evaluation $\acute{\Pi}\Delta_B$ is used as true value of parameter $\Pi\Delta_B$. As a result of the threshold usage, the required knife-edges $B(x,y)$ will be selected. Realization of boundary curve $U(x)$ is determined in direction perpendicular to image of knife-edges $B(x,y)$:

$$U(x_0) = \int_{-\infty}^{x_0} B(x,y)dx \quad .$$

To calculate LSF, module $U(x)$ is differentiated:

$$A(x) = |dU(x)/dx| \quad . \qquad (2)$$

MTF $T_1(\nu)$ in OETS path is determined as a module of Fourier transformation of LSF(2):

$$T_1(\nu) = \left|\Im\{A(x)\}\right| \quad , \qquad (3)$$

where $\Im\{\cdot\}$ - operator for Fourier transformation.

RMS evaluation of noise is based on measurements of intensities for the top and bottom parts ΔW of boundary curves (Fig.1b). Light and dark areas of knife-edge images correspond to these parts. In RMS calculation of noise σ the values of noise power for top $\langle E^2 \rangle$ and bottom $\langle F^2 \rangle$ parts are averaged:

$$\sigma = \sqrt{(\langle E^2 \rangle + \langle F^2 \rangle)/2} \quad , \qquad (4)$$

where $\langle \cdot \rangle$ - averaged value over square $\Delta W \times L$, L - length of indicator line.

Probability of mire resolution is defined by probability of its center mark detection on the background of the neighboring spacing. It is determined of the known formula:

$$P = \frac{1}{2}\left\{1 + \mathrm{erf}\left[\frac{\Psi - C_0 \cdot 3.2 - 2 \cdot \Omega}{\sqrt{2 \cdot (1 + \Omega^2)}}\right]\right\} \quad , \qquad (5)$$

where $\mathrm{erf}[z]$ - reduced Laplace function, Ψ - ratio signal/noise, C_0 - adjusting coefficient for compensation of an error due to incorrect description of OETS path model, including the observer model, Ω - ratio of vision noise to system noise averaged over bare.

Value Ω is determined as follows:

$$\Omega = \frac{K_0 \cdot I_a}{2 \cdot S} \quad ,$$

where K_0 - threshold contrast of vision reception, I_a - signal value averaged over mire image, S - system noise averaged over mire bare. And

$$\Psi = B_0 \cdot E \cdot \frac{(\Phi_1 - \Phi_2)}{S} \quad ,$$

where

$$\Phi_1 = \int V(\bar{\nu}) \cdot T_2(\bar{\nu}) \cdot T_3(\bar{\nu}) \cdot F(\bar{\nu}) \cdot d\bar{\nu}$$

- signal form the central mark of mire image, and

$$\Phi_2 = \int V(\bar{\nu}) \cdot T_2(\bar{\nu}) \cdot T_3(\bar{\nu}) \cdot F(\bar{\nu}) \cdot \exp(2\pi i \cdot \nu_x \cdot h_s) \cdot d\bar{\nu}$$

- signal from spacing between mires,

$$S = \sqrt{\int F^2(\bar{\nu}) \cdot T_3^2(\bar{\nu}) \cdot (G_3(\bar{\nu}) + T_2^2(\bar{\nu}) \cdot (G_1(\bar{\nu}) \cdot E^2 + G_2(\bar{\nu}))) \cdot d\bar{\nu}} \quad ,$$

$\bar{\nu} = (\nu_x, \nu_y)$ - vector of spatial frequencies,

B_0 - a part of dynamic range where signal is above background in mire image without blurring,

E - coefficient of dynamic range extension,

$V(\bar{\nu})$ - specter of discrete blurring mire image,

$T_2(\bar{\nu})$ - MTF of photo- registering device (PRD),

$T_3(\bar{\nu})$ - MTF of visual system,

$F(\bar{\nu})$ - specter of mire bare, over which a signal is summing up,

h_s - bare width,

$G_1(\overline{\nu}) = (\sigma / N_0)^2 \cdot C_1 \cdot C_2$ - level of power level for OETS noise,

N_0 - number of quantization levels for OETS,

σ - RMS of OETS noise (4), determined over digital image,

C_1, C_2 - steps of receiver digitization,

G_2 - level of power specter of PRD quantization,

G_3 - level of power specter of photo-material grain.

The level of blurring image of 3-bared mire with digitization considering is as follows:

$$V(\overline{\nu}) = \sum_{k,j} V_0(\nu_x + k / C_1, \nu_y + j / C_2) \cdot T_1(\nu_x + k / C_1, \nu_y + j / C_2) \cdot \\ \cdot \cos(2\pi \cdot k\Delta_1) \cdot \cos(2\pi \cdot j\Delta_2),$$

where

$V_0(\overline{\nu})$ - specter of sharp image of 3-bared mire,

$T_1(\overline{\nu})$ - MTF (3), determined over digital image,

Δ_1, Δ_2 - shifts along axes of digitization grid in respect to mire (exponents of the imaginary argument with consideration of object symmetry are replaced by cosines).

3. EXPERIMENTAL RESULTS

To check algorithms of recognition for knife-edge image and MTF measuring under different conditions of survey (filming), three types of scenes for the same district were realized. These scenes are presented in fig.2. The first scene - initial non-distorted image (fig.2a), the second one - the image, registered with low luminance (fig2b),the third one - the image distorted by defocusing of an optical system (fig.2c).

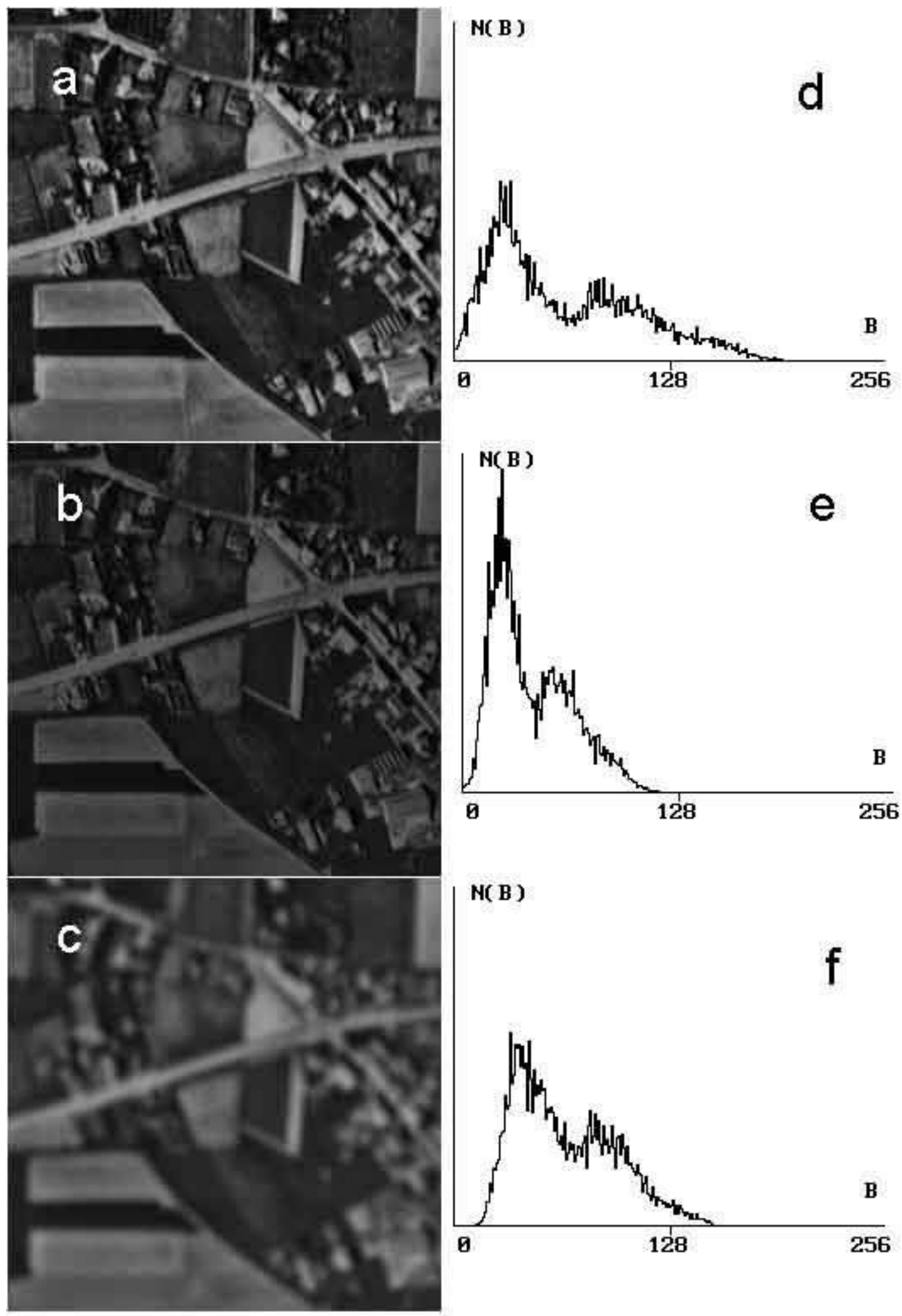

Fig.2.

All three scenes are introduced into computer by input TV system including a CCD-receiver and a lens. Histograms of distribution of intensity levels corresponding to scenes in fig.2(a,b,c) are presented in fig.2(d,e,f). For each image evaluating distributions $\acute{P}(\Delta B)$ were obtained, and reverse task of determination of the threshold parameter $\Pi\Delta_B$ was solved. These results are presented in fig.3(a,b,c) in accordance with the initial scenes.

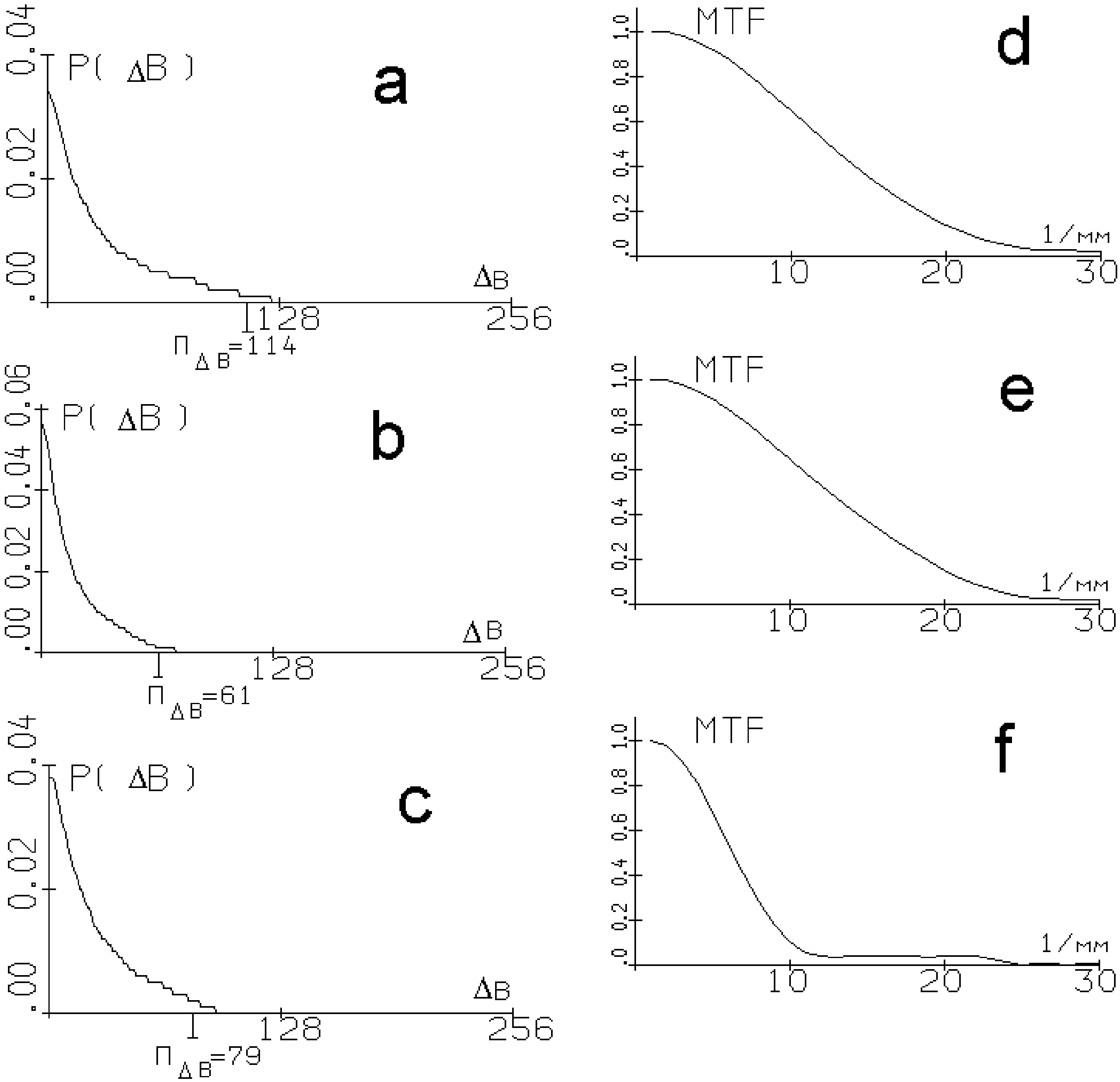

Fig.3.

With the help of the obtained parameters $\Pi\Delta_B$ the required knife-edges were distinguished, realizations of boundary curves $U(x)$ were measured, corresponding PSF and MTF were determined. MTF data for three represented scenes are shown in fig.3(d,e,f), correspondingly.

Comparison of fig.3a and fig.3b shows that reducing of external luminance brings to automatic change of threshold $\Pi\Delta_B$. With this, change of MTF (fig.3d and fig.3e) at the spatial frequency $20\ mm^{-1}$ has made about 6%. So, change of the external illumination characterized by change of video-signal dynamic range in 1.7 times (fig.2d and fig.2e) brings to insufficient errors in MTF measuring. Response to defocusing of an optical system may be evaluated by comparison of graphs in fig.3d and fig.3f.

Procedure of error correction in formula (5) stipulated by incorrect description of OETS path including model of visual analyzer is periodically performed. At video-data receipt in OETS maintenance, the evaluation of resolution by the developed software is done. In automatic mode by the video-data obtained evaluations of MTF, RMS of noise, resolution are performed. Periodically, depending on survey(filming) conditions while Earth sounding, correction of resolution calculation is done. Algorithm for determination of the correcting parameter C_0 in formula (5) is presented in fig.4.

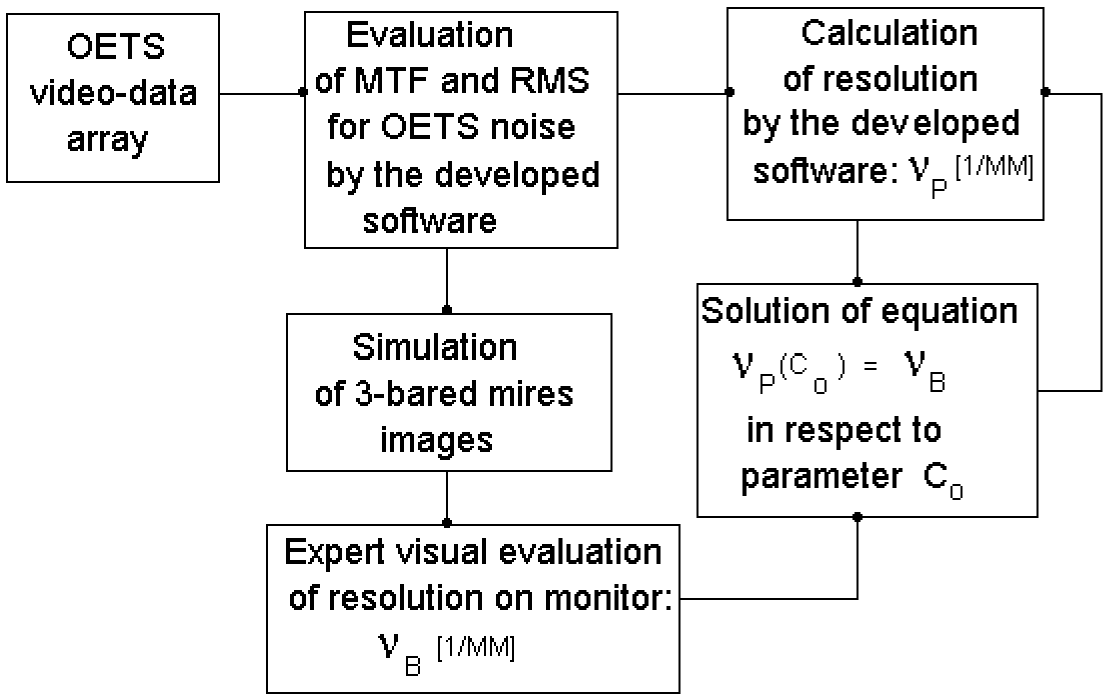

Fig.4.

MTF and RMS of OETS noise obtained with our software are used for simulation of a set of 3-bared mires with different frequency. These images are shown on monitor for visual evaluation of the ultimate-resolved mire. The example of such image is presented in fig.5.

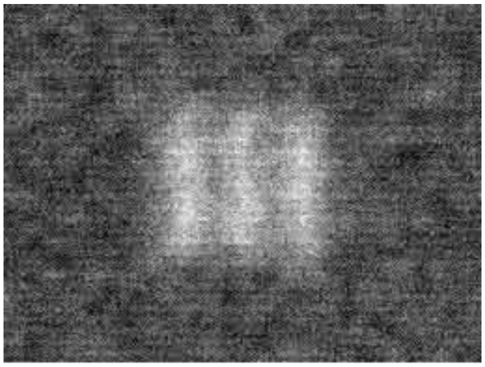

Fig.5.

The result of calculation for resolution $\nu_P[mm^{-1}]$ obtained by the developed software and that of expert visual evaluation $\nu_B[mm^{-1}]$ are used for the decision of table equation $\nu_P(C_0) = \nu_B$ in respect to C_0. So obtained value of C_0 acts as the current correcting coefficient in formula (5).

According to the described algorithm (fig.4) experiments on evaluation of resolution on model and real images introduced into computer by standard TV system were performed. Comparison of calculation results obtained by software and that of visual evaluation shows that for model images the error of resolution makes about 5%, for real ones - about 7%.

4. REFERENCES

1. I.N. Beloglazov, Automated Technique of Determination of Dependence of Resolution of a Optical- electronic System of Remote Sounding from Height of Supervision, Earth Research from Space , 1994, N3, p.53-61.
2. V.V. Gogokhiya, Definnition of a Spatial Resolution for Multispectral Scanning Devices Using Test Survey Data, Earth Research from Space, 1993, N 2, p.57-62.
3 A.L. Gorelic, I.B. Gurevich, V.A. Skripkin, Modern condition of a problem of recognition, Radio&Sviaz, Moscow, 1985.
4. R.O. Duda, P.E. Hart, Pattern classification and scene analysis, Wiley Interscience Publication Wiley&Sons, New York, 1973.