Method for image coordinate definition on extended laser paths

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ABSTRACT

Both the methodology and results of experimental research performed for the laser path images normalization by means of compact models description that describe image classes are considered in this paper. The problems of preliminary image processing based on the method of generalized Q-transformation are being solved. The image segmentation with the formation of connectivity matrices and the formal description of the resulting components are taken into consideration as well. The calculating algorithms based on the methodology of dichotomous balance of the images with the analysis of the shape and definition of coordinates being prepared have been used for the classification of laser path images.

The research paper submitted consists of two parts. The first part deals with the change of images of a laser path, the second one deals with their coordinate definition.

Keywords: laser path, image preparing, *Q*-transformation, connectivity indexes, dichotomia principle.

1. INTRODUCTION

To create effective image convertors that function in the Real Time Scale (RTS) some special methods are required. They have to provide optical input, fast and compact processing, flexible and simple image classification. Modern computing devices are productive enough (up to 10^{14} operations per second). However, this index doesn't include the time required for data entering. Besides, computing devices process data taking into account time consequence. The commands are given and executed according to tree-like laws. This means that all intellectual procedures based on the hierarchical principle only. Therefore, there are tasks within the scope of which fast image processing throughout the whole RTS is impossible even with the help of the most advanced technologies. These devices are not able to provide *apriori* the combined productivity required to implement RTS. The possible solution of this problem is the concept of specialized parallel optoelectronic convertors. This concept makes it possible to use parallel optic channels to enter and process images. The further processing needs such an arrangement of parallel channels that would provide noiseproof and fast pre-processing compact description and flexible image classification.

The general methodology of the compact image presentation is given in accordance with the scheme of *coarse - fine* processing. The coarse processing consists of image quantization and is followed by its division into spatially-connected segments[1]. The results of this coarse processing are separate segments structured in some fields according to their connectivity indexes. These image segments are formed from spatially connected pixels of a quantified image and then create connectivity fields. Then separate segments undergo the *fine* processing scheme.

2. METHODS

2.1. Method of the image shape analysis on extended laser paths

This work deals with the influence of deforming environmental factors on the image rendered by a laser beam. Its goal was to study how a laser beam distortion is influenced by the atmosphere and to how to predict the state of atmosphere for extended laser paths for a short period of time (5 msec). For this purpose 4 galleries of distorted images of a laser beam (each containing 100 to 140 objects) have been analysed. The method of pre-processing and the principles of formal description of its results have been developed.

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The preliminary processing includes all subsequent operations. The input 2D grey-scale image is presented by the matrix of light intensity pixels $A = \left[a_{i,j}\right]$, $i = 1 \div N$, $j = 1 \div M$, where $M \times N$ is the input image dimensions. The general mean of the present matrix A is found as

$$\bar{a} = \frac{1}{NM} \sum_{i,j} a_{i,j}. \tag{1}$$

Then sets of differences between pixels and obtained means of the whole image or its segments, are determined

$$R_{i,j} = a_{i,j} - \bar{a}. \tag{2}$$

In order to obtain the set of preparations this differences are compared with the threshold δ [2,3]:

$$q_{i,j} = \begin{cases} 1, \text{ if } R_{i,j} > \delta \\ -1, \text{ if } R_{i,j} < (-\delta) \\ 0, \text{ if } \left|R_{i,j}\right| \le \delta \end{cases}. \tag{3}$$

The threshold δ is chosen from the following condition[3]:

$$MAX\left(N_t^{(1)}, N_t^{(-1)}, N_t^{(0)}\right), \tag{4}$$

where $N_t^{(1)}, N_t^{(-1)}, N_t^{(0)}$ is the number of positive, negative and zero preparations within each grey level *-t*. The matrix of preparations $Q = \left[q_{i,j}\right]$ is formed as a result of the above mentioned operations.

In order to get certain features from the obtained matrices of preparations, the connectivity indexes are determined separately for positive, negative and zero preparations. Connectivity v of preparations $q_{i,j}$ is defined as:

$$v_{i,j}^{q} = \sum_{k=i-1}^{i+1} \sum_{l=j-1}^{j+1} g_{k,l} \tag{5}$$

$$g_{k,l} = \begin{cases} 1, \text{ if } q_{k,l} = q_{i,j} \\ 0, \text{ if } q_{k,l} \ne q_{i,j} \text{ or } (k = i \text{ and } l = j) \end{cases}, \quad k = \overline{i-1, i+1}, \; l = \overline{j-1, j+1},$$

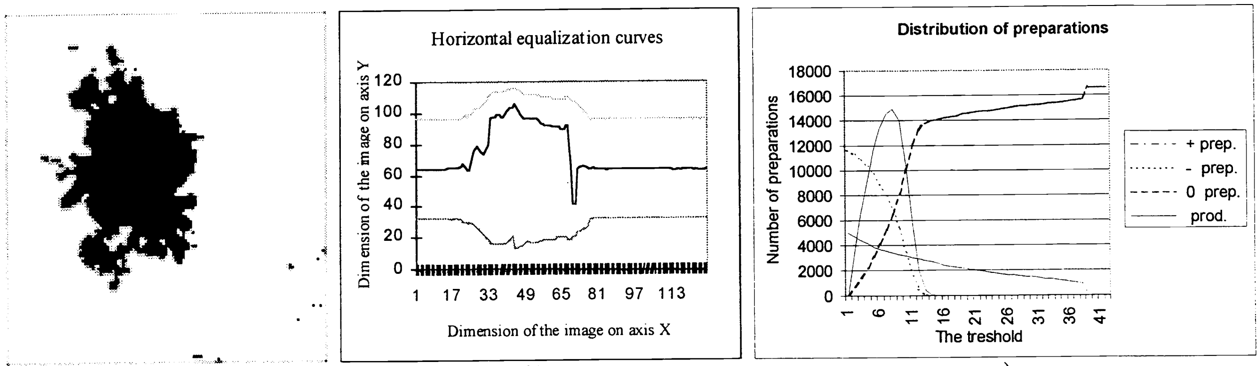
where $v_{i,j}^{q}$ is an element connectivity of the image with *ij*-coordinates.

The following decomposition based on dichotomous principle could be used to analyse the obtained connectivity spectrum. For each level of dichotomous partitioning of a prepared image, an operation of column-by-column (or row-by-row) equalization is performed and the equalization curves are generated. The local column equalization function $U^{*} = \left[u_j^{*}\right]$ has to meet the following requirement:

$$\sum_{i=1}^{u_j^{*}} v_{i,j}^{q} = \sum_{i=u_j^{*}+1}^{N} v_{i,j}^{q}, \; u_j^{*} \in \{1, 2, .., N\}. \tag{6}$$

Thus pre-processing[4,5] is based on the analysis of separate segments and consists in the preparing of images i.e. in the rendering of the images into binary ones and their consequent transformation by establishing the local and integral functions of equalization on the basis of the binary preparations and their further correlation analysis.

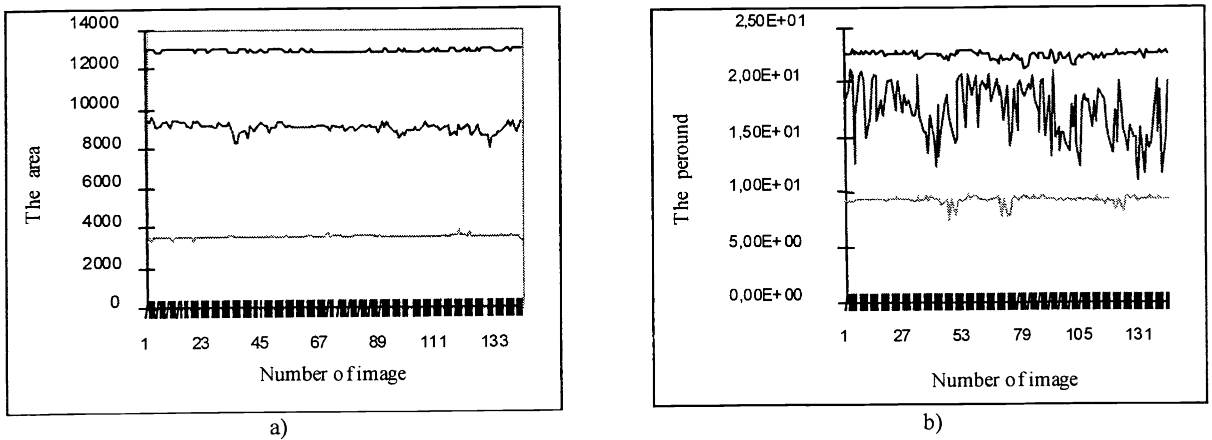
The results of the study are based on the processing of four lines of images of extended laser paths. The equalization curves were generated by two thresholds as per the expressions (4). The obtained results have been submitted to statistic and correlation analyses. Fig.1 a, b, c respectively show the halftone distribution of zero preparations for the threshold as (4), equalization curves and distribution of preparations. For formal description of the relevant equalization curves a rated (normalized) value of the relation of the area to the perimeter of a equalization curve (the image model *peround*)



a) b) c)

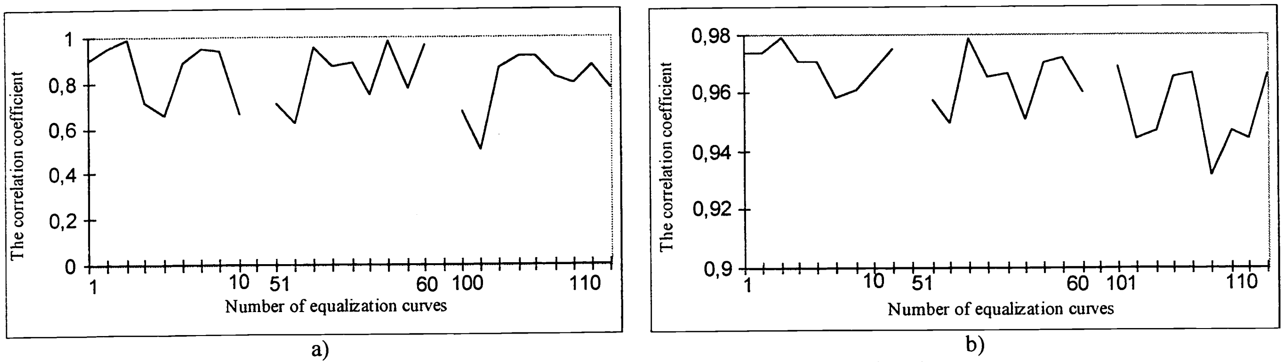
Fig. 1 a) The halftone distribution of zero preparations for the threshold as (4), b) equalization curves, c) distribution of preparations

The functions of changing of the area and peround are shown on the example of one laser path (Fig.2 a, b).



a) b)

Fig.2 The functions of changing of the area and peround.



a) b)

Fig.3 Functions of correlation of two dichotomizing equilibrations

As is shown by the established statistic analysis the peround data between series of laser path images are more differentiated than area data. That is why the peround function suits the purpose of further classification better. The coefficient of correlation of equalization curves for each two adjacent images on one laser path has been evaluated (Fig.3 a, b). For the first dichotomous balance the correlation coefficient was above 0.5, and for the other one it was above 0.93. That is why to select the criteria for the classification it is quite desirable to perform a number of equalization procedures. At the same time the equalization curves for different lines of laser beam images do not correlate at all (the correlation coefficients assume negative values).

Finally, the extended laser paths images are classified (both within their lines and between their lines).

2.3. The method for image coordinate definition on extended laser paths

During the analysis of the sequence of fast changing images on extended laser paths there appears a problem of definition of the centre of the beam trace. Under the influence of various environmental factors a cross-section image of a laser path (in the plane perpendicular to the direction of the beam) becomes dithered, with its shape constantly changing with time. Thus it is next to impossible without analysing the preceding images in the sequence to determine such a "power" centre $\alpha_e^i = (x_e^i, y_e^i)$ of the current (i-th) beam image, which would be permanent during the analysis of the image sequence $\Omega = (\omega_0, ..., \omega_{N-1})$ of the extended laser path in question. The power centre must not move when analysing a path which never changes its direction and therefore the location of its power centre is to be permanent, that is $\alpha_e^i = \alpha_e^{i-1}, i = 1..N-1$, where N – is the number of images in the sequence. In case when a beam changes its direction the calculated power centre must be automatically shifted and match the new position and features of the beam. During image analysis the method of location of an image centre is used with the help of absolute moments[6] of order 0 and 1. Thus for quantized image of $m \times n$ size with weight factors $B(x, y)$ $x=0.m-1$, $y=0.n-1$ the absolute moment m of order j, k is determined as below:

$$m_{j,k} = \sum_{x=0}^{m-1} \sum_{y=0}^{n-1} B(x,y) \cdot x^j \cdot y^k \tag{7}$$

Then the image centre $\alpha = (x, y)$ is found out from the ratio of the moments:

$$\alpha = \left(\frac{m_{11}}{m_{01}}, \frac{m_{11}}{m_{10}} \right) \tag{8}$$

For weight factors in formula (7), the brightness of the given image element $B(x,y)=I(x,y)$ is widely used. In this work as weight factors we take also a simple connectivity Δ_k under analysis (hereinafter simple connectivity) and normalized connectivity $\overline{\Delta}_k$ of k-th cross-section where the value of brightness of the given point $I(x,y)$ (10) belongs to. To find the simple and normalized connectivity all the range of image brightness is broken into separate sections with predetermined step ∂I. Thus, for example, if an image has 256 levels of grey ($I(x,y) \in [0..255]$, $max(I)=255$) and the step is $\partial I = 1$, then to the i-th section only those points will be related that have i brightness. At any other step the i-th section will have points with the brightness as $I(x,y) \in [\partial I \cdot i \,..\, \partial I \cdot (i+1) - 1\,]$. A point with $I(x,y)$ intensity belongs to section number

$$R(x,y) = \left[I(x,y) / \partial I \right] \tag{9}$$

where $[x]$ – is an integral part of x.

Two points (x_1, y_1) and (x_2, y_2) are called coherent if they are adjacent, i.e.

$$\max\{|x_1 - x_2|, |y_1 - y_2|\} = 1 \tag{10}$$

and if they belong to one section or two neighbouring sections.

Therefore, each image point (*x, y*) is defined by the connectivity $\delta(x,y)$ – that is the number of points associated with it. (max{ $\delta(x,y)$ }=8).

The connectivity Δ_k of the *k*-th section is the sum of all points pertaining to it. It can calculated according to the formula:

$$\Delta_k = \sum_{x=0}^{m-1} \sum_{y=0}^{n-1} if\left(R(x,y)=k, \delta(x,y), 0\right), \qquad k = 0..\max(R) \tag{11}$$

Except the connectivity Δ_k it is important to define the quantity of section elements

$$\sigma_k = \sum_{x=0}^{m-1} \sum_{y=0}^{n-1} if\left(R(x,y)=k, 1, 0\right), \qquad k = 0..\max(R) \tag{12}$$

Then the relative connectivity may be represented as

$$\overline{\Delta}_k = \frac{\Delta_k}{\sigma_k}\ . \tag{13}$$

A sample of simple and relative connectivity for one of images on an extended laser path is given at figure 4.

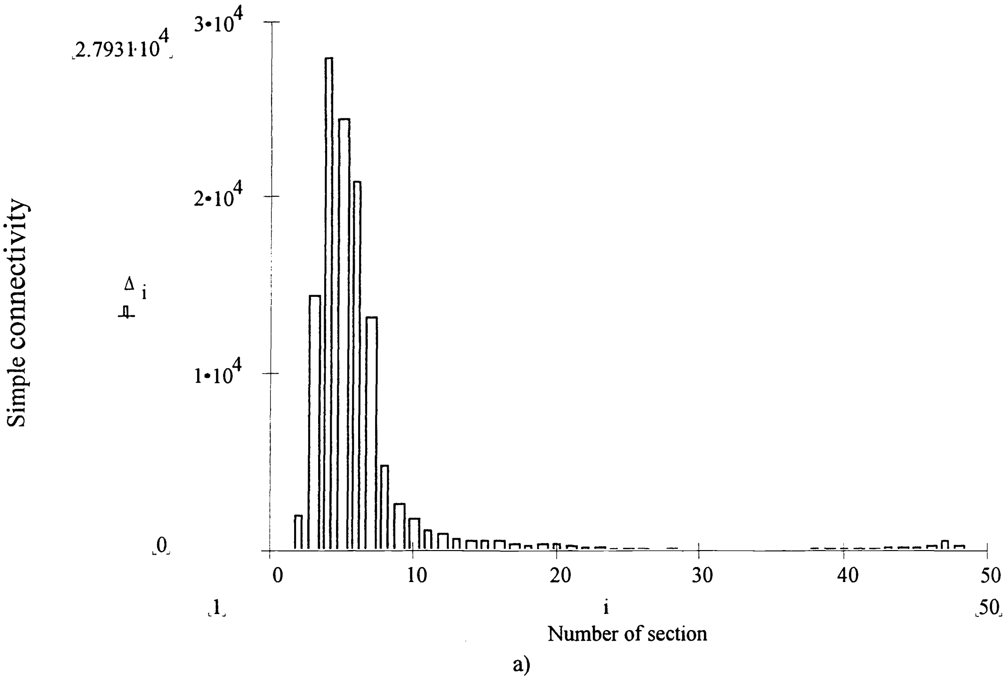
The centre found out with the method of moments is not invariant to the change of the shape and orientation of a laser path image and therefore the location of the centre of an image changes significantly along the path.

This study proposes a method for defining a certain small area δ^{i-1} in the vicinity of the centre of the preceding spot on the path. If the centre of the current spot α_e^i falls within this area the direction of the extended laser path does not change and consequently the power centre coordinates remain intact. Otherwise power centre coordinates are calculated according to the algorithm below.

For the definition of area δ^{i-1} a recurrent method of balancing - division of an image into "equivalent" areas. At the *j*-th step balancing of the active area of the spot image is done along 4 directions resulting in 4 equalization curves. Two equilibrium curves are defined along 0X and 0Y axes of the Cartesian coordinate system and the other two in the Cartesian system rotated at 45^0 along the 0X’ and 0Y’ axes (as shown in Fig.5). The active area at the first step covers the entire spot image. The weight coordinates *B(x,y)* prove the availability of the point (*x,y*) within the active area; if it outside the active area its weight coefficient is equal to zero and consequently this point does not affect the result of balancing.

$$\begin{aligned} N_x^j(x) &= \frac{\sum_{i=0}^{n-1} B(x,y)\cdot y}{\sum_{i=0}^{n-1} B(x,y)}, \qquad & N_y^j(y) &= \frac{\sum_{i=0}^{m-1} B(x,y)\cdot x}{\sum_{i=0}^{m-1} B(x,y)}, \\ N_{x'}^j(x') &= \frac{\sum_{i=0}^{n'-1} B(x',y')\cdot y'}{\sum_{i=0}^{n'-1} B(x',y')}, \qquad & N_{y'}^j(y') &= \frac{\sum_{i=0}^{m'-1} B(x',y')\cdot x'}{\sum_{i=0}^{m'-1} B(x',y')} \end{aligned} \tag{14}$$

Equalization curves have its maximum and minimum values at the *j*-th step of balancing, thus defining on the appropriate axis of values (for example, for a equalization curves directed along the 0X - OY will be the value axis) the range of possible values $\left\lfloor \min(N^j)..\max(N^j) \right\rfloor$. The overlapping segments of these areas form area D^j (as shown on fig. 6), which will be the active area for the next step of recurrence. If an area consists of more than one point, the transition is made to another recurrent step. If the area consists of one point this point is considered to be the power centre of a spot image.



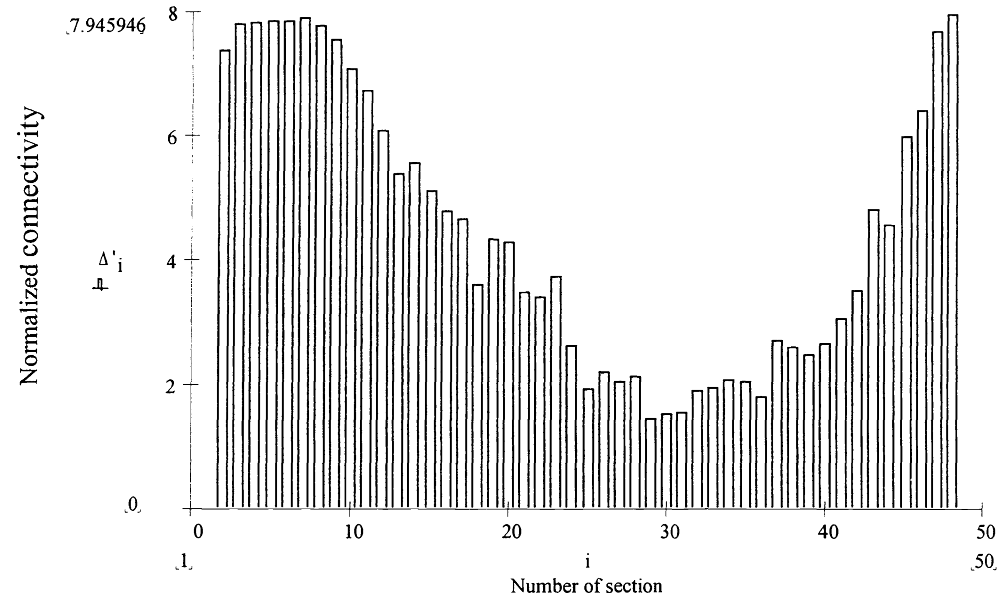


Fig. 4. Diagrams of simple (a.) and normalized (b.) connectivity for a laser beam image.

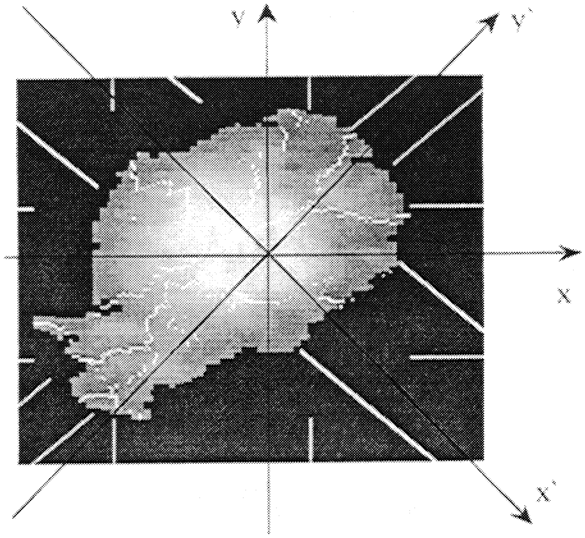


Fig. 5. Equalization curves in two coordinate systems.

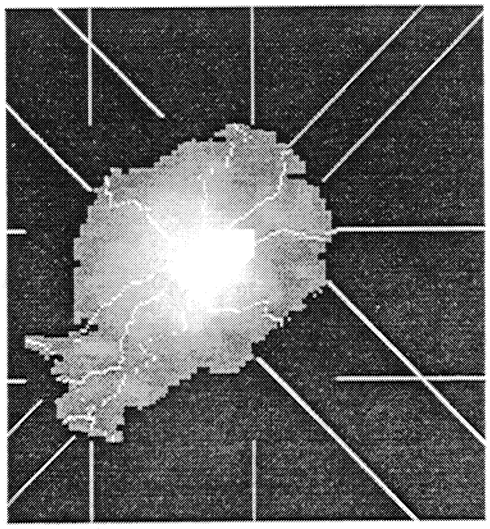


Fig. 6. The active area obtained at the 1-st step of balancing.

When analysing a bean section image it is quite useful to pick a certain part the image on the threshold basis and to delete the background. In this study we use the method of threshold limiting[3] and the threshold itself is chosen depending on the weight coefficient used.

As is shown at the connectivity diagrams (fig. 4) the spot images under analysis feature two local maximums of connectivity values for the sections relating to the background (the first maximum $\Delta_{\max 1}$) and to the object (the second maximum $\Delta_{\max 2}$) respectively. It is quite evident that the sections preceding the first maximum relate to the background and those to the right of it - to the data part of the image, i.e. to the object. It is necessary to determine the boundary section $\Delta_{\lim}$ that divides all of the sections into two groups: the sections to the left of the boundary ($k < \Delta_{\lim}$) that constitute the background, and the sections to the right ($k \geq \Delta_{\lim}$) that refer to the data part of the spot image.

Three methods of defining a boundary section have been considered:

1-st method: the background possesses the sequence of sections lying to the right of the first maximum of the connectivity diagram. The connectivity of these sections does not exceed the connectivity of the previous section $\Delta_{k-1} \geq \Delta_k$, i.e. it causes a monotonous slope on the connectivity diagram. The drawback of this method is the availability of small local extremums within the range of background sections it the step between the sections is small ($\partial I = 1$) and large brightness range (for example, when *max(I(x,y))=255*).

2-nd method: definition of the minimum connectivity value $\Delta_{\lim}$ when it is possible to classify all sections into two groups, i.e. when the condition below is satisfied

$$\Delta_k > \Delta_{\lim}, \quad k \in [max1..\lim] \tag{15}$$

This minimum value is minimum connectivity value between the two maximums.

$$\Delta_{\lim} = \min\{\Delta_k\} \quad k \in [max1..max2] \tag{16}$$

3-d method: by analogy with method 2 it deals with the normalized connectivity $\bar{\Delta}$. The normalized connectivity diagram has more delineated maximums since the values of the sections that are related to the central point of a spot tend to the maximum value. The same process is typical for sections of background points.

$$\overline{\Delta}_{\mathrm{lim}} = \min\left\{\overline{\Delta}_k\right\} \quad k \in \left[\overline{max1}..\overline{max2}\right] \tag{17}$$

where $\overline{max1}$, $\overline{max2}$ are the numbers of maximums' sections of the normalized connectivity diagram.

In the experiments we used the set of 269 images. Results of the algorithm work are presented on fig. 7.

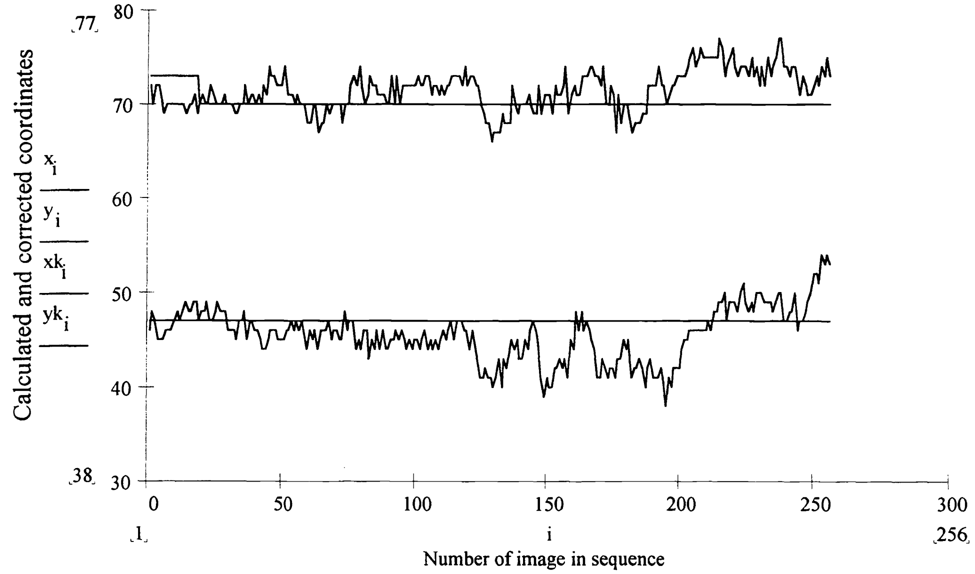


Fig. 7. Calculated and corrected by hitting to δ area on non 0 step of balancing. All images in sequence have the same corrected coordinates

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