A New Method for Important Points Extraction

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Abstract: *Template matching is one of the most important problems in the vision industry. This problem is solving by many different ways, but along with the requirements of high reliability, there are high requirements of run-time decreasing. One of the ways to speed-up the processing is to reduce the number of points (pixels) which take part in the calculations. We propose a new method for important point's extraction, based on the equipotential surfaces. By the properly potential threshold these surfaces give a possibility to extract the elements of searched subset of points, which are in conformity with the criterion of D-optimality. The successful fulfillment of this extraction can be made by the properly conditions. For this purpose we propose a method for nonlinear interval transformation of the color function. This transformation leads to the image contrast improvement and thence to the more easily determination of the coordinates (x,y), corresponding to the intersected points of the relief with the surface of the properly chosen potential.*

Key words: *Template Matching, Equipotential Surfaces, D-optimality, Normalized Correlation*

INTRODUCTION

Visual control systems have wide place in the modern industry. Their purpose is to ensure precisely vision of the robots, dispatcher stations, etc. Great part of these various applications needs to solve the problem of template matching. Some of them are [3, 4, 6, 8, 9, 11]:

- Wafer alignment, using arbitrary artwork as the pattern to recognize.
- Fiducial recognition for PCB assembly by a pick-and-place robot.
- Registration of alignment marks on printed material to be inspected (e.g., wallpaper rolls, currency sheets).
- Robot vision guidance, locating objects on conveyor belts, pallets, and trays.
- etc.

The problem reflects to the choice of matching criterion and its realization. One of the most reliable criterion is the normalized correlation. Computational complexity of this algorithm is very high. That is why the effort is directed to the computational time decreasing and in the same time – to maintain the high reliability of the criterion. One of the approaches is to reduce the number of points [5] that are used in the calculations.

The purpose of this work is to propose a new method for the essential point's extraction in order to decrease run-time and in the same time to maintain reliability of the normalized correlation as a criterion of template matching.

FORMULATION OF THE PROBLEM

We discuss the problem about template matching in monochrome image with the normalized correlation as a criterion for matching estimation [1].

$$NC = \frac{\sum_x \sum_y (Img - \overline{Img}).(Tmp - \overline{Tmp})}{\sqrt{\sum_x \sum_y (Img - \overline{Img})^2 . \sum_x \sum_y (Tmp - \overline{Tmp})^2}} \qquad \textbf{(1)}$$

where: *Img* is the current pixel (x,y) color inside the current frame – *PixelColor*(*i*);

$\overline{Im\,g} = \frac{1}{N} \sum_x \sum_y Im\,g$ is the mean value of the current frame colors;

Tmp is the color of the current pixel of template;

$\overline{Tmp} = \frac{1}{N} \sum_x \sum_y Tmp$ is the mean value of colors in the template;

N is the number of pixels in the template.

We should say that the colors *Img* and *Tmp* in this case are the intensity values, corresponding to the values in the interval [0, 255] of the grey scale.

The algorithm for correlation coefficient calculation has the following computational complexity [1, 4]:

$$K = O(n^4)\,, \qquad \textbf{(2)}$$

where *n* is the number of pixels.

We can say this classical and reliable criterion for matching estimation needs much computational time. Thus, in the conditions of high-speed requirements the problem of computational operations decreasing is actual. The matching criterion is the same.

THE ESSENCE OF THE EQUIPOTENTIAL SELECTION

With reference to above mentioned understanding we naturally make the conclusion that the number of computational operations, needed to calculate (1), can be decreased if the number of pixels representing the image will be reduced. Thus we will present and ground a new decision and we will comment the results of its using.

We can present the image in the space if we use the every pixel color of it as a third coordinate. Two exemplary black and white images are presented on the figure 1 and their spatial views are presented on the figure 2.

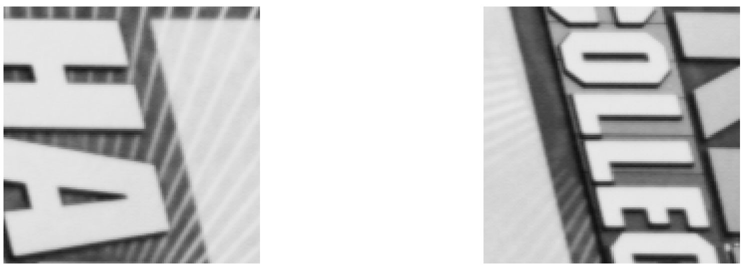

Fig. 1. Exemplary images No1 and No2

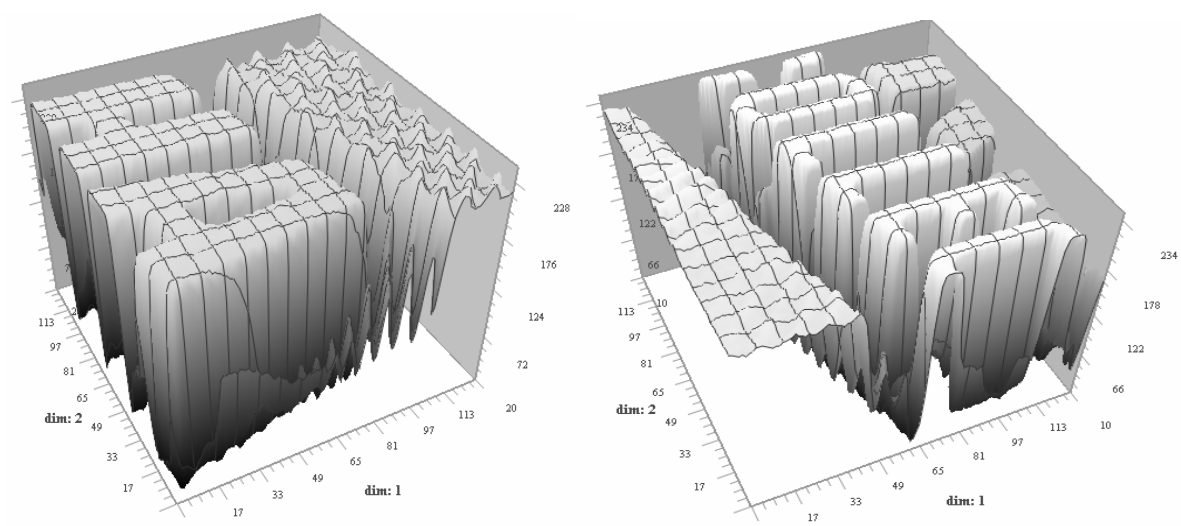

Fig. 2. Spatial views of the exemplary images No1 and No2

Thus we can interpret equation (1) as a peculiar estimation of mean Euclidean distance. The estimation of the distance between the image and the template in this sense permits to identify it as the same or to reject it as a different one.

The separation of two sets in their space by a plane is based on the principle of the minimum distance to the template. When the classification or the identification are based on this principle, this approach is summarized as a correlation one [2]. That is a reason we think the space interpretation of the image is a proper base to influence it by the method of the D-optimized subsets [13] forming, as a subset which will minimize computations of correlation estimating. In other words we propose not to present the original image by the full set of pixels, but to present it by the properly chosen pixels, which will keep and present it spatial structure with high enough power of conformity.

The criterion of D-optimality is formal expressed as follows:

$$det(V^t.V)^{-1} \Rightarrow min, \tag{3}$$

where V is a matrix of training subset.

It is known [13] that any procedure for linear separation based on the criterion of D-optimality of chosen subset has the best linear valuation for the coefficients of separating function. The last means that such choice of elements from the selected subset presents the spatial structure of the image best. The analysis of such formed subsets shows that the spatial disposition of their elements forms the protruding peripheral wrapper of the object structure.

Proceeding from this final conclusions in order to decrease number of computations needed for correlation coefficient calculation by minimization of elements from the observed set of points in the image template, here, in the conditions of three-measured space we propose the approach of equipotential surfaces. By the proper selection of the potential thresholds (low and high), i.e. the color value on the third axis, by these surfaces we can select the elements for the searched subset of points, which are in full conformity with the nature of the D-optimality criterion, because they present the spatial structure of the source image better than all the rest.

To select the elements of the given subset we define the following function:

(5) **if**

$$\left(\begin{bmatrix} (PixelColor(i) \le Potential_{max}) \cap \\ (PixelColor(i+1) > Potential_{max}) \end{bmatrix} \cup \begin{bmatrix} (PixelColor(i) \ge Potential_{max}) \cap \\ (PixelColor(i+1) < Potential_{max}) \end{bmatrix} \right) \cup$$

$$\cup \left(\begin{bmatrix} (PixelColor(i) \le Potential_{min}) \cap \\ (PixelColor(i+1) > Potential_{min}) \end{bmatrix} \cup \begin{bmatrix} (PixelColor(i) \ge Potential_{min}) \cap \\ (PixelColor(i+1) < Potential_{min}) \end{bmatrix} \right) = True$$

then

$$PixelColor(i) \in \Im ,$$

end if ;

where: i is the next element in a row in the coordinate system (x,y) of the source set, which color *PixelColor(i)* becomes the next element of the new-forming subset $\Im$;
$Potential_{min}$ and $Potential_{max}$ are two potential thresholds (low and high).

PROVIDING PROPERLY CONDITIONS FOR THE EQUIPOTENTIAL SELECTION

It is necessary to note, that the relief disposition of the interpreted image in the spatial coordinate system is arbitrary and this makes difficult to apply the selecting function (4). That is the reason to create properly conditions for this purpose before. We define these conditions when the relief is amplified at the vertical axis so that the colors reach at the same time two possible extremes – 0 and 255 and on the other hand to be improved the brightness features of the image. We define this conditions proceeding from the comprehension that we search for the coordinates (x,y) of the intersected points of relief with the plane of the corresponding level, but not for the very value of the color. Thus we arrive at the idea to transform the color function at the intervals of low and high levels.

We define the following transformation function $f(x) > 0$, *when* $x > 0$:

$$y = \begin{cases} f_1(x), \text{ for } x \in [min, \alpha) \quad ; \\ \qquad\qquad 0 \le min < \alpha, \quad y \le x \ , \\ \qquad\qquad \text{and if } x = min, \text{ then } y = 0 \ ; \\ x, \quad \text{for } x \in [\alpha, \beta] \quad ; \\ f_2(x), \text{ for } x \in (\beta, max] \ , \\ \qquad\qquad \beta < max \le 255, \quad y \ge x \ , \\ \qquad\qquad \text{and if } x = max, \text{ then } y = 255. \end{cases} \tag{5}$$

The goal of this functional transformation is to inhibit function values for argument values, which are under the level α and in the same time to intensify function values for argument values which are over the level β, so the function maximum always get to the minimum possible level of 0, keeping its values in the interval [α,β].

The graph of the defined transformation function *y* is presented on the figure 3.

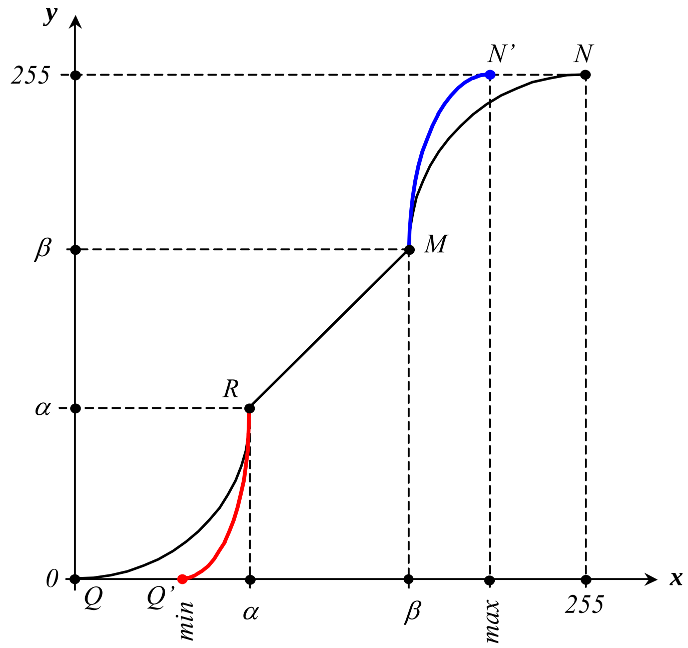

Fig. 3. Graph of transformation function in the interval [0, 255]

TRANSFORMATION FUNCTION IN THE INTERVAL [*min*, α)

We search transformation function $f_1(x)$ in the interval [*min*,α) as a second power polynomial, which has positive values for the values of argument in the interval [*min*, α). In these conditions the canonical equation of parabola with a pick at the point *Q'(min, 0)* is

$$(x - min)^2 = 2.p.y \quad , \quad p > 0 , \tag{6}$$

where $y = f_1(x)$.

In addition we know that the point *R*(α ,α), lies on the parabola and always has equal coordinates, i.e. $x_R = y_R = \alpha$. Then the coordinates of that point are to satisfy the parabola equation [10] (6):

$$(\alpha - min)^2 = 2.p.\alpha \quad . \tag{7}$$

Here we define the parameter *p:*

$$p = \frac{(\alpha - min)^{2}}{2.\alpha} . \tag{8}$$

Finally, the function $y = f_1(x)$ after the substitution of p is as follows:

$$f_1(x) = \frac{\alpha}{(\alpha - min)^{2}} .(x - min)^{2} . \tag{9}$$

TRANSFORMATION FUNCTION IN THE INTERVAL (β, *max*]

In this case we search transformation function $f_2(x)$ again as a polynomial of second power. The right end of the interval is variable, but it is known, that its value can not be greater than 255. Hence it follows, the graph of function $f_2(x)$ we will search in the set of parabolas, each of them passes through the point M(β ,β) and has a pick at the point N'(max, 255).

The equation of parabola with searched position looks as follows:

$$(x - max)^{2} = -2.p.(y - 255) , \tag{10}$$

where the point N' with coordinates (max, 255) is the pick of the parabola.

The other point which lies at the parabola is M(β ,β). Therefore its coordinates have to satisfy the equation (10). So, we can write:

$$(\beta - max)^{2} = -2.q.(\beta - 255) , \tag{11}$$

and we can express the unknown parameter q:

$$-q = \frac{(\beta - max)^{2}}{2.(\beta - 255)} . \tag{12}$$

Thus, the equation (10), after the replacement of parameter q by the founded value becomes:

$$(x - max)^{2} = 2.\frac{(\beta - max)^{2}}{2.(\beta - 255)} .(y - 255) . \tag{13}$$

Now we can write the final expression of transformation function $y = f_2(x)$:

$$f_2(x) = 255 + \frac{(\beta - 255)}{(\beta - max)^{2}} . (x - max)^{2} . \tag{14}$$

EXPERIMENTAL RESULTS

The synthesized interval nonlinear transformation function is tested on the set of exemplary images. We can see two visible results. First of them is the significant contrast increasing. Second of them is the more clearly contours outlining. Figures 4 and 5 show two original images (left sides of figures) and the same images after the transformation by the proposed nonlinear interval function (right sides of figures).

Fig. 4 The original image No1 (left side) and the same image after the transformation (right side)

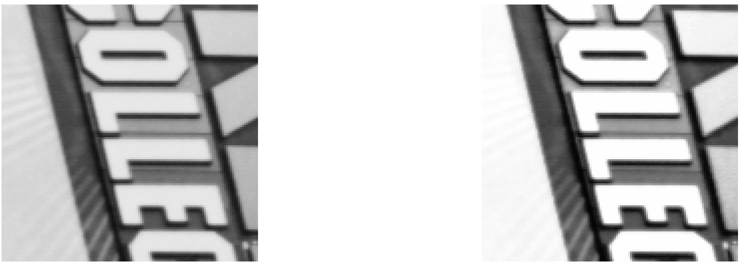

Fig. 5 The original image No2 (left side) and the same image after the transformation (right side)

In principle color increasing is an distortion of the image, which is not always desired in literal sense. But there are many cases when we search the coordinates of boundary pixels and their color has not any significance. Their successful founding depends on the power of image sharpness. Although this transformation brings an error in the coordinates of the boundary pixels, but methods of their assessments bring more serious errors if we work with the original image. That is the reason the suggested above image preprocessing has its place in the combination of methods for image analysis. The value of the error, which is inserted in the contour pixel coordinates we can regulate by the levels α and β. We don't carry about it because our purpose is another.

The result of the function (4) effect upon the prior prepared test images is shown on the figure 6, where as templates are chosen the central square fragments (with the coordinates of the upper left corner (32, 32)) with the size of 64 x 64 and containing 4096 pixels. It is clearly visible the formed closed contours of the selected points.

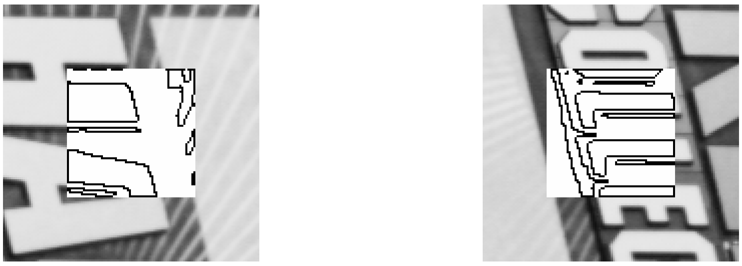

Fig. 6 Equipotential curves in the images No1 (left side) and No2 (right side)

The number of selected points in the first image is 532 – this is 7.7 times less than the full number of points in the source set which is 4096. In the second set selected points are 833, which number is about 5 times less.

RESULTS OF TEMPLATE MATCHING

We have carried out two series experiments for searching chosen templates into the test images, which are subjected in advance to uniform distributed noise. The first test series is carried out with the full number of 4096 points of the template, and the second one – with the reduced number of points which are selected by the proposed method and also with the points selected by the well known Sobel [4,11,12] an Roberts [4,11,12] operators.

The criterion of matching is the normalized correlation.

The observed parameters are run-time and exactness of the results (exact template location). For carrying out the experiments it is used a personal computer with Pentium II processor and 128 MB SDRAM.

Test results are shown in the table 1 and in the table 2:

Table 1

Image No1								
	Roberts		Sobel		Equipotential Points		Full Number of points	
SNR	NC	Coordinates	NC	Coordinates	NC	Coordinates	NC	Coordinates
no	1,000	32 32	1,000	32 32	1,000	32 32	1,000	32 32
10	0,989	32 32	0,973	32 32	0,996	32 32	0,992	32 32
4	0,927	32 32	0,890	32 32	0,981	32 32	0,961	32 32
2,5	0,852	32 32	0,757	32 32	0,948	32 32	0,911	32 32
2	0,791	32 32	0,689	31 32	0,937	32 32	0,904	32 32
1,33	0,618	31 32	0,543	31 32	0,871	32 32	0,783	32 32
1	0,538	31 32	0,444	31 32	0,759	30 32	0,649	32 32
Run-time	01:06:85 min		01:02:83 min		00:56:46 min		07:44:34 min	

Table 2

Image No2								
	Roberts		Sobel		Equipotential Points		Full Number of points	
SNR	NC	Coordinates	NC	Coordinates	NC	Coordinates	NC	Coordinates
no	1,000	32 32	1,000	32 32	1,000	32 32	1,000	32 32
10	0,993	32 32	0,996	32 32	0,996	32 32	0,996	32 32
4	0,961	32 32	0,971	32 32	0,982	32 32	0,971	32 32
2,5	0,911	32 32	0,950	32 32	0,957	32 32	0,951	32 32
2	0,904	32 32	0,899	32 32	0,931	32 32	0,899	32 32
1,33	0,783	31 32	0,820	32 32	0,850	32 32	0,821	32 32
1	0,649	31 32	0,718	31 31	0,799	31 32	0,718	32 32
Run-time	01:06:73 min		01:02:40 min		01:16:46 min		07:44:34 min	

It is visible that the computational time with the reduced number of points is several times less than the classic algorithm, keeping the accuracy of the normalized correlation criterion.

CONCLUSIONS AND FUTURE WORK

The proposed method for extraction the important points of an image can be used in many task from the area of pattern recognition and image processing. In particular this method is applicable in the tasks for template matching where the normalized correlation is using as a matching criterion.

Our future work will estimate the behaviour of the proposed method in the conditions of other matching criteria. We also will make a comparative analysis with other known methods and algorithms for essencial points extraction.

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