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USING IMAGE PROCESSING TO AUTHENTICATE ARTWORK (II)

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Abstract: *The paper proposes to validate an algorithm for the automatic identification of 2D elements by image processing based on Cross Correlation. The algorithm uses a modified version of Cross Correlation that allows the identification of a template even if they change its position and orientation in an image. The validation of the mathematical model was carried out in Matlab on a series of standard photographs. Having the mathematical model validated, the proposed algorithm has been used in the authentication of works of art.*
Keywords: *artwork, image processing, cross-correlation, pattern detection.*

1. INTRODUCTION

There is an increasing trend and interest for art institutions world-wide to digitize their cultural repository [1-3], not only to increase their audience, but also to further investigate, or submit digitized artwork to all kinds of analyses. For this demarche image processing is used, which facilitates investigations such as image emotion detection [4], feature and pattern recognition [5, 6] or even artwork authentication [7][6]. All these are challenging tasks which often are completed by calculating the correlation degree between a reference and an examined image, thus providing a clear indication of affinity or divergence between the two. This process is referred to as cross-correlation, an algorithm which evolved significantly over time, from accuracy analysis [8] to fast normalized cross correlation [9-11] and pattern detection using normalized neural networks [6].

1.1. Main objectives

The project's main objectives are:

- Development of a specific methodology for data and image acquisition, management and processing, dedicated for 2D artwork artifacts;
- Adaptation and integration of existing hardware and software instruments to provide maximum efficiency for the automated feature recognition;
- Definition, implementation and optimization of a dedicated database, which would assist the academic communities in their future studies and research work**.**

2. PROPOSED ALGHORITM

2.1 Matching Templates using Cross – Correlation

The term cross-correlation which refers to the correlation between two signals is viewed as a standard approach when trying to detect features [12, 13]. Literature presentations of correlation describe the convolution theorem. They also describe the attendant possibility of computing correlation efficiently in the domain of frequency analysis using the fast Fourier transform. Unfortunately, the correlation coefficient, which is the normalized form of correlation that is preferred in template matching, does not have simple and efficient expression in the frequency domain [14]. This is the reason why normalized cross – correlation has been computed in the spatial domain [15]. Because of the high computational cost of spatial domain convolution, several fast but inexact spatial domain matching methods were developed [14]. The algorithm [16] used in order to obtain the normalized cross correlation will be presented using the equations represented below.

The use of cross-correlation for template matching is motivated by the distance measure (squared Euclidean distance)

$$d_{f,t}^2(u,v) = \sum_{x,y} [f(x,y) - t(x-u, y-v)]^2 \quad (1)$$

where f is the image and the sum is over x,y under the window containing the feature t positioned at u, v. In the expansion of d^2:

$$d_{f,t}^2(u,v) = \sum_{x,y} [f^2(x,y) - 2f(x,y)t(x-u,y-v) + t^2(x-u,y-v)] \quad (2)$$

the term $\sum t^2\,(x-u, y-v)$ is constant.

If the term $\sum f^2(x,y)$ is approximately constant, then the remaining cross – correlation term
:

$$c(u,v) = \sum_{x,y} f(x,y)t(x-u,y-v) \quad (3)$$

is a measure of the similarity between the image and the feature.

There are several disadvantages for using (3) for template matching:

- If the image energy $\sum f^2\,(x,y)$ varies with position, matching with (3) can fail. For example, the correlation between the feature and an exactly matching region in the image may be less than the correlation between the feature and a bright spot.
- The range of c(u,v) is dependent on the size of the feature
- Equation (3) is not invariant to changes in image amplitude such as those caused by changing lightning conditions across the image sequence.

The issue that needs to be addressed is the identification of artwork using an array of graphical elements that define the work style of each studied painter. In the first stage of algorithm development there will be used images that contain average items (screws, coins, etc.) in different positions or alignment.

One of the identified issues was the variation of the light in the images if they were not taken in a studio using the same light conditions. (Fig. 1).

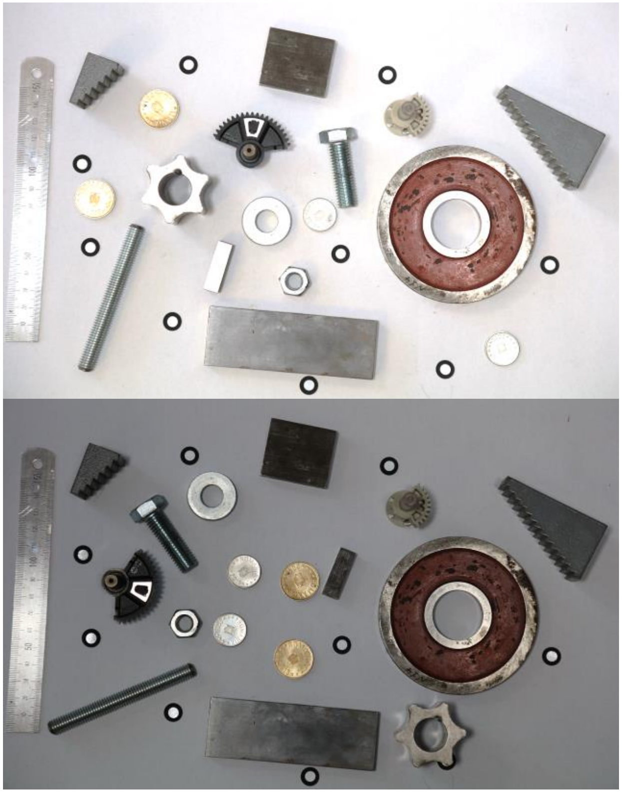


Fig. 1 Imagines used for algorithm validation

For image-processing applications in which the brightness of the image and template can vary due to lighting and exposure conditions, the images can be first normalized. This is typically done at every step by subtracting the mean and dividing by the standard deviation.

That is, the cross-correlation of a template, t(x, y) with a sub image f (x,y) is :

$$c(u,v) = \frac{1}{n}\sum_{x,y} \frac{1}{\sigma_f\,\sigma_t}\big(f(x,y) - \mu_f\big)\big(t(x,y) - \mu_t\big) \quad (4)$$

where n is the number of pixels in $t(x,y)$ and $f(x,y)$, μ_f is the average of f and σ_f is standard deviation of f .

After eliminating the effects of brightness and contrast of the image, the next problem to be solved is the orientation t (x, y) (ROI) with respect to f (x, y).

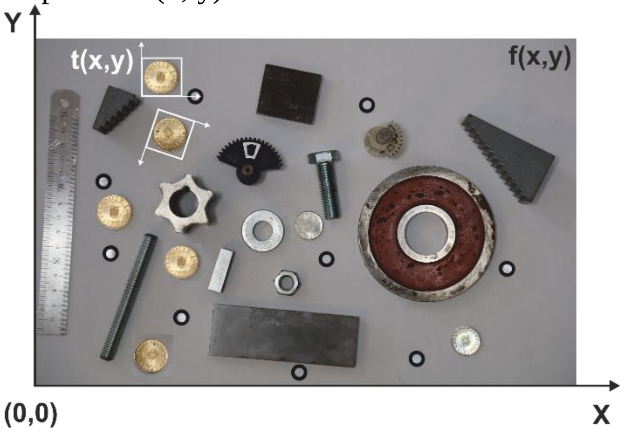


Fig. 2 ROI relative positions

To solve the orientation problem, a rotation matrix between these two images t (x, y) and f (x, y) must be determined. A loop is created in which the image t (x, y) is incrementally rotated clockwise and incrementally translated to the image f (x, y). For each position it is determined the correlation factor that allows quantitative assessment of the degree of matching between ROI (Region Of Interest) (t) and the image in which it is searched (f).

$$\gamma = \frac{\sum_{x,y}(f(x,y) - \overline{f}_{u,v})(t(x-u,y-v) - t)}{\sqrt{\sum_{x,y}(f(x,y) - \overline{f}_{u,v})^2 \sum_{x,y}(t(x-u,y-v) - t)^2}} \quad (5)$$

3. ALGHORITHM IMPLEMENTATION

3.1 Imagine acquisition

In the validation stage the image acquisition has been done in the laboratory under controlled conditions to minimize the influences due to the variation of light and contrast. A composition of items that contains several similar objects has been created, several photographs were taken in which the positions of three objects remained constant and the rest were modified so that it could be tested to identify similar elements in different positions. In Fig. 3 presents the images that have been used and Fig. 4 highlight the results.

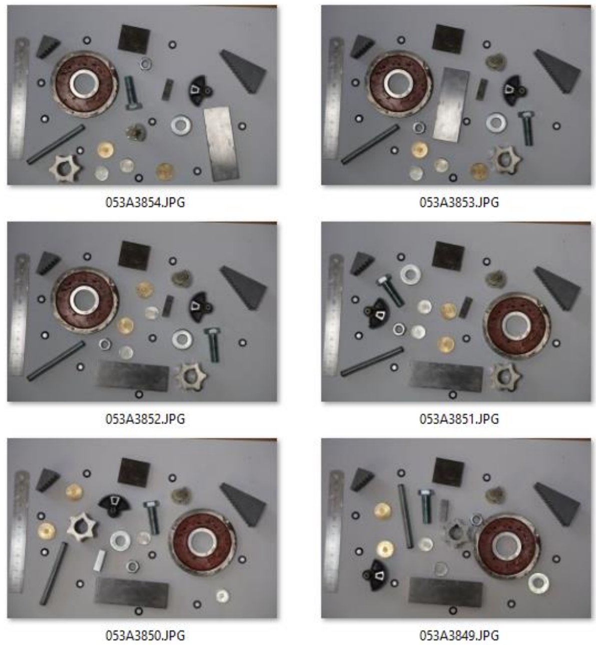


Fig. 3 The images used to validate the mathematical model

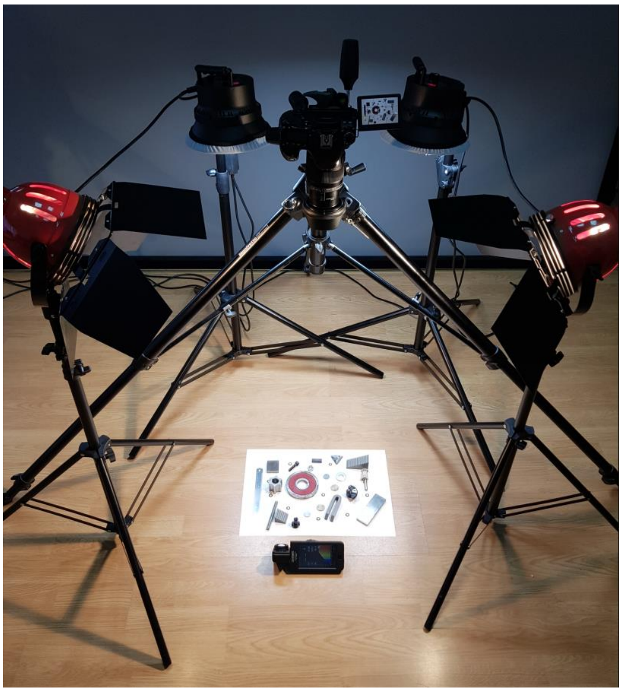


Fig. 4 Image acquisition

The images were acquired using a DSLR Canon 5DSR camera with 50 MPx resolution, the light intensity was measured using Sekonic Spectromaster C-700.

3.2. Algorithm automation

The automation of the algorythm was realized using Matlab software. Every image that will be verified will receive an element that will be compared to that image (e.g. coin element for a standard image, or ear element for a work of art). Two regions will be identified, one in the image that is used for comparison and one in the element. For those regions the normalized cross – correlation algorythm will be applied and it will generate an array where these sub regions intersect themselves. This array can later be used in order to identify the position of the element inside the image that was analized (e.g. the presence of a coin 2 times in the image, fig.2, or the presence of an ear in a painting, fig.6).
The algorythm was tested on three types of iamges (Fig. 5), one in the vizible specter and the other two in the IR and UV specters.

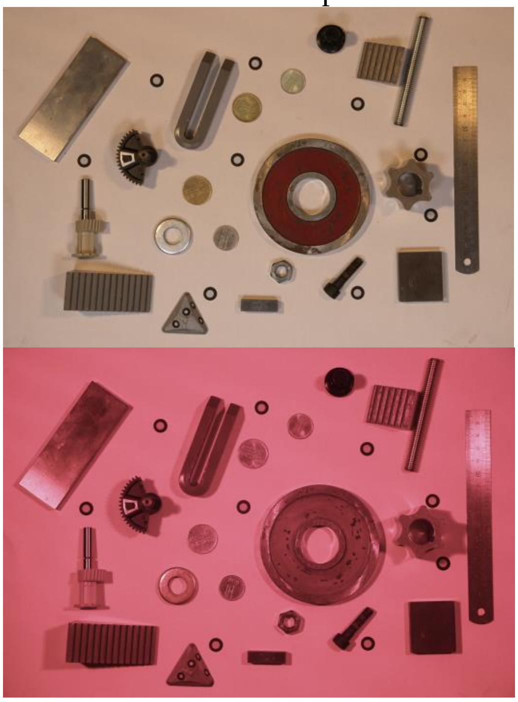


Fig. 5 Types of photos used: visible, IR, UV

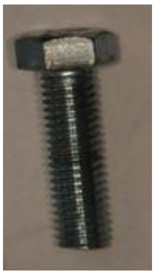
The algorithm was successful in identifying the elements in all three types of images that were used, but at different rates and processing time and power. It also showed that using different resolution for the elements modified the processing time and power of the algorithm. The chapter below will present these results.

4. RESULTS

The table below presents a couple of pictures of some of the elements in the paper at different resolutions in order to identify a connection between the resolution and the time required for image processing. The pictures of the elements will be presented at different resolutions.

Table 1 Different resolutions and processing time for elements of the images

Element	Resolution	Processing time
	8688x5692 pixels	20 minutes
	4344x2896 pixels	10 minutes
	2172x1488 pixels	3 minutes
	1086x724 pixels	30 seconds
	8688x5692 pixels	20 minutes
	4344x2896 pixels	10 minutes
	2172x1488 pixels	3 minutes
	1086x724 pixels	30 seconds
	8688x5692 pixels	20 minutes
	4344x2896 pixels	10 minutes
	2172x1488 pixels	3 minutes

	1086x724 pixels	30 seconds
	8688x5692 pixels	20 minutes
	4344x2896 pixels	10 minutes
	2172x1488 pixels	3 minutes
	1086x724 pixels	30 seconds

5. CONCLUSION AND FUTURE WORK

The algorithm was successfully applied on the images that showcased various engineering elements (gauges, screws, washers, coins) as well as the images showcasing the field of cultural heritage. Fig. 6 illustrates the results obtained after the application of the algorithm on a work of art, where the element of interest, (the ear) can be identified in the image.

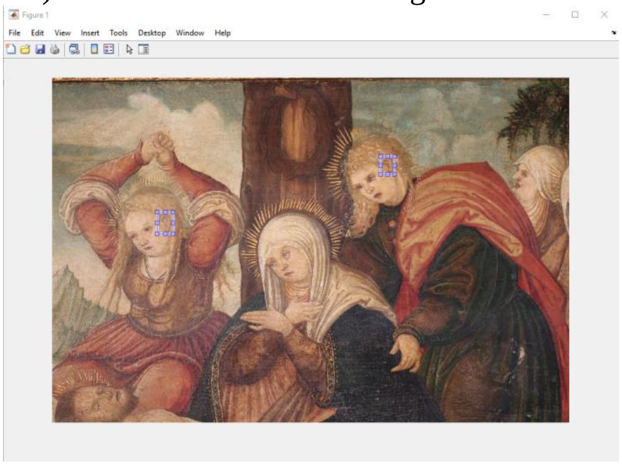


Fig. 6 Results of application of algorithm on art

Time is a factor in image processing. In order to reduce the time needed to process a certain image a series of operations should be performed, such as: reducing the image resolution, choosing an optimal color spectrum for the image.
The algorithm can be successfully applied in the field of cultural heritage, as shown in the example showcased above.

6. ACKNOWLEDGMENTS

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UTILIZAREA PROCESARII IMAGINILOR PENTRU VERIFICAREA AUTENTIFICITATII ARTISTICE

Rezumat: Abordarea tradițională utilizată pentru studiile de artă pictată se bazează pe observațiile studenților privind diferențele subtile în detaliu și caracteristicile de periere. Având în vedere metodele empirice implicate, în unele cazuri interpretarea poate fi influențată de o serie de aspecte, cum ar fi experiența personală, acuitatea vizuală sau percepția individuală a culorilor. Dezavantajele acestei tehnici sunt agravate de lipsa personalului calificat suficient. Lucrarea descrie pașii preliminari necesari dezvoltării platformei "ID-Art", o soluție integrată cu scopul de a furniza cunoștințe științifice complementare și argumente matematice necesare investigării artefactelor 2D sau a altor eforturi de autentificare a operelor de artă pictate.

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