TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics and Mechanics
Vol. 57, Issue I, March, 2014

IMAGE PROCESSING BASED ON THE CROSS-CORRELATION MODEL

Dan HURGOIU, Vasile TOMPA, Călin NEAMȚU, Daniela POPESCU

Abstract: *The Kosons are ancient gold coins categorized as treasury coins which were not exchanged in commercial trades. This specific particularity of the Kosons enables scientists to use image processing techniques in the classification and authentication work. Because this type of coins have no signs of wear specific to a long time of circulation, it is now possible, by a rigorous inventory, to establish the number of molds used in the minting process. The only viable method for the identification and classification of an important amount of coins is a semi-automated or automated process. This paper presents the working algorithm and concepts implemented by the authors for Koson coins inventory, and also presents the hardware and software platforms designed for this application. The algorithm used to develop the software application is based on the Fast Fourier Transform (FFT) and Discrete Fourier Transform (DFT) applied in a correlation filter.* ***Keywords:*** *image processing, cross-correlation, gold Kosons, Dacian treasury*

1. INTRODUCTION

The Kosons represent gold coins found only in Dacia, in a relatively small area around Dacian fortresses from Orăştie Mountains. These coins were always found in large stashes with no sign of being in circulation and buried in isolated places sometimes with artefacts such as the gold spirals/bracelets. They may be regarded as religious offerings. As for metrology they were minted at the weight of Greek/Hellenistic stater, between 8.20 to 8.70 grams. As in majority cases of the mintage process, the Kosons blanks were strike while still hot. Except for the Greek inscription, and possible the monogram, the design on both obverse and reverse of the coin are of Roman inspiration.

The presumed obverse depicts an eagle, standing on a scepter, a claw raised and holding a wreath, an image copied from a Roman republican denarius of Q. Pomponius. On the presumed reverse, the Koson copies a silver Roman depicting a Roman republican denarius of M. Iunius Brutus.

Although the Dacians have chosen the symbolism from Roman coins, the writing on reverse, in exergue, is in Greek: ΚΟΣΩΝ. Most likely this a name of a Dacian king, attested after the reign of Burebista. An argument on this line, can be considered the monogram that appears in the on the 'reverse' and which may be red as BA ΚΟΣΩΝ.

Given the particularities of this coin, the authors want to conduct a unique study in numismatics: establishing the number of molds used to mint these coins.

Considering that these coins were treasury coins, most likely owned by the king and the nobility, the minting was rigorously controlled. Theoretically, if it is possible to inventory and classify all gold Kosons from various collections of heritage, then, based on the geometrical elements that embroider the obverse and reverse, it will be possible to establish and reconstruct the molds used for their minting. After classifying the coins according to the die used to mint them, it would be possible, using laser scanning techniques, as shown in [3], to determine the height of the profile and the chronological order in which they were minted, based on the analysis of the mold wear.

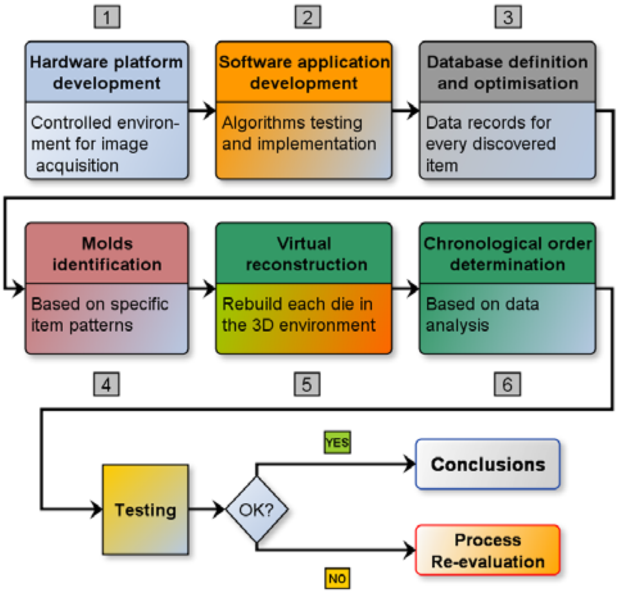

Fig. 1. Step by step approach for the coin classification

The authors have identified the steps illustrated in Figure 1, which should be completed in order to accomplish the coin classification process. This paper describes the first three steps with examples and case studies conducted by the authors until present day.
Image processing is a widely used concept in applications regarding measuring or inspecting certain products, medical analysis equipment use image processing in order to highlight the results as shown in [10], inspecting luggage in airports, forensics experts use image processing techniques to extract information from video or photo sequences, detection of physiological and psycho-emotional data from facial expressions [11] or in cultural heritage [12].

Using image processing in analyzing numismatics is not a totally new approach; it was previously used by Zaharieva [4] and Zambanini [5] in algorithms based on robust dense correspondence estimation for exemplary-based image classifications adapted to ancient coin classification.

Other adopted techniques involve Eigen-space approaches [8], statistical pattern analysis based on Eddy-current sensors [9], or systems based on image segmentation [13].

The approach proposed by the authors in this paper studies in parallel both the software and the hardware parts used to acquire the image so that results can be reproduced with high repeatability.

2. METHODOLOGY

2.1 General overview

For the application's development, the authors chose MATLAB as testing environment, which was used to create and validate the algorithm. The implementation was done through LabVIEW and MySQL.

The MySQL database stores two photos for each coin: obverse and reverse of the coin and some additional information: serial number, source data, etc. The photos are taken in a room specially designed for image acquisition.

Coins are classified into families (Figure 2), where each coin can be part of maximum two families, one for each of its sides. For each family is declared a template coin (standard), which is established when comparing all the coins in that family. After comparing the coins within a family, each coin is given a ranking scotr that reflects the degree of match.

When there is a coin that cannot be placed in either of the populated families, it is put in FA0 and FR0 where, if an identical coin is found, a new family will be formed. If an identical coin is not found in either of the two families, the new coin must be examined by a numismatist in order to be validated as genuine to avoid indexing counterfeits.

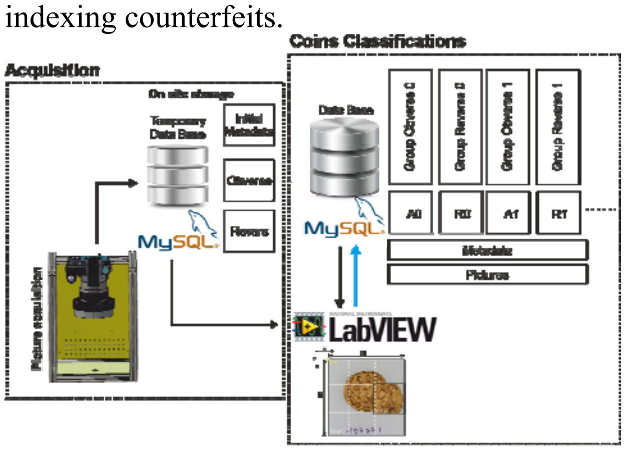

Fig. 2. General overview of the algorithm

When inserting a new coin into the database, it is compared with all the standard coins in order to establish the family to which it belongs (Figure 3). After establishing the family to which it belongs, the coin will be compared with all the coins in the family to determine the ranking for the coin inside that family. In the database there are two families with special status FA0 and FR0, where are stored those coins that cannot be classified in the other families.

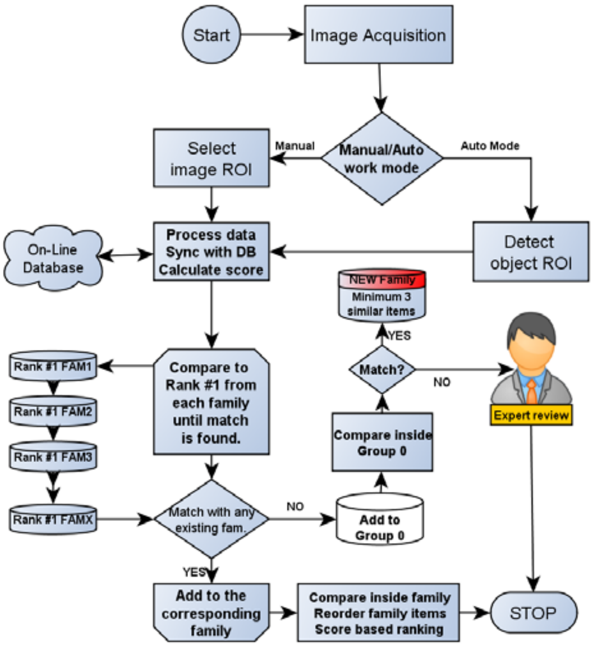

Fig. 3. Algorithm for coin classification

Each coin is recorded using the following set of metadata:

- Koson obverse and reverse images (High Resolution with EXIF data)
- Inventory number, date and place of discovery (GPS coordinates, if available)
- Image Acquisition Date and Time
- Measured light intensity inside enclosure (for each picture)
- Database uploading details (date, time, user)
- Cross correlation factors (scores) for the obverse and reverse group
- Coin weight, diameter and axis data
- Gold composition

2.2 Hardware development

In order to ensure identical conditions for taking pictures of the coins, a device was designed and built, like in Figure 4. Aluminum profiles and PVC walls provide ambient light obstruction to a 99.9% rate. Superflux type LEDs were used to illuminate the enclosure, which emit cold white light, each LED being able to generate a light flux of 20 lumens. Luminous intensity of these LEDs may be modified by changing the power supply voltage to ensure steady lighting over time.

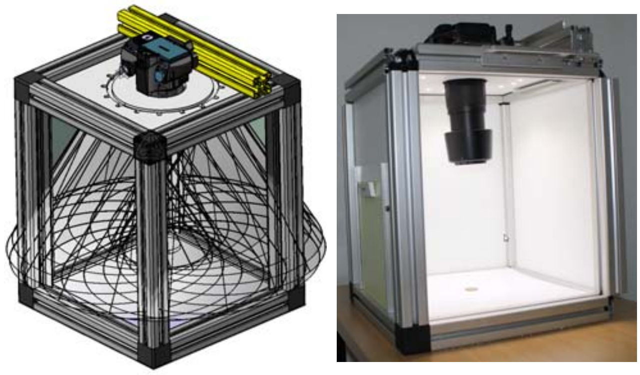

Fig. 4. Image Acquisition platform: CAD model on the left side and real model on the right side

The arrangement and number of LEDs was calculated so that the center of the enclosure (Fig. 5) represents an area where all light cones overlap in order to avoid shadows.

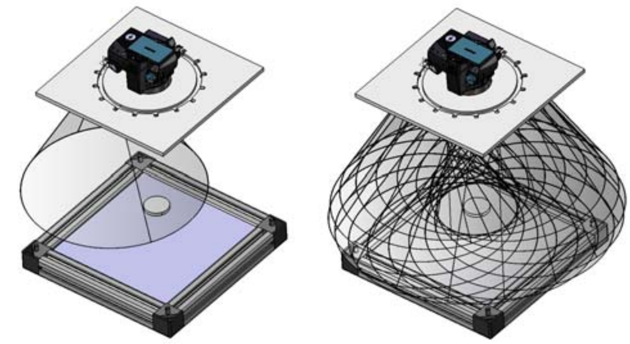

Fig. 5. LED light cone and evenly illuminated area of the coin surface

2.3 Software development

The algorithm used to develop the application is based on the Fast Fourier Transform and Discrete Fourier Transform applied to a cross correlation filter (Fig. 6).

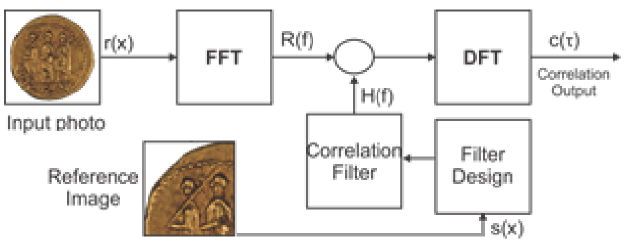

Fig. 6. General overview of correlation algorithm

The algorithm was implemented in LabVIEW and uses two matching algorithms: Normalized Cross-Correlation and Rotation-Invariant Matching. The first one will be used when coins are photographed in the same position with a rotation of ±10°, and the second one for higher rotation values. The two algorithms will be used to optimize the use of computing resources and for shortening the search time.

Normalized Cross-Correlation is the most common method of finding a pattern in an image. Since the basic mechanism for correlation is based on a number of multiplication operations, the correlation is time consuming [7]. To speed up the matching process, we can reduce the size of the image and restrict the image area where the set template pattern is searched.

Rotation-Invariant Matching involves scaling or resizing the template and then conducting a correlation operation. This significantly increases the calculations necessary for the matching process. If the rotation's nature is unknown, determining the best correlations requires an exhaustive number of rotations of the template.

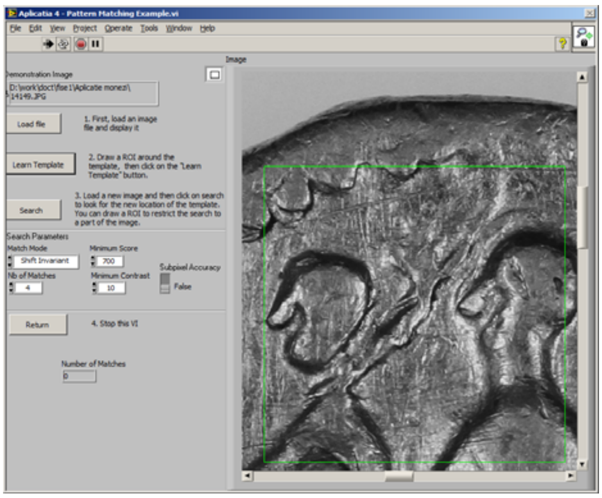

Fig. 7. LabVIEW application

Correlation between two images can be described as follows: an image w (x, y) of size K × L (Figure 8) is considered the template and an image f (x, y) of size M × N where K ≤ M and L ≤ M, the correlation between w (x, y) and f (x, y) at a point (i, j) is given by:

$$C(i,j)=\sum_{x=0}^{L-1}\sum_{y=0}^{K-1} w(x,y)\,f(x+i,y+j) \qquad (1)$$

where, i = 0, 1, . . . M - 1; j = 0, 1, . . . N - 1, amount is calculated for the region where images w and f overlap. The correlation factor is:

$$cf=\frac{\sum_{i=0}^{N-1}(x_i-\bar{x})\cdot(y_i-\bar{y})}{\sqrt{\sum_{i=0}^{N-1}(x_i-\bar{x})^2\cdot\sum_{i=0}^{N-1}(y_i-\bar{y})^2}} \qquad (2)$$

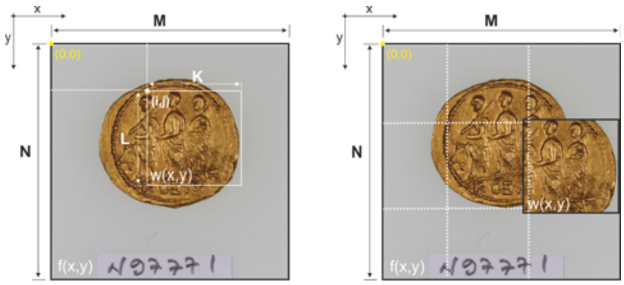

Fig. 8. Correlation principle applied in coin classification

Figure 8 illustrates how the template is searched for inside the input image, if the image f origin is the upper left corner (point (0,0). Correlation is the process in which the template w is moved systematically inside image f in order to calculate variable C.

This involves multiplying each pixel in the template with image pixels that overlap and then summing up the results for all pixels in the template. The matching degree of an image region with the pattern is obtained by calculating a numeric index which indicates a value that represents how well the pattern matches with the content of that region.

High cross-correlation values indicate the presence and location of the template we are looking for. Figure 9 is an example of large cross-correlation factor between "O" and "Ω".

One of the goals of this research is to develop methods that preserve large cross-correlation with desired targets, while suppressing cross-correlation with undesired images (sometimes called the clutter), and reducing sensitivity to noise and distortions such as rotations, scale changes, etc. This is possible through the use of filters, which were developed especially for this case study.

Fig. 9. Large cross-correlation factor between the letter ‘‘O’’ and the letter ‘‘Ω’

3. RESULTS

By using the application developed in LabVIEW, a numismatic expert is able to check if two coins are part of the same group by defining the areas (regions) of interest. The selection of these areas of interest is at the user’s choice or, if selected, predefined sets of areas may be used. These regions of interest are considered reference images (Fig. 6) and based on them the correlation factor defined by Equation 2 is calculated.

Table 1

The correlation factors determined for various coins.

Inventory number	Group Averse	Correl ation factor	Group obverse	Correl ation factor
14146	F1	408	A1	448
14147	F1	408	A1	408
14148	F2	425	A1	HF
14149	F2	425	A1	406
97762	F5	354	A3	474
97763	F5	HF	A3	HF
97764	F5	389	A3	532
97765	F3	374	A2	359
97766	F3	414	A2	319
97767	F3	362	A2	328
97768	F3	HF	A2	HF
97769	F3	251	A2	349
97770	F0	HF	A2	377
97771	F3	357	A2	397
97772	F3	286	A2	287
97773	F3	367	A2	484
97774	F3	345	A2	458
97775	F3	272	A0	HF
97776	F4	HF	A4	HF
97777	F3	125	A2	321
97778	F4	463	A4	314
97779	F4	472	A4	524
97780	F3	259	A2	448
97781	F3	368	A2	342
97782	F3	346	A2	388
97783	F3	247	A2	486

Table 1 presents the correlation factor calculated for various coins and the families identified based on experimental data.

Fig. 10. Visible differences between gold Kosons

Figure 10 illustrates three golden Kosons and three areas of interest; the differences are visible with the naked eye both in the area with fascia of the two lictors and in the ΚΟΣΩΝ inscription area.

4. CONCLUSIONS

This paper presents the first steps of a scientific approach that seeks, through an interdisciplinary approach, to determine the number of molds used to mint the gold Koson, a coin used in the ancient capital and religious center of Dacia, Sarmisegetuza Regia (ancestors of the Romanian people). Gold Kosons have a unique history in numismatics and, because of their destination (treasury coins) and restricted area in which they were discovered so far, it is possible that these coins were fabricated in a single monetary center.

The inventory and classification of coin families for obverse and reverse can lead to theoretical determination of the number of molds used to mint them. Classification of gold Kosons is done through an algorithm developed by the authors, based on correlation filters developed using the cross correlation method.

Two algorithms are used to search areas defined as templates: Normalized Cross-Correlation and Rotation-Invariant Matching to minimize errors that can occur because of distortions such as rotation, scale, etc.

The algorithm was implemented in LabVIEW and tested on all the coins of this type held by the National History Museum of Transylvania in Cluj-Napoca. The authors have developed a MySQL database that can be used to classify gold Kosons and image acquisition hardware intended to ensure identical image acquisition conditions for any given location.

Once the database is populated with all the coins that are legally in possession of institutions or collectors, the application could be used in detecting fakes and authenticating items which are illegally traded.

The next step in the application's development is the enhancement of matching algorithms that generate consistent results if used on images taken outside our controlled environment, in order to allow a primary item classification.

5. REFERENCES

[1] http://www.icollector.com
[2] http://www.moneymuseum.com
[3] L Morovič, P. Pokorný, *Optical 3D Scanning of Small Parts*, Advanced Materials Research, Volumes: 468-471 pp. 2269-2273, Trans Tech Publications, Switzerland; 2012.
[4] M. Zaharieva, M. Kampel, S. Zambanini, *Image based recognition of ancient coins*, 12th International Conference on Computer Analysis of Images and Patterns (CAIP'07), pp. 547–554, 2007.
[5] Zambanini S., Kampel M., *Coarse-to-Fine Correspondence Search for Classifying Ancient Coins*, 2nd ACCV Workshop on e-Heritage, Daejeon, South Korea, 2012.
[6] http://www.slrgear.com/product/157
[7] ***, *NI Vision Concepts Manual*, PN: 372916J-01, National Instruments, 2010.
[8] R. Huber, H. Ramoser, K. Mayer, Harald Penz, Michael Rubik, *Classification of coins using an eigenspace approach*, Pattern Recognition Letters, Volume 26, Issue 1, Pages 61-75, ISSN: 0167-8655, 2005
[9] Chih-Cheng Lu, Wen-Liu Chang, Chih-Chen Wang, Sheng-Fong Yu, Jen-Tzong Jeng, *A statistical pattern analysis approach for rapid coin identification based on Eddy-current sensors*, Procedia Engineering, Vol. 15, pp. 5579-5583, ISSN 1877-7058, 2011.
[10] A. Dehghani, H. Moghaddam and M.S. Moin, *Optic disc localization in retinal images using histogram matching*, Eurasip Journal, DOI: 10.1186/1687-5281-2012-19
[11] A. Poursaberi, H. Noubari, M. Gavrilova, S. Yanushkevich, *Gauss–Laguerre wavelet textural feature fusion with geometrical information for facial expression identification* EURASIP Journal, 2012.
[12] Ghanem T.M, Moustafa M.N, Shahein H.I, *Gabor wavelet based automatic coin classsification*, 16th IEEE International conference on image processing, ISBN: 978-1-4244-5653-6, pp. 305-308, 2009.

PRELUCRAREA DIGITALĂ A IMAGINILOR PE BAZA MODELULUI "CROSS-CORRELATION"

Kosonii sunt vechi monede dacice care nu erau utilizate în schimburile comerciale. Această particularitate specifică le permite oamenilor de ştiinţă să utilizeze tehnici de prelucrare digitală a imaginilor în procesul de clasificare şi autentificare. Lucrarea de faţă prezintă conceptele şi algoritmul de lucru dezvoltate de către autori în vederea inventarierii monedelor de tip Koson, fiind descrise platformele hardware şi software necesare aplicației. Algoritmul de prelucrare a imaginilor utilizat se bazează pe un filtru software de corelaţie bazat pe transformări Fourier (FFT şi DFT).

Dan HURGOIU, PhD, Lecturer, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, 103-105 Muncii Blvd, 400641 Cluj-Napoca, +40 264 415 710, e-mail: dan.hurgoiu@muri.utcluj.ro

Vasile TOMPA, PhD Student, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, 103-105 Muncii Blvd, 400641 Cluj-Napoca, +40 264 415 710, e-mail: vasile.tompa@muri.utcluj.ro

Calin NEAMTU, PhD, Lecturer, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, 103-105 Muncii Blvd, 400641 Cluj-Napoca, +40 264 415 710, e-mail: calin.neamtu@muri.utcluj.ro

Daniela POPESCU, PhD, Professor, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, 103-105 Muncii Blvd, 400641 Cluj-Napoca, +40 264 415 710 e-mail: daniela.popescu@muri.utcluj.ro