Automatic Rotation of the Copper-Brass Seal's Images During Their Verification

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Key Words: *Copper-Brass Seals; Seal Verification; Image rotation; Image comparison.*

Abstract. *The International Atomic Energy Agency (IAEA) and the European Atomic Energy Community (EURATOM) use thousands of Copper-Brass Seals every year to keep continuity of knowledge of nuclear material. The verification, done at headquarters is a time consuming procedure, whose operations are performed almost manually, i.e. the seals under verification are manually rotated until they can be compared to the image stored in the Database (DB) that has been taken before sending the seal on the field. We are proposing an algorithm for automatic rotation of the image to match with the reference image from the DB. The main considered parameters are reliability of the algorithm and speed. A set of couple seal images was captured by an industrial vision system and pre-processed. A programming code for image rotation in each degree was developed, which estimates the similarity between the original and rotated image by the following parameters: Euclidean Distance (ED) and Sum of Absolute Differences (SAD) and returns the angle, for which one the min value of ED and SAD were found. The program was tested for 304 digital images of real seals, provided from IAEA and EURATOM. The maximum error during the experimental determination of angle of seal rotation was 0.3%. A proposal for a faster algorithm for rotation and determination of the rotation angle of the image related to the reference image is made. The proposed algorithm was tested for the same set of images.*

1. Introduction

A particular application of seals is related to nuclear materials, which require high levels of safety for tracking and/ or inspection. In this case, the „Copper-Brass Passive Seal“ (CBS) finds application. It is known also as an „E-Type seal“ and is used in great numbers since the last decade (about 20 000 pieces per year) [1] by the Directorate General Energy (EURATOM safeguards) of Luxembourg, and also by the International Atomic Energy Agency (IAEA) of Vienna [2]. The seals are used to ensure the detection of an integrity breach in the containment [3]. Most safeguards seals are applied for an extended period of time, typically from several months to years [4].

The seal consists of two metallic halves (caps) (*figure1*), which can be interlocked. A piece of wire is used to attach the seal; the ends of the wire are tied inside the seal before closing it. The seal is designed in such a way that any attempt to open it would be detectable. The substitution can be determined only at the headquarters of the safeguards authorities. The seal is a commercial seal, which is simple and inexpensive. The identity of each seal (codification) is created by using a drop of tin which is placed inside the caps, and then scratched in random manner so as to obtain a unique pattern (*figure1b*). Prepared in this way, the identities of the two caps are photographed and stored digitally in a Database (DB). Then the seal is ready for its use. Inspectors apply such seals in nuclear facilities to keep the knowledge on previously verified materials, freeze stocks of nuclear material or protect their equipment from unauthorized access.

The positive aspects of this kind of seal are the low unit cost, the simple use and the difficulty to tamper with. The negative aspects are mainly the time and the cost for verification. The verification of the seals is a long lasting and laborious procedure and includes: the inspection of the seal in the field (and the integrity of the associated cable), its removal and its shipment to a special laboratory for a careful study of seal parts [5]. After contamination checks, the seal is cut in two and the internal identities are again photographed and then compared with the correspondent images previously taken before the seal was sent to the field [6]. Most operations during the verification are performed manually and their automation could reduce the time and cost of the verification process. The purpose of our current research is the automation of the rotation of the seal during its verification in the laboratory. At the best of our knowledge there is no available published work on this problem. Currently the seal rotation is performed manually by the operator in order to align the image of the seal under verification to the one stored in the DB before it is affixed. After rotation, the identities are compared visually by the operator. This paper

a) CBS before codification b) CBS with codification c) locked CBS

Figure 1. Copper-Brass Seals

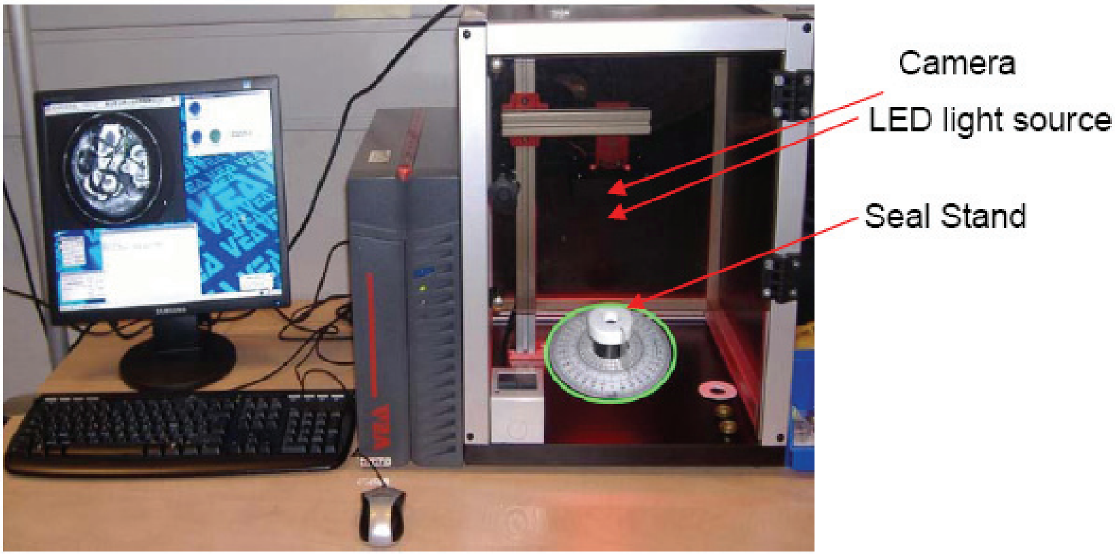


Figure 2. HQV VEA System with integrated additional seal stand

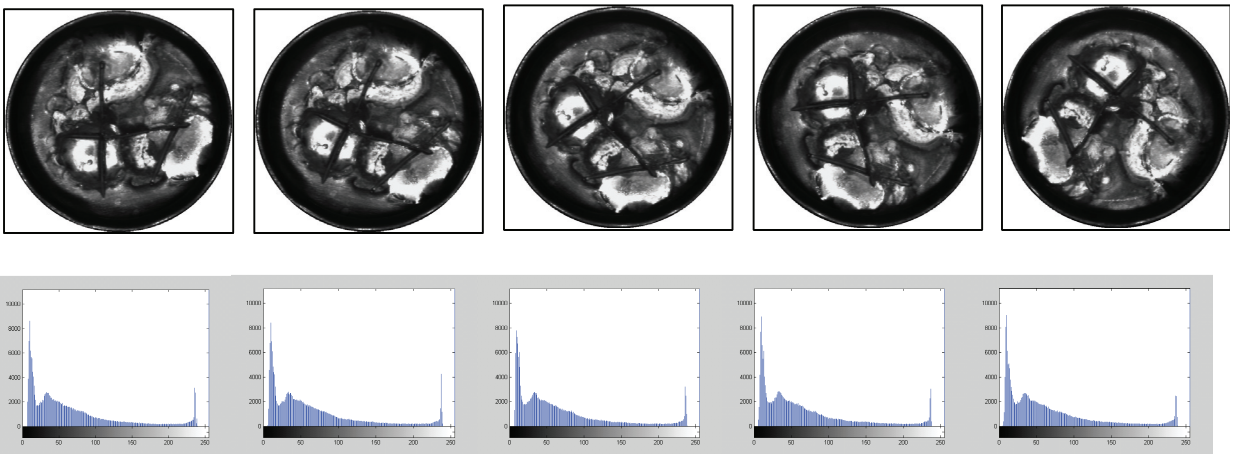


Figure 3. Images of seal codification after its random rotation and their histograms

explains possible software solution for automatic rotation of the seal image according to the seal reference in the DB).

2. Seal Image Capturing and Pre-processing

An artificial visual system „HQV VEA System“ 0574 was used for capturing the digital seal images in the current experiment. An additional seal stand and angle scales, which give the possibility of rotation, were developed (*figure 2*). Eight Copper-Brass seal parts with unique codification were provided by IAEA and EURATOM and used in the experiment.

All the images are pre-processed by extracting only the area of interest (seal codification). In many papers [7,8,9,10,11,12,13,14,15,16] Euclidian Distance (ED) and Sum of Absolute Differences (SAD) are used like parameters of similarity in comparing the images, calculated as follow:

$$(1)\quad ED = \sqrt{\sum_{i=1}^{W}\sum_{j=1}^{H} (IA_{i,j} - IB_{i,j})^2},$$

where IA_{ij}, IB_{ij} are intensities of i, j-pixel from compared images (A, B), W and H are width and height of the images. Both images A and B have the same dimension.

$$(2)\quad SAD = \sum_{i=1}^{W}\sum_{j=1}^{H} \left| IA_{i,j} - IB_{i,j} \right|,$$

The histogram evaluation of the grey scale images of the CBS showed that the basic shape of the histogram stays permanent for all the seal images with very little changes. Five images of seal codification after random rotations with their histograms and five different seal codification with their histograms are shown in *figure 3* and *figure 4*. It is obvious, that using only the histogram as a parameter for seal comparison is not sufficient to confirm identity (see the similarity in the last two histograms in *figure 4* of two different seals), but this parameter could be used in the initial seal comparison (see the similarity of the histograms of the same seal after random rotations in *figure 3*), which will decide immediately if the seals are totally different.

3. Image Rotation by Using ED and SAD

An additional seal stand (*figure 5*) was developed and installed in the VEA system. The seal base has two holes: one

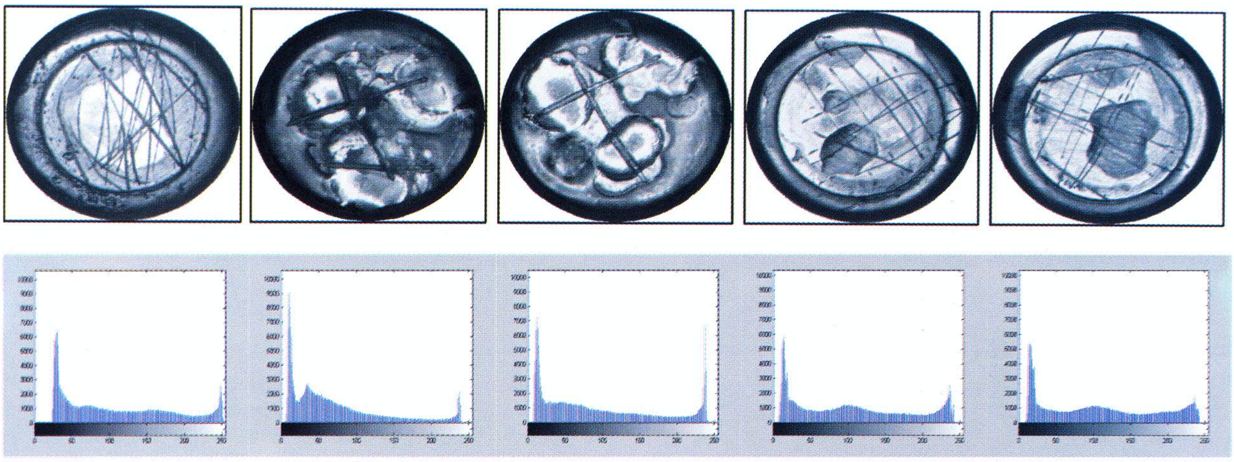


Figure 4. Different seal codification and their histograms

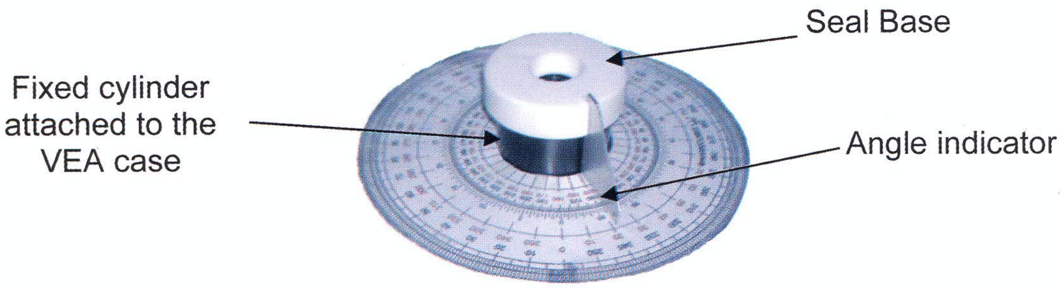


Figure 5. Seal stand with indicator for the angle of rotation

on the top with the diameter of the seal, where the seal lies without the possibility to move and one on the bottom with the same diameter of the holding cylinder (*figure 5*). An indicator for degrees and an angle scale was attached to the seal base and the VEA case. These settings allow the rotation of the seal base without horizontal or vertical movements. The maximum dimension of the indicator and scale were chosen according to the limits of the available space in the VEA box. This connection allows a precision in the manual placement of ±2°. Two images of a seal were captured with resolution 560x560 pixels and resolution 960DPI, called respectively reference and sample. The reference was captured with indicator in 0 and the sample in 335° (-25°).

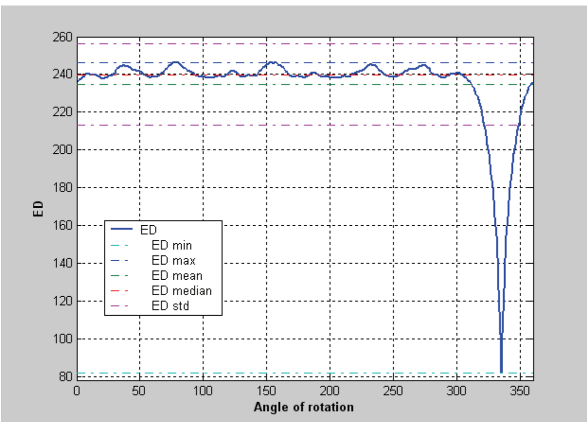


Figure 6. ED for the compared images

Both images are then converted to binary with a threshold of 0.5 (*figure 5*) and the image processing is performed as follow:

a. rotation of the sample to each degree from 1° to 360°;

b. calculation of ED and SAD for each two images (rotated sample and the reference).

The graphical representation of all 360 values of ED can be seen in *figure 6* and of SAD in *figure 7*. The minimum value for ED and SAD is found at 335°, which is exactly the angle of rotation. The reference, the sample and the sample after the rotation at 335 degree can be seen in *figure 9*. Visually, the angle of rotation looks correct, but in the next paragraphs we will try to prove experimentally that the minimum in the value of ED

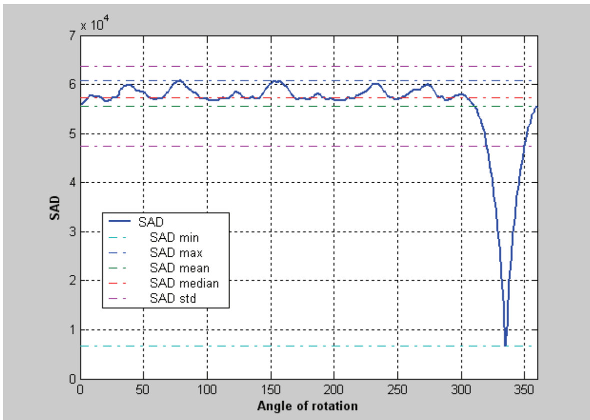
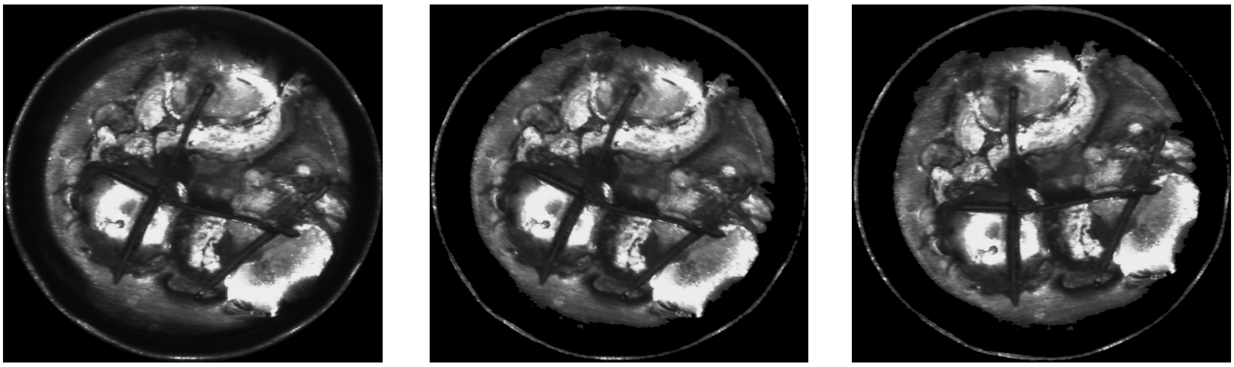


Figure 7. SAD for the compared images

Reference Sample after rotation at 335º Sample

Figure 8. Binary images of inner side of the copper seal part



Reference Sample after rotation at 335º Sample

Figure 9. Grayscale images of inner side of the copper seal part

can be used as an indicator for the angle of rotation between the sample and the reference.

Visually, the rotation seems correct, but if both images are compared more precisely, differences between the reference and the rotated sample can still be found. The subtract image of reference from the rotated sample can be seen in *figure 10* (the subtract image is inverted for better visualization). These differences could be the result of the horizontal and vertical seal translations during the capture, image pre-processing or noise from the camera. Therefore, some other pre-processing steps are needed, and a linear translation of the seal images is also a required step during the seal verification.

Figure 10. Inverted subtract of the reference from the rotated sample

4. Test of ED Utility for the Determination of the Seal Rotation Angle

Considering the fact that ED and SAD are calculated by a similar equation, in the current test only ED was used. This test was performed on more seal images to prove the usefulness of ED as a parameter for the determination of the angle of rotation between the sample and the reference image. The test was performed acquiring 38 digital images for each of the 8 seal parts (total 304 images). The resolution of the images is 960DPI, their size 560x560 pixels (14.82 cm x 14.82 cm) and the diameter of the real seal is 2 cm. The test was executed, as follow:

- each seal is placed in the seal stand and a reference image is taken (Indicator is directed to 0°);
- other 36 images (called samples) are taken at an interval of 10 degrees of rotation (i.e. in 10°, 20°, 30°, ..., 340°, 350°, 360°).
- An additional sample is captured at a selected angle of rotation of 25°.

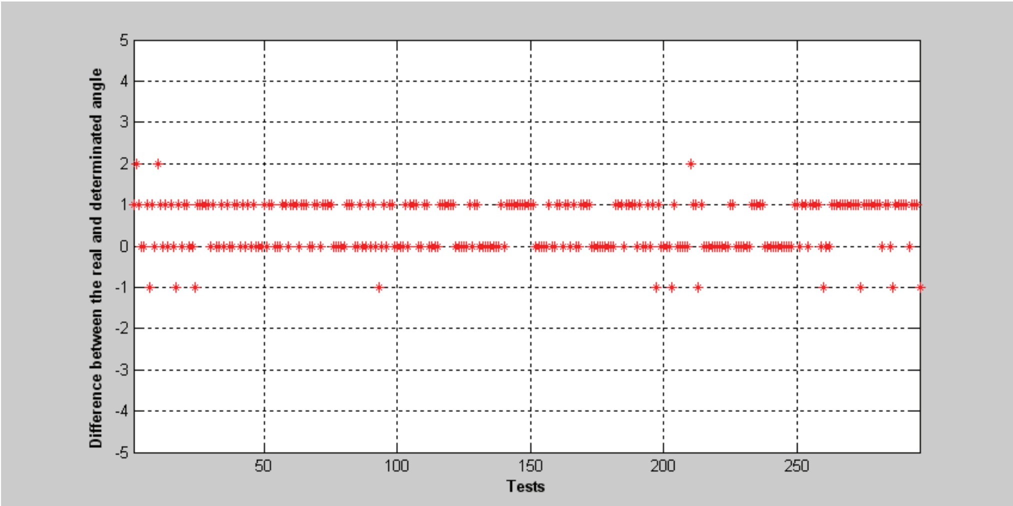


Figure 11. Differences between the real angle of rotation and the angle obtained by ED

A program was written using MATLAB, which takes two images - sample and its reference, converts them to binary images, rotates the sample over 360 degrees at 1 degree increments and calculates the ED between the rotated sample and the reference. The angle of rotation obtained by ED was compared with the real angle of seal rotation. All the differences were calculated and are presented in *figure 11*.

The results show that in almost half of the tests (138 from 296) the angle obtained was exactly the real angle of rotation, in 155 cases the difference was just ±1°, and only in 2 cases the difference was +2°. So, considering that the angle can vary from 0° - 360°, the maximum error obtained is only 0.3%, which could be the result of the inaccuracy in the manual placement of the seal and/or horizontal image translation. Visually, all the rotated images look exactly like the references.

The time for the determination of the angle where the parameter of similarity (no matter which one - ED or SAD) has its minimum value, is around 80 seconds. This time is considered too long, so we tried to find a faster solution.

5. Algorithm for Faster Determination of the Angle of Rotation

Considering some of the plots of ED (such as the one in *figure 6* but also for other seals), the steep fall (*figure 13*) of the ED values is in a fork of less than 40°. This gave a hint for some modifications of the code, which would reduce the computing time for image rotation. Instead of calculating the ED for the image rotated at 1° intervals (total 360 calculations), only 57 calculations are made, as follow:

• 18 ED are calculated. These ED are calculated for the image rotated at 20° steps, such like: 1°, 21°, 41° ... 301°, 321°, 341°.

• Find the minimum ED from the 18 previously calculated ED and determinate its corresponding angle. This angle is considered like „Center for detailed search" (CDS).

Interval for detailed search (IDS) is determined by adding and subtraction of a step (20°) to the CDS - (CDS - 20°, CDS + 20°).

• The sample is rotated at a 1° steps inside the interval for detailed search and the ED between the rotated sample and the reference is calculated for all 39 rotations.

• The right angle of rotation is determined by searching the minimum value of the ED in the IDS.

The range of 20° is determined experimentally for a few seal samples. Research of more seal samples could lead to determination of a better maximal possible step, which will

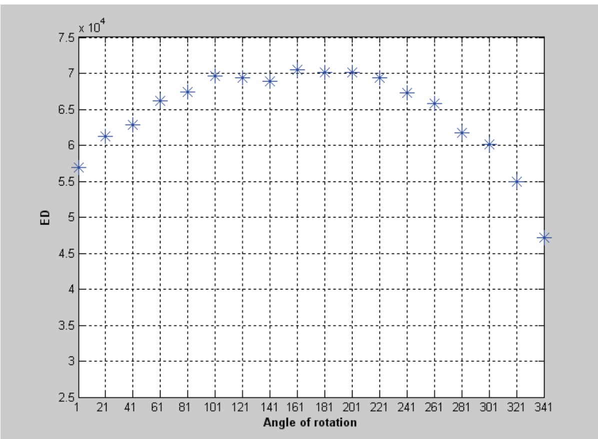


Figure12. ED for 18 angles of rotation

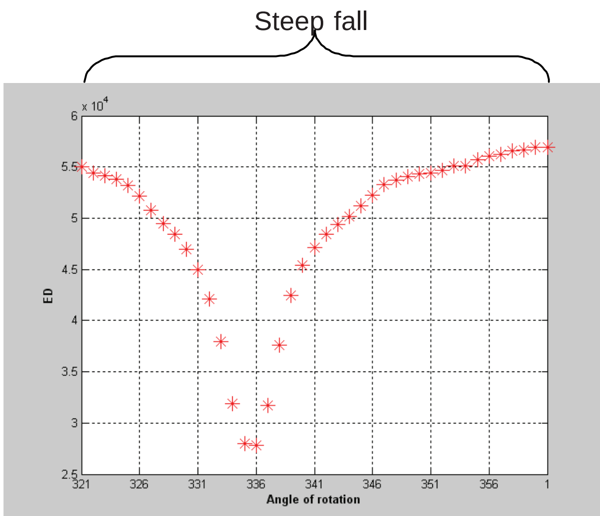


Figure 13. ED for all angles from IDS

increase the speed of the algorithm. The step can not be too big, because the area of steep fall of the Euclid distance, near to the global min ED is around 30° - 50°.

The modified algorithm rotates the image and calculates the ED 57 times (18 + 39) instead of 360 times. The time for implementation of the first algorithm is 80 seconds and the modified algorithm - 13 seconds.

The algorithm is executed also for the sample, rotated at -25° (335°) in the previous paragraphs. The min ED in the initial search (CDS) is 341° (*figure 12*). The IDS is from 321° to 1°. The general minimal ED is found in 335°, like it can be seen in *figure 13*.

The proposed algorithm for fast determination of the angle of rotation is executed for all 304 images, and the determined angles results are the same as angles calculated with the former method. We believe that the algorithm can be further optimized with the help of a larger experimental base.

6. Conclusion and Future Work

In this paper, we propose an iterative algorithm to determine the angle of rotation of a seal under verification to be compared to the seal image taken before it was affixed. Experiments with 304 real seal images were performed in order to evaluate the proposed algorithm. The only used indicator of similarity in the algorithm is the Euclidean distance. The max error of the determined angle is only 0.3%, which could be caused from a not precise manual seal rotation or horizontal and/or vertical image translation.

The proposed non algorithm can save a lot of time and burden of the operator who rotates the seals manually today. An additional modification which controls the ED threshold could select immediately certain faulty seal identities. Further research is needed to investigate the exact method to speed up the algorithm.

It should be noted that the proposed algorithm is just part of a set of pre-processing steps for the image comparison of the seal during its verification. Considering the noise in the seal images, pre-processing procedures must include the application of a proper filter as well. Another step in preprocessing obtained from subtracting the rotated image and the reference is the horizontal and vertical translation of the seal image. All these possible pre-processing operations on the seal images for their verification will be objects of future research.

This work is part of a larger project aiming at fully automatic verification of seals. In the current moment, we are working on development of complete system with color cameras in closed stand with certain light sources where seal's images will be captured. This would reduce the influence from the surround light and give us many possibilities for better analysis and comparison of the images including work with color images and gradients of their intensity images in different color models. This will create the necessary also for a research of the color representation of the seals, resolution of video sensor and applying of pre-processing operations, i.e. white point correction by Macbeth Colour Checker, which is used in Ref. [17] for solving a similar problem.

Additional research is necessary to be done as well, applying ones other methods for image rotation and comparison of the results with the results from applying ones the method presented in the current paper. Such methods include the circular symmetry filter of Gabor, which can be very useful, because it is already used successful for recognition of grey characters in [Ref.18], Gauss-Markov random fields, Fourier transform as well.

References

1. Commission of the European Communities. Report from the Commission to the European Parliament and the Council. Operation of the Euratom Safeguards Office 1999-2000, Brussels, 26.07.2001.

2. US Patent 6888241, Electronic Multipurpose Seal with Passive Transponder. US Patent Issued on May 3, 2005.

3. Surveillance and Containment Measures to Support IAEA Safeguards - *IAEA bulletin*, 19, 2003, No.5.

4. Council of the European Union - General Secretariat. The European Union Strategy against the Proliferation of Weapons of Mass Destruction - Effective Multilateralism, Prevention and International, Consilium, November 2008.

5. Johnston Roger, G. Tamper-indicating Seals for Nuclear Disarmament and Hazardous Waste Management. - *Science & Global Security*, 9, 2001, 99-112.

6. Safeguards Techniques and Equipments, International Nuclear Verification Series No. 1 (Revised), Vienna, IAEA, 2003 Edition.

7. Gesù, V., V. Starovoitov. Distance-based Functions for Image Comparison. - *Pattern Recognition Letters*, 20, February 1999, 2, 207-214.

8. Zamperoni. P., V. Starovoitov, How Dissimilar Are Two Grey-Scale Images?, Informatik Aktuell, Mustererkennung 1995, DAGM-Symposium, 1995, 448- 455.

9. Hertz, T. Aharon Bar-Hillel and Daphna Weinshall. Learning Distance Functions for Image Retrieval. IEEE Conf. on Computer Vision & Pattern Recognition, Washington DC, 6, 2004.

10. Sun, Z., A. Hoogs. Image Comparison by Compound Disjoint Information. Proceedings of the 2006 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'06), 2006.

11. Ulrich, M., C. Steger. Performance Evaluation of 2D Object Recognition Techniques, Technical Report, PF-2002-01. 2001.

12. Wang, L., Y. Zhang, J. Feng. On the Euclidean Distance of Images. - *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 27, 2005, No. 8.

13. Dreuw, P., D. Keysers, T. Deselaers, H. Ney. Gesture Recognition Using Image Comparison Methods. Gesture and Sign Language in Human-Computer Interaction and Simulation, Lecture Notes in Artificial Intelligence, 3881, Springer, Berlin, 2006.

14. Li ,J., L. Bao-Liang. An Adaptive Image Euclidean Distance. - *Pattern Recognition*, 42, 2009, 349-357.

15. Chaur-Chin, C., C. Hsueh-Ting. Similarity Measurement between Images. 29th Annual International Computer Software and Applications Conference (COMPSAC'05), 2, 2005, 41-42.

16. Rahman, M., P. Bhattacharya, B. Desai. Similarity Searching in Image Retrieval with Statistical Distance Measures and Supervised Learning. Pattern Recognition and Data Mining, Lecture Notes in Computer Science, Springer, Heidelberg, 3686, 2005.

17. Dimitrova, T., L. Georgieva. Applying of Pre-processing Techniques in Bruise Images. CompsysTech'07, Proceeding of the 2007 International Conference on Computer Systems and Technologies, 17, 116-120.

18. Piefeng, Hu, Yannan Zhao, Zehong Yang, Jiaqin Wang. Recognition of Gray Character Using Gabor Filter. ISIF, 2002.

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