IMAGE ANALYSIS TECHNIQUES FOR CULTURAL HERITAGE RESTORATION METHODS EVALUATION

Oana Loredana Buzatu[a,], Bogdan Tudor Goras[a], Liviu Goras[a,b], Emil Ghiocel Ioanid[c]*

[a] "Gheorghe Asachi" Technical University of Iasi, Romania
[b] Romanian Academy, Institute of Computer Science
[c] Romanian Academy, "Petru Poni" Institute of Macromolecular Chemistry
[*] *email: lbuzatu@etti.tuiasi.ro*

ABSTRACT

In this paper a new approach to assess the efficiency of a cultural heritage restoration method is proposed. A case study for a multi-stage treatment applied to an old wooden smoke-damaged painting is discussed. The restoration procedure is evaluated by analyzing the evolution of several statistical measurements like mean value, standard deviation (STD) and blind image quality assessment (IQA) indexes applied to several selected areas of the cleaned object imageries. The results regarding the restoration assessment suggest the applicability of the proposed method in artwork restoration evaluation.

Index Terms— cultural heritage restoration, image analysis techniques, statistical measurements, blind IQA

1. INTRODUCTION

Led by the diffusion of digital imaging tools into analysis, preservation, restoration and evaluation of the cultural heritage [1], this paper proposes a multidisciplinary application, gathering together restoration artwork techniques and image processing tools. Performing a cleaning treatment for an old smoke-damaged wooden painting, the restoration process is computer-guided by applying image analysis techniques to monitor and assess the actual recovery of the artwork.

The aim of this framework is to reveal the applicability of specific image analysis techniques for the evaluation procedure implied in artwork restoration.

It is well known that restoring a cultural heritage item it is a challenging, art task, and according to the restoration specifications [2], it should not only improve the physical state of the object, preserving the specific look, but also must ensure its continuity in time. Thus the restoration task is not only about finding the optimal restoration method, but also finding the best way to monitor and evaluate this procedure, making sure that the item to be recovered it is not expendably damaged.

The study refers to one of the newest methods used in artwork restoration: high-frequency cold plasma cleaning/decontamination. Used mainly for small sized items, given the specific equipment design, this cleaning procedure has been reported as a noninvasive efficient method [3]. The method, which does not involve mechanical contact, realizes the cleaning treatment by surface oxidation and has an insignificant loss of surface material removed.

As far as it concerns the effectiveness evaluation, because a simple visual inspection is not consistently enough, there are some more robust approaches. One of them has been reported in [4], where the cleaning process was evaluated using reflectance measurements from selected areas of the considered objects. The monitoring process required complex and expensive specially designed equipment, unlike the method proposed in [5]. This last method evaluates the cleaning efficiency applied to some heritage silver coins by analyzing the evolution of several statistical measurements. These measurements were applied to the imageries of the coins obtained before and after the cleaning treatment.

Following a similar approach and using image quality assessment methods, we propose a method to evaluate a multi-stage cleaning treatment performed on a smoke-damaged wooden painting.

In order to remove the smoke layer which was randomly covering the painting, a high-frequency plasma cleaning treatment was applied. The cleaning efficiency was assessed by monitoring the evolutions of the statistical measurements and of the IQA indexes applied to the patches cropped from the imageries of the object, images which were provided by a snapshot taken at every cleaning stage.

This paper was realised with the support of POSDRU CUANTUMDOC "DOCTORAL STUDIES FOR EUROPEAN PERFORMANCES IN RESEARCH AND INNOVATION" ID79407, project funded by the European Social Fund and Romanian Government.

The rest of the paper has the following structure: in Section 2 the experimental environment, data acquisition setup and testing procedure are detailed, in Section 3 brief discussions concerning the experimental results are presented and the last section is devoted to the concluding remarks.

2. PROCEDURE

2.1. Test Object

The plasma cleaning treatment was applied to an old wooden painting heavily damaged by smoke and other kinds of dirt. The general look of the painting was severely darkened, and after visual inspection it was concluded that the painting suffered several physical damages like holes, carvings, surface scratches and cracks. Also, the paint layer presented numerous cracks and the varnish layer was almost completely removed. Hence, the paint layer was even more exposed to degradation. The smoke layer which was covering the painting made even harder to estimate the paint colors and the figures exposed in the painting.

2.2. Experimental Equipment and Images Acquisition

In order to remove the smoke layer, the painting was plasma cleaned using a vacuum chamber specifically designed to accommodate paintings suspended inside, in a vertical position, between two electrodes. The whole equipment and experimental settings were the same as those presented and figured in [5].

The surface smoke layer (containing mainly Carbon) was exposed to atomic oxygen and, as result of the surface oxidation, was removed. The total exposure time was 180 minutes, the treatment being performed in stages of 30 minutes. After every stage the painting was removed from the vacuum chamber and a snapshot was taken.

The data set (images) acquisition system was placed in a dark room and consisted in a digital camera with 35 mm f/3.5 macro lens and four halogen lamps. The white balance, the shutter time and the aperture were manually adjusted and kept unchanged during experiment. The whole acquisition system and the stand in which the painting was fixed for photo shots were maintained in the same positions and orientations during all experiments. The slightly misalignments of the images were digitally removed using dedicated software. Also the images settings were digitally cross-checked comparing similar background areas.

2.3. Assessment Methods

The key of a successful restoration consists in the used evaluation method. Monitoring a restoration procedure, it offers a complete control of the process, removing the risk to damage the test item. Generally, when a plasma cleaning treatment is applied, the test object is exposed for hundreds of hours. Since the proposed test object was strongly damaged (mainly the paint layer, the varnish being almost completely removed), our exposure time was significantly reduced. The assessment methods applied showed that after 180 minutes, the risk to damage the wooden support of the painting was getting too high; hence we could not go further.

Given the fact that the smoke layer was un-uniformly covering the painting, the cleaning procedure had only a local effect. Thus for evaluation were chosen only those patches exhibiting clear improvements. In Figure 1 several patches which were cropped from the imageries of the test object prior and after 180 minutes of plasma cleaning are given.

Figure 1: Sample patches cropped from the painting imageries; from left to right before and after 180 minutes of cleaning treatment.

In the context of image analysis, the smoke layer was interpreted as a random noisy distortion source interfering with the good image signal. Thus, the cleaning treatment had a filtering similar effect. The random distribution of the smoke dregs all over the painting surface and the poor physical and visual quality of the entire painting made it difficult to estimate a noise model, but nevertheless, from a human observer point of view, it was perceived as a blurry effect, a dark-gray layer which was significantly covering fine details, such as light colored patches, cracks in the paint layer or other physical defects or fine structural features and textures.

Motivated by all these observations, the restoration treatment was evaluated using several statistical measurements (mean value and standard deviation) in order to appreciate the optical expected improvements, and image quality assessment indexes as a quantitative estimation of the removed noise.

As far as it concerns IQA, this has a fundamental importance for many image processing/analyzing applications. Whether we are talking about acquisition, compression, processing, storage, transmission or reproduction, IQA is specific for applications in which images are ultimately to be viewed by humans. Thus, the role of IQA is to assess the visual quality of a digital image using objective methods, keeping a good consistency with the subjective behavior of a human observer. This means that the main goal in image quality assessment is to build measures which can automatically and quantitatively predict the perceived image quality.

According to the availability of an original distortion-free image, the objective IQA methods are classified into three major categories, namely, full-referenced (FR) [6-8], reduced-reference (RR) [9, 10] and no-reference (NR) [11, 12]. In this framework, because we could not reproduce a realistic distortion-free image version of the tested object, no-reference IQA indexes were used.

It is stated that a NR IQA algorithm generally assumes that the distortions affecting the image are known or can be estimated. Considering the fact that the distinction between image features and artifacts is often ambiguous, assessing the visual quality without a reference becomes intrinsically difficult [11]. As previously mentioned, we have assumed that the smoke layer presence over the painting surface is perceived as a random noise distribution, namely a blurring distortion. The visual blurring effect is often described by smearing of edges, which produces a general loss from fine to coarse details.

For this framework the approach proposed in [12] i.e., the blind image quality index (BIQI) was adopted. This quality index is developed in a two-stage framework based on natural scene statistic (NSS) [13] models of images. In the first stage the distorted image statistics (DIS) are obtained, and then a modular strategy is adopted for each distortion in question. Five distortions were considered: JPEG, JPEG2000 (JP2K), white noise (WN), Gaussian blur (Blur) and Fast fading (FF). These distortions are those from the LIVE IQA dataset [14], which was used further to test the actual performances of the BIQI index. For any given distorted image the BIQI is computed as a probability-weighted summation:

$$BIQI = \sum_{i=1}^{5} p_i \cdot q_i \qquad (1)$$

In relation (1), p_i are the probabilities estimated for each distortion, which are obtained in the classifying stage, and q_i are the quality scores from each of the five quality assessments performed in the second stage of the algorithm.

As it was previously mentioned, this quality assessment framework has a modular approach, implying that this method is truly flexible in that addition or exclusion of any distortion category can be easily accomplished. Thus we have adapted the BIQI index to our framework, considering only the Gaussian Blur and the White noise distortions. This consideration was motivated not only by the visual interpretation of the smoke dregs which were un-uniformly covering the painting, creating a blurry effect, but also by the fact that trials performed on the LIVE IQA data set showed that the BIQI approach based on DIS had good performances for images corrupted by WN and Blur [12]. On the other hand, JP2K, FF and especially JPEG distortions had less impressive performances, and, in addition, we did not find them to be appropriate for this application.

3. RESULTS AND DISCUSSIONS

As it was mentioned in the previous section, the cleaning procedure was performed in six stages, 30 minutes for each stage. After these six stages, the cleaning treatment was stopped, avoiding damaging the painting wooden support. At the end of each stage, the painting was removed from the vacuum chamber and a snapshot was taken. Furthermore, the digital imagery was used for the visual evaluation of the cleaning efficiency, by locally applying image analysis techniques.

In the performed experiment, the highlight was on the evolution of the statistical measurements: mean value and standard deviation, and on the adopted BIQI index. Both statistical and image quality assessment methods were used since they complement each other for a more complete evaluation.

In order to analyze the results of the supposed *filtering* operation, different relevant image patches were taken into consideration. Since no prior analysis regarding the composition of the dirt covering the painting was performed, the selected areas were only those exhibiting clear improvements. Basically, the chosen regions were those where the smoke dark gray dregs were removed, revealing light colors, cracks in the paint layer, carvings and holes in the wooden support, or other fine structural features such as wood or paint textures, edges of the objects.

For the image analysis context, considering the suggested evaluation methods, the expected improvements consist in increasing of the mean values for a light colored region, higher contrast for dark colored textured patches or increasing of both mean values and STDs for colored, slightly textured or with edges areas. For both statistical measurements increases were expected, but for specific areas, one of them was more relevant.

As far as it concerns the BIQI index evolution, we were expecting an improvement especially in case of textured regions. This is because a modified BIQI version was adopted; this version takes into account only the Blur and the white noise. These two distortions affect manly the edges or the textures. For the proposed framework the BIQI computational relation (1) becomes:

Table 1: Average values of the 16 selected patches at each cleaning stage.

Time (min)	Initial	30	60	90	120	150	180
Mean value	73.4692	76.6957	71.4537	75.2763	73.6547	81.8387	85.6134
STD	17.0728	22.9429	20.3357	20.3177	21.1772	22.2155	22.6238
Blur	10.3098	7.0017	8.8132	7.5161	6.4247	7.5202	5.1801
WN	3.5913	4.4323	2.6157	3.0892	4.0203	2.6051	3.1141
BIQI	13.9010	11.4340	11.4290	10.6052	10.4450	10.1253	8.2942

$$BIQI = \sum_{i=1}^{2} p_i \cdot q_i \qquad (2)$$

This relation expresses the quantitative and qualitative scores of the images quality reported to blur and WN distortions, and can range between 0 and 100 (0 represents the best quality, by means of distortion-free image, and 100 the worst quality). Thus the expected BIQI evolution is generally decreasing with the cleaning stages. In this case, the smaller the BIQI index value is, the cleaner the painting.

Evaluation measurements were performed for 16 patches cropped from several relevant painting areas, which were sizing different dimensions. All the measurements were conducted using the grayscale versions of the tested object imageries. For the statistical measurements mean value and standard deviation, as for the image quality assessment index BIQI, average values over the entire image patches data set at every treatment stage have been computed and presented in Table 1. Thanks to the modular approach of the BIQI, the evolutions of the Blur and WN, respectively, were separately given.

Analyzing the resulted values from Table 1 we can conclude that, despite the slightly random evolution, the statistical parameters mean value and STD have shown consistent increases. The slightly random evolution is caused by the diversity of the chosen test patches. As far as it concerns the quality scores for Blur and WN distortion, only the blur distortion have shown the expected decreasing evolution, whereas the WN scores had small values along treatment stages, proving the fact that this distortion did not affect the painting in a significant measure. However, the final BIQI values have shown that when these two scores are gathered together, the slight deviation of the Blur removing evolution is compensated by the WN scores, and thus the final BIQI scores had a strait decreasing evolution.

Even though the final BIQI value was not close to zero, by means of distortion-free image, the decreasing evolution along cleaning experiments proved the efficiency of this index in cleaning assessment and the final obtained value is small enough to consider that a major dirt quantity was removed, revealing more obvious painting features.

As already shown, the previous results were obtained as an average value over a set of different patches. These results give a general image regarding the cleaning efficiency. For a more relevant evaluation, specific patches were considered. In Figure 2 a light colored patch, with a nearly uniform look is presented. After 6 treatment stages, the general aspect was improved, revealing a slightly paint textured region, with an obvious increased mean value, whereas the blur has been consistently removed.

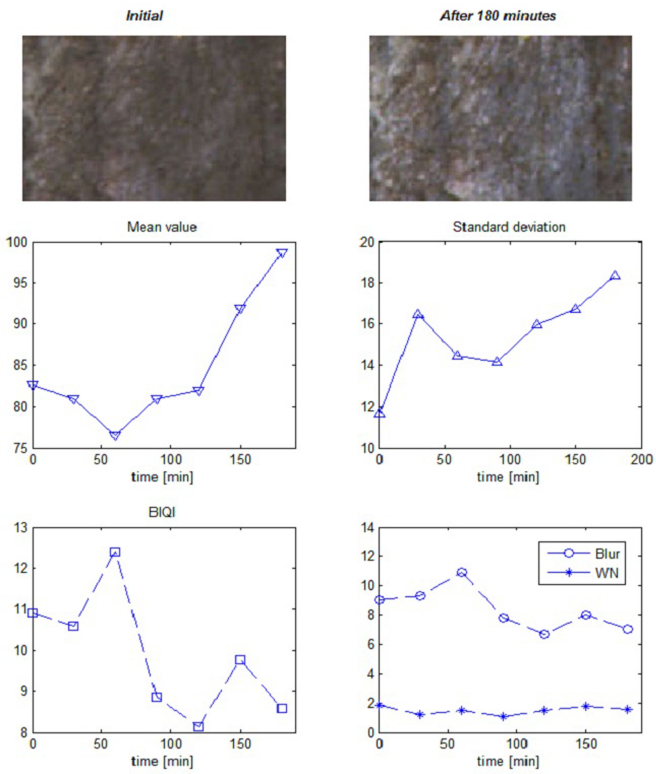

Figure 2: Light colored nearly uniform patch; before and after 180 min of plasma cleaning; statistical parameters and image quality indexes evolutions.

Other sample patch is given in Figure 3, where a light colored painting region with several edges and structures is presented in the initial state and after 180 minutes of plasma cleaning. The treatment effect is visually obvious and is supported by the statistical measurements STD and mean value strong increases and also by the decreasing evolutions of the image quality scores.

Referring this patch to the previous one from Figure 2, which had a nearly uniform texture, in this case the BIQI index had a stronger decreasing provided mainly by the Blur distortion removing. This evolution is due to the fact that after dirt removing, a more textured region with multiple edges was revealed.

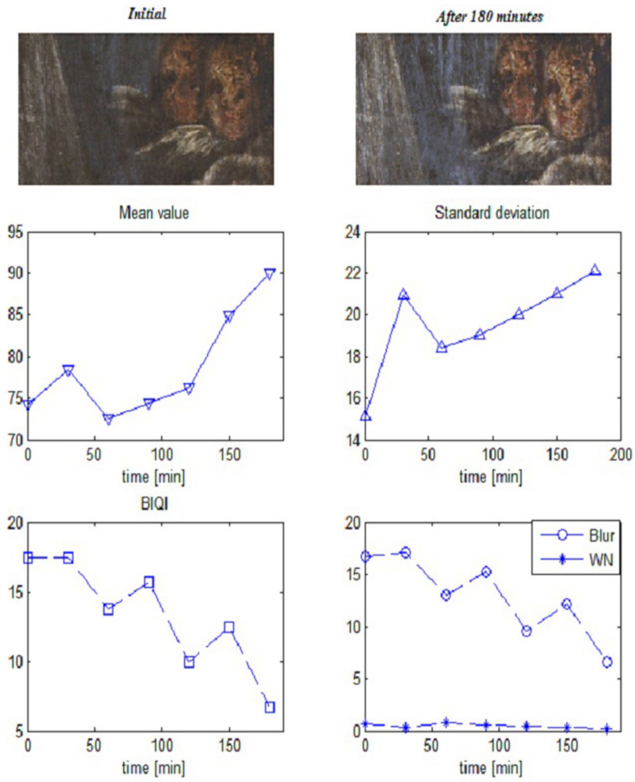

Figure 3: Light colored patch with multiple edges and structures; before and after 180 min of plasma cleaning; statistical parameters and image quality indexes evolutions.

4. CONCLUSIONS

In this paper a new efficient low-cost method to assess and monitor a high-frequency cold plasma cleaning treatment used in heritage restoration has been proposed. The test object used in this framework was an old wooden painting, severely damaged by smoke and other kinds of dirt, with multiple physical defects. The used cleaning procedure had the goal to remove the smoke dregs and was applied in several equal stages. In order to avoid a subjective evaluation of the cleaning efficiency, image analysis techniques were locally applied on the test object images.

Motivated by the blurry visual effect of the smoke dregs, an adapted version of the blind image quality assessment index BIQI was applied. The used version takes into account only the Blur and the WN distortions. For an even more complete evaluation, statistical parameters mean value and standard deviation have been computed.

To assess the cleaning treatment efficiency, only the regions with clear improvements (by means of smoke dregs removing) were considered. The experimental results along the treatment stages proved the applicability of these image analysis techniques in monitoring the process of artwork recovery. It may be concluded that the applied measurements are an efficient and objective method to assess a demanding procedure such as heritage restoration.

REFERENCES

[1] V. Charvillat, A. Tonazzini, L. van Gool, and N. Nikolaidis, “Image and Video Processing for Cultural Heritage”, *EURASIP Journal on Image and Video Processing*, article ID 163064, 2009.
[2] B. T. Hoffman, *Art and cultural heritage: law, policy, and practice,* Cambridge, 2006.
[3] E. G. Ioanid, D. Rusu, A. Ioanid, S. Dunca, A. Muresan, Pattent: RO 122 396 (2009).
[4] S. K. Rutledge, B. A. Banks, M. Forkapa, T. Stueber, E. Sechkar, and A. Malinovski, “Atomic oxygen treatment as a method of recovering smoke-damaged paintings”, *JAIC*, vol. 39, no.1, Article 5.
[5] B. T. Goras, E. G. Ioanid, D. Rusu, L. Goras, “Optical evaluation of heritage silver coin plasma cleaning using statistical methods”, *Optoelectronics and Advanced Materials- Rapid Communications*, vol. 4, no. 12, pp. 2157- 2161, December, 2010.
[6] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, “Image quality assessment: from error visibility to structural similarity”, *IEEE Transactions on Image Processing*, vol. 13, no. 4, pp. 600-612, April, 2004.
[7] Z. Wang, and A. C. Bovik, “Mean squared error: love it or leave it?”, *IEEE Signal Processing Magazine*, pp. 98-117, January, 2003.
[8] L. Jin, N. Ponomarenko, K. Egiazarian, „Novel Image Quality Metric Based on Similarity”, in *IEEE Proceedings of 10th International Symposium on Signal, Circuits and Systems (ISSCS)*, 2011.
[9] Z. Wang and E. P. Simoncelli, „Reduced-Reference Image Quality Assessment Using a Wavelet-Domain Natural Image Statistic Model”, in *Proceedings of SPIE Human Vision and Electronic Imaging,* vol. 5666, January, 2005.
[10] F. Y. Zhang, T. Sun, Y. F. Tu, Q. Q. Qin, “Reduced Reference Image Quality Assessment Based on Wavelet Domain Singular Value Decomposition”, in *Proceedings of SPIE 7498,* 74984H, 2009.
[11] P. Marziliano, F. Dufaux, S. Winkler, T. Ebrahimi, “Perceptual Blur and Ringing Metrics: Application to JPEG2000”, *Signal Processing: Image Communication*, vol. 19, no. 2, pp. 163-172, 2004.
[12] A. K. Moorthy and A. C. Bovik, “A Two-Step Framework for Constructing Blind Image Quality Indices”, *IEEE Processing Letters*, vol. 17, no. 5, May 2010.
[13] A. Srivastava, A. Lee, E. Simoncelli, and S. Zhu, “On advances in statistical modeling of natural images”, *Journal of Mathematical Imaging and Vision*, vol. 18, no.1, pp. 17-33, 2003.
[14] H. R. Sheikh, Z. Wang, L. Cormack, and A. C. Bovik, “LIVE image quality assessment database, Release 2”, available at http://live.ece.utexas.edu/research/quality.