Mapping the Conservations Status of Easel Painting. Craquelure Structure Visualization by Binary Image Segmentation Approach

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Abstract. In easel painting (icons) mapping the status of conservation (MCS) is a complex process of prospecting in various spectral, graphic, and spatial techniques, integral analysis and "technical" visualizations of the data whose function is to lay out detected damages or symptoms, not directly perceivable from the VIS, UV, IR or X-r imaging. In this work, the results of a multi-methodological survey applied to the end of detecting sharp discontinuities (boundary of cavities, wrinkles and fractures in the host medium) are illustrated. As, due to the microscopic size and depth of a crackle/wrinkle fragment or net, it may be rather difficult to single out its position and extent because of the generally low signal-to-noise (S/N) ratio, binary image segmentation and high-resolution data acquisition has been adopted for improving the visibility of the studied area.

Keywords: Mapping the Conservation Status, Spectral Imaging Techniques, Integral Analysis, Binary Image Segmentation.

1 Introduction

Mapping of conservation status (MCS) is widely used in archaeometry and its goals and instruments change significantly from sector to sector. In easel painting (icons) MCS is a complex process of prospecting in various spectral, graphic, and spatial techniques, integral analysis and "technical" visualizations of the data whose function is to lay out determined damages or symptoms, not directly perceivable from the VIS, UV, IR or X-r imaging.

In conformity with the character of the causes, aging symptoms can be classified in two main groups: anthropological and natural, the second ones being subdivided in physical and chemical.

Anthropological factors may be passive, due to products formed in consequence of human presence, or intentional, for example interventions on the original undertaken to the purpose to repair or falsify it. These last could be documented or not; imitating the original only stylistically, stylistically and technologically or stylistically and technologically adopting also artificial aging together with restoration (professional or not).

Consequences of natural aging in the reality occur in reciprocally contaminated forms; however a conventional division between physical and chemical is adopted in the praxis. Its subcategories are:

1. Physical: .

- Losses of the protective and/or paint layer, of the *levcas*, of the wooden support
- Structural deformations (of the entire system support-painting)
- Crackle sinteresting all or single layers

2. Chemical:

- Darkening or bleaching of the colors
- Chemical transformation of the fillers

MCS of easel painting is an essential phase in its scientific documentation and in long term monitoring of less or more rapid deformations of the originals occurring in response to the ambient conditions. Its other purpose is to define the specific alterations that could have been introduced not only by natural and ambient factors, but also by human hands.

The technical visualizations pertinent to the MCS may have the task to delineate, for example, the original from the secondary areas in the support and in every single layer (Fig.1), or between distinct degrees of preservation [1,3]; to localize presence of biological microorganisms; extension, typology and intensity of the crackles, etc.

Accurate technical visualizations of aging symptoms, resulting in modifications of the chromatic and spatial characteristics of a painting is of fundamental importance for the correct diagnosis of its preservation state, for its authentication and attribution. While monitoring of chemical modifications actually can be easily performed with spectrophotometers, the measuring of the physical deformations and the separation of intentional from natural ones represent several difficulties as there aren't still good methods for their high precision registration and processing that enable further detailed comparison and assessment. To the purpose to fill up this gap we dedicated a series of experiments addressing concretely binary processing of crackle micro and macro structures and of various kinds of spectral imaging (VIS, UV, and IR).

2 Crackle Typology as Symptom of Aging Processes in Icons

2.1 The State-of-the-Art

Crackle typology as indicator for status of conservation, presence of non-original interventions, art-technical and art-technological characteristics of icons (on wood, on canvas or on wood covered with canvas) has been since long object of attention; in the last decades - also of scientific investigations using UV-VIS luminescence, high resolution microscope, raking light, professional photography; X-ray imaging [1, 5].

Contemporary with this, in Russia have been reported [6, 7, 8, 9] interesting facts on discovering of Old Believers' fakes in museum collections. Several artificial aging methods aimed to come nearer to the client's requirements have been retrieved in historic sources already in the 19th c. The "agers" specialized in the imitation of old paintings selecting, first of all, wooden tables bearing obvious signs of "natural" patina, hence of dark color, old, incurved, worm-eaten, etc. In second place they accurately cared that the surface is well covered with crackle net, that there are well visible paint and *levcas* losses, traces of burning candles, dirty, nails. The iconography corresponding to the earliest and most venerable models was the third rule for agers.

Old bars were bought in dozens of thousands, back sides were impregnated with a mixture of *alifa* and soot; crackle was produced in different manners. One of them was to applicate the *levcas* on a piece of linen, paint the image over and then get the textile support away in a manner that provokes the rupture of the ground, which than is recomposed on a wooden support. Another technique used also nowadays by fakers was to tighten the textile support with *levcas* round a cylinder (bottle) as this produced crackles more similar to natural. Third variant was to heat the fresh painted icon in an oven or expose it to intense cold (thermic crackle). Losses and burnt places were imitated mechanically, while deposits – by brush. Being well aware that with time crackle edges accumulate dirty, Old Believers filled the fresh ones with black paint or with old *alifa* [6].

All the cited works demonstrate that the symptoms of natural aging affecting over time the chromatic and spatial consistence of a work, due to their complexity result the most difficult to imitate and, properly for this reason, constitute a reliable reference point for material characterization and attributions. Moreover, these publications share important observations concerning the relation between shapes of crackle "gap" and painting support or chemo physical characteristics of employed materials, between the regularity of the edges and the period in which they have been formed, as well as between the form of the macro structures and the authenticity of the work.

2.2 Challenges and objectives of the work carried out

One impetus for these experiments constitute the promising results in discovering of fakes and in fast, simple and successful indicative dating as well as distinguishing originals from secondary works, for which other (non-contact) methods do not exist to the moment, and where crackle typologies result precious indicators about running aging processes [4, 5, 12].

Guiding line in the definition of our research objectives and experiments have been the problems encountered during identification of Old Believers' fakes described in the literature. One of the earliest and most alarming – for its extension - case occurred at the beginning of the 1980-ies, by the restauration of the so called "Stroganov" icons kept in the Russian museum [6]. To the greatest surprise of the restorers, the original painting of some of the icons traditionally linked with the production of the Stroganov School resulted damaged and lost to such a degree that the works couldn't be dated than on base of posterior interventions only. In this same occasion several 100% fakes were discovered basing on accumulated knowledge about crackle typology. The icons were painted mainly in the 19th century, but using preliminary designs and in the style of Stroganov 17th c. icons. Greatest part of these Old Believer's fakes were produced in workshops of Mstera organized as shareholdings, after really "industrial" principles, to judge from the number of personnel involved, the minute specialization of the masters, terms and quantity of realized products (icons) pro hour, transnational management structures, capital investments, etc.[6, 7].With the nationalization of the SU icon collections these fakes contaminated several great soviet museums: except the Russian in Peterburg, also the Tretyakov Gallery etc., while illegal exportation scattered them in small private icon collections outside Russia as those of the National Museum of Stockholm (Sweden), the Vatican Pinacoteca or Palazzo Leoni Montanari, Vicenza (Italy); in Authenried and Recklinghausen (Germany) [8].

The individualization of these fakes using various non-contact investigative methods and technological expertizes causes strong polarization of opinions, as observed damages allow divergent, even contrasting interpretations [10, 11]. Degree of 19th c. fakes perfection is also open to discussion. It is hardly to believe, for example, that agers had a scientific understanding about the mechanism of natural crackle formation.

What happens in the reality is that when one of the bar sides is covered with *levcas* and painted (the facial side), humidity exchange with the ambient occurs via the back side and the borders, causing a specific deformation (face moves forward). Further exchange continues through the borders that absorb and expel it in periods corresponding to that of vegetation growing. In result of this continuous intermittent movement of the wooden support - swelling alternated to drying – in the *levcas* appear discontinuities that first are microscopic and subtle, but over time get deeper and in the arc of some hundred years form well developed systems of naturally branched crackle nets [5, 6, 12]. Whenever some authors state that today their imitation doesn't represent more problems, we agree with [6] that in the 19th c. this should have been hardly possible, and that the clients of these fakers were yet less introduced into the particularities of the natural crackles.

2.3 Purpose of Craquelure Structure Documentation and Classification

In first place, the documentation and classification of craquelure structures are indispensable for authenticity certification, non-destructive diagnostic of the conservation status, elaboration of archaeometric references and deterrents against fakes [5, 6].

As each type of ground damage requires an individual approach to its liquidation, by the mapping of the conservation state must be verified eventual presence of:

- detachments of solid, non-deformed *levcas* from the wooden support;
- detachments of the *levcas* together with the canvas from the wooden support;
- presence of crunched and deformed l*evcas* with hard, detached crackles; destructions, swelling ruptures, spherical swelling (bubbles), invaded by insects, affected

by microorganisms, mica; by fresh mold; weakened by mold, without peeling and flaking of the paint layer;

- sprayed *levcas* (the result of lesions of mold fungi or bacteria);
- *levkas*, broken into fragments;
- fragile *levcas* with excess of restoration glue;
- re-gap and deformation of the *levcas* after covering painting & varnish;
- gesso, mixed with wax.

Our experience has demonstrated for example that different structures of supports (amorphous plaster or regular weave of textile) impart their form on this of the craquelure patterns: so, for icons on wooden support are characteristic the patterns on Fig. 4-5, while for textiles - regular rhomboid sets of discontinuities. Instead, for destructions affecting only the protective layer other types of patterns (Fig. 7) result characteristic. They can be further classified on base of the principal components. Between these, poppy oil varnish appears as the most vulnerable and easy to recognize: in relatively short periods it forms crackle macrostructures of almost regular and "closed" edges (Fig. 7).

For paintings on wooden support it has been further realized that the typology of the crackles strongly depends on the morphology of the wood species, of the cut type and of the concrete timber part employed, as shown in [12].

Except for non-contact scientific documentation, functional to detailed authenticity investigation and art technical and technological assessment, documentation of crackle typology in the frame of MCS must be obligatory carried out also before any sampling for in-lab exams, in order to avoid contaminations between original texture and posterior interventions. The practical experience and the historic documents demonstrate that easel painting (icons) often underwent renewals and only a minimal part of what has survived to our days is 100% original, therefore selection of probes and interpretation of issues must be performed on base of stratigrammata (Fig.1) and fragmentarizations [3] elaborated with the greatest possible precision. Such prospects actually are carried out in great part manually, as methods for visualization that overwhelm the surrounding "noise" and solve the problem of the low signal to noise (S/N) ratio still have not been developed.

In general, the dependence between aging factors and individual reaction of the different materials and application techniques necessitates further qualitative and quantitative studies. In the dating/authenticity certification of paintings or icons there is also acute need for more variegated and high resolution references supplied with instructions how to interpret distinct crackle patterns. Actually however, despite the progress in the assessment of crackle typologies, their technical visualization is limited to photos in less or greater (up to 50x) magnification.

We believe that in the frame of our joint spectral and radiological investigations, supported by computational methods, it will be possible to can markedly increase the variety and efficiency of such multi-functional technical visualizations and their precision, creating conditions for further processing as pattern recognition, alignment, and other algorithms for automated assessment of the collected mass data.

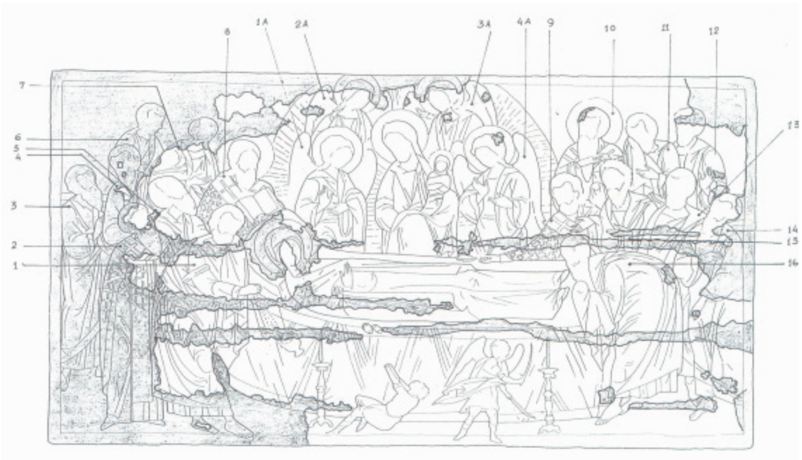

Fig. 1. The mapping of the status of conservation includes a *stratigram* of every layer of the artefact's structure. Here: a map of the *levcas* layer of a Dormition icon. (Source [8]).

3 Experimental part

Our work was projected and carried out in support to the COSCH STSM 2014 hosted at Galerija Matica Srpska, Novi Sad (Serbia), dedicated to the scientific documentation of icons painted in classic and in mixed tempera, representative for the artistic tendencies in Serbia during the 15th - 18th centuries [1]. The experiments have been extended also to other examples of easel/icon painting.

3.1 Techniques

Multidimensional spectral and photographic surveys were used to pin-point chromatic mutations on the surface, layer by layer, together with the in-depth deformations of the icons' structure, but more importantly, the wide-area mapping of the surface of these paintings allowed global, integral visualization of their status and history of preservation, yielding many new insights and answering the questions concerning the authenticity, chronology of interventions, and the attribution.

3.1.1 Digital Image Acquisition Process

In the first stage, the selected icons were "digitized" by high resolution camera [1]. As the quality of the digital copies highly affects the success of the further image processing, the lighting conditions were carefully arranged, in order to obtain as much as clearer and sharper reproductions, with minimal presence of noise.

The spectral techniques usually employed for documentation of paintings as macro and micro imaging in VIS, UV, IR and X-ray without doubt are fundamental and give indispensable information about the state of the different strata, however these are inadequate for the precise mapping and graphic rendering of the damages. Difficulties are due mainly to the enhanced reliefs [1] and cracks of the surface, to the darkening of the protective layer, of the pigments, to the coexistence of all these deformations with strongly reflecting (gilded or silvered) areas and other "noise" that hinder the application of a common corrective principle.

To the moment analysis of crackle typology is carried out on macro photos (12x – 50x), simply by visual comparison: methods for their binary processing functional to further precise measuring and automated classification prior to this publication yet have not been experimented.

It should be noticed as well that documentation of the crackle structure and intensity requires further particular techniques that enable monitoring and visualization of these microscopic processes in their dynamic evolution as, over time, surface discontinuities acquire ever greater extension and depth. Therefore the ideal detectors should be in the condition to can in time- and cost-efficient limits register and analyze causes, intensity, and speed: in correlation with the damages afflicted to the chromatic and spatial parameters of interest.

Fig. 2. . General flowchart of the crack segmentation and analysis process. The major part of this process is refers to image processing, which is described with more details in Fig. 3.

3.1.2 Binary Image Segmentation

The second stage of the work was dedicated to the development and application of image processing methods for segmentation of the crack structures. The inputs were the digital images, provided by the first stage of the research. The goal was to obtain an image clearly representing the corresponding crack net structure. The output images are binary type (black/white) images, where the crackle net is indicated by white color.

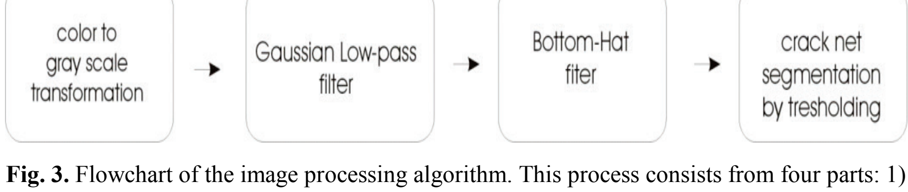

Fig. 3. Flowchart of the image processing algorithm. This process consists from four parts: 1) Transformation of the input image to gray scale type; 2) Smoothing by Gaussian Low-Pass filtering; 3) Emphasize the bottom/valley material of the image by Bottom-Hat filtering; 4) Visualization of the crackle net by thresholding.

The input color image is transformed to its gray scale counterpart. In the true color, RGB type image, the hue and saturation information is eliminated, while the brightness is emphasized. To reduce the possible noise and to get image areas with approximately the same intensity values, as a next step, we apply a smoothing operation. This operation is realized by Gaussian low-pass filtering in Fourier frequency domain, with variance value equally to 50. After this operation, a Top-Hat transformation is applied, with the aim to emphasize the low intensity areas of the image, which are probably caused by cracks on the image/icon. More precisely, we apply the Bottom-Hat filter with a structural element selected as a disk with radius 12. Finally, at the end of the image processing algorithm, a thresholding operation is applied to get the final binary image. The threshold value is selected to be the mean value of the intensity range of the image.

Several binary images showing crackle net structures, obtained by the above presented image processing method, are shown in Fig. 4-9.

3.1.3 Visualization and Assessment of the Results

In the third phase, the crackle structures are extracted from digitized VIS, UV, IR, or X-Ray images using the developed image processing method. This method is a combination of mathematical operations often used in image and signal processing problems. There are image feature enhancing operators acting in both frequency and spatial domains. For processing in frequency domain we use the Fast Fourier and the Inverse Fast Fourier Transforms, while in the case of the spatial processing the convolution operator is applied. The parameters of these operators (variance for Gaussian filter, structural element for Top-Hat filtering, and the threshold value for final thresholding) are empirically determined in experiments, in order to obtain visually most appealing results, that is, the corresponding crackle structure to be well signed out/segmented from the rest of the image.

According to our experience, the best results are achieved by adjusting/adapting the parameters of the method for each particular image. This is due to the fact that each particular icon has specific image characteristics which are the consequences of several factors, for example, different origin, style, age, conditions of storage and also the diversity of the so far applied restoration techniques. However, our intention is that these parameter adjustments should be a part of the "fine tuning" only, but not to significantly affect the results.

The developed image processing algorithm is completely implemented in MATLAB environment and is executed on a PC with Intel Core i5, 2.3 GHz processor. The running time is pretty fast, approximately 1 or 2 seconds per analyzed image.

4 Results and Potential Interdisciplinary Value of this Research

Our experiments had to visualize the state of preservation by single layers (*stratigrammata*) of the surface, of the protective and paint layer, of the *levcas* and of the wooden or textile support, exploring methods for optimal graphical rendering of the icons' imaging in VIS, UV, IR and X-ray. For the first time at such a precision level has been possible to compare individual microscopic crackle structures and edge creation processes which collectively lead to macroscopic properties of crackle nets.

These mass data will serve for further explorations concerning crackle net formation, whose concrete goals are to establish which factors play a critical role in location, pattern typology and speed of evolution using a methodology based on the maximum-likelihood principle and correlating these results to the available information about the age, conservation history, technique and materials of the works.

As mentioned above, the conservation status of a painting depends on many factors whose exact impact not always can be predicted or yet has not been well understood. To these should be listed, in first place, the chemical and physical properties of the employed materials, their individual resistance to ambient factors (humidity, pollution, physical and thermic stresses), and the ambient conditions in the place the works have been preserved. The application technique is another element that must be always considered in the diagnosis of paintings because essential indicator of the professionalism and originality of the item. The methods used by fakers we briefly illustrated unequivocally demonstrate that imitations can confuse technical analysis to such a degree that in some cases practically only establishing the speed of aging can provide any reliable information about the history of an icon. Given that the unique nondestructive opportunity to extract such is analyzing the physical deformations, we concentrated this first phase of our experiments on documentation of crackle segments and on methods for their binary processing.

Without doubt, the results obtained in such limited format still cannot be used as base for exhaustively structured classifications, measurement or dating. These objectives need much more abundant and variegated input – from one side – and data assessment on the background of complex expert knowledge – from the other. And yet, even in this initial phase, on the base of what has already been collected, it is possible to formulate some key points.

In cases where the ground layer is sufficiently elastic, it, for a certain period rests compact and its deformation (surface extension due to swelling) doesn't exceed the linear dimensions of the wooden support (Fig. 7). But by fluctuations in humidity and temperature even a solid ground layer yet not in destruction easily detaches from the base (Fig. 8a).

Due to aging of the adhesive and of the ground components, the elasticity of the latter decreases; increases its rigidity and fragility, which causes development of a crackle net (Fig. 6). The detached areas may have additional destructions in the form of fractures (Fig. 8a-d).

Swellings of various shapes (spherical, transverse, vertical, rigid, open and closed, with broken edges, etc.) appear in consequence of detachment between ground and paint layer, and are accompanied by deformation [12]. They represent a relevant symptom of damage and appear mostly as a result of intensive evaporation of moisture from the wooden support. As a rule, large swellings interest the deeper layers of the work, and fine - only the upper part of the ground and the paint layer. Swelling, not promptly eliminated, leads to shedding of the paint layer and ground (Fig. 8a).

An indispensable condition for efficient metadata extraction and any kind of mathematical post processing of the acquired images is their high resolution. This fundamental in MCS problem has been addressed here by the selection of the acquisition techniques, conditions (opportune illumination, wave length, filters), and devices. As particularly promising for the precise rendering in 3D of the various crackle systems [12] appears to be the Computed Tomography, to which possibilities and limits are dedicated presently other experiments.

4.1 Binary processing of crackle segments

At Fig.4 and 5 are presented examples of binary processed crackle segments extracted from VIS macro photos of the Russian “Tre ierarhi” icon, GMS P 633 (1687) and of the Serbian “SS. Theodore Tiron and George” icon, GMS P 554 (1700 circa). Thanks to the absolute isolation of any occasional signals and to the optimal contrast, even the minimal ruptures of the surface have been registered in a form that allows analyzing and comparing patterns, as well as measuring their intensity, distribution, dispersion.

Thus, it can be demonstrated with certainty that both the cases represent naturally grown crackles, as they are horizontally and vertically extended, and size and depth gradually increase from the nodes to the arrivals of the edges. On the contrary, in the case of artificially produced ruptures such distinction between intensity/depth at nodes and arrivals doesn’t exist, and there cannot be noticed the treelike branched macrostructures [5] as here, but only more uniformly shaped and distributed discontinuities, arisen in consequence of momentary (mechanical or thermic) stresses. It is interesting to note that, whenever there is only 13 years difference in the date of creation, and conditions of conservation of these icons have been very similar, the crackle patterns of the later one are more intense.

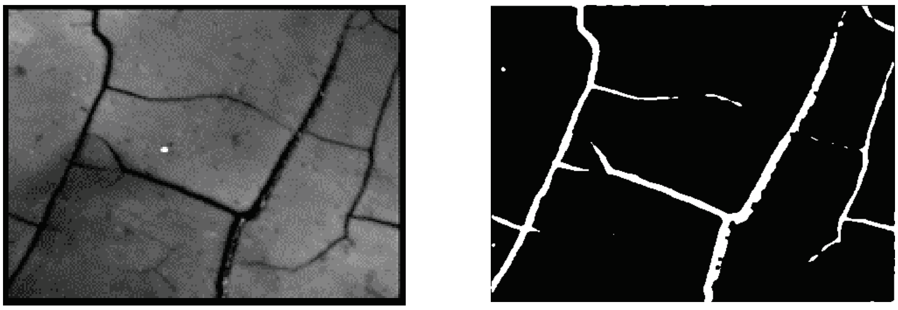

Fig. 4. a and b. Close up of the Russian “Sveta tri Jerarha,” icon, GMS P 633 (1687). Crackle structure in VIS (a) and its segmented version (b).

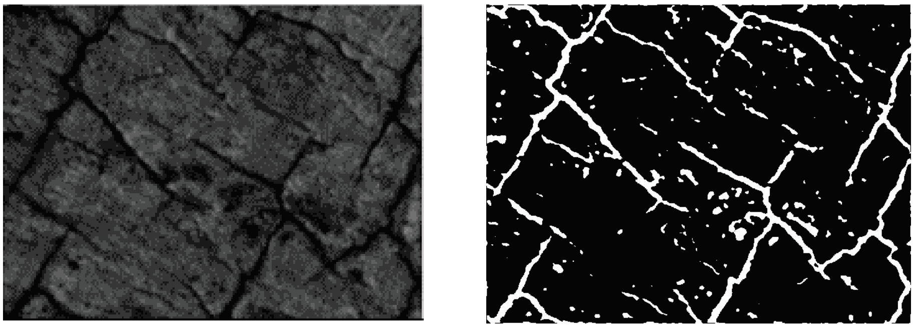

Fig. 5a and b. GMS P 554 (1700 circa), *SS. Theodore Tiron and George.*
Crack structure close up in VIS (a) and its segmented version (b).

This can be explained with the different material composition of the host media that differ in each of the studied cases: calcium carbonate (chalk)-glue *levcas* covered with painting in mixed tempera that implicates use of oil together with the egg binder in GMS P 633; gypsum (calcium sulphate perhaps with kaolin impurities) and egg tempera – in GMS P 554.

Comparisons between the long term behavior of Russian icons from the Armory School and such from the Balkan area, traditionally painted on gypsum *levcas* (and impurities) clearly demonstrate the superiority of the first, due also to the addition of drying oils – as aforementioned. Interesting data on dependence of crackle net intensity and form from chemical composition of ground and pigments appeared by the comparisons with icons from the beginning of the 20th c., that use different systems for ground preparation (very thin layers, of different composition; underpainting in ocher and different set of pigments) [6].

By principle, surface analysis must always be integrated with the UV, IR and X-ray images for to can check the authenticity of the crackle nets and ascertain their in-depth position [13].

4.2 Visualization of Crackle Macrostructures

This kind of technical visualization is the starting point for the global MCS. On base of previous surface analysis and other evaluations, the restorer separates in the graphically processed image the areas of diachronic origin. For the high dependence from specialized expert knowledge, this operation is carried out manually, whenever some facilities to its automation are offered by the actually existing programs for image elaboration as *Picassa, Photoshop, Corel*.

4.2.1 Crackle Macrostructures based on Global VIS Imaging

So, the spectral screening evidence the icons at Fig.6 a-b (actually in the Russian State Hermitage) display, hints at eventual presence of diachronic aging symptoms resulting from restorative interventions: the integration of the losses in the *levcas* and in the paint has provoked formation of crackle macrostructures of different patterns and intensity.

Fig. 6. a, b. Icons from the State Hermitage. Global view of the macro crackle net.

4.2.2 Crackle macrostructures based on macro details in VIS.

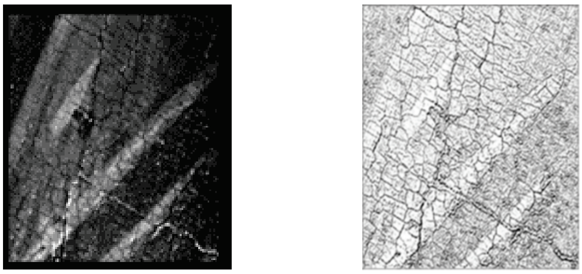

Fig. 7. a, b. Graphic visualization (b) of a macrophoto in VIS (a) aimed to enhance the varnish destruction

4.3 Stratigrammata of single layers

- **Stratigraphy in VIS** (Fig. 8a, b)
- **Stratigraphy** (of the surface) **based on UVr** (Fig. 8c, d)
- **Stratigraphy based on the IRr** (Fig. 9. a, b). In the icon GMS P 554, 1700 circa,
- (Fig. 9. a, b) previously invisible crackle net under the varnish and the paint layer, branched like a tree, was revealed by graphic transformation of the IR reflectography by the capacity of these rays to penetrate beyond varnish, vegetable and many mineral pigments. This enabled not only the visualization of the *levcas* deformation, but also to understand to which class belongs its chemical composition.

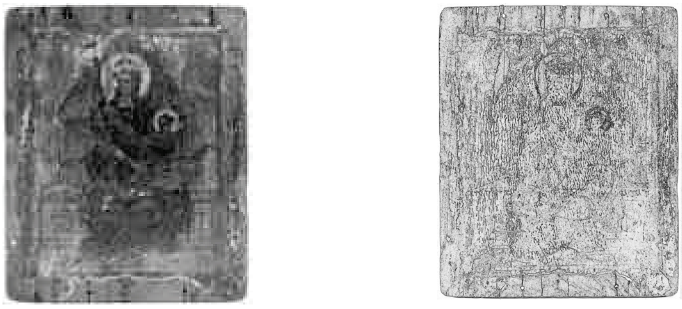

Fig. 8. a, b. The VIS image in incident light of an icon originating from North Italy (Mother of God with the Child, 13th c., 37 × 30.5 cm. Prinz Johann Georg Collection, Mainz) (Source: M.Thuns [2]).

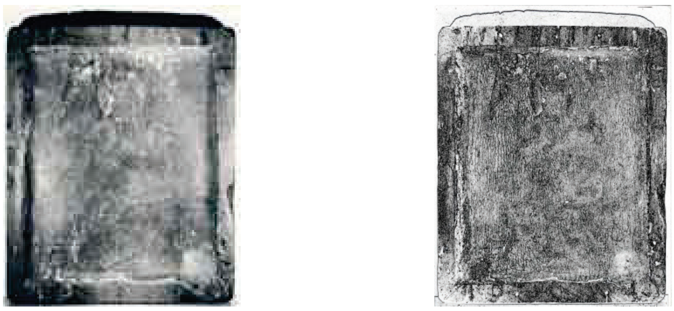

Fig. 8. c, d. Graphic transformation of the UV image of the same icon. (Source: M.Thuns [2]).

Fig. 9. a, **b.** GMS P 554 (1700 circa) IRr (a) and its graphic transformation (b) evidencing the dense macro crackle net on *the levcas* (Source: Nedeljko Marković;, GMS, Novi Sad)

5 5. Conclusion

Technological advances in our ability to measure the chromatic and spatial characteristics of cultural heritage objects and in our computer modeling capabilities have led to the creation of an increasing number of high-fidelity 2D and 3D models of easel painting. These models are often supplemented by additional metadata information as well as schematic reconstructions of missing data. This growing collection of models brings with it new needs and opportunities in the scholarly community and the public it serves: efficient access to interoperability between, and scientific authentication of the models.

In the same time, there is a pressing need for documenting methods that ensure precise registration, monitoring and analysis of the complex and interconnected aging processes, in full scale, and in their dynamic evolution. While only some MCS questions can be addressed by spectral and spatial techniques, integrated computational methods can provide an opportunity to face some important tasks that are fundamental to CH preservation.

The experiments presented here are designed on transforming big quantities of data into usable information, subdividing it by categories adopted in CH conservation and restoration. We believe this information will only have value in the context of big, appropriate expert systems, since that is the only way of benefiting from the registered symptoms and moving them into preventive actions, for a more time- and cost-efficient management of CH.

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