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Abstract This is the fifth work of a series which is showing applications of Retinex filters. In the first paper, we considered the images from microscopes. In the second, we discussed how a Retinex filtering can help us in the investigation of motion of sand dunes. In the third and fourth, underwater and night images have been considered. Here we give examples concerning an application to artworks. We show how the visibility of craquelure can be strongly enhanced by means of Retinex filtering. Used filter is GIMP Retinex, based on the original Retinex method developed by Fabien Pelisson.

Craquelure is a fine pattern of cracking visible on the surface of materials and artworks, such as tempera or oil paintings, which the term is most often referring to [1]. Its appearance can be quite different such as its origin, because craquelure is the result of several factors, among which we find drying, aging, intentional patterning, or combination of them.

Analysis of craquelure has been proposed as a manner which can be useful for the authentication of artworks [2]. In fact, the study of mechanisms involved in craquelure formation and its resulting crack morphology can provide information about methods, materials and artists. Their paintings are the result of a composition of several layers, each of them having its specific mechanical properties. These properties depend on the used drying oil or paint medium, and on the presence of paint additives. As a consequence, the features involved in craquelure allow to classify the painting according to its pattern of cracking.

The key features used to describe craquelure morphology are [1,3]: 1) Local and global direction of cracks, 2) Relationship to weave or grain direction of support, 3) Crack shape, 4) Crack spacing, 5) Crack thickness, 6) Termination of cracks, and 7) Organization of crack network. These seven features have been used to relate crack patterns to various historic schools of art [1,2].

In [2], it is described the approach that was used to consider the crack patterns "as unintentional 'signatures' for painters". It is based on a surveying over 500 paintings. "Areas of sky or flesh paint (which had high tonality paint, against which the cracks were easily visible) were photographed. The selected areas were small (20–30 cm^2) and chosen to avoid cracks due to identifiable causes (such as impacts on canvas or splits in panels) and to reduce

any visual clues in the paint layer (choosing homogeneous passages with no stylistic clues). The paintings were selected to belong to artistic traditions that could be distinguished in terms of their materials and methods" [2]. After an analysis of the human visual perception of cracks, samples of craquelure, in number of 40, were digitized and characterized by software that analyzed the lines in terms of Bezier curve parameters, and a neural network classification was then applied [2].

As told in [2], the area considered for the analysis is small, about 5 cm x 5 cm, and with high tonality painting. We could ask, however, if it is possible to apply a method to increase the visibility also in other parts of the painting. Previously, we have seen that GIMP Retinex [4], an image processing tool of the GIMP program, can be quite useful in many cases to see details in images recorded in different environmental conditions [5-16].

The Retinex methods for image processing have been developed according to some experimental observations, from which it resulted that it is easy to find discrepancies between an image that we have recorded by a camera and the real scene that we have observed. The reason is the following: humans are able to see details both in the shadows and in the nearby illuminated areas, whereas a photograph of the same scene is showing either the shadows as too dark or the bright areas as overexposed [17].

Using as a model the peculiar features of human vision, which are quite different from those of the recording devices [17-19], several algorithms of image processing have been developed to simulate the human ability of adapting to adverse conditions. These algorithms are known as Retinex algorithms. The first of them was conceived by Edwin H. Land, an American scientist and inventor, best known as co-founder of Polaroid Corporation. As explained in Ref.17, through the years, Land made several models, until the last that he proposed in 1986. The term "Retinex" was coined by Land himself, combining the words "retina" and "cortex", to indicate the results of his researches. They tell that the human colour perception is involving all levels of vision processes, from the retina to the cerebral cortex. Several Retinex approaches exist [17-25]: the single-scale Retinex (SSR), the multiscale Retinex (MSR), and, for colour images, the MultiScale Retinex with Colour Restoration (MSRCR). Among MSRCR we find the GIMP Retinex, a freely available filter originally developed by Fabien Pelisson [4]. The resulting image of this filter can be adjusted selecting different levels, scales and dynamics. In particular, three "levels" exist. The "uniform" level tends to process both low and high intensity areas fairly; the "low" level "flares up" the lower intensity areas on the image; the "high" level tends to "bury" the lower intensity areas in favor of a better rendering of the clearer areas of the image.

Due to its peculiar features, a Retinex filter such as the GIMP one is suitable for enhancing the images recorded in foggy conditions and in night scenes, and in the processing of underwater images [5-16]. In [26], we have shown that Retinex filtering is also useful to increase the visibility of details in artworks. In [26] we applied GIMP Retinex for filtering the digital images of the masterpieces of an artist that used the Chiaroscuro, a strong tonal contrast between light and dark, in his painting technique. The artist is Gerrit van Honthorst, known in Italy as Gherardo delle Notti. The filter allows the vision of significant details in the shadows of the images. Here in the following, we provide examples which shows that the application of Retinex can be useful in the analyses of craquelure too. From the given examples we can clearly see the effect of the Retinex filtering and the results are remarkable. Therefore, GIMP Retinex, or other Retinex filters, could be the proper tool for a preprocessing of images, before any further analysis, based on the Bezier curves as in [2], or on measurements of craquelure domains as in [27]. In the following examples, we have also used other GIMP filters such as Thresholding, Generic Erode and Dfference of Gaussians.

Images are here in low resolution. Their high resolution versions are given at specific links.

High resolution image: **https://doi.org/10.5281/zenodo.3956123**
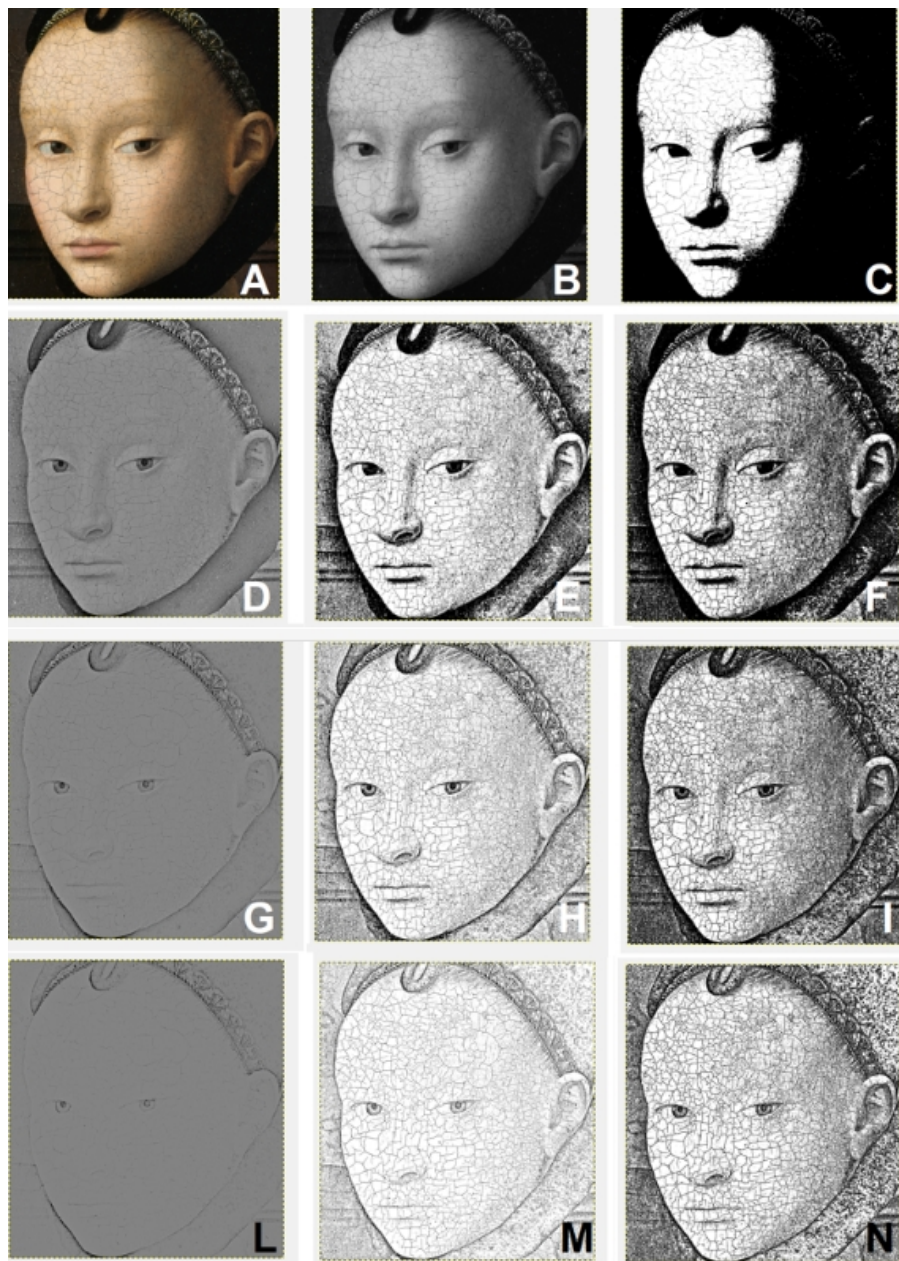
Example n.1: In the image, A represents the original image. It is a detail of the Portrait of a Young Girl, by Petrus Christus, courtesy Wikipedia. B is the grey-tone corresponding image. C is the image that we can obtain using the GIMP thresholding (threshold tone T = 127), applied to B. D is the image that we can have, applying GIMP Retinex on B (level=low, scale=250, scale div.=8, dynamics=4,0). E is the result of the thresholding of D (T = 127). F is the image obtained by means of the use of generic filter Erode on E. G is the result of applying Retinex (the same parameters used to obtain D) on D. H is the result of thresholding (T = 127), and I is the craquelure as we can see it after applying Erode. L is the Retinex filtered G (the same parameters as for G and D), M is the effect of thresholding and N the final result after using Erode. The example shows that the use of a thresholding on a Retinex filtered image gives much better results than the simple thresholding. This approach, that is the use of Retinex filtering, represents a fast manner for enhancing the visibility of craquelure. The iteration of the Retinex filter is also interesting for working on very dark areas. *Let us stress this fact, that in the given example we have used iteration (B → D → G → L). The visibility of the craquelure changes accordingly.*

High resolution image: **https://doi.org/10.5281/zenodo.3956203**
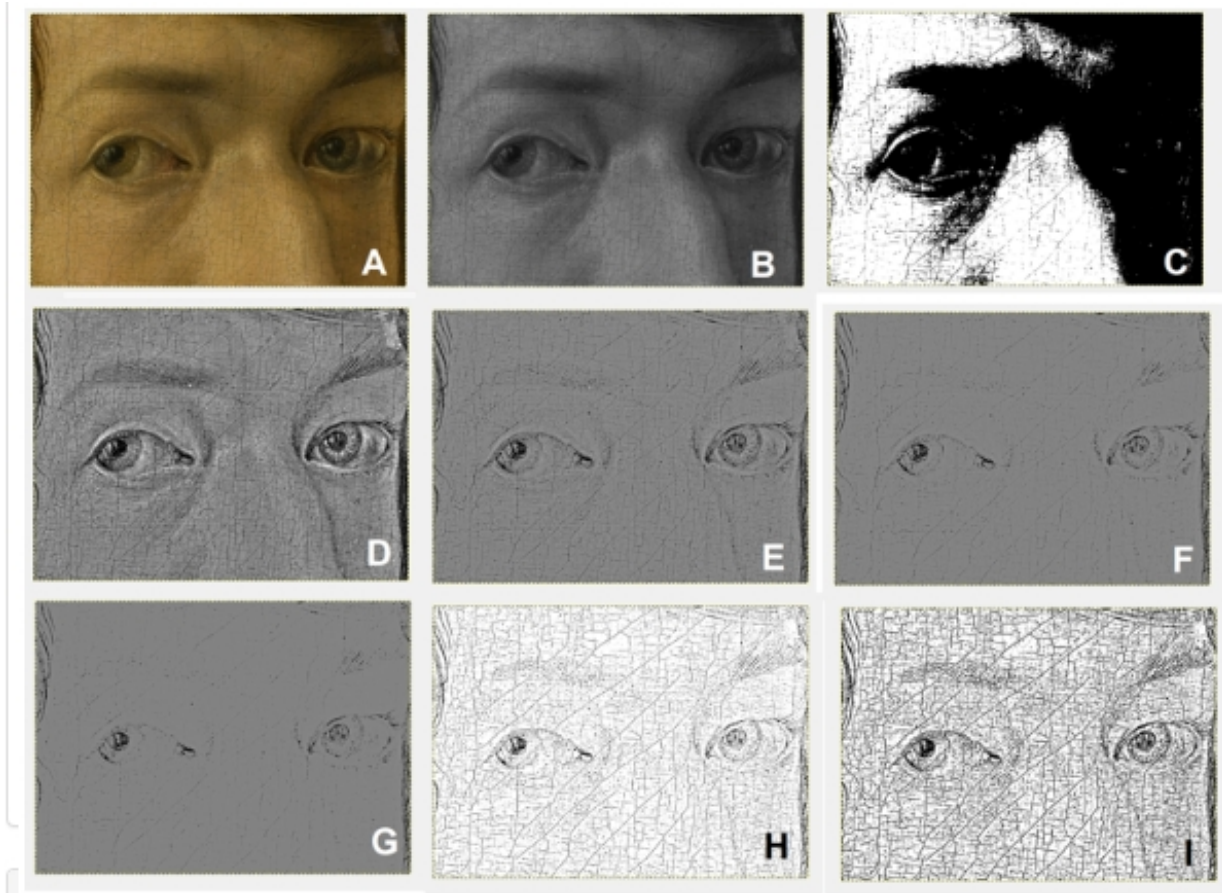
Example n.2: In the image, A represents the original image. It is a detail of the Self-Portrait (Madrid), by Albrecht Dürer, (highest resolution), courtesy Wikipedia. B is the grey-tone corresponding image. C is the image that we can obtain using the GIMP thresholding (threshold tone T = 65), applied to B. D is the image that we can have, applying GIMP Retinex filter on B (level=low, scale=250, scale div.=8, dynamics=4,0). E is the result of applying Retinex once more (the same parameters used to obtain D) on D. The iteration continues obtaining E from D, F from E, and G from F, using the same parameters. H is the result of thresholding the G image (T = 127), and I is the craquelure as it appears, after applying the generic filter Erode of GIMP. The example shows that the use of a thresholding on a Retinex filtered image gives much better results than the simple thresholding. The iteration of the Retinex filter is able to enhance the visibility of the craquelure in the dark areas. This approach, that is the use of Retinex filtering, represents a fast manner for enhancing the visibility of craquelure.

Let us stress that also in the given example we have used iteration. In this case: B → D → E → F → G. After the iteration, we have image H enhanced in I. Note that we can see the craquelure in bright and dark areas.

High resolution image: **https://doi.org/10.5281/zenodo.3957438**
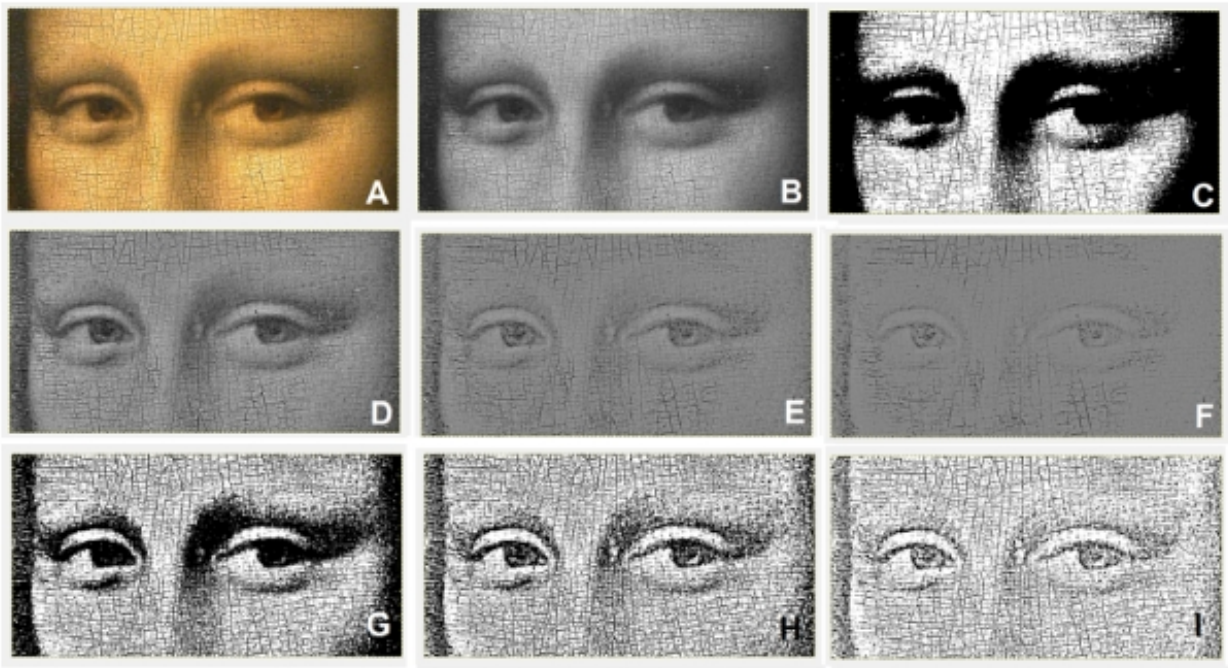
Example n.3: In the image, A represents the original image. It is a detail of the Gioconda, by Leonardo da Vinci, (highest resolution), courtesy Wikipedia. B is the grey-tone corresponding image. C is the image that we can obtain using the GIMP thresholding (threshold tone T = 127), applied to B. D is the image that we can have, applying GIMP Retinex filter on B (level=low, scale=250, scale div.=8, dynamics=4,0). E is the result of applying Retinex once more (the same parameters used to obtain D) on D. The iteration continues obtaining E from D, and F from E, using the same parameters. G, H and I are the result of thresholding of the D, E and F images respectively (T = 127). The example shows that the use of a thresholding on a Retinex filtered image gives much better results than the simple thresholding. The iteration of the Retinex filter is able of enhance the visibility of the craquelure in the dark areas. This approach, that is the use of Retinex filtering, represents a fast manner for enhancing the visibility of craquelure.

High resolution image: **https://doi.org/10.5281/zenodo.3957798**
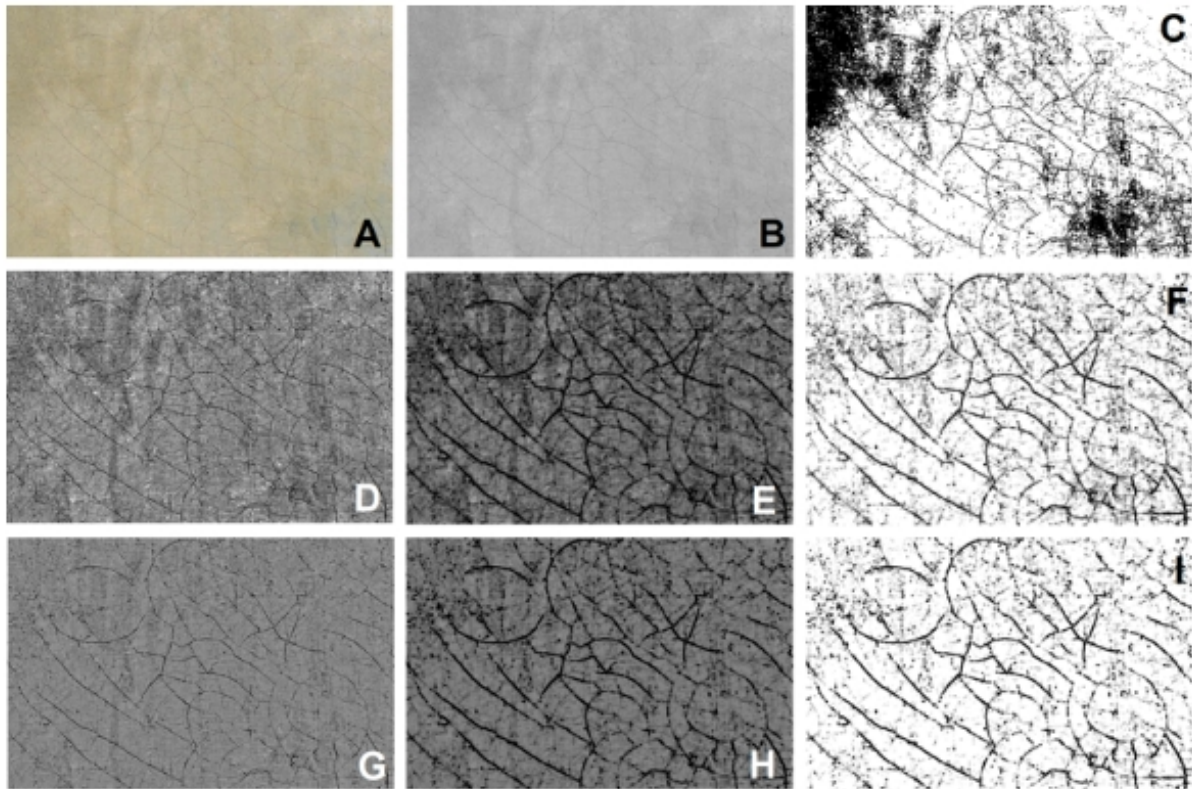
Example n.4: In the image, A represents the original image. It is a detail of Woman with a Water Jug, a painting finished between 1660–1662 by the Dutch painter Johannes Vermeer (highest resolution), courtesy Wikipedia. B is the grey-tone corresponding image. C is the image that we can obtain using the GIMP thresholding on B, adjusting the value of the threshold to have the best possible visibility of the craquelure. D is the image that we can have, applying GIMP Retinex filter on B (level=low, scale=250, scale div.=8, dynamics=4,0). E is the result of the GIMP generic Erode filter applied to D. F is the result of the GIMP edge detection, obtained by using the so-called "Difference of Gaussians" algorithm, applied to the image E. G is the result of applying Retinex once more (the same parameters used to obtain D) to image D. H is the result of the use of the generic Erode filter on G. I is the result of the GIMP edge detection, "Difference of Gaussians" algorithm. The example shows that the use of an edge detection (F,I) on a Retinex filtered image, enhanced by means of Erode (E,H), gives much better results than the simple thresholding. This approach, that is the use of Retinex filtering, accompanied by other GIMP filters, represents a fast manner for enhancing the visibility of craquelure.

In this example, we used also the GIMP edge detection based on the "Difference of Gaussians" algorithm.
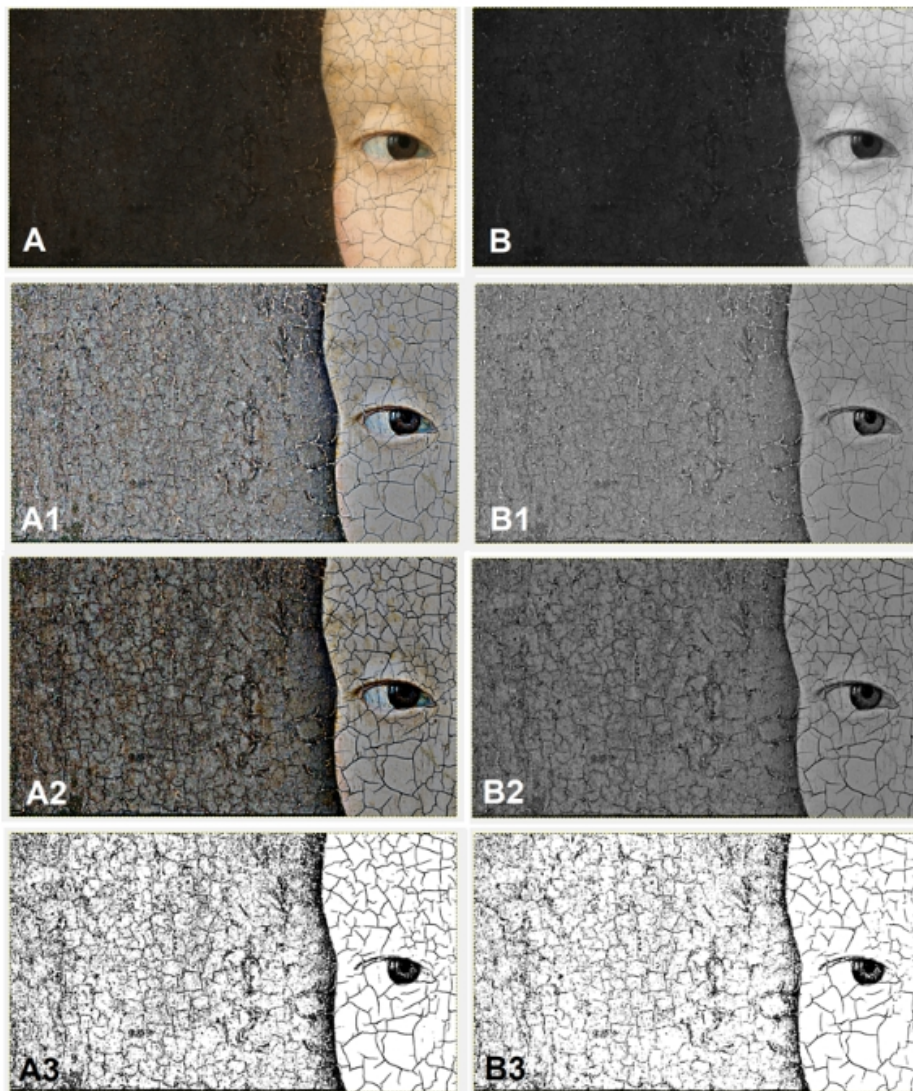
Example n.5: In the previously proposed examples, the GIMP Retinex filter had been applied to greyscale images, to enhance the visibility of dark craquelure in bright backgrounds. After processing, a black and white map had been obtained, suitable for any possible further processing, even for automatic processing. Craquelure exists also in dark background, but it is more difficult to enhance its visibility. However, also in this case, the GIMP Retinex filter can be suitable for analyses. In the case that the investigated area, where craquelure is present, contains bright and dark scenes, it seems that it is better to use the GIMP Retinex directly on the colour image. Here an example is given using a detail of the Portrait of a Young Girl, by Petrus Christus, (highest resolution), courtesy Wikipedia. In the image, A represents the original image. B is the grey-tone corresponding image. A1 is the image that we can obtain applying GIMP Retinex on A (level=low, scale=250, scale div.=8, dynamics=2,0). A2 is the image A1, after using the GIMP generic Erode filter. A3 is the result of a thresholding of A2. For what concerns the grey-tone image, B1 is the image that we can obtain using GIMP Retinex on B (level=low, scale=250, scale div.=8, dynamics=4,0). B2 is B1 after using Erode filter. B3 is the result of a thresholding of B2. The example shows that a Retinex filtered image can be useful in the investigation of craquelure in dark areas too.

High resolution image: **https://doi.org/10.5281/zenodo.3959040**
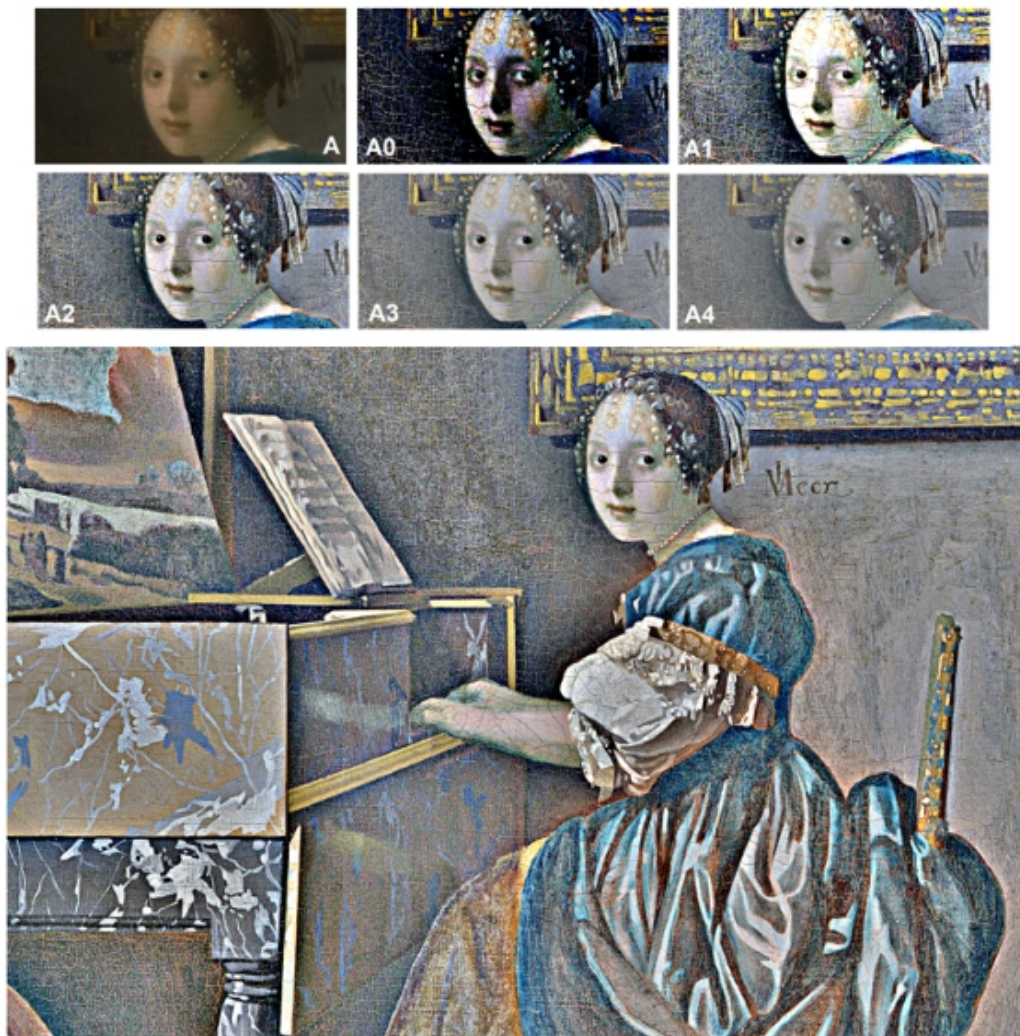
Example n.6: In the previously proposed figures, the GIMP Retinex filter had been applied to greyscale images, to enhance the visibility of dark craquelure in bright backgrounds. After processing, a black and white map had been obtained, suitable for any possible further processing, even for automatic processing. In the previous figure n.5, we have shown an example of the use of GIMP Retinex to observe the craquelure in dark areas. We observed that when craquelure is present in bright and dark scenes, it seems better to use the GIMP Retinex directly on the colour image. Here an example is given using the Lady Seated at a Virginal, a painting created by Dutch artist Johannes Vermeer (highest resolution), courtesy Wikipedia. A is a detail. A0, A1,A2, A3, and A4 are the images we can obtain by applying GIMP Retinex filter on A, level=low, scale=250, scale div.=8, with dynamics equal to 0,0 1,0 2,0 3,0 and 4,0 respectively. For this detail, it seems that the best manner to enhance the visibility of craquelure is that of using dynamics 2,0. In the lower panel, a larger detail of the painting is given, processed by the filter with dynamics 2,0. The example suggests that use of Retinex filtering on colour images represents a fast manner for enhancing in them the visibility of craquelure.

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