FRESCO RESTORATION: DIGITAL IMAGE PROCESSING APPROACH

Jan Blažek [1], *Barbara Zitová* [2], *Miroslav Beneš*[1,2], *and Janka Hradilová*[3]

[1]Faculty of Mathematics and Physics, Charles University
Malostranské nám. 25
Prague, Czech Republic
E-mail: gimli@centrum.cz

[2]Institute of Information Theory and Automation
Academy of Sciences of the Czech Republic
Pod Vodárenskou věží 4
Prague, Czech Republic
E-mail: {zitova,benem9am}@utia.cas.cz

[3]Academic Laboratory of Materials Research of Paintings
Academy of Fine Arts
U Akademie, Prague, Czech Republic
E-mail: janka@avu.cz

ABSTRACT

In this paper, we present an application of digital image processing algorithms for the process of fresco restoration. Modern methods for image preprocessing and evaluation such as image registration, image fusion, and image segmentation are applied on images of the fresco, obtained in different modalities (visual and ultraviolet spectra) and at different times. Moreover, local chemical analyzes are taken into account during the image analysis. The robustness of proposed algorithms should be high due to the bad state of the fresco. Achieved results can give to art restorers better insight into the evolution of the fresco aging and in this way a proper conservation method can be chosen. Developed methods are illustrated by generated output images.

1. INTRODUCTION

Nowadays, methods belonging to digital image processing can help even in the restoration of historical art pieces. During the conservation process various sensors working in different modalities (UV - ultraviolet, IR - infrared, or complete evaluation by means of spectroscopy, when up to 32 various filters are employed) are often used and efficient preprocessing of these data is crucial for their further evaluation [1]. These algorithms take as an input all the acquired images available and their aim is to fuse the contained information and in this way achieve a content-rich detailed image, which parts are distributed among the input images but they are difficult to perceive all in once. Sometimes even such details can be generated which are not recognizable in any of the individual input images.

From digital image processing point of view we are working with a data set taken in different modalities, possibly from different viewpoints and at different times. That is why we face the problem of multi-modal and multi-temporal **image registration**, when data taken within different geometrical coordinates and differing in modality (captured wavelength spectrum) and possibly originating in different times have to be geometrically aligned. The image registration is very well studied, there are several survey papers on this topic [2]. After the data alignment, the very image processing analysis can start. At this moment, the corresponding parts of the images depict the same parts of the scene and thus they can be automatically compared or fused.

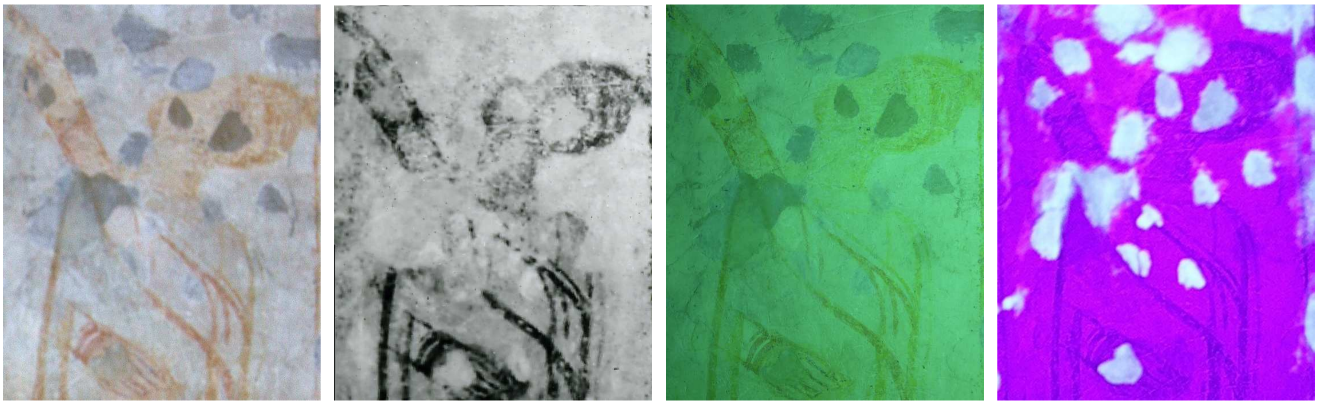
In the **image fusion** result various information sources are combined in order to see all important features and relations, which can be derived, in one multi-informational image. In this way we can see for example under-drawings (apparent in infrared images) and patterns created by applied biological materials (captured by ultraviolet spectra) at the

Figure 1: One of the part of the Kostolany pod Tribečom fresco. There is apparent current bad state of the fresco. The white areas are windows.

same time in the resulting fused image. Such data visualization can be very useful and without computer-based assistance can be done just by very experienced restoration experts. The image fusion can work on the pixel-wise level, when the output values are function of the intensity values of the corresponding pixels from all data sources or their close neighborhoods. Otherwise, the output can be constructed from the input data using some more higher level image analyzes such as object segmentation, data denoising, edge detection, etc. to stress out the scene content. The pixel-wise fusion is for example very well studied for the processing of the Earth remote sensing imaging [3] and the higher level fusion can make a use of the various existing methods for object segmentation and other mentioned image processing tasks.

There are several possibilities how the acquired data sets and the fused results can be used. One of them is virtual restoration of the analyzed art piece [4], [5], when the aim is the visualization of the original state of the artwork. It is sometimes a little bit controversial issue, when aging and possible destruction is removed. Even the real art restorers' intentions to "improve" the state of the art piece can be questioned to which extent it is really valuable and responsible.

On the other hand, such virtual restoration can be used as a preliminarily test, which restoration method would be the most appropriate. In this manner, no harm is done and better knowledge necessary for final decision was collected. An interesting possibility is to use virtual restoration for tourist purposes, because the visualization of the original beauty of the historical pieces can attract more visitors, both virtual and



(a) (b) (c) (d)

Figure 2: An example of the data set for the fresco: (a) - a visible spectrum image of the recent state (VS); (b) - a visible spectrum image from the 60's (BWS); (c) - a broad-band ultraviolet spectrum image (UVB); (d) - a narrow-band (with the spectrum maxima at 368 nm) ultraviolet spectrum images (UVN)

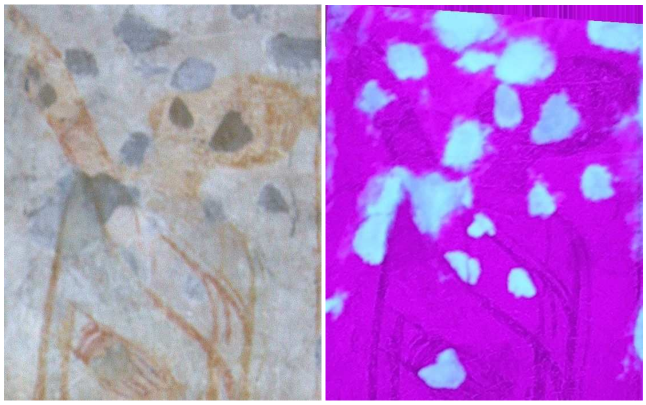
real ones.

Our application belongs to the category of the virtual restoration for the decision about the best restoration method. We were asked to joint the team of the restorers and try to figure out as much as possible from the data they have. The more effective analysis and visualization of measured data will help to achieve deeper understanding of the art piece evolution and structure, which materials were used and what is the material distribution across the fresco. The goal of proposed method was to combine all available images of the fresco (from different time and taken using different modalities) in order to emphasize the structure details of the fresco. Secondly, using the generated structural information, we were asked to expand the point-wise results of chemical analysis across the detected segments of the fresco. We use for the method development the data set of multi-modal and multi-temporal images together with results of locally taken chemical analyzes. It is necessary to mention that the robustness of proposed algorithms should be high due to the bad state of the fresco. Moreover, the reliability of the method was difficult to validate because of the not sufficient set of testing data due to the delayed site analysis. The proposed approach was designed for the described case, however the general ideas can be utilized in similar situations, when the virtual restauration of such extent is needed.

The rest of the paper is organized as follows. In Section 2, the studied object will be introduced together with the data set used for experiments. Section 3 covers individual steps of the data processing - image registration, image fusion, and image higher level analyzes - together with illustrative results. Finally, last Section 4 concludes our achievements and lists our plan for the future.

2. FRESCO

The data set we worked on comes from the fresco (Fig.1) situated in the 11th century church in Kostolany pod Tribečom, a small village in the Slovak Republic. The whole fresco covers quite large area of the inner church walls and as it is apparent from the picture (Fig.1) that it is in quite bad state. Restoration works have been started recently. Small subsections of the fresco were used for the method development in our laboratory, an example of which you can see in Fig.2.



(a) (b)

Figure 3: An example of the reference and corresponding registered images: (a) - visual spectra (VS); (b) - near band ultraviolet spectrum (UVN). See top right part of the (b) image for the geometry difference.

We obtained the fresco photographs in the visible spectrum (VS) and ultraviolet broad-band spectrum (UVB), and ultraviolet narrow band spectrum (UVN) with the spectrum maxima at 368 nm, see Fig.2 (a), (c), and (d), respectively. Next to this, we have black and white photographs (BWS) of the fresco from the 60's (see Fig.2 (b)), which captured the fresco before aging changes during last forty years. All the recent image data were taken by the Czech-Geo company.

Microscopic minute samples were manually taken out at several locations on the fresco, which are of the high interest for art restorers. Then they were tested using spectrometry. In this way, full chemical description of these samples was found out and these results were included to the data processing stream. The grid of the sampling spots is up to now not regular and quite sparse but this situation will be changed in the future.

3. IMAGE ANALYSIS

As it was stated before we are facing problem of the multimodal and the multi-temporal registration, followed by the image fusion. Scene details should be stressed out. Moreover, the extra results from the sampling spots, which are representing chemical content of individual points, should be included into the result, too. They should be spread within the neighborhoods, defined by the structural information contained in data (edges, object shapes).

The used methods can be divided into three categories:

- image registration
- image fusion
- image higher level analysis

3.1 Image registration

Image registration is the process of transforming one image into the coordinate system of another image. Here, the process is complicated by the fact that the images can differ by the modality [6] used for scanning and possibly by the acquisition time [2]. In our case the most complex task is the registration of the BWS old photographs to the reference coordinate system (the one of the VS images). As it is apparent from the Fig.2 (b), there has been a big change in the fresco state.

The multi-modal and multi-temporal parts of registration were solved separately. In the later case feature points for the estimation of necessary geometric transform were chosen manually in both images (VS and BWS) and then the transformation parameters were computed, using known correspondences (significant differences due to multimodal nature of the data violated any automatic feature detection method). The first, multi-modal case was solved by means of the *mutual information* [7], which represents usual method for such cases. An example of the registered data can be seen in Fig.3 (see the top right corner for geometric difference). In the end, we have set of four images, which coordinate system corresponds to each other and we can directly compare and combine pixel values, because they depict the same object from the scene.

3.2 Image fusion

The goal of the image fusion is to find data combination and hidden dependencies which are difficult to find by looking at images separately. There exists many methods, often we can meet them in remote sensing applications (combining high spatial - panchromatic and frequency - multispectral resolution images) or in medical imaging (fusing functional - fMRI, PET information with the structural one - CT, MRI). The algorithms working on pixel-wise basis are using various image transforms such as principle component analysis (PCA) [8], independent component analysis (ICA) [8], or wavelet transform [9]. The very combination is then done in the chosen transform domain.

Here, we have tried wavelet transform and PCA transform. In the wavelet case, higher coefficients in the wavelet decomposition of images are combined, while PCA looks for the reduction of the dimensionality of the fresco representation and it sorts individual dimensions according to their importance. The latter solution gave us better results with respect to the detail visibility and distinctive features combination. One example is shown in Fig. 4. Details, which were hardly recognizable or distributed among several modalities,

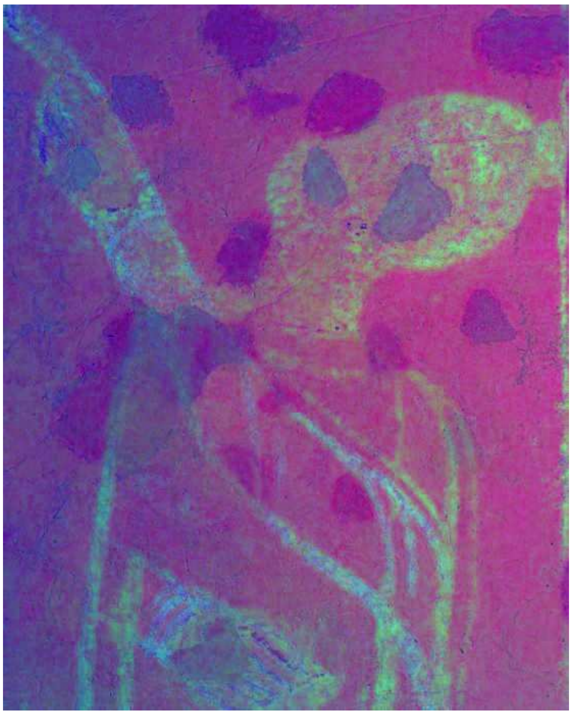
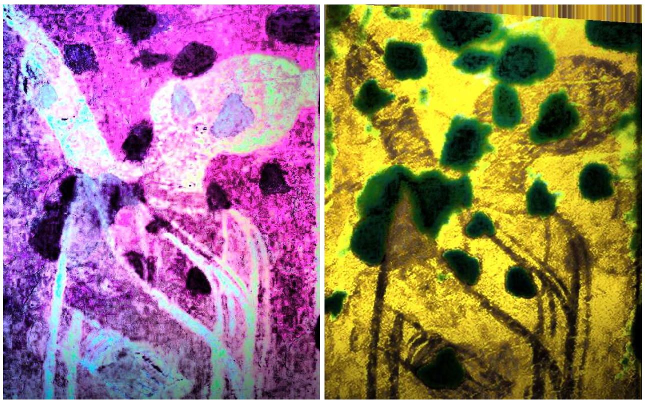


Figure 4: An example of the fused data using PCA transform. There are visible details, which were hardly recognizable before, such as the collar part or the stripes around the wrist.



(a) (b)

Figure 5: An example of the PCA fused data, when their contrast has been locally improved. The images differ in the chosen combination of input sources - (a): VS + UVN; (b) UVN + BWS.

appeared in the resulting image (the collar details, the stripes around the wrist).

It is difficult to judge automatically which source combination can be more useful for the art restorers thus we provide them with several combinations. Moreover, local contrast enhancement was implemented for better visualization. In Fig.5. achieved improvement can be seen. Fig.5 (a) is an enhanced image from Fig. 4, (b) part depicts the enhanced version of the fused UV narrow-band image (UVN) and the old fresco photograph (BWS). It is noticeable, that on these two images different features are captured depending on used modalities ((a) represents better the depicted person while the (b) image reflects more the destruction of the fresco).

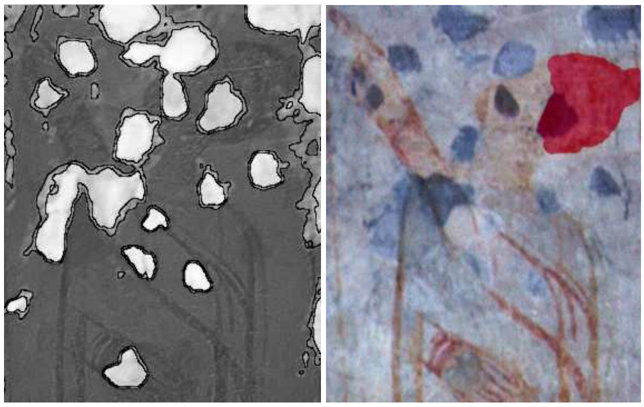
3.3 Image higher level analysis

While in the previous section we did not care too much about objects depicted on the images, this last part of our approach is interested mainly in these structures. If any further virtual restoration should be considered than it is necessary to have an idea where are object boundaries and which parts of the image belongs to each other. Using the fused as well as the registered original data, we have applied edge detection and segmentation algorithms to achieve the notion of the scene content. This part of the project is still under progress so we would present our preliminary results.

As it is apparent from the Fig.2 (b) image, the fresco was heavily destroyed and repaired afterwards, sometimes very insensitively. One of the interests of the art restorers is the detection of these lacunas. The Canny edge detector [10] run on the quantized UV data source followed by morphological post-processing gave us borders of these areas, as you can see in the Fig. 6 (a). These can be leaved out from further material analyzes as they are not native to the fresco. Original visual content of these areas is lost forever, however their filling up [11], [12] will be discussed in the Conclusion Section.

The second part of the image higher level analysis considered the sampling spots and usage of their information. There is the sparse grid of the sampling spots where we know exact chemical analysis (spectrometry) of the fresco content (the density of grid should be increased in the future in-site measures). Knowing the spot coordinates and the structure of the scene - the distribution of edges, borders, and flat areas - we can spread the content knowledge thorough the uniform neighborhoods till any border is reached. The idea behind is that if the intensity color is the same in the acquired images the chemical content is probably the same as well.

The robustness of such approach can be increased using the higher level content when we put individual borders and flat areas into the mutual relations. An outcome of the proposed solution is better visualization of the fresco colors and efficient representation of the chemical analyzes results - their extrapolation to the plane, because even that they are taken point-wise, they should represent an area and not just single points (see Fig. 6(b) for the person's hat representation).



(a) (b)

Figure 6: Image analysis results. (a) - lacunas: segmented areas, where the fresco was destroyed and then artificially repaired. (b) - spread information from the sampling spot about the chemical content (spectrometry), limited by structure-based neighborhood.

4. CONCLUSIONS

In our paper we present the application of the digital image processing methods used during the fresco restoration. The art restorers have images of the fresco in three modalities - perceived in the visual, the narrow-band ultraviolet, and the broad-band ultraviolet wavelength spectra and, moreover, the old black and white photograph of the fresco from the 60's. Our aim was to combine all available information in a way to see all details in one fused image which enables better evaluate the state of the artwork. The second reason for the fresco processing is better visualization of the chemical analyzes, done on the sparse grid of the sampling spots. To achieve given goals, we have applied multi-modal (mutual information) and multi-temporal (it was done semi-automatically) registration. The registered data were fused by means of the PCA transform. Wavelet fusion did not return any good results. For the sampling spots value spread image higher level analysis was realized, including the edge detection (Canny edge detection followed by morphological post-processing) and segmentation. Achieved results are illustrated by several Figures.

The project of an application of image processing methods for such fresco restoration is still running. All the work is done in tight cooperation with the restoration experts, because the applicability of the results has to be re-evaluated for every change of experiment settings. Moreover, the state of the fresco is very bad, thus it is often difficult to find robust enough algorithms.

In the near future we would like to point our attention to the inpainting for more tempting visualization of the fresco. As we mentioned in the Section 3., this is quite controversial issue, however we believe we could find reasonable consensus with the art restorers. The extrapolation of structures and textures across missing corrupted areas could improve the perception of such valuable art pieces. Once again, due to the bad state of the fresco we expect semiautomatic solution, allowing the experts interactively influence the output.

5. ACKNOWLEDGEMENT

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