THE MATERIAL DESCRIPTION AND CLASSIFICATION IN *NEPHELE* SYSTEM FOR ARTWORK RESTORATION

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ABSTRACT:

We present a comprehensive information system for processing and archiving material analyses data produced during art restoration process - *Nephele*. The *Nephele* is a database system extended with image analyzing modules - image registration, segmentation, and object description and classification - designed for archiving and working with material analyses reports. The aim of the material analyses of paintings is to identify inorganic and organic compounds using microanalytical methods, and to describe painting layers and their morphology. Archiving all these data, *Nephele* can act as a knowledge base and an expert system for future advanced analyses. Image-type data of the archived reports are pre-processed, analyzed, and described for further evaluation. Moreover, next to the classical text-query database search *Nephele* supports report retrieval based on the similarity of the sample image to the archived image data, which can notably facilitate selection of relevant records to the current restoration case. In the near future, the *Nephele* system will be extended by the module for automatic painting material classification, based on neural network architecture and newly designed material taxonomy using object descriptors, capturing the layers morphology, their homogeneity or heterogeneity, and their color properties.

1 INTRODUCTION

Nowadays art conservators make use of new sensors and modern techniques to study, conserve, and restore old and often damaged artworks. Then, they are able to obtain more precise results by combining various data sources (Pelagotti et al., 2008). However the key issue of the art restoration stays still the same - an identification of the used materials. This is the subject of the material analyses research. Its aim is the location and the classification of inorganic and organic compounds using microanalytical methods, and description of painting layers and their morphology, where the layer is defined as consistent and distinguishable part of the painting profile. All this helps to determine the age of the

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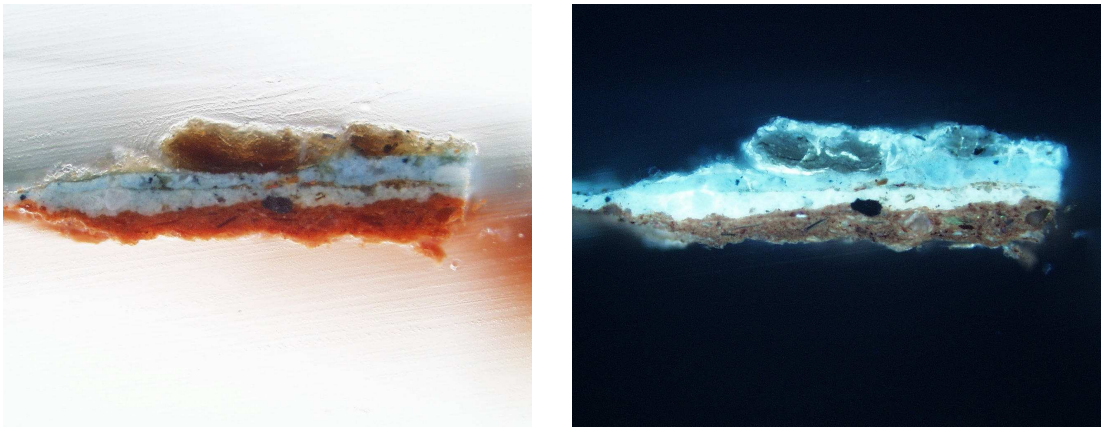

Figure 1: The images of the artwork cross-section in the visible (VIS - left) and ultraviolet (UV - right) spectra.

used materials and their possible places of origin (Hradilova et al., 2003). Stratigraphy (learning about layers) is usually studied using visible spectrum images (VIS), ultraviolet spectrum images (UV) (see Fig.1), and images from electron microscope (SEM).

As it is apparent from the previous, next to the new data acquisition sensors, methods capable of image analysis can be beneficial for restorers, too. Recently, there has been many papers on the exploitation of digital image processing methods for the art conservation and cultural heritage preservation in general, for example (Kammerer et al, 2003; Cappellini et al., 2003). Considering the stratigraphy and processing the multimodal images (VIS, UV, and SEM), there are several possibilities how image processing can be exploited. We focused our research on the automation of the layer detection and description and on more efficient work with archived material analyses. In the past, all the image analysis work was done manually by experienced professionals. An automatic preprocessing of the input data can align images taken in different modalities by means of the image registrations techniques, it can segment the individual painting layers and material grains, and, finally, it can help to represent detected layers and grains by means of the object descriptors, capturing the layer morphology, its homogeneity or heterogeneity, and its color properties. Such layer representation can be further used for material classification.

All proposed image processing modules were incorporated into the database system, handling results of material analyses in the form of reports. Material analyses report fully records the research of used painting materials, which contains general information about the artwork and the description and the results of analyzes which were held. Archive of such reports could serve as a knowledge base for future restoration cases. Having the image processing tools included into the database, the possibility of content based image retrieval facility has shown up. This feature enables, unlike the usual text querying approach, the retrieval of reports based on similarity of the sample image to the archived image data. The look-up using image similarities can notably facilitate selection of relevant records to the current restoration case.

2 SYSTEM *NEPHELE*

The *Nephele* system was designed for archiving and work with painting material research reports. The content of this extended database system reflects the structure of the report, which describes the process of material research of given artwork. It contains all acquired information about the object: general information about the artwork itself and its author, information about samples taken off of the artwork at several places, scanned parts, and results of chemical analyses. Such database with broad spectrum of reports can serve as the knowledge base for future restoration cases. Possibly the most important

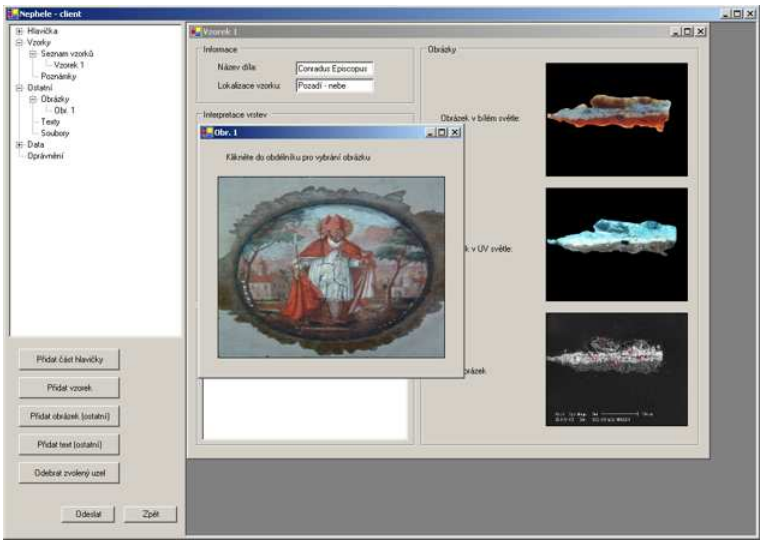

Figure 2: Illustrative example of Nephele user interface.

functionality of the system is the *search* function, which selects required reports. The user has two options: to use textual information for looking up the report, or content-based image retrieval, which compares archived image data with the query image sample. The latter is enabled due to the included image processing modules, which go beyond the ordinary database functionality and are intensively used in the very process of artwork analysis and report creation.

The illustrative example of *Nephele* user interface can be seen in Fig.2. The restored artwork is shown, with VIS, UV and SEM images of one microscopic cross-section. The software was implemented in C++ programming language with .NET framework support on client side. The database is based on relational model with SQL querying language.

3 IMAGE ANALYZING MODULES

Several image analyzing modules are incorporated in the *Nephele* system. They were designed for processing input image data acquired during the material research: microscopic images of minute surface samples (0.3mm in diameter). They are taken off of the selected areas, embedded in a polyester resin, and grounded at a right angle to the surface plane to expose the painting layers of the artwork. The microscopic images are taken in several modalities. Stratigraphy (learning about painting layers) is usually studied in VIS and UV images, where the UV analysis makes use of the luminescence. Different materials have different luminescence, which can help distinguish materials not resolvable otherwise. Lately, the data set was extended by SEM images from electronic microscope.

The ultimate goal of the image preprocessing is the identification and description of the individual material layers. Before the layer localization can start, the multimodal input data have to be brought into geometric alignment, because the VIS and UV image pairs of the sample are often geometrically misaligned due to manipulation errors etc. They can be mutually shifted and rotated in the scanning plane. The proposed image registration module of the system solves the spatial alignment of the image pairs.

After the image rectification, the color layers can be estimated. The segmentation module performs segmentation of the cross-section from the noisy background and also preliminary layer segmentation based on both VIS and UV images. The construction of the full and correct segmentation turns out to be a very complex task, because expert knowledge is often necessary (certain materials cannot be neighbors, others are always together, etc.).

After the layer segmentation, we have the set of base structures, which are *homogenous* and can be further described, analyzed and used for

more sophisticated tasks such as image based retrieval or material classification.

3.1 Image registration

Image registration is the process of overlaying two or more images of the same object taken at different times, from different viewpoints, and/or by different sensors. The task of VS and UV registration belongs to the multimodal registration category, where images of the same scene are acquired by different sensors. The main complication of such task is that the intensity values do not correspond to each other and it is more complicated to find an appropriate similarity function or features, which are invariant to such changes.

Mutual information (MI), originating in the information theory, is recognized solution for the multimodal registration problem. It is a measure of statistical dependency between two data sets and it is particularly suitable for registration of images from different modalities. MI was chosen because it does not impose strong limitations on used sensors. One of the first articles proposing this technique is (Viola and Wells, 1997).

In our approach, we use a speed up technique of the method, based on averaging pyramid together with discrete estimate of histogram. The optimization of the maxima location is a modified version of the method published in (Penney et al., 1998). Moreover, we exploit one-channel data, either green channel of the RGB image representation or the first element of principal component transform (PCT), to reduce the dimensionality of the problem.

3.2 Image segmentation

Image segmentation is the process of separating the input image to multiple regions, which represent consistent and distinguishable parts of the painting profile. The image segmentation task consists here of two steps: first, the cross-section has to be isolated from the background, and second, the painting layers of the sample are distinguished.

Background segmentation: During the acquisition process, the cross-sections are photographed along with polyester resin, which forms the noisy background of the image (see Fig.1). This should be removed before any other image processing technique can be applied. The proposed method is based on appropriate thresholding of pre-blurred image, which diminishes the hostile effect of the errors in the resin. The blur smooths the input image, therefore the cross-section can be clearly separated from the background.

Layers segmentation: Input information to the module for the layer detection consists of the set of three RGB channels of VS and three RGB channels of UV specimen images. Various segmentation methods were tested and compared to the ground truth provided by experts. We found out that expert knowledge is used widely during the segmentation process, such as an enabled and disabled adjacency, obligatory sequence etc. Thus we restricted ourselves to producing preliminary estimates of the color layer segmentation as the first proposal for the operator. It is possible to include the expert knowledge for layer order using the feedback, this is one of our goals for the future. However, even this first sketch can considerably facilitate the tedious manual work needed.

The proposed method is based on the cluster analysis using the VIS and UV six color channels plus spatial information (x and y coordinates are included as another two channels). It starts with iterative *k-means* clustering, where the number of classes is set a priori as a maximum expected number of layers by the user. The enhancement of the results was achieved after applying morphological operators on detected segmentation and performing minimum class check.

3.3 Image retrieval

For better functionality of the *Nephele* database, effective tools are implemented to look-up relevant reports. One of them is content-based image retrieval (CBIR), which is recently very popular (Veltkamp and Tanase, 2000) and is used as a part of multimedia systems in art galleries (Addis et al., 2003; Goodall et al., 2004). The

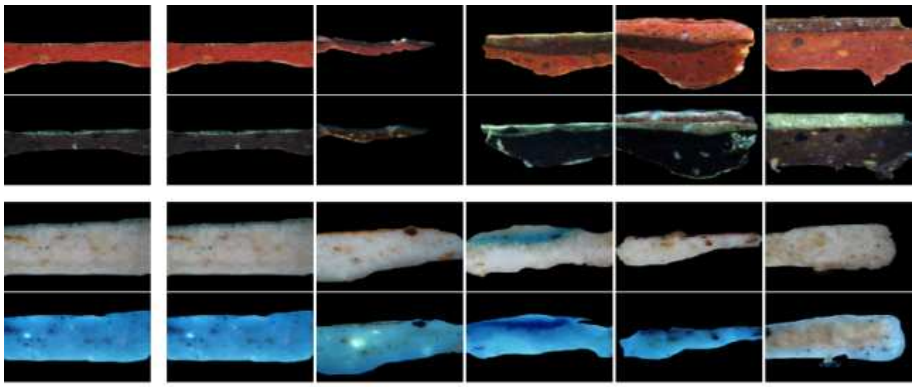

Figure 3: Results of the image retrieval. Left column contains query specimens, next columns in the corresponding rows are results of the retrieval in order of similarity.

image retrieval exploits similarity of the query sample to the images contained in the archived reports. The visual similarity can point to the same author, used material, or technique. In our *Nephele* system, we applied two possible classes of used features: the energy descriptors (Smith and Chang, 1994) computed from the wavelet decomposition of the SEM images and the combination of texture features - the *co-occurrence matrices* and Haralick descriptors (Haralick et al., 1973) - and color features - the image average color and the spectral standard deviation, both applied on VIS and UV data. The weighted Euclidean metric was chosen and the R^*-tree indexing structure (Beckmann et al., 1990) was implemented to speed-up the retrieval. Figure 3 shows the applicability of the second approach. Leftmost column represents query images. The most similar responses are in the respective rows in order of similarity from left to right.

4 THE MATERIAL DESCRIPTION AND CLASSIFICATION

As it was stated before, the classification of the used materials is a key issue in the restoration process and task of our near future work. Our preliminary idea is to exploit texture patterns of the material and describe it with a set of descriptors. Afterwards multilayer backpropagation neural network will be used for material classification and identification. Neural networks are often used as classifiers in pattern recognition (see (Bishop, 1996)). The layers segmentation can use this method as well in the future.

Other possibility is to exploit the morphology of the layers. One material is among others determined by its shape, size, and density of the grains. One of the first necessary steps forward is segmentation of the grains in the individual layers. Our algorithmic solution of grain segmentation is based on parametric snakes and works on the SEM data (Xu and Prince, 1998).

The proper design of the material descriptors is tightly tied down with the systematization of features important for the material classification. It is important to know which characteristic is able to distinguish among two used materials and thus what we should be focused on. We plan to create such taxonomy of material descriptors as a byproduct of the proposed research.

5 CONCLUSION

The proposed system *Nephele* can help art restorers and conservators in their work and offer them better access to the archived material reports they use. The image processing methods (image registration, segmentation, and object description) improve the outcome of the analyses and the database. The included image retrieval system is able to provide fetching of reports with visually similar cross-section data. This functionality eases the complicated task of the retrieval of relevant experience from previous restoration cases.

The future work is aimed to precise identification of the used materials in single layers. Presented examples of achieved results show the ap-

plicability of the system. All work was realized in close cooperation with the experts from Academic Materials Research Laboratory for Painted Artworks, joint site of the Academy of Fine Arts in Prague and Institute of Inorganic Chemistry AS ČR.

REFERENCES

Addis, M., Boniface, M., Goodall, S., Grimwood, P., Kim, S., Lewis, P., Martinez, K., and Stevenson, A., 2003. Integrated image content and metadata search and retrieval across multiple databases. *LNCS*, 2728, pp. 91–100.

Beckmann, N., Kriegel, H.-P., Schneider, R., and Seeger, B., 1990. The R^*-tree: An efficient and robust access method for points and rectangles. In *1990 ACM SIGMOD International Conference on Management of Data*, 19, pp. 322–331.

Bishop, C. M., 1996. *Neural networks for pattern recognition*. Oxford University Press, Oxford, UK.

Cappellini, V., Barni, M., Corsini, M., Rosa, A. D., and Piva, A., 2003. Artshop: an art-oriented image-processing tool for cultural heritage applications. *Journal of Visualization and Computer Animation*, 14, pp. 149–158.

Goodall, S., Lewis, P. H., Martinez, K., Sinclair, P., Giorgini, F., Addis, M., Boniface, M., Lahanier, C., and Stevenson, J., 2004. Sculpteur: Multimedia retrieval for museums. *LNCS*, 3115, pp. 638–646.

Haralick, R. M., Shanmugam, K., and Dinstein, I., 1973. Textural features for image classification. *IEEE Transactions on Systems, Man and Cybernetics*, SMC-3(6), pp. 610–621.

Hradilová, J., Hradil, D., and Bakardjieva, S., 2003. Microscopy in conservation. *Vesmír*, 12, pp. 676–681.

Kammerer, P., Zolda, E., and Sablatnig, R., 2003. Computer aided analysis of underdrawings in infrared reflectograms. *Proc. of the fourth Int. Symp. on Virtual Reality, Archaeology and Intelligent Cultural Heritage, VAST2003*, Brighton, England, pp. 19–27.

Pelagotti, A., Mastio, A. D., Rosa, A. D., and Piva, A., 2008. Multispectral imaging of paintings. *IEEE Signal Processing Magazine*, 25, 27–36.

Penney, G. P., Weese, J., Little, J. A., Desmedt, P., Hill, D. L. G., and Hawkes, D. J., 1998. A comparison of similarity measures for use in 2D–3D medical image registration. *IEEE Trans. Medical Imaging*, 17, pp. 586–595.

Smith, J. R. and Chang, S. F., 1994. Transform features for texture classification and discrimination in large image databases. *Proc. IEEE Intl. Conf. on Image Processing (ICIP)*, pp. 407–411.

Veltkamp, R. C. and Tanase, M., 2000. Content-based image retrieval systems: A survey. *Technical Report*, UU-CS-2000-34.

Viola, P. and Wells, W. M., 1997. Alignment by maximization of mutual information. *International Journal of Computer Vision*, 24, pp. 137–154.

Xu, C. and Prince, J. L., 1998. Snakes, shapes, and gradient vector flow. *IEEE Trans. on Image Processing*, 7(3), pp. 359–369.

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