Image Processing Techniques in the Study and Restoration of Byzantine Mural Paintings

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My participation in a project of recording Byzantine churches on the islands of the Dodecanese, in south-eastern Greece, encouraged me to search for ways in which digital image enhancement and analysis techniques could be of support in the study, virtual restoration and decay monitoring of their mural paintings. As a result of limited time in which to perform the necessary experiments and due to a variety of technical problems, in part this paper should be considered as a theoretical approach rather than as remarks and observations based upon extensive field and laboratory research. All the examples presented refer to mural paintings in the 14th century church of St. Catherine in the Old Town of Rhodes. [Pl. 1]

The study and interpretation of mural paintings is based on the ability of the scientist to see and understand, as clearly as possible, image details which are obscure or hidden through years of weathering or damage by man. Image processing is used to improve the visual appearance of images to the viewer and to prepare images for identification of their remaining features, extending sometimes human vision beyond its natural limitations. Improved accessibility to image processing technology over recent years means that more powerful and flexible computer applications for digital image analysis and enhancement are now available to a greater number of scientific disciplines and to users of a non highly computer-specific, educational background.

Digital image acquisition can be direct, using a digital camera, or indirect, using an ordinary camera and scanning the developed film or the printed image. [Pl. 2] Although digital cameras are still expensive, their use is preferable because indirect image acquisition can lead to the loss of data integrity. Images usually refer to the visible spectrum, or to specific areas of it if filters are used. Special camera lenses are required to take pictures in the ultraviolet area of the electromagnetic energy spectrum. [Pl. 3] Broad-band digital cameras or infra-red films are used for images in the near infra-red or infra-red area of the spectrum. If complete coverage from the ultraviolet to the infra-red area is required, at least two camera bodies, two lenses, four filters and approximately ten differently taken pictures of the same object are an absolute necessity. The whole procedure is not very convenient. Skill, knowledge and experience are required to make the best use of the photographic equipment and record as much information as possible. But this is a subject for another paper! Our aim is to use computer applications to make the information available in these images more comprehensive and therefore more valuable.

The level of information present in a digital image depends heavily upon its resolution. The smallest square-shaped unit of the digital image, called a pixel, has to correspond to the smallest drawn detail in the real image, or, even better, to be half its size. Lower resolution leads to loss of information, whereas higher resolution increases computation requirements. For the Byzantine mural paintings examined a resolution of 2048X2048 pixels, corresponding to one square metre of painting, is adequate whereas a resolution of 4096X4096 pixels is ideal.

For many years the technique of water-spraying mural paintings [Pl. 4], to make colours more vivid and highlight different features, has been widely used. The same and even better results can be achieved by using computer based histogram transformations of the relevant digital images. A histogram shows the frequencies of each of the pixel values of an image and is useful as an analysis tool. The distribution of frequencies gives an indication of the possibility of image enhancement. A histogram transformation changes actual pixel values in the image to output pixel values, according to the particular method, having as a result a rather sophisticated contrast enhancement. An even distribution of the frequencies of pixel values increases the entropy of the image, highlighting details not easily perceivable by the human eye and improving the pictorial information for human interpretation.

Pseudocolour is another method of monochromatic image transformation to highlight specific details. In this method, each class of pixel values in an image is coded to some colour based on a so-called "Colour Look Up Table". This rather simple method is widely used in medical and environmental applications. Since the human eye is much more sensitive to change in colour than to change in brightness, the distinctness of features and the number of perceivable details is increased. [Pl. 5]

Filtering of digital images is used to reduce, remove, or amplify specific components of the image. A filter is a technique used to produce an enhanced image, in which each pixel value is calculated as some operation of the corresponding pixel value and its surrounding pixels in the original image. [Pl. 6] Smoothing filters can suppress

unwanted effects; sharpening filters and edge or line detection filters are used to increase the visual interpretability of the image. Depending on the required result, a matrix of coefficients, by which pixel values in an image are multiplied, has first to be specified. The size of the matrix determines the number of surrounding pixels taken into consideration, and has direct effect on computation requirements. Adoptive filtering is frequently applied, if a specific condition has to be satisfied, before the input value is replaced by the filtered value in the enhanced image. A number of general purpose filters are available. Although there exists modern software that supports user-definable filters, the specification of a new filter, for a particular case of interest, requires much knowledge and experience.

Filtering can be widely used as a means of virtual restoration of mural paintings. Capillary cracks, common on most mural paintings, can be successfully removed by applying a smoothing, but edge and detail preserving, non-blurring filter, which uses the median value of pixels in the neighbourhood, rather than the mean one. The image of the mural painting can also be improved, by filling the gaps usually present. A new value can be assigned to pixels of undefined value, which correspond to gaps, using a conditional, digital, filling filter. The result might not be as aesthetically pleasing as a hand drawn addition, but it has the advantage of being an homogeneous and clearly describable intervention.

A correction of geometric distortions, resulting from the acquisition process, is often necessary, before the study and analysis of images. This procedure is known as image rectification and is based on modelling distortions, by selecting clearly defined points and specifying what the co-ordinates of these points would be, in an undistorted image. Rectification is important, because it leads to an accurate representation of the decorative scheme, in each of the churches we looked at. Geometric patterns and decorative features can be easily studied and correctly drawn to scale. [Pl. 7]

Image registration is based on defining a relationship between the pixel co-ordinates of an image and a co-ordinate system of reference. If this is not possible, an image to image registration could be used to perform analysis and comparison of images, taken from different positions, under different conditions or in different moments. In such case, one image has to be considered as a "master" and all the others must be registered to that. The procedure is based on locating easily definable points on both the master and the "slave" images. A variety of algorithms (for example, mean normalized similarity or mean normalized correlation) can be used to perform image to image comparison and auto-locate reference points present on both images.

Image registration is an absolute necessity for multi-channel analysis and for autonomous machine comparison of digital images. Multi-channel analysis is the computer application, that provides a means to extract as much information as possible from the available images of mural paintings. On the other hand, autonomous machine comparison of digital images, acquired in different moments, forms the basis of a decay monitoring system by a) clearly indicating the areas of the mural painting that have changed; b) automatically locating new cracks and surface peeling; and, c) identifying the spread of humidity or expansion of mould or lichens.

Colour is always a powerful descriptor and simplifies the identification of painting details. Colour is a property connected with the ability of objects to reflect electromagnetic waves of different wavelengths. [Pl. 8] A colour image can be described as consisting of three spectral components (red at 700 nm., green at 546.1 nm., and blue at 435.8 nm.). Colour image processing refers to enhancements and transformations in each waveband. The dull colours of a mural painting can be virtually restored to their former glory by histogram transformations, in each of the colour image components.

Instead of using colour film, the use of special camera-lens filters, lenses, and films allows the acquisition of images in different light bandwidths. Such images, digital or digitized, can be combined to produce a colour composite image. The combination depends on the accuracy of the image registration of each of the components. The combined image contains more information, than any directly acquired colour image, and gives a better indication of pixel- vector differences, than any of the component images alone.

Additional component images in the infra-red band can provide more information on fungi or humidity problems, and show details invisible to the human eye. There is also a possibility of acquiring images in the ultraviolet band, which can give information about the original pigments used in mural painting. Because of technical problems, however, so far we have not had the opportunity to experiment with ultraviolet light.

Processing a colour image often presents two main problems. Hardware requirements increase rapidly, depending on image resolution and there is the possibility of correlation between colour image components, which reduces the level of available information.

In cases where correlation between the channels of multi-spectral images shows poor colour separation, the method of producing the first three principal components [Pl. 9] of the image, on which a colour composite is based, may be used. This composite is not a true colour representation of the original image, but it can be helpful to highlight some details, not easily seen otherwise. Principal components transformation is simply a method, that attempts to improve feature separation, by producing transformed channels, which have the correlation minimized.

Computer interpretation of digital image data is referred to as "quantitative analysis", because of its ability to identify pixels, based on their numerical properties. Classification is a method, by which labels may be attached to pixels in view of their spectral character. Specific computer applications are used to recognize pixels with spectral similarities. Image segmentation - that is the separation of classes of features - is

possible, if spectral properties determine classes sufficiently well. The limited number of pigments, used in Byzantine mural paintings, makes it possible to use classification methods to identify areas, originally painted with the same colour, even if faded pigments and other reasons of decay make this identification very difficult to the human eye. Conservation problems of the mural paintings, such as humidity, accumulated surface salts, and different types of mould or lichens can be identified as having different spectral properties. [Pl. 10] A knowledge base can slowly be constructed, and seeking features of known spectral properties is then possible.

Similarities in mural painting fragments can also be traced, based upon their pictorial correlation. Similar spectral characteristics, due not only to the use of the same pigment, but to the results of decay factors in different areas of the original mural painting as well, make preparatory work in the identification of adjacent pieces, possible.

An image operation computer language, which refers to automated arithmetic and logical functions on images, has been developed to facilitate the whole procedure of image enhancement and analysis. Programming is simple, but peculiarities in each mural painting create requirements which are different in each case and do not allow for an homogeneous approach.

Concluding, I would like to point out that digital image processing techniques provide many possibilities for the study of mural paintings, but they depend largely upon the practical experience, as well as upon the scientific knowledge, of the operator.

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All Figures in CD-ROM.