Tear feature extraction with spatial analysis: A thangka case study

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Abstract

This paper on Conservation of Cultural Heritage explores the use of spatial analysis functions for fe ature extraction. The study evaluates the performance of neighbourhood functions for the delimitation of a tear in a thangka painting. The pathology area was documented with a non-conventional technique in painting conservation.

Keywords

Painting conservation, spatial analysis, neighbourhood statistics, feature extraction, *thangka*.

Resumo

Este artigo em Conservação de Património Cultural explora a utilização de funções de análise espacial para extracção de características da superfície. O estudo avalia o comportamento das funções de vizinhança na determinação de um rasgão numa pintura *thangka*. A patologia foi documentada por intermédio de uma técnica de diagnóstico em conservação de pintura não convencional.

Palavras-chave

Conservação de pintura, análise espacial, estatística de vizinhança, determinação de características, *thangka.*

Resumen

Este estudio en Conservación de Patrimonio Cultural explora el uso de las funciones del análisis espacial para la identificación de características de la superficie. El artículo evalúa el comportamiento de las funciones de proximidad en la delimitación de un desgarro en una pintura *thangka*. La zona de la patología ha sido documentada con una técnica no convencional de diagnóstico en conservación de pintura.

Palabras clave

Conservación de pintura, análisis espacial, estadística de proximidad, determinación de características, *thangka*.

1. Introduction

In conservation and restoration, methods of inspection and analysis are essential in the characterization of the conservation state of works. This study is focused on the use of spatial analysis concepts in a less conventional area – artworks.

We suggest and explore the applicability of some solutions to perform a graphic documentation with the use of Geographical Information Systems (GIS). The described methodology addresses the diagnosis and interpretation of a digital image – a macro-photography of a type of pathology -, depicting a tear in a thangka painting. A research goal was to explore the potential contact between spatial analysis, performed with the use of computational resources, and the conservation and restoration. As well as in more conventional application areas which use GIS as a tool, the use of spatial analysis for feature extraction on an artwork provides information about its metric characteristics, which may be interesting for documenting purposes.

In conservation, a few works on this specific subject were presented: the analysis of *craquelures* (Abas, 2004), the use of global filters in the panel of Leonardo - Mona Lisa (Mohen, Menu and Mottin, 2006:98), the principal component analysis (PCA) on panel paintings of Tomar (Pires *et al*., 2007), and segmentations with Bayesian classifiers in lacunas of ancient Chinese mural paintings (Liu and Lu, 2008:121-131). Also for mural paintings measuring the *lacunas* with a maximum likelihood classification enabled the characterization of its extension (Henriques *et al*., 2009:13-15). In other areas, such as architectural heritage, this typology of works has been more developed (Lerma, 2001:255-258), (Lerma, 2005:73-77).

In the spatial analysis field, some of these functions are used to delimitate and describe areas that present identifiable quantitative characteristics. For example, in the pattern recognition area, a digitized image containing several objects is analysed through a process consisting of three major phases: image segmentation, feature extraction and classification (Castleman, 1996:448). In the process described as follows, analytic operations were carried out with GIS by the application of several spatial analysis tools (neighbourhood statistics functions, reclassification and region grouping). At the end of the operation sequence a tear region in a painting was extracted and quantified.

2. Methods of surface inspection and analysis

2.1 Traditional methods

The use of inspection and analysis methods in the conservation of paintings is a common task. We reference some known analytical results for thangkas, useful to explore data correlation via spatial analysis, where it is possible to present a chemical documentation of the painting materials. A variety of techniques can be applied for the inspection of these works and, for instance, some studies on thangkas from the Himalayas were done by

X-ray fluorescence (XRF), infrared spectroscopy with Fourier transforms (FTIR), Raman spectroscopy (RS), high performance liquid chromatography (HPLC) and scanning electronic microscope (SEM) (Mass et al., 2008:661).

2.2 Use of GIS in documentation of artworks

Some of the main advantages that can be enumerated for GIS-based techniques are the possibility of using a non-contact system, the ability to execute the analysis of pictorial data and the information retrieval concerning the state of conservation of the analysed artwork. The layer-based operating paradigm of GIS data and operations is a valuable resource that allows the representation of datasets in a logical model, and the production of new datasets which may correspond to the extraction of interesting features in artwork analysis. Another interesting capacity is the rapid and easy thematic mapping capability of GIS software, useful for visualizing purposes.

GIS-based methods differ from traditional image software because GIS software has the possibility to combine alphanumerical data with graphic information. For the conservator-restorers, the principal disadvantage of spatial analysis is the fact of being a computer-dependent technology requiring the availability of software and hardware systems and the specialized formation of operators. The specificity of theory and terminology requires a particular knowledge in spatial data processing technologies.

3. Spatial data and operations

A *raster* data format is one of two primary approaches to represent the locational component of geographic information. The other, not referred here, is the *vector* format (Burrough and McDonell, 1998). The raster format represents data in a grid of regularly distributed values, called cells, each one storing a single value. A data collection is usually displayed as a *layer*, in a matrix-like layout. This is similar to the usual representation of images, such as the digital photographs applied on this paper, where there is a correspondence between pixels and cells in a raster layer.

In raster operations, analytical functions can be grouped in the following typologies: local, focal, zonal and global (Burrough and McDonell, 1998). The differences between the various function types are explained by the range of cells included in the calculus, which is called the neighbourhood. Both spatial or geometric representation of data, as well as the attributes that the cells portray, can be used and evaluated to produce a new data layer.

Local functions are defined as combinations of one or more raster layers, only taking into account the value of the corresponding cells. They include overlay operations and reclassification (change of values according to a function).

Focal functions take the values of cells in shape-defined neighbourhoods around each cell in the layer to calculate the value for it. This defines a moving window, sequentially applied to each cell $C_{i,j}$, defining the cells over which some statistical function applies. Any cell that is inside the neighbourhood will be included in the processing. This type of operation is also commonly known as convolution (Burrough and McDonnel, 1998: 186). The window is usually a square with 3x3 cells, but any other size or shape is possible (the size of the window can be defined in number of cells or map units). The general equation for rectangular windows (sized 2*m*+1 by 2*n*+1 cells) centred on cell at position i, j is:

$$C_{i,j} = f\left(\left\{c_{k,l} : i-m \le k \le i+m, j-n \le l \le j+n\right\}\right)$$

where f stands for a given operator and $c_{k,l}$ is the value of the layer at position k,l. Several types of statistics can be a choice for function f : for example, average, majority, maximum, mean, minimum, minority, range, standard deviation and sum are some options. The average statistic, also designated as low-pass filters (Burrough and McDonnel, 1998: 186), has the effect of removing extremes from data, producing a smoother image. In the majority, minority, maximum, minimum, medium and sum statistics, if the input raster values are integer, the output values are integer. If the values of the input use floating point, outputs are also of the same type. If there is more than a single value for majority/minority in the neighbourhood, the process gives *No Data* to the output cell.

Zonal functions use groups of cells with the same value (called "zones") to perform some statistics or geometric calculation on them. These zones can be defined in the layer being analysed or in a second layer. All the statistics applicable in focal functions can be used as zonal statistics. Examples of geometric options include thickness and area of individual patches, and the computation of the distance from any cell to the closest cell with a specific value.

4. Methodology

4.1. The thangka and its conservation state condition

A thangka is a painting in cloth linen or silk, and an artistic and religious demonstration of the Tibetan culture [figure 1]. This painting was made with a particular technology, painted directly over the tissue, without preparation and has the following size: 115X91cm (nearly).

When the photographic documentation was done, the painting had a good adhesion of the chromatic layer and a significant number of small tears. In some of these tears, several back small cloths of original reinforcement were applied.

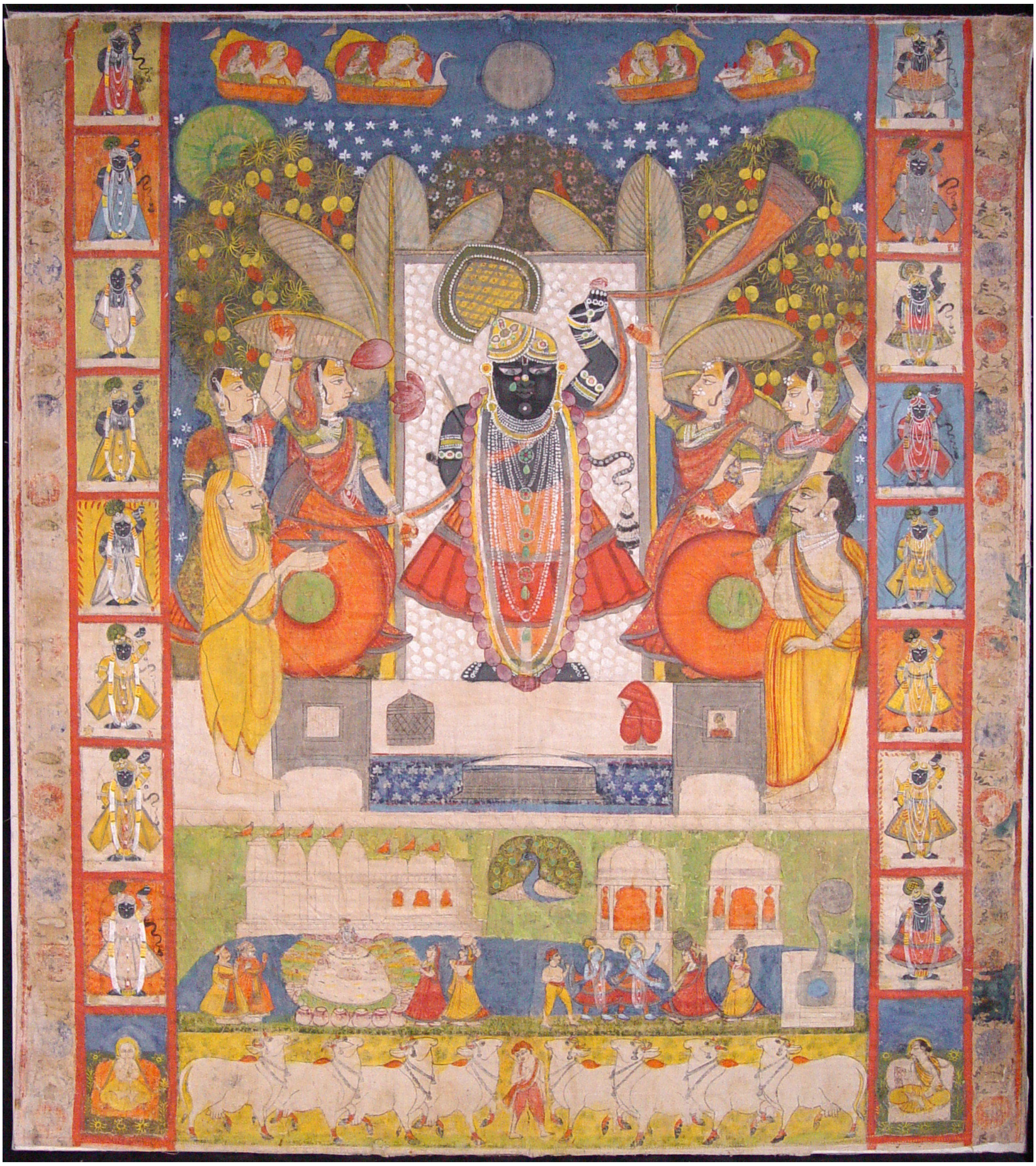

figure 1 - The thangka

4.2. Equipment and data

Photographs of the thangka were taken with a Sony Cyber-shot F-717 5 Mpixels digital camera with a sensor charge-coupled-device (CCD). This was converted to 8-bit raster, with 3 bands, in TIFF format. The hardware used for the proceedings was a Pentium 4, CPU 3.00 GHz, with 1.0 GB of RAM. For the analytic operations *ArcGIS 9.3*™ software, with the

Spatial Analyst™ extension (which allows the processing of raster data) was used.

Operations were conducted in an image section, with 460 columns per 632 lines and 851.72 kB of size, depicting the area of one of the tears, near the chin of one of the three figures in the scene left side [figure 2].

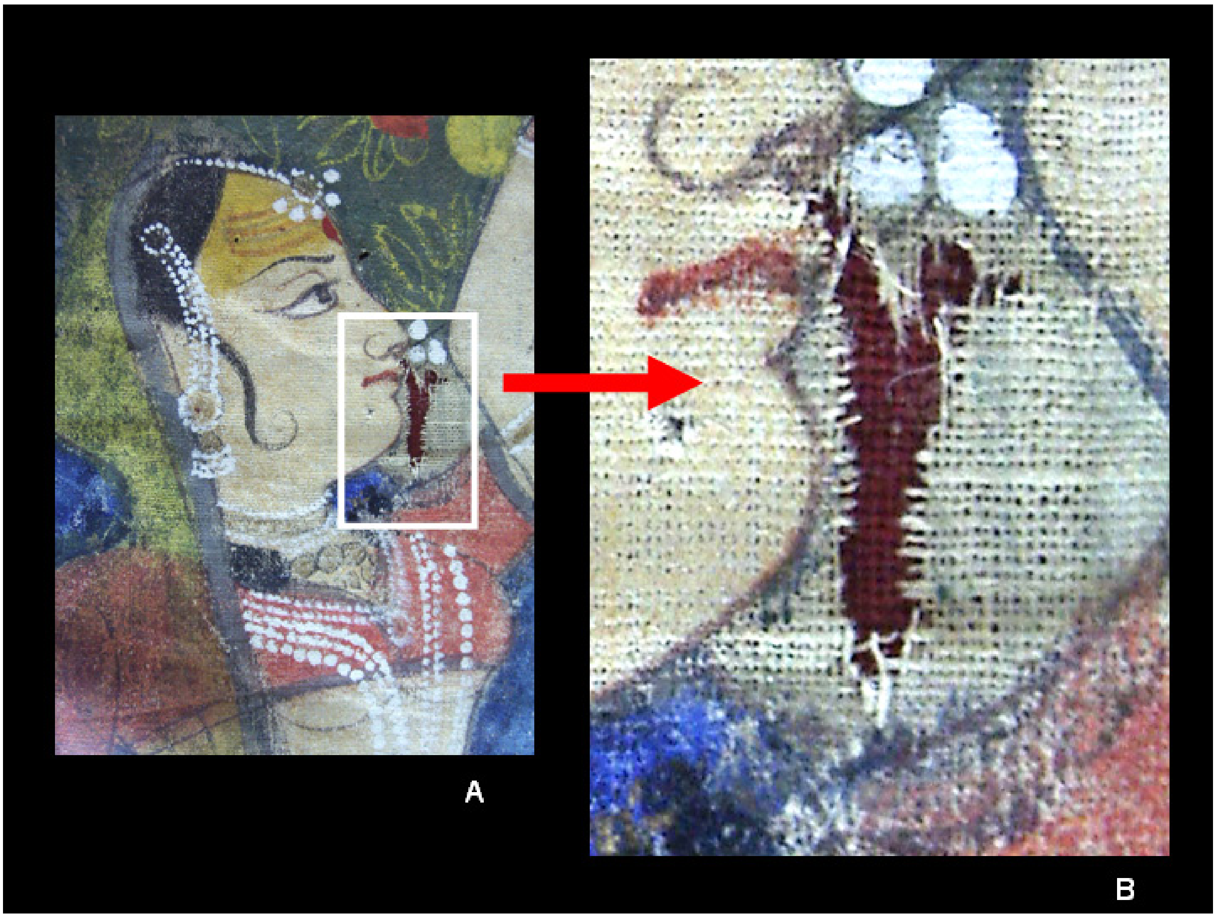

figure 2 - The tear
A) Near the goddess chin; B) Detail

4.3. Application

To recognize an area with a very irregular geometry, and to differentiate it from the background, a variety of functions and process flows can be applied. In our case, the tear segmentation was implemented using a sequence of operations consisting of a focal function, followed by a reclassification (local function) and a region group (zonal function).

The sequence of operations was performed to explore the capacity of enhancement of the cells in the tear limits, and the homogeneity of the cells in the interior of the tear.

The three bands of the image (RGB) were imported as individual raster layers, and multiplied, originating a new single-band raster layer with 461 columns per 633 lines. For it, the application of a scheme of graduated colours enhances the layer's extreme values, when compared to the original layer. The purpose of this step is to force lowest values (represented in the most dark tones), which hypothetically depict the features to extract, to move further in the scale limits, enabling an easier distinction of these cells from their closest neighbour cells.

Focal functions were applied to the resulting layer (minimum, maximum, range, sum, mean, standard deviation, variety, majority, minority and median statistics). The considered neighbourhood was a circular window with a 3-cell radius. [figure 3].

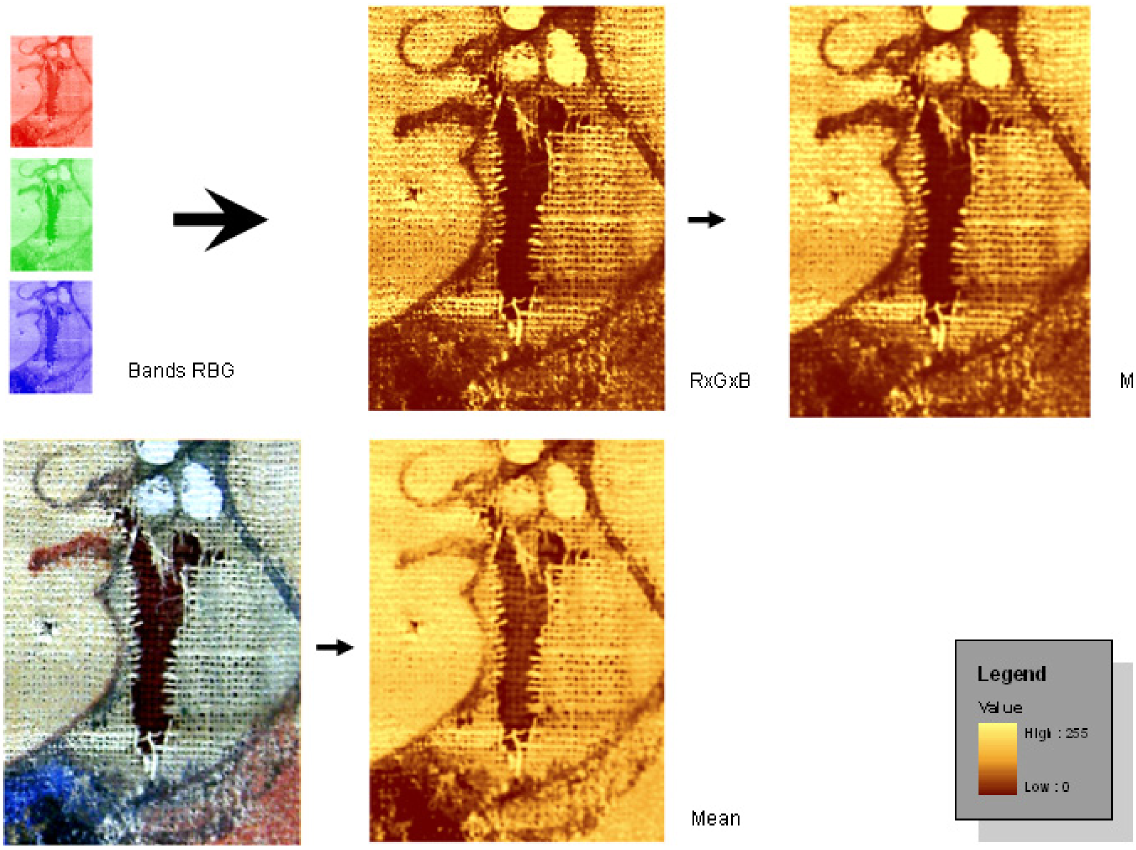

figure 3 - Comparison between a focal function applied to the original image (below) and to the multiplication of the three bands (above)

Some of these functions have the effect of smoothing the cell values and others enhance the distinction between the tear cells and the adjacent zones. Being the goal of the process the tear feature extraction, the enhancement functions appear to be a good intermediate step. However, when each of the two zones (tear and non-tear) is individually observed, these functions have the effect of augmenting the range of cell values, and delimitation and identification of the tear would be more difficult to execute. Considering this, the mean focal function was chosen because it provided good results in achieving some homogeneity of cell values inside the tear – useful for a later extraction of the tear shape – but did not jeopardize a noticeable distinction between tear and non-tear areas.

In the next step of the process a reclassification to two classes ("tear" and "no-tear") was done [figure 4].

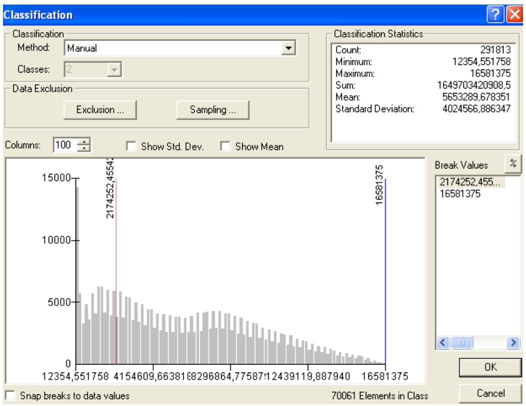

figure 4 - Dialog box of a classification operation.

The reclassification operation implies the attribution of different values to the cells, where input values are replaced by new values according to a rule. Reclassification is frequently used to simplify or to modify the interpretation in raster data, grouping intervals or unique values into different classifications - for instance, assigning a value of 1 for cells with values from 1 to 50, assigning a value of 2 for cells from 51 to 100, and so on. In our case, a classification with two resulting classes, that is, the cutting value defines a threshold. The threshold value for the reclassification was tuned by empirical tests, being chosen a value that established a clear distinction between tear and non-tear areas. Class 1 ("tear") had 47.438 cells and class 2 ("non-tear") had 244.375 cells. [figure 5].

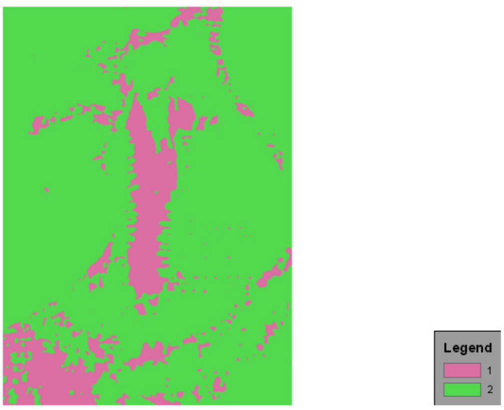

figure 5 - Image reclassified in two classes:
in violet, the "tear" cells; in green, the "non-tear" cells.

A significant amount of isolated class 1 cells (i.e., cells reclassified as "tear" but with no adjacent cells in the same class) appeared. To minimize this, an operation called boundary clean was performed in the sequence [figure 6].

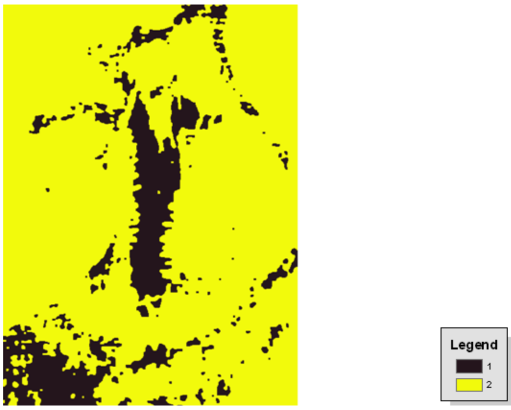

figure 6 - After the operation boundary clean.

This operation is used mainly to move isolated cells to nearby cell groups with the same value (ESRI, n/d). It uses firstly an expansion of the cells classified as "tear" and subsequently a retraction: initially, "tear" cells invade their neighbour "non-tear" cells in all eight directions and change their values. Next, a shrinking of the "tear" cells is done. So, any cells that are not interior, i.e., that have at least one of the eight nearest neighbours with a different value, may be substituted. This results in class 1 ("tear") having 46.170 cells and class 2 ("non-tear") 245.643 cells.

The next operation is called *region grouping*. Regions, which may also be called "patches", are defined as contiguous zones, i.e., contiguous group of cells with the same value. The identification of regions is a zonal function that produces a new data layer, where each region is assigned a unique code. If available, the count of the number of cells for each region provides an estimation of its area [figure 7].

figure 7 - Result of region group:
each identified region is displayed with a different colour.

The final step is a selection of the regions that match the tear, which is done manually. Six regions were identified. The number of cells in each region is displayed in [table 1].

ObjectID	Value	Count
24	25	543
31	32	17442
43	44	235
44	45	127
84	85	161
87	88	243

table 1 - Number cells in the six regions that matched the tear.

After this last operation, it is possible to identify and to select (using a minimum area threshold) the region associated to the tear [figure 8].

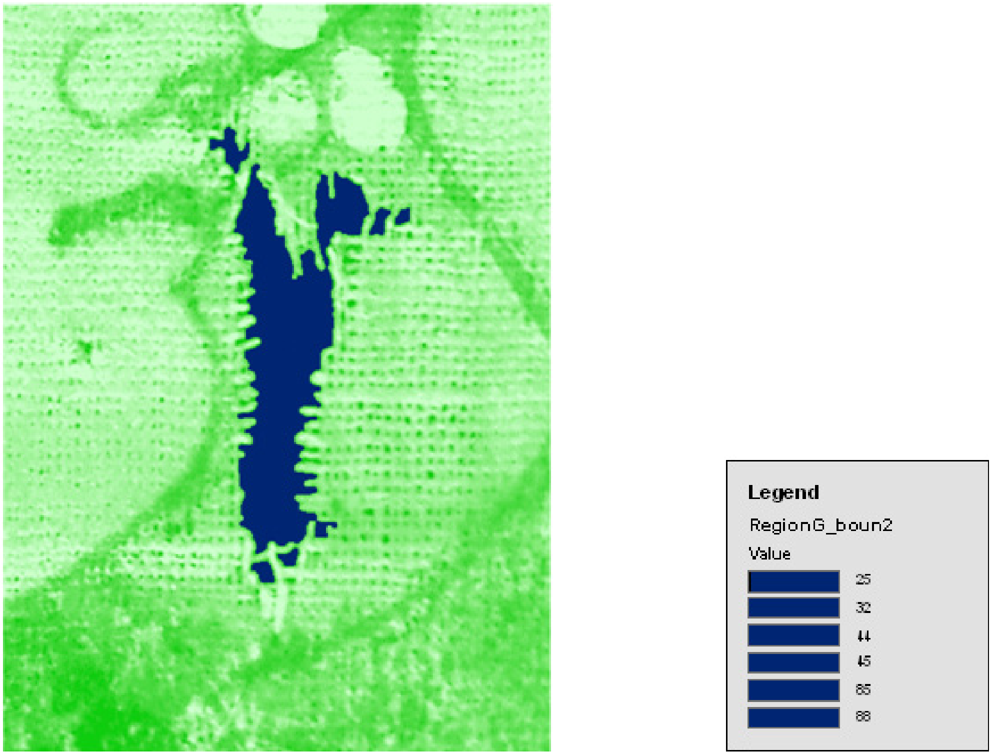

figure 8 - The final area identified as "tear".

We can recall the set of applied proceedings as a neighbourhood statistic local and focal function (mean; a reclassification on two classes; a boundary clean operation; a region grouping and a selection of the regions that have at least a specified area.

4.5. Results and discussion

According to the statistical function being used, a better or worst outline enhancement occurs. The application of these operations contributes to a better characterization performance of the pathology area, when compared with the absence of a focal function in the process sequence. Reclassification is a fundamental step in the process, and the ideal cutting value is usually extracted with tests (thus, a training phase is recommended). When segmentation is an objective, the boundary clean operation can be used to simplify the "transition pixels" of the cell regions. It demands, from the operator, a subjective recognition of the analysed item, in order to check which is the largest possible achievable accuracy using several threshold values. After the region group operation, and the extraction of all the areas, it was possible to get the quantitative characteristics (area, perimeter, thickness and other geometric properties) of the tear shape.

The set of applied operations demonstrates a process to execute a two-class segmentation with raster basic operations. However, after this experience, the choice of a threshold value in the reclassification appears to be the bottleneck of the sequence, because of its dependency on the operator expertise and on the light parameters of the photographic images. This demonstrates the application of the process in feature extraction for the study of pathologies in Cultural Heritage, but requires an adequate assessment of the results in each intermediate state.

5. Concluding remarks

With the use of basic raster spatial analysis operations it was possible to segment tear-type pathology in an easel painting.

The subjectivity of some parts of the process, and the dependency on expert operators to tune the parameters in some of the used functions, make us believe that it not predictable that an error-free fully-automated segmentation process is achievable. However, the process provided good results with a careful and meaningful tuning of the parameters. The choice of the best parameters and their values is a field to explore further.

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