THE USE OF MULTISPECTRAL IMAGES FOR MONITORING THE STATE OF CONSERVATION OF BUILDINGS' ROOFS: CASE STUDY OF LEIRIA DOWNTOWN HISTORICAL CENTRE

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ABSTRACT

This study aims to evaluate the application of multispectral aerial images with Very High Spatial Resolution (VHSR), in the monitoring of the state of conservation of roofs where, usually, building degradation starts. The test was carried out using two multi-spectral aerial images with a spatial resolution of 0.5 m, from different years, 2004 and 2010, of the historical downtown of Leiria, in Portugal. To extract the required information, a hybrid methodology was developed, that includes the following steps: (1) a soft pixel-based classification of both images to extract information about main roof materials and the presence of pathologies; (2) classification at the building level, based on decision rules which include the results of the soft pixel-based classification and its uncertainty; (3) the automatic production of maps for 2004 and 2010 of roof materials and roof pathologies; (4) a change detection of roof materials and roof pathologies, using maps of 2004 and 2010, respectively. The classification accuracy was assessed from a set of samples selected by random stratification and from a second set of samples which take into account the degree of certainty of the classification obtained with each decision rule. For the map of roof materials, it was found a global accuracy of 90% and 72%, respectively, while for the roof pathologies, the global accuracy was 90% and 84%, respectively. The results obtained show that multispectral images can be an alternative to the traditional manual methods to extract ancillary information to monitor the state of conservation of building roofs.

INTRODUCTION

In Portugal, the historical downtown areas generally present a high level of degradation. For this reason, it is essential to know the specific pathologies of each building element and its origin to act accordingly, in order to ensure its functionality and durability.

In order to preserve the historical centers it is necessary, in a first stage, to proceed to the assessment of the state of conservation of the building´s roof materials. The traditional techniques used to obtain the information require an individual and in-situ analysis of each building, making it time-consuming and demanding for large areas under assessment. Nowadays, with the increasing urban rehabilitation actions, it is important to explore other sources of information and develop new methods to identify the construction materials structural and non-structural anomalies, which may be an alternative or complement, to the traditional manual methods (Garcez, 2009; Gonçalves et al, 2009).

Several studies have shown that the use of multispectral images, obtained by photogrammetric processes or by sensors aboard satellites, in detecting anomalies in the roof materials and façades of buildings is rather promising (Bassani et al., 2007; Gonçalves et al., 2009; Lerma et al., 2011; Hemmleb et al., 2006; Valença et al., 2011).

Gonçalves (2009) studied the assessment of the conservation status of buildings through the mapping of their roofs, using high spatial resolution aerial imagery. In this case, multi-spectral images were used to get information about the conservation status of roofs. The method was tested in the classification of the historic city of Coimbra, in Portugal, which included more than 800 buildings, with very satisfactory results. As an example, we can mention that the classification of the Map of Anomalies of the roof covers was carried out with a global accuracy of 78%.

In this study an evolution of the method developed by Gonçalves (2009) is presented. The article intends to evaluate: (1) the applicability of multispectral images of very large resolution from different years, for the automatic detection of changes in time of building's roofs materials and non-structural anomalies; (2) if the classification decision rules developed by Gonçalves (2009) allow to obtain high values of accuracy when applied to other case studies; (3) if multispectral images can be an alternative to the traditional manual methods to extract ancillary information to monitor the state of conservation of building roofs. To assess the potential of this type of images, several buildings in the historical centre of Leiria were selected. Multispectral aerial images of the years 2004 and 2010 were used, with a spatial resolution of 0.5 m, in four bands (blue, green, red and near-infrared).

For the automatic production of roofing materials maps and anomalies, a hybrid approach was used that combines pixels and objects, incorporating the information associated to the uncertainty at pixel level in the classification process at the object level. To extract the information at the pixel level the Bayes soft classifier (BAY) was used. The uncertainty of classification can arise due to confusion or difficulty of the classifier to assign, in the process of classification, a class to a pixel. The classification results of the roofing materials and the presence of anomalies, obtained in different years were compared using Geographic Information System (SIG) tools.

DATA SET AND CASE STUDY AREA

The study area is located in the historical center of Leiria city, with an area of approximately 0.40 km^2 and 671 buildings.

To verify the type of the existing roof materials and their state of degradation, multispectral aerial imagery with a spatial resolution of 0.5 m was used. The aerial images belong to the group of digital multispectral images of the Portuguese Geographic Institute (IGP), acquired with the 4 multispectral bands and were obtained in 2004 and in 2010, as shown in Figure 1.

Figure 1: Aerial image (RGB 321) of the study area: a) Typo-morphological groups of the historical centre of Leiria, overlaid on the image of 2010; b) Extract of the image of 2004; and c) Extract of the image of 2010.

Figure 2: Extract of the aerial image (RGB 321) overlapping with the cartographic information of the buildings

METHODS

The classification method has several stages. First an analysis of the image was made to identify the building's roofs materials existing in the case-study area and the presence of anomalies. The main roof materials in the study area are: dark ceramic roof tile, bright ceramic roof tile, fibrocement corrugated roof sheet, zinc roof panel, steel roof panel, concrete roof tile and roof shadow. Since the ceramic roof tile is the most representative material of roofs the study focuses only in the identification of ceramic tile roof with and without pathologies. This first analysis was important to define the nomenclature. The subsequent step was the choice of the set of samples to train and evaluate the classifiers. A hundred samples (pixels) per class were selected, half were used for training and half for testing. Since this is a study to identify the changes occurred in building's roof materials and pathologies between 2004 and 2010, it would be advisable to choose, in both images, samples with the same location. However, due to the different sun exposure existing at the time the aerial photographs were taken, there was a need to consider samples in different locations for each year.

To evaluate the quality of the training samples set, selected for each class, the spectral separability analysis was performed using scatter diagrams. This method allows, on the basis of the sample set, to recognize the classes with similar spectral signature. The quality of spectral separability between the classes is directly related to the quality of classification and the less ambiguity of the classifier in assigning a single class to the pixel. The choice of the training samples is an iterative process, assisted by spectral analysis. After obtaining satisfactory results the images classification was then carried out. The behavior of the classifiers was analyzed with the test samples, checking which of them got the best results.

The methodology developed involved a classification on two levels: the first, at pixel level, to extract the information of the types of materials (RM) and anomalies (RA), and the second, at the level of the building (object), to obtain the Map of building's roofs ceramic material (MBC) and the map of their anomalies (MBA). Since we intended to create a map for identify changes that occurred between 2004 and 2010, four maps were obtained: the MBC and the MBA for the year 2004, and the MBM and the MBA for the year 2010.

The nomenclature used to for the RM was dark ceramic roof tile (TC-D), bright ceramic roof tile (TC-B), fibrocement corrugated roof sheet (F), zinc roof panel (Z), steel roof panel (S), concrete roof tile (C) and roof shadow (S), and for the RA was ceramic roof tile with anomalies (TC-A), ceramic roof tile non deteriorated (TC-ND) and ceramic roof tile with shadow (TC-S).

In the classification of the images at the pixel level, a soft classifier was used, the Bayes' classifier (BAY). The process of extracting information using this type of data requires the classification of the images in a set of classes, selected according to the characteristics and the resolution of the images, and the purpose of the map. However, the application of different classifiers can provide different results. In the study of the anomalies of the façades, performed by Valença et al. (2011), using this classifier, the authors obtained good results.

Finally, the analysis of the accuracy of the classification is obtained using two sampling protocols. One consisted on a stratified random sample, in which the strata were the classes, and the second one consisted on a selection of samples where the strata were the certainty level of the classification obtained with each of the decision rules.

In the first sample protocol a stratified random sample of 50 samples per class were selected, considering the building as a unit sample. In the second protocol the selected samples were the buildings classified with less certainty with each decision rule (Table 1). The first rule was used to identify buildings with ceramic roof tile through the calculation of the percentage of pixels classified as ceramic roof tile in its interior. Therefore, in the calculation of certainty is only used the percentage of pixels classified as ceramic roof tile inside the buildings.

The classification at the building level, to obtain the MBC and the MBA, is carried out based on the arrangement of pixels inside the buildings and on the uncertainty of the pixel classification. For this classification ancillary information in vector format was used that was converted to raster format, to obtain a map of buildings in that format. This map served as a mask in order to use only the information of the RM, RA and their uncertainty, inside the buildings. Summarizing the MBC was obtained through the application of rules that incorporate the information on the membership grades assigned to the several classes at each pixel in the previous soft pixel based classifications and the degree of uncertainty associated with these assignments.

The uncertainty information of the classification was obtained using an indicator of the classification uncertainty given by:

$$RI = \frac{\max\limits_{i=1,\dots n}(p_i) - \frac{\sum_{i=1}^{n} p_i}{n}}{1 - \frac{1}{\eta}}$$

where (i=1,…,n) are the probabilities associated with the several classes and n is the number of classes under consideration. This indicator assumes values in the interval [0,1] and only depends on: the maximum probability; the sum of all probabilities assigned to the class; and the total number of classes. RI evaluates up to which point the classification is dispersed over more than one class and the degree of compatibility with the most probable class, providing information regarding the classifier difficulty in assigning only one class to each pixel.

To obtain the MBC, the classes: “Buildings with Ceramic Roof Tile” (B-C) and "Buildings without Ceramic Roof Tile” (B-NC) were used. The set of rules 1 to 3 aimed to distinguish the “Buildings with Ceramic Roof Tile” (B-C) from the “Buildings without Ceramic Roof Tile“ (B-NC). To obtain the MBA, it was necessary to first acquire a map of ceramic roofs tiles (MBC), to assure that only ceramic tile roofing with or without anomalies would be classified. The classes used to obtain the MBA were: “Buildings with Ceramic Roof Tile with Anomalies" (B-C-A) and "Buildings with Ceramic Roof Tile not deteriorated" (B-C-ND), considering the latter as in good state of conservation. The rules 4 to 6 assign the buildings with Ceramic Roof Tile" (B-C) to one of two classes: “Buildings with Ceramic Roof Tile with Anomalies" (B-C-A) and “Buildings with Ceramic Roof Tile not deteriorated” (B-C-ND). Table 1 presents the classification rules.

Table 1 : Rules to obtain MBC and MBA.

Nº	Rules	If true	If false
1	If more than 50% of the pixels of the RM, inside the buildings, were classified as "Ceramic Roof Tile" with uncertainty less than 0.25.	Assign Class B-C	Apply Rule 2
2	If the percentage of pixels of the RM, inside the buildings, classified as "Ceramic Roof Tile" with an uncertainty of less than 0.25, is higher than the percentage of pixels classified either as: "Zinc Roof Panel"; " Fibrocement Corrugated Roof Sheet "; " Steel Roof Panel "; "Concrete Roof Tile"; " Roof Shadow ".	Assign Class B-C	Apply Rule 3
3	If the percentage of pixels of the RM, inside the buildings, classified as: "Zinc Roof Panel"; " Fibrocement Corrugated Roof Sheet "; " Steel Roof Panel "; "Concrete roof Tile" is less than 50% and if the percentage of pixels classified as “Roof Shadow” is higher than 10% or if the percentage of pixels classified as “Ceramic Roof Tile” is higher than 25%.	Assign Class B-C	Assign Class B-ND
4	If more than 50% of the pixels of the RA, inside the buildings are classified as “Buildings with Ceramic Roof Tile” and are “Buildings with Ceramic Roof Tile with Anomalies” with uncertainty less than 0.25.	Assign Class B-C-A	Apply Rule 5
5	If the percentage of pixels of the RA classified as “Ceramic roof tile with anomaly”, inside the buildings classified as “buildings with ceramic roof tile” is higher than the percentage of “ceramic roof tile without anomaly” and higher than the percentage of “roof shadow”.	Assign Class B-C-A	Assign Class Rule 6
6	If the percentage of pixels of the RA classified as “Ceramic roof Tile with Anomaly”, inside the buildings classified as “Buildings with Ceramic Roof Tile” is higher than the percentage of “Ceramic Roof Tile without Anomaly” and the percentage of “Roof Shadow” is higher than 50%.	Assign Class B-C-A	Assign Class B-C-ND

To conclude, after getting the MBC and the MBA, the final maps obtained for the different dates were compared using Geographic Information System (SIG) tools, producing a map of changes.

Summarizing the methodology applied to aerial images for the study of change detection, consisted of the following steps: 1) definition of the nomenclature; 2) selection of the training sample set for the years 2004 and 2010; 3) supervised classification using the classifier BAY to obtain RM, RA and the uncertainty of both classifications at the pixel level ; 4) evaluation of the accuracy of the classification; 5) classification at the building level to obtain the MBC and MBA for the years 2004 and 2010; 6) comparison of MBC and MBA obtained for the years 2004 and 2010; assessing the evolution of pathologies in this time frame.

RESULTS AND DISCUSSION

The accuracy evaluation of the MBC obtained with the stratified random samples set, presented a Global Accuracy (GA) value of 93%, and with the selected samples taking into account the degree of certainty, the GA was 72%.

When comparing the accuracy of the user and producer for both sampling protocols (Figure 3), it is evidenced that the class of non-ceramic roof tile (B-NC), presents accuracy values for the producer higher than for the user, which means that, despite the correct identification of the non-ceramic roofs existing in the study area and the reduced number of omission errors, there are ceramic tile roofs according to the reference data that were misclassified as non-ceramic tile, originating commission errors.

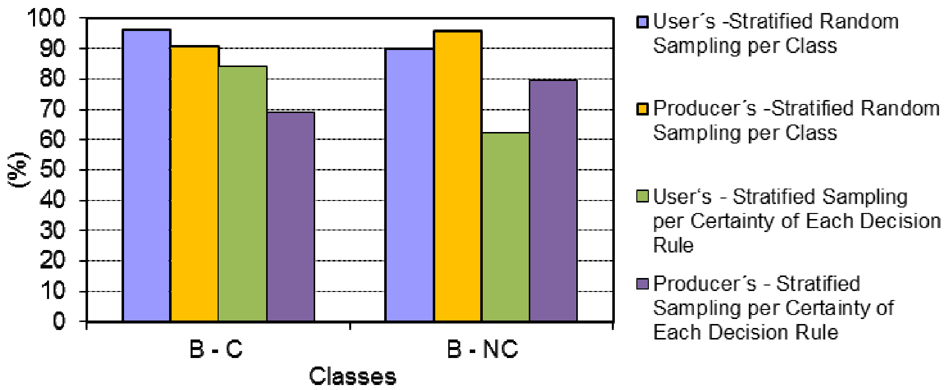

Figure 3: Graph showing the level of user' accuracy (UA) and producer´s accuracy (PA) to assess the thematic accuracy of MBC, with stratified random samples and with samples taking into account the certainty of classification, for Building with ceramic roof tiles (B-C) and Building with non-ceramic roof tiles (B-NC).

The assessment of the thematic accuracy of the MBA with stratified random samples presented a GA value of 91%, while from samples taking into account the degree of certainty the GA value was 88%.

The comparison of the accuracy of the user and producer of the MBA, shown in Figure 4, for both samples, evidences that the class of buildings with ceramic tile coverage with anomalies (B-C-A), presents higher producer accuracy values than the accuracy of the user. This means that, although the ceramic tiles roofing with anomalies were properly identified, there are rooftops without anomalies that were classified initially as having anomalies. The low values of accuracy of the producer and user of the class of buildings with ceramic tile coverage not deteriorate (B-C-ND), are affected by the small size of the samples. For ceramic tile roofing with anomalies 50 samples were selected while only 7 samples were available for ceramic tile roofing without anomalies, resulting in a disproportional comparison.

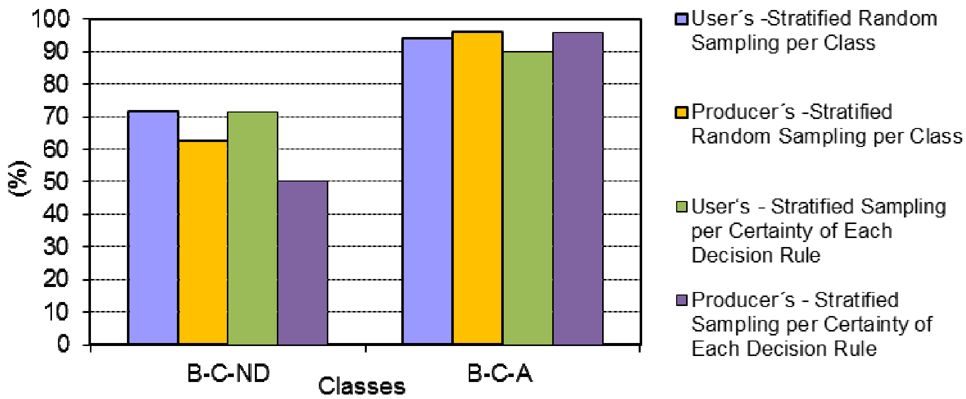

Figure 4: Graph showing the level of accuracy of user' accuracy (UA) and producer´s accuracy (PA) to assess the thematic accuracy of MBA with stratified random samples and with samples taking into account the certainty of classification of building ceramic roof tile not deteriorated (B-C-ND) and with anomalies (B-C-A).

The results obtained with the multispectral image of the year 2004 show that 601 covers (90%) were identified as having ceramic tile coating and for the image of the year 2010, 582 covers (87%) were identified, which corresponds to a decrease of 13%. Figure 5 shows the MBC for the years 2004 and 2010.

Figure 5: Maps of the types of roofs: a) 2004 and b) 2010.

From the MBA information produced automatically, it was found that, building roofs with ceramic tile, for the year 2004, 537 (89%) were classified as ceramic tile with anomalies and 575 for the year 2010 (99%). Comparing the anomalies in the building roofs also classified as ceramic tile for the years 2004 and 2010, it was found that there were 4 rooftops classified as having anomalies in 2004 and in 2010 these roofs were classified as having no anomalies. This is due to incorrect classification or rehabilitation operations. The problems in the classification result from the high presence of shadow areas and different sun exposure in the multispectral image of 2004. In 2010 it was verified the existence of 58 roofs classified as having anomalies, while in 2004 they were classified as having no anomalies, which confirms the occurrence of anomalies over time and the scarce requalification activities in this study area.

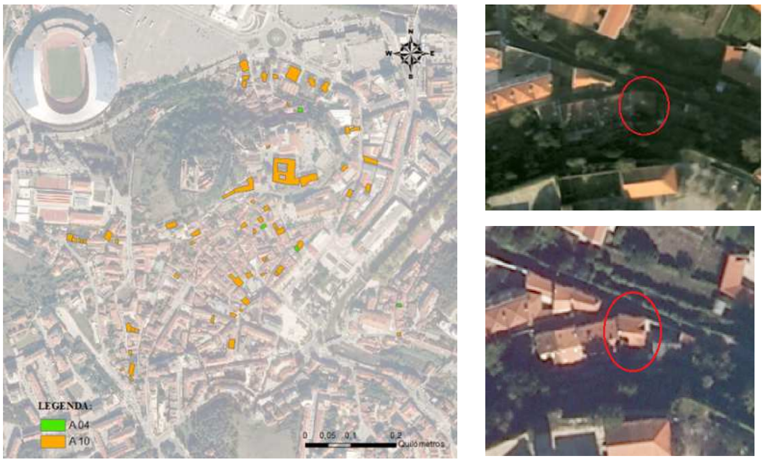

Figure 6: Aerial images (RGB 321): a) Differences in the classifications of anomalies for the years 2004 (A 04) and 2010 (A 10); b) Extract of the multispectral image of 2004 in which the coating was classified as having anomaly due to the presence of shade and sun exposure; and c) Extract of the multispectral image of 2010 in which the roofs were classified as having no anomaly

CONCLUSIONS

The results obtained show that the use of multispectral images to extract ancillary information to assess the state of conservation of the building roofs is advantageous. It is possible to retrieve information about the existence of anomalies and different types of roof materials, with high accuracy.

The use of multispectral images from different years is advantageous because it allows the assessment of the evolution of anomalies and changes occurred in building roofs, such as changes in the type of coating and the existence of rehabilitation activities.

The multispectral aerial images with 0.5 m spatial resolution, allowed the detection the different types of roof materials however only the identification of the roofs with anomalies is enable and do not allow the identification of the different types. In the future, the increasing technological innovation and the use of images with a higher spatial resolution, or hyperspectral images, may provide a way to distinguish the different types of roof anomalies.

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