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Spectral modelling used to identify the aggregates index of asphalted surfaces and sensitivity analysis

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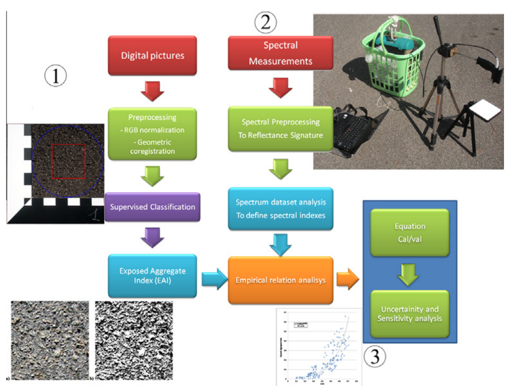
HIGHLIGHTS

- Definition of Exposed Aggregate Index (EAI) by classification of pictures.
- Investigation asphalt's spectral characteristics.
- Empirical relation among spectral and pictures data was obtained.
- Results allowed to test robustness of equation for retrieval of EAI.

GRAPHICAL ABSTRACT



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ABSTRACT

This article focuses on the spectral variability of asphalt compared with its surface characteristics, in particular, with the amount of exposed aggregate. Any uncertainties in the chemical or physical composition of the asphalt or in its alteration status may cause erroneous results. Improved understanding of the spectral properties of asphalt can be used to optimise road network management policies. Pavement aging and degradation detection is one of the primary issues in infrastructure management faced by local authorities in the area of safety standards. In this study, various asphalt samples from Central Italy are characterised by digital RGB photos combined with their spectral signatures. Because the spectral response is influenced by the presence of exposed aggregate and bitumen, it is crucial to define an objective index that could indicate either their presence or absence. Using the Exposed Aggregates Index (EAI) method on each photo, the aggregates surface occupation is determined by the supervised classification of the RGB photo dataset using the parallelepiped method. The result is then compared with a spectral response of the target. Using this process, a series of new spectral indices is identified in a range of wavelengths from 400 to 900 nm that show statistical correlation and physical significance to changes in bitumen and exposed aggregates. In particular, the first derivative of the spectrum at 400 nm and the reflectance values at 460, 490, 740 and 830 nm are very sensitive to changes in the EAI. An empirical relation for the exposed aggregates is found during the calibration step for any of the relations between the spectral index and the EAI. This relation is linked to the degradation of the targets with an RMSE of 0.09. The final phase of the work focuses on uncertainty and sensitivity analyses of the model, demonstrating the robustness of the equation identified for the relation.

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1. Introduction

Because of recent advancements in imaging spectrometry, physical and chemical properties of materials at very detailed levels can now be detected. There is evidence that road properties such as aging and material composition can affect spectral characteristics; however, the relation between the reflectance and the specific road surface quality has yet to be determined.

The use of spectroradiometric data to characterise aggregates and bituminous mixtures can help improve the analysis to discriminate different types of man-made surfaces, such as paved areas. Generally, in the range of wavelengths between 350 and 2500 nm, the radiometric response of currently used asphalts is dominated by bitumen, which absorbs most of the incident solar radiation. The composition and dimensions of the aggregates have only a marginal influence on the spectral behaviour; because of the degradation processes over time, the asphalt surfaces lose bitumen, thus increase in reflectance [1,2]. Oxidation processes and exposure of the rocky components modify the spectral signature of the new asphalt, as exhibited by the appearance of the iron oxide absorption peaks at 520, 670 and 870 nm, while the loss of the oily compounds is seen in the disappearance of the characteristic peaks of the hydrocarbons [3,4]. The absorption of hydrocarbons, particularly evident in new asphalts, is seen at 1750 nm and after 2100 nm, with a significant doublet at 2310 and 2350 nm [5,6]. In addition, in old asphalts, the spectral signature presents a significant change of slope between 2100–2200 nm and 2250–2300 nm, from the influence of silicate minerals outcropping and hydrocarbons [7]. Simultaneously, in the VIS region, bitumen loss causes a slope change [8].

Currently, most spectroradiometric studies are focused on new road pavement management systems, to identify relations between spectral data and paved surface quality conditions. The analyses of multi- and hyper-spectral remotely sensed imagery enable the discrimination of road networks and the evaluation of the weathering of asphalt surfaces using spectral indices [9,4,10]. The spectral difference between 490 and 830 nm was used by [5], who correlated the pavement condition index (PCI) and the spectral data with an R-squared of 0.63. Additionally, [11] used this difference to evaluate paved area conditions. Wavelengths at 490 nm and at 830 nm are sensitive to iron oxide absorption. The spectral difference between both bands emphasises the spectral contrast between new and aged roads, and increases the change of spectral shape in the VIS. The first-order derivative was used by [2] to distinguish 4 types of asphalt surfaces. Based on the slope change in the VIS region for new to oldest paved areas, 400 nm and 700 nm were used to categorise asphalt during laboratory measurements [11].

Viewing the effects of the presence of hydrocarbons on the spectral signatures of asphalts, there is a need to develop a method to evaluate the bitumen content in asphalt surfaces. In [8], the percentage of bitumen covering the aggregates was evaluated in the field using the geologic classification of Shvetsov [12]. Digital photos were used for descriptive data validation.

Pictures taken using digital cameras are treated in different ways for different purposes. Statistical analysis of RGB values for snow cover monitoring [13], supervised classifications for automatic agriculture inspection [14], and statistics computation of achromatic and chromatic spatial patterns of colour images for indexing and content-based retrieval [15] are some examples. Elaboration techniques performed using cameras could represent the real added value to environmental monitoring when combined with remotely sensed data. Digital photos then become a useful tool at the local scale providing statistical analysis of RGB values for component quantification in the pictures.

In this study, an image classification of calibrated RGB digital photos was initially performed to evaluate the Exposed Aggregates Index (EAI). To develop an equation for the relation with spectroradiometric data, different spectral indices were computed. Based on the results, a sensitivity analysis of the equation was performed. The purpose of this research is to increase the knowledge of how the variation of the surface characteristics of asphalt may affect spectral measurements. This paper is organised as follows. First an overview of the technique to identify the physical index is presented, followed by a discussion of the experimental results. Then, the cal/val analysis and the sensitivity analysis is presented.

2. Data and methods

2.1. Data description and processing

This study focused on spectral signatures combined with digital photos of asphalted roads in Central Italy during the summers of 2010 and 2011. The dataset used in this work includes 230 targets at different states of degradation, with the possible presence of oils, grass and sand resulting from decay. The sampling method was based on the acquisition of 4/5 points per site, whose area was 81 m^2, to describe the local conditions of the asphalt. The study areas were all parking lots beside motorways and malls.

The processing scheme used in this research is shown in Fig. 1. Work activities were based on the identification of the EAI and the spectral index to determine their empirical relation. Digital photos were processed to obtain a geometric and colourimetric co-registration, and spectral measurements were converted to reflectance to obtain the spectral signature of each target. Then, the statistical information for each wavelength was used to analyse the spectral variability. A regression analysis, based on different spectral indices, provided a series of equations; subsequently, the indices whose regression models had the highest Bravais–Pearson correlation indices and R-squared values were chosen to perform the calibration/validation step, uncertainty analysis and sensitivity analysis.

2.2. Picture data and exposure aggregate index (EAI)

Asphalt surfaces lose bitumen from traffic and weather wear, resulting in increased reflectance and the appearance of absorption peaks related to the mineralogical characteristics of the outcropping aggregate fragments. In these conditions, paved surfaces react similarly to colourimetric changes. This observation is in agreement with [3], who found that the overall colour of paved areas is correlated with the removal of bitumen covering the granules.

Recently, photos captured by digital cameras became a useful tool on the local scale, providing statistical analyses of RGB values to quantify objects such as snow cover extension [13,16] or, using minimum distance (MD) and maximum likelihood (ML) classifications, for automatic visual inspection of seed maize [14].

This study focused on the opportunity to extrapolate, in a more rapid process, a quantitative value to describe changes of surface pavement conditions using the determination of the grey scale values of RGB pictures. Bright colours are assigned to old asphalt with lower levels of bitumen and dark colours to newer asphalt. To assess a quantitative value of surface bitumen presence or aggregate exposition, a digital picture was taken of each asphalt using a Nikon Coolpix S560. This compact camera is assembled with a 1/2.3″ sensor CCD (approximately 10.7 million pixels) and a 35 mm lens. To obtain more accurate data for subsequent analyses and data calibration, a 40 cm × 40 cm reference ruler was fabricated. The reference ruler consists of 5 cm white and black stripes, which were also used as a dimensional scale for image pre-processing. If the pictures were taken in different lighting conditions, the white stripes on the ruler were used as a reference for manual normalisation in the field. The camera was fixed on a tripod, looking at the ground target vertically, which was 68 cm from the camera. This geometrical setup was chosen in consideration of the ruler's external dimensions and the Fieldspec field of view (FOV) to produce a picture area representative of each spectral signature. Maintaining a constant shooting distance from the targets helped to standardise the photo acquisition and to facilitate the pre-processing. The pictures were pre-processed and classified to obtain a physical index of aggregate exposition to relate to spectral signatures. To find this index, the RGB values of the aggregates, bitumen and shadows were first measured separately because they were the main elements present in the photos. This was used to define the non-parametric thresholds of the RGB feature space. From this analysis, the supervised classification was implemented to classify the presence of aggregates in the area of interest (AOI). The Exposed Aggregate Index (EAI) was then obtained by the ratio of the amount of total aggregate classified pixels to the total AOI (Eq. (1)) as follows:

$$\mathrm{EAI} = \frac{Ip}{Tp} \tag{1}$$