International Journal of Applied Engineering Research ISSN 0973-4562 Volume 15, Number 10 (2020) pp. 990-995

Identifying Flexible Pavement Distresses Using Spectro Radiometry Classification on Worldview 3 Images

Indira Pachón-Cendales MSc

Sustainable Pavement and Materials Research Center. Universidad Distrital Francisco Jose de Caldas. Master in Geomatics - Bogotá Colombia.

Alexander Ariza-Pastrana PhD

Adjuntc Professor Master in Remote Sensing, Universidad Católica de Manizales Colombia.

Wilmar Fernández-Gómez PhD.

Director of Sustainable Pavement and Materials Research Center. Universidad Distrital Francisco Jose de Caldas. Faculty of Environmental and Natural Resources - Bogotá Colombia.

Abstract

Road agencies need information about pavement conditions to make decisions on road networks. In most cases, road management systems have three decision-making levels, known as strategic, network, and project. This article presents a methodology to assess pavement conditions on flexible structures at the network level with higher performances than the conventional PCI (Pavement Condition Index) technique. Data of multispectral image from WorldView – 3 satellite was used for a study area located in a section in an urban Bogotá highway. Field spectral information of the different deterioration conditions was acquired using a FieldSpect 4ADS (Analytical Spectral Devices, Inc.) spectroradiometer. The image classification was performed using the SAM (spectral Angle Mapper) pixel oriented spectral classification algorithm. As a result, the overall classification accuracy was 85%, and the value of the Kappa statistic index was 70%. The methodology proposed allows estimating the pavement state with a reasonable degree of fit between the predicted and actual classes to a road network level.

Keywords: Pavement deterioration, flexible pavement, WorldView - 3, SAM (Spectral Angle Mapper), Bogotá

Cite this Article: Pachón-Cendales I, Ariza-Pastrana A, Fernández-Gómez W. Identifying flexible pavement condition using Spectro radiometry classification on worldview 3 images.

1. INTRODUCTION

The road system of a country represents an asset of great value; this is due to the significant investment that it implies over time to build and maintain it, which is why road maintenance programs represent a factor in the valuation of this physical capital [1]. In Bogotá, Colombia, a city of 7.2 million people and 15,000 km/lane of urban roads, the Urban Development Institute (IDU) and the Road Maintenance Unit (UMV) are responsible for building maintaining the cities roads. According to the latest official statistics, 36% of the cities roads are in good condition, 19% are in fair condition, and 45% are in poor condition.

The techniques currently used by highway agencies to determine the deterioration of the pavement involve different methods such as the Pavement Condition Index (PCI), the Modified Distress Ratio (MDR), the Critical condition Index (CCI), among others. The IDU and the UMV use the PCI to determine the road condition surface state in Bogotá [2]. This method evaluates flexible pavements surface condition through visual inspection forms filled out by specialized technical personnel. Although the method is highly reliable and precise due to the evaluation carried out by observing directly on the road, there are some disadvantages. First of all, it is related to the data capture time; there are delays caused by vehicle circulation and the considerable extensions to be evaluated. The method is also sensitive to the technician's expertise, which implies that the evaluation is subjective, causing a lack of reliability in the results and, therefore, errors in its interpretation, distorting the final result. Also, there are disadvantages due to the large volumes of information obtained, delays in processing results, and incomparable data [3].

Despite the experience and support on determining the pavement condition with this method, pavements engineers seek a tool that allows performing in an agile, automated, and objective way. The condition survey is necessary to carry out effective maintenance planning since a surface in poor condition affects transportation operating costs related to the consumption of fuels, lubricants, tires, repair and spare parts, depreciation, insurance, and transportation time the goods and people. Therefore, during the service life of a pavement structure, its surface condition, serviceability, structural capacity, and safety must be periodically evaluated [2]

In the last decade, there have been several studies of the potential of the techniques used in remote sensing to evaluate the condition of the pavement [4-8], where the work carried out through field Spectro radiometry techniques is highlighted. This technique has been used to obtain information on the earth's surface by analyzing spectral reflectance, measured as the ratio of reflected light to incident light from different material compositions. Accordingly, studies carried out with the field, and laboratory Spectro radiometry has shown that asphalt aging and deterioration show measurable changes in the spectra of each of the surfaces evaluated [7, 9, 10].

Spectrometry offers many benefits to remote sensing studies, given that these sensors use a larger number of samples of spectral bands, and it is possible to distinguish objects from others in terms of their reflectance curves. Each object or feature has a different spectral curve due to its physical and chemical characteristics [11]. With the use of Spectro radiometry, studies have been carried out to extract information about urban textures and surface materials [6], [12] - [14]. In hyperspectral and multispectral images combined with spectrometry techniques, it had been possible to map road surface conditions using these technologies. According to Kavzoglu et al., [11], the most efficient band for classification in multispectral images in aging is the near-infrared band.

In this sense, an alternative to achieve the aging condition evaluation in flexible pavements is through the classification and interpretation of multispectral images, since the analysis of pavement surface images can speed up the process and reduce the subjectivity of the results. In this study, an investigation is intended to understand the spectral behavior of asphalt in use and discover the feasibility of using widely available multispectral satellite sensors in determining road surface conditions.

Figure 1. Segment Road location in Bogota (red polygon)

Source: DigitalGlobe®, Satellite Image WorldView-3, RGB (321) Bogotá, date January 15 2015.

2. DATA AND METHODS

The study was applied in a section located in one of the main urban roads of Bogotá. This road is made up of 4 roadways, two in each direction of traffic (E-W and W-E.); each roadway has two traffic lanes of 3 meters wide, presents average daily traffic (TPD) of 2788 of trucks and buses [5]. This section was selected due to the variability of the PCI pavement condition index (Pavement Condition Index) in this area (Good, Bad, Fair).

The WorldView-3 sensor has eight multispectral bands ranging from 400 - 450 nm for Coastal Blue, Red: 630 - 690 nm, Blue: 450 - 510 nm, Spectral band on the edge of red: 705 - 745 nm, Green: 510 - 580 nm, Near IR 1: 770 - 895 nm, Yellow: 585 - 625 nm and Near IR 2: 860 - 1040 nm. The sensor spatial resolution of 2 m is adequate for mapping these types of urban features. The spectral characterization curves of the condition of the pavement features were acquired with an ASD spectroradiometer model FieldSpec 4 Standard-Res Spectroradiometer. This instrument captures wavelengths between 350-2500 nm, with a separation in the electromagnetic spectrum of 3 nm at 700 nm and 10 nm at 1400/2100 nm. For each reading, the instrument was calibrated with a spectralon, for these ten measurements were taken per sample at 2 meters height to avoid any bias or instrumental error. Field spectroradiometer data is widely used and considered to provide high-quality spectral measurements. The processing of spectral signatures (curves) was performed using the SAMS® software (Spectral Analysis and Management System) from the University of California, Davis, with absorption and reflectance analysis. Homogeneous samples of each group were selected to construct the representative spectral profile of each of the deterioration levels studied.

All objects and features were documented and integrated into a spectral library. The spectral library contains the different representative analysis units of the deterioration conditions in flexible pavements such as gravel segregation, raveled pavement, new pavement, and some types of pavement deformation and fatigue failures such as longitudinal and transverse cracks, fatigue cracking, and potholes. The multispectral image used for the classification was previously prepared, making the geometric correction through an adjustment with a digital elevation model (DEM). Indeed, the atmospheric correction of the image was carried out using the ATCOR model implemented in PCI's Geomatics software. The digital processing method used in the image classification worked with ENVI 5.2® software.

3. RESULTS AND DISCUSSION

The aging of asphalt cement is considered a cause of the deterioration of flexible pavements, which is presented as detachment of the stone aggregate and specifically the wearing course (Barriga & Chávez, 2009). The asphalt cement found in the cracks undergoes the same process when exposed to the environment, resulting in larger cracks. The asphalt mat's aging is manifested on the surface through the following cracking patterns: longitudinal cracks, transverse cracks, cracked mesh cracks, crocodile skin, and flaking [15, 2]. The signals or spectral signatures obtained for each type of characteristic surface of the deterioration in flexible pavements present significant differences (See figure 2) to be easily distinguishable between them when they are classified in the multispectral images.

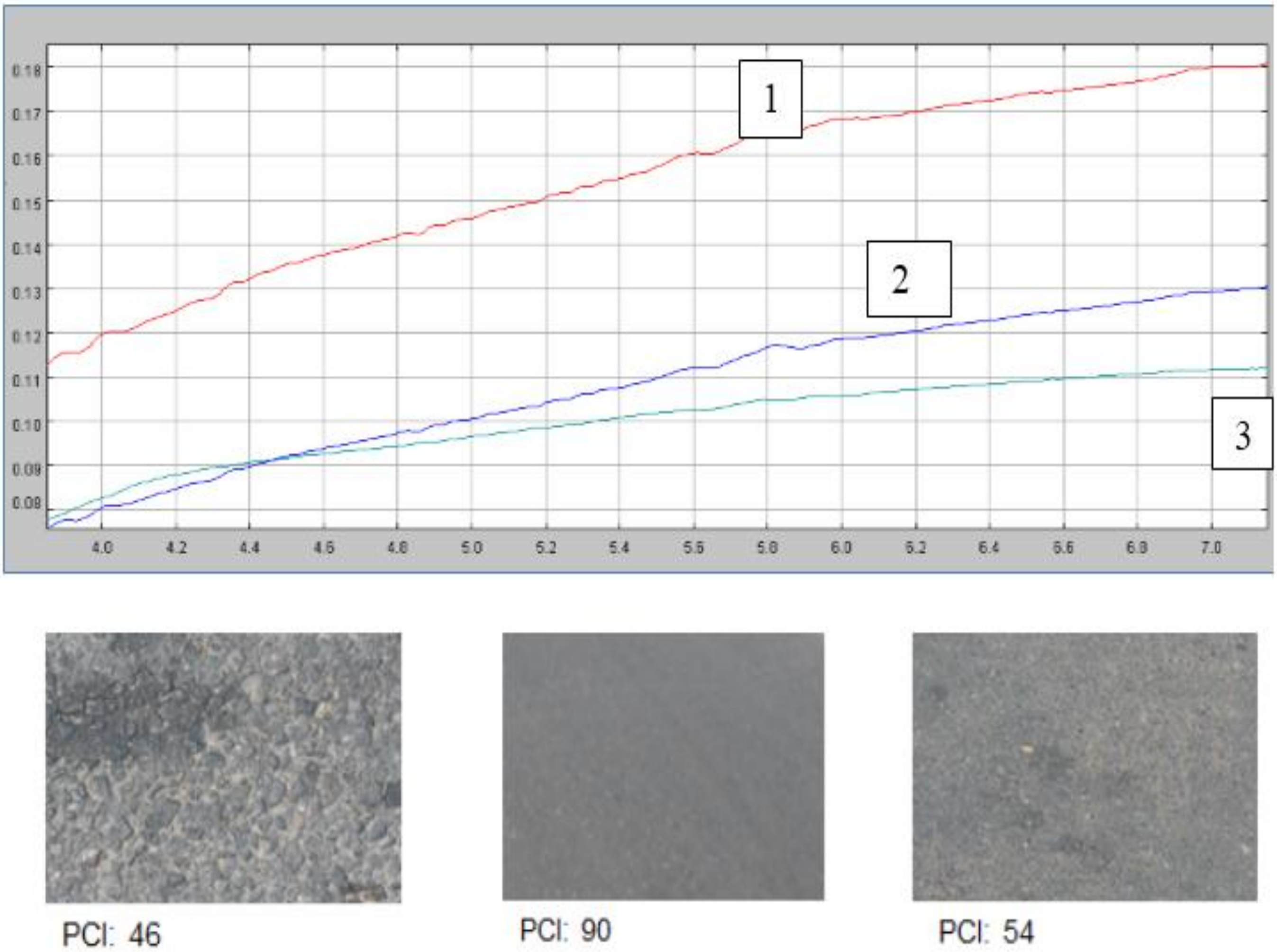

Figure 2 Spectral signatures (Up) y Pavement deterioration (Down) 1) Ravelling high severity 2) new pavement 3) Raveling low severity

Spectra 2 and 3 in Figure 2 are compared with a new pavement of an asphalt surface (2) and with a pavement that shows a slight loss of the asphalt layer (3) or aggregate outcrop (gravel). The crumbling exhibits a greater quantity of rocky components on the surface, which increases the gloss of the surface due to the increase in reflectance produced by the mineral component, presenting less prominent asphalt absorptions. Spectrum (1) reflects a gravel surface with more advanced deterioration. Compared to that of new pavement (2), this surface has higher reflectance in the visible and near-infrared due to the absence of absorption of asphalt hydrocarbons [7].

Analysis of image classified data

The multispectral image classification needs a spectral library with pavement distresses. Accordingly, because all earth elements have a unique spectral feature, either pavement in good condition (new), pavement with low severity raveling, or flexible pavement with high severity raveling have one as shown in figure 3.

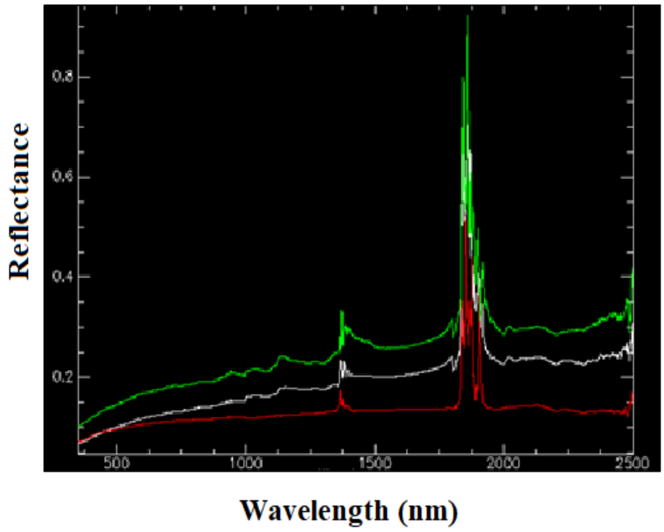

Figure 3: Pavement deterioration features spectral library. New pavement (white), Ravelling high severity (green) Ravelling low severity (red)

Figure 4 shows the classification obtained with the SAM algorithm after performing the training with the pavement deterioration spectral library. A total area of 8.94 hectares was classified, corresponding to 2.5 linear kilometers in evaluating the state of deterioration of the pavement at the road network level for four lanes. After running the classification several areas with the same features (distresses) were detected by comparing the image with spectral signatures (Table 3). Besides, in figure 4, we can also be observed how the algorithm discriminated the vegetation class (Trees and grass on the separator roadway) represented in black, shadows classified as new pavement can also be observed, as well as the classification of an area within this class that if it corresponds to new pavement.

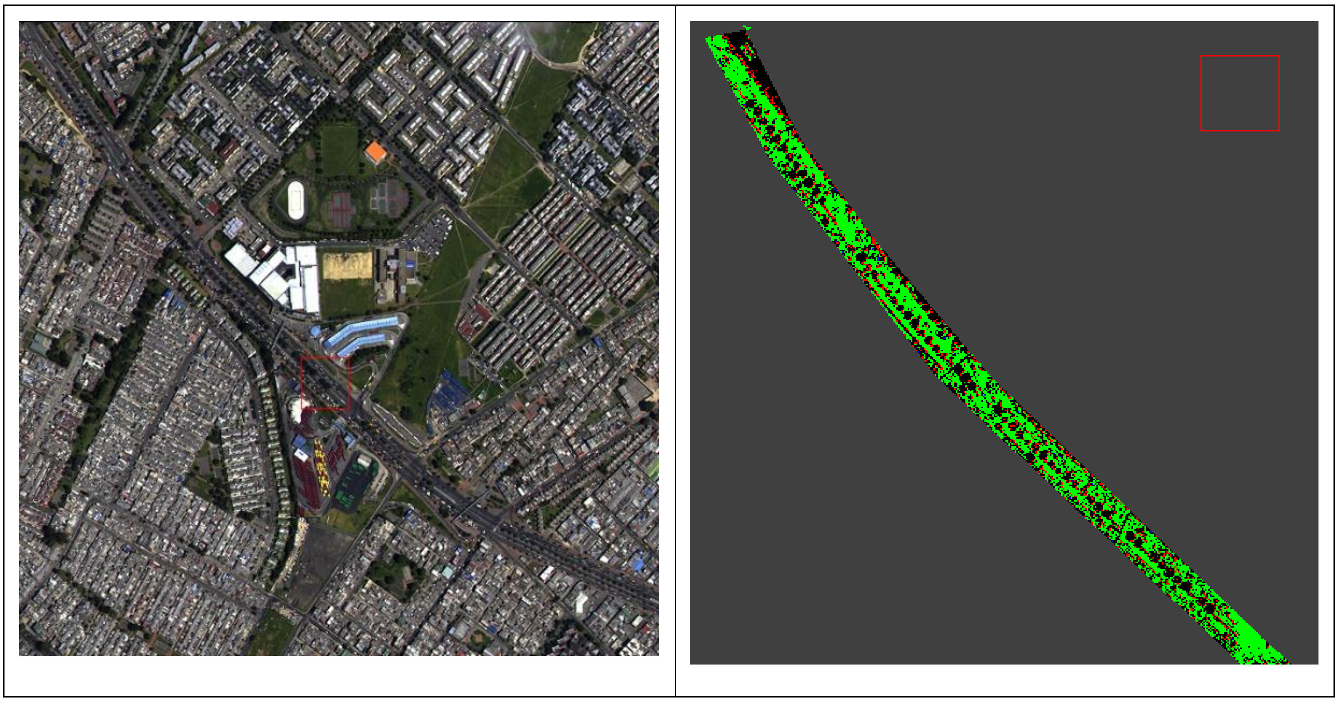

Figure 2: Pavement condition classification images. (a) Overall view (b) Classification results

A predominant class in green color was estimated, defined as the pavement with low severity raveling in a state of medium to regular deterioration, which corresponds to the PCI evaluation provided by the IDU in that estimated area. The blue color class (high severity raveling) was not predominant given that significant cracking damage was not located in the area; this may also be a consequence of the spatial resolution of the images

Finally, the red color class corresponding to new pavement appears regularly, but not because of the presence of a high% of new pavement coverage in the study area, but because the algorithm tends to classify the shadow areas of buildings, cars, and trees in this category, incurring a failure in the classification (See figure 5).

Table 1. Statistical results of SAM classification

Class	Color	Distress	Classification area (Ha)	PCI condition	Observation
1	Red	New pavement	0.8	Good	The pavement in good condition
2	Green	Raveling low severity	4.8	Regular	Low wearing
3	Blue	Raveling high severity	0.02	Poor	High wearing
0	Black	Other	3.32	No condition	Tres, shadows, cars, and other surfaces
		Total	8.94		

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 15, Number 10 (2020) pp. 990-995
© Research India Publications. http://www.ripublication.com

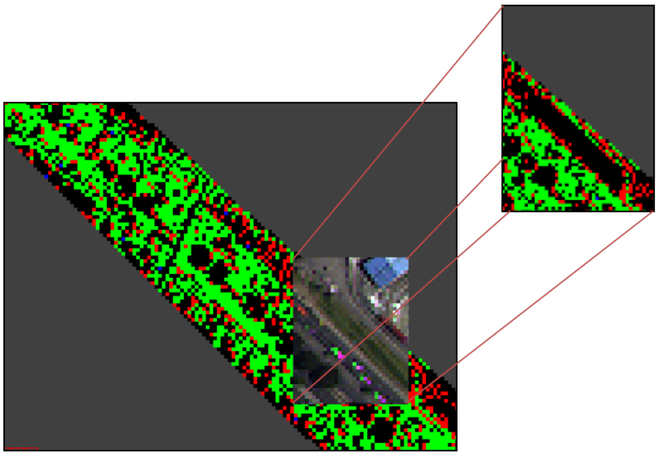

Figure 5. Zoom in of Classification results

Analysis and validation

The validation of the results was carried out through an error analysis using the overall reliability metrics such as the confusion matrix and the k index. In the validation process, we picked 33 samples in total, which have the same condition evaluated by PCI pavement method. The number of validation samples was selected according to the inspection carried out in the field. In Table 2, the confusion matrix is presented constructed through the sample counts, where the rows correspond to the classes of the map classified by SAM, and the columns to the reference classes evaluated in the field (PCI) appropriate to the reality of the road. Additionally, reliability measures corresponding to the user and producer exactitude estimated directly on the class counts. In general terms, the process got high accuracies.

Table 2. Confusion matrix and reliability indices

	Reference					
Class	**Good**	**Poor**	**Regular**	**Total**	**ACC User**	**Error**
Good	5	0	3	8	0,63	0,38
Poor	0	3	1	4	0,75	0,25
Regular	0	1	20	21	0,95	0,05
Total	5	4	24	33		
ACC Productor	1,00	0,75	0,83			
Error Omission	0,00	0,25	0,17			
Global Reliability 0.8485						
Kappa Index 0.6881						

In this regard, it can be seen from the matrix that the highest user ACC was associated with Regular coverage, with 95% of the classification accuracy. On the other hand, the highest ACC associated with the producer corresponds to Good with 100%. Concerning the overall ACC between user and producer, the producer's accuracy is higher than those obtained for the user in the entire classification. As regards errors of omission and commission, it is not clear whether a more significant number of coverages (Good and Bad) are evident; this means that the SAM classification coverages did not correspond to the same class in reality. Besides thematic ACC accuracy, it showed overall classification reliability of 85%; this means that ultimately, it can be assured, with 95% probability, that the map's overall accuracy is at 85% of the actual reliability achieved by the classification.

Kappa index indicates the difference between reality and the values read or extracted from the image (classified.). The Kappa statistic value obtained was 0.6881, corresponding to 70%, it reflects a good adjustment degree between classes obtained in the thematic evaluation compared with the predicted classes and the real classes, better than expected at random. This also indicates that the interest categories discrimination was significantly greater than those obtained in the random assignment; therefore, it presents good concordance.

4. CONCLUSION

The samples' spectral curves show the reflectance of the asphalt pavement components in different pavement distresses, thus obtaining significant deterioration differences in the spectral response; it is possible to detect asphalt pavement features ad categorize them in several classes. Those signatures allowed a spectral library creation and subsequent classification of the pavement condition in the study area,

In this work it was estimated the classification of the pavement aging using the definition of three thematic classes (Good, regular and bad) attributed to the state of deterioration of the asphalt pavement. In order to verify, it is possible to make a quick evaluation of the state of deterioration at the level of the road network using the application of the SAM algorithm, obtaining factual accuracies in the classification.

From the practical point of view, it was possible to observe that the methodology allowed estimating the state of the pavement with a 70% of the agreement at the level of the road network at a rate of 5 Ha in a methodological process that covered a total of 4 days between field and office activities, which implies higher yields compared to the yields obtained with the PCI methodology.

The accuracy of the process confirms that although the method depends on the accuracy of the data used, the classification's reliability allows the evaluation to be carried out at the network level, which facilitates the global economic assessment for decision-making at the level of project budget and programming. The validation process is easy to apply, allowing permanent quality control on the evaluation resulting from the methodology used.

ACKNOWLEDGEMENTS

The authors express many thanks to Procalculo Prosis S.A. for providing the multispectral WorldView-3 image to run the study. To ESRI Colombia to provide access to ENVI® 5.2 software.

REFERENCES

[1] Corporación Andina de Fomento, *Mantenimineto Víal. Informe Sectorial*. 2010.

[2] H. Rondón, W. Fernandez, and L. Fuentes, *Evaluación de Pavimentos Flexibles*. 2012.

[3] M. Corros, E. Urbáez, and G. Corredor, *Manual de Evaluación de Pavimentos*. Venezuela, 2009.

[4] V. Noronha, M. Herold, D. Roberts, and M. Gardner, “Spectrometry and Hyperspectral Remote Sensing for Road Centerline Extraction and Evaluation of Pavement Condition,” *National Consortium on Remote Sensing in transportation - Infraestructure Management*, 2002.

[5] M. Herold, D. Roberts, O. Smadi, and V. Noronha, “Road Condition Mapping With Hyperspectral Remote Sensing,” 2004.

[6] M. Herold and D. Roberts, “Spectral characteristics of asphalt road aging and deterioration: implications for remote-sensing applications,” *Appl. Opt.*, vol. 44, no. 20, pp. 4327–34, Jul. 2005.

[7] M. Herold, D. Roberts, V. Noronha, and O. Smadi, “Imaging Spectrometry and Asphalt Road Surveys,” *Transp. Res. Part C Emerg. Technol.*, vol. 16, no. 2, pp. 153–166, Apr. 2008.

[8] M. Resende, L. Bernucci, and J. Quintanilha, “Monitoring the condition of roads pavement surfaces: proposal of methodology using hyperspectral images,” *J. Transp. …*, vol. 8, pp. 201–220, 2014.

[9] M. Herold, “Spectral Characteristics of Asphalt Road Surfaces,” pp. 237–248, 2007.

[10] A. Mei, N. Fiore, R. Salvatori, A. D’Andrea, and M. Fontana, “Spectroradiometric Laboratory Measures on Asphalt Concrete: Preliminary Results,” *Procedia - Soc. Behav. Sci.*, vol. 53, pp. 514–523, Oct. 2012.

[11] T. Kavzoglu, Y. Sen, and M. Cetin, “Mapping Urban Road Infrastructure Using Remotely Sensed Images,” *Int. J. Remote Sens.*, vol. 30, no. 7, pp. 1759–1769, Apr. 2009.

[12] M. Herold, M. Gardner, and D. Roberts, “Spectral Resolution Requirements for Mapping Urban Areas,” vol. 41, no. 9, pp. 1907–1919, 2003.

[13] R. Salvatori, A. Mei, and R. Salzano, “Caratterizzazione spettrale di superficie asfaltate e realizzazione di una libreria di firme spettrali,” no. Bassi 1993, pp. 1697–1702, 2009.

[14] A. Mei and R. Salvatori, “URBAN MAPPING USING IKONOS IMAGERY,” *Int. J. Remote Sens. Geosci.*, vol. 2, no. 3, pp. 55–58, 2013.

[15] C. Barriga and L. Chávez, “Estado del Arte y Perspectiva del Envejecimiento de los Pavimentos Asfálticos,” vol. 19, no. 77, pp. 30–39, 2009.