

CYPRUS UNIVERSITY OF TECHNOLOGY  
DEPARTMENT OF CIVIL ENGINEERING AND GEOMATICS



## **Postgraduate Thesis**

STUDY OF ASPHALT PAVEMENT DETERIORATION THROUGH  
REMOTE SENSING

ANDREAS NIKOLAOU

Limassol 2016



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**APPROVAL FORM**

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Presented by

ANDREAS NIKOLAOU

Dissertation Supervisor: \_\_\_\_\_

Committee member: \_\_\_\_\_

Committee member: \_\_\_\_\_

Cyprus University of Technology

September 2016

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The approval of the thesis from the Department of Civil Engineering and Geomatics of the Cyprus University of Technology does not necessarily imply acceptance of the opinions of the author, on behalf of the Department.

I express the deepest gratitude to my supervisor Professors Diofantos Hajimitsis and Mr. Christodoulos Mettas for his persistent and kind support throughout the whole process of this dissertation, it would have been practically impossible to complete the project without him.

Afterwards, I would like to address special thanks to Demetriou and Nikolaou Construction and Development Ltd., Mr. Lakis Lazarou, Mr. Petros Andreou and Mr. Demetris Kouhartsiouk for being such a valuable source of information.

Finally, I would also like to express my thanks to my family especially to my parents George Nikolaou and Myrofora Socratous, friends and classmates who contributed in a special way and helped me all the way through with their consistent mental support and advises.

## **ABSTRACT**

Asphalt pavement surface is a very important parameter of the transportation infrastructure assessment. Due to the high cost of asphalt pavements and the hazard of the pavements that are in bad condition, many studies focused on how can asphalt road pavements be monitored and mapped and also identify the best remote sensing methods for the structural damages that were presented. When the deteriorations of asphalt pavements, such as potholes, cracks, raveling, rutting and others, which were caused from natural and physical conditions, are detected, the government authorities and road agencies can develop maintenance plans.

This study examines in depth different methods and techniques of remote sensing. Also, this study is based on research that will represent a large number of literature reviews from studies. Moreover, the deterioration of asphalt is explained in one of the following chapters.

Most of the authors emphasized on that most remote sensing techniques are cost effective and need much less time to be studied. Remote sensing methods can give continues observation and reduce risks and hazards as well.

The literature review was based on the methods of remote sensing that the researchers used, in order to detect the different methods of asphalt pavements. Furthermore, the results of this research study showed that the most used method is the spectral library and then the satellite sensors. In addition, most studies were made for the cracked area of asphalt and also for mapping the conditions of asphalted road pavements.

Finally, the results of this research study showed that the remote sensing methods are a useful tool for transportation infrastructure assessments, both, for monitoring the condition of asphalt pavement and detecting structural damages of asphalt.

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## ABBREVIATIONS

ANOVA:	Analysis of Variance
ASD:	Analytical Spectral Devices
ASTER:	Advanced Space-borne Thermal Emission and Reflection Radiometer
AVIRIS:	Airborne Visible/Infrared Spectrometer
CASI:	Compact Airborne Spectrographic Imager
DIP:	Digital Imaging Processing
EAI:	Exposed Aggregate Index
GPR:	Ground Penetrating Radar
HST:	HyperSpecTIR
LCAMS:	Low Cost Air Monitoring System
LiDAR:	Light Detection and Ranging
MCT:	Mercury Cadmium Telluride
MESMA:	Multiple End member Spectral Mixture Analysis
MIVIS:	Multispectral Infrared and Visible Imaging Spectrometer
NIR:	Near Infrared
nm:	nanometer
PCI:	Pavement Condition Index
REI:	Road Extraction Index
RGB:	Red, Green, Blue
TIR:	Thermal Infrared Region
UAV:	Unmanned Aerial Vehicles
UHI:	Urban Heat Island
μm:	Micrometer

## **Introduction**

This dissertation aims to evaluate the benefits of remote sensing technologies and methods which are being used, in order to identify and detect damages on asphalt pavements. In other words, remote sensing techniques can provide wide information to local authorities, for urban planning and environmental monitoring (Mei et al. 2014a). The detection of damaged asphalt pavements is the most important issue for the road agencies and government organizations in order to take decisions early and make maintenance plans (Mettas et al. 2015). In addition, the financial criteria of early detection of distresses are extremely important.

Furthermore, according to Schnebele et al., the transportation infrastructure is very expensive, is a labour intensive and time consuming process. Previously, the data were collected and taken in situ with visual examinations and interpretations. The evolution of the technology and remote sensing in general, give to professionals who deal with transportation assessments and asphalt pavements surfaces, tools that will not be needed in field surveys, the time required to complete a survey. Remote sensing methods and techniques can reduce the time and are considered to be the most cost effective methods.

In addition, nowadays, the usage of remote sensing methods, which are non-destructive techniques in the transportation assessment, is the tool which can provide an opportunity for frequent, comprehensive and quantitative surveys of transportation infrastructure (Schnebele et al. 2015).

Nowadays, there are cities that accommodate a large number of motorways and roads. This means that the number of cars is increasing by the day during the years and the circulation is getting higher. The main natural and anthropogenic factors of the deterioration of the asphalt pavement are the age of the asphalt, oxidation, temperature, traffic loads and water appeals structural problems such as raveling, cracks, potholes and other deteriorations (Pan et al. 2016). Also, advantages of the remote sensing usage can be identified as the chemical and physical

properties of the asphalt pavement materials and the composition and the age of asphalt surface (Manzo et al. 2014; Mei et al. 2012).

In Cyprus, due to the high temperatures and dry conditions in the summer periods and relative low temperatures in winter, sudden changes of the temperatures between day and night affects negatively the asphalts and creates natural hazards on the asphalt pavement surface. Also, distresses of asphalt pavement will be presented during rainfall, especially if there is intense rainfall in winter.

This paper is based on different methods that were used in previous studies. Firstly, it will analyse and present the different deteriorations which appear on the asphalt pavement surface and the causes of those distresses. According to Pavement Distress Identification Manual, the deteriorations of the asphalt pavement are divided into categories such as cracks, which could be many, rutting, potholes, ravelling, polishing, patches, blending, flushing and polishing.

Then, an extensive literature review of several assessments and journals that deal with remote sensing methods and also how they can detect the different deterioration problems of asphalt pavements will be mentioned. As it is referred in the title of this thesis, the purpose of this study is to examine the asphalt pavement deterioration through remote sensing methods.

# 1 Type of structural damages (distresses) of asphalt pavement

There are several types of distresses of asphalt pavements that occur during its lifetime. The weather conditions and traffic loads are factors that produce these distresses. This study will be analysing the types of distressed asphalt pavements and the reasons of the distresses.

## 1.1 Cracks

There are different types of cracks created on the asphalt pavements. Alligator cracking is type of crack that can be observed wherever in a road lane. It's a sequence of interconnected cracks of different stages of the development. Additionally, the alligator cracks expand into many sides, sharp-angled pieces and are more often observed to the longest side of the road lane (Miller, J. S., Rogers, R. B. and Rada 1993). This type of cracking occurs mainly to the roads with repeated traffic loads and is considered to be a parallel longitudinal crack due to the wheel path that expands with time and loads (Miller and Bellinger 2003).



Figure 1: Alligator cracking on asphalt pavement ([www.roadscience.net/node?page=2](http://www.roadscience.net/node?page=2)).

Block cracking is similar to alligator cracking although these types of cracks are divided into rectangular pieces which are usually classified as longitudinal and transverse cracking. The reasons of block cracking are the age of asphalt binder the poor mixture of the binder.



**Figure 2: Block cracking of asphalt pavement ([www.roadscience.net/node?page=2](http://www.roadscience.net/node?page=2)).**

Longitudinal crack is running parallel to the centreline of the road. This type of crack is a wheel path versus non-wheel path which means it could be spotted anywhere within the lane (Federal Highway Administration 2009). Moreover, it is linked with the beginning of an alligator cracking. Additionally, these types of cracks are discontinuous, broken and they appear in the wheel path (Stein and Wressell 1999). Additionally, the reasons that longitudinal cracks occur are basically the shrinkage of the asphalt layer, cracks from the below layers which reflect up through the pavement and poor joint construction or location (Miller, J. S., Rogers, R. B. and Rada 1993).



**Figure 3: Longitudinal cracks in the asphalt pavement ([www.roadscience.net/node?page=2](http://www.roadscience.net/node?page=2)).**

Transverse cracking is mainly perpendicular to the asphalt pavement centreline (Federal Highway Administration 2009). Also, transverse cracking can occur anywhere within the lane. The causes of transverse cracking are the paver blocks related to the incorrect set up, from the mixture of the asphalt, low temperatures and from cracks on the sub base of the pavement layers (Stein and Wressell 1999).



**Figure 4: Transverse cracking in the asphalt pavement ([www.roadscience.net/node?page=2](http://www.roadscience.net/node?page=2)).**



## 1.2 Potholes and Patching

A pothole is a bowl-shaped hole which sometimes is created in more than one layer of the asphalt pavement. In other words, the hole in the asphalt surface penetrates all the asphalt layers to the base course. Potholes usually occur on the surfaces of hot asphalt mixture road and they are about 25mm to 50mm. Also the minimum diameter of pothole is 150mm (Miller and Bellinger 2003). The main reason that causes the pothole is when the water gets into the cracks and destroys the area below the cracks causing a pothole (Miller, J. S., Rogers, R. B. and Rada 1993). In addition some other causes of potholes are the weak subgrade, poor mixture of surface and the traffic. These can accelerate the potholes (Asphalt Institute 2016).



Figure 5: A pothole on the asphalt pavement ([www.roadscience.net/node?page=2](http://www.roadscience.net/node?page=2)).

Patch/ Patch deterioration is the piece of asphalt pavement surface with area greater than  $0.1 \text{ m}^2$ , which has been removed and replaced or added material in the area of portion after the existing construction of asphalt pavement. The cause of deterioration of patches is the quality of asphalt mixture, poor construction and poor perimeter connection with the existing asphalt pavement. Also, may be appeal rutting settlement at the perimeter or in to the interior of the patch (Miller and Bellinger 2003).



Figure 6: Patch on the road pavement surface ([www.roadscience.net/node?page=2](http://www.roadscience.net/node?page=2)).

### 1.3 Surface deformation

Rutting is a depression of the longitudinal surface in the wheel path, which can lead to other types of cracks and deteriorations of asphalt pavements. Additionally, rutting is the deformation of the road surface and the lateral movement of the materials due to traffic loads which appear mostly at braking and stopping traffic areas (Federal Highway Administration 2009). Mix rutting and subgrade rutting are the main types of rutting. In addition, parameters that affect rutting are feeble mixture of asphalt, thickness of layers, destruction of the pavement layers from moisture and lack of compaction (Asphalt Institute 2016).



Figure 7: The two types of rutting, on left the wheel path rutting and on the right severe mix rutting ([www.roadscience.net/node?page=2](http://www.roadscience.net/node?page=2)).

## 1.4 Surface defects

Raveling is the loss of the aggregate particles and asphalt binder. Due to weathering and raveling the asphalt binder loses the bond with the aggregate (Miller, J. S., Rogers, R. B. and Rada 1993). The roadway loses its smooth surface (Stein and Wressell 1999). The poor mixture quality of asphalt, the traffic, the water and asphalt hardening due to the aging of the asphalt pavements are the reasons of the raveling (Asphalt Institute 2016). Due to the high temperatures especially in the summer, the UV rays destroy this binder between them and cause the raveling on the surface.



**Figure 8: Raveling on the asphalt pavement ([www.roadscience.net/node?page=2](http://www.roadscience.net/node?page=2)).**

Blending and flushing are the results of the loss of surface texture on the asphalt pavement because of excess asphalt. Also, it is a shiny pavement surface due to the hot temperatures which is known as the reflective surface. Bleeding reduce the friction of the asphalt pavement and is therefore very important for the safety of the consumers (Miller and Bellinger 2003). Causes of bleeding and Flushing are too much asphalt into the mixture, improperly construction of seal coat and by using too heavy material into the mixtures (Asphalt Institute 2016). In general, flushing is the excess material of the asphalt bitumen rising on the surface and this is caused by a poor asphalt mix design.



**Figure 9: Bleeding and flushing on the asphalt pavement ([www.roadscience.net/node?page=2](http://www.roadscience.net/node?page=2)).**

Polished aggregate is the worn away of the bitumen of the mixture to expose coarse aggregate (Miller and Bellinger 2003). The possible cause of polished aggregate is the use of soft aggregate that polish quickly under the traffic and the surface loss its macro texture as well as the surface sooth and rounded (Asphalt Institute 2016).



**Figure 10: Polished aggregate on the asphalt pavement surface ([www.roadscience.net/node?page=2](http://www.roadscience.net/node?page=2)).**

## **2 Remote sensing techniques and methods for asphalt pavement distresses**

According to Schnebele et al. (2015), remote sensing techniques consists different types of methods such as high spatial and temporal resolutions that are very helpful for a transportation assessment. These are non-destructive methods that use unmanned aerial vehicles (UAV's), satellites, airplanes and moving vehicles.

Each type of remote sensing method has different sensors which have alternative parts of electromagnetic spectrum and contribute to data collection and measurements of the road surface. Furthermore, the use of remote sensing is cost effective and important in transportation infrastructure researches. Additionally, remote sensing methods can identify and analyse pavement defects and distresses from the traffic loads and the weather. Finally, the data collection from air and space borne platforms can identify the destructions of natural and anthropogenic disasters as well as the destruction of the asphalt through time while they could be multisource and provide multi spectral data.

Moreover, it is valuable to acknowledge that remote sensing methods are working with solar energy and also electromagnetic radiation which travels from the space to the surface of the earth and then waves can be reflected, absorbed or scattered from the different kinds of surfaces on the earth. These are called spectral signatures.

The electromagnetic radiation is the range that is summarized by wavelength or frequency by the electromagnetic spectrum (Schnebele et al. 2015). The measurements for the spectral signatures of each surface measured by Solar Spectrum Reflectometer have been correlated with surface brightness. The most well-known remote sensing method for the asphalt pavements is photographs (Despini et al. 2016)

This section analyses the different methods and techniques of remote sensing in order to identify and detect the distresses of the asphalt pavements. The follow table shows the methods and techniques of remote sensing that were used and collected from previous studies. Table 1 gives information about the authors and the methods of remote sensing which they used.

**Table 1: Data used in recent journals papers.**

N/A	References / Data acquisition methods	Remote Sensing Methods and Techniques								
		Common Methods	Digital RGB	INFRARE D	LiDAR/ laser scanner	Satellit e	Spectra l Library	Therma l	UAV	GPR/ SAR
1	(Andreou et al. 2011)						✓			
2	(Despini et al. 2016)			✓		✓	✓	✓		
3	(Diamanti and Redman 2012)						✓			✓
4	(Dumoulin et al. 2010)			✓				✓		
5	(Herold and Roberts 2005)	✓					✓		✓	
6	(Herold et al. 2004a)	✓				✓	✓		✓	
7	(Herold et al. 2008)	✓					✓		✓	
8	(Koch and Brilakis 2011)				✓					
9	(Manzo et al. 2014)		✓				✓			
10	(Marchetti et al. 2008)			✓				✓		
11	(McRobbie et al. 2010)				✓					
12	(Mei et al. 2012)						✓			
13	(Mei et al. 2014a)		✓	✓			✓			
14	(Mei et al. 2014b)		✓			✓	✓			

15	(Mettas et al. 2015)					✓	✓		✓	
16	(Mettas et al. 2016)			✓		✓	✓			
17	(Miraliakbari et al. 2014)		✓	✓	✓					
18	(Mohammadi 2012)				✓	✓				
19	(Moropoulou et al. 2001)			✓				✓		
20	(Noronha et al. 2002)					✓	✓			
21	(Ouma and Hahn 2016)	✓								
22	(Pan et al. 2016)		✓			✓	✓			
23	(Pascucci et al. 2008)					✓		✓		
24	(Radopoulou and Brilakis 2015)	✓								
25	(Resende et al. 2014)								✓	
26	(Shahi et al. 2015)					✓	✓			
27	(Solla et al. 2014)							✓		✓
28	(Yun et al. 2010)					✓				



Andreou et. al. (2011), conducted an investigation of hyperspectral remote sensing in order to create a spectral library and minimising the dimension of the hyperspectral space, for asphalt and its conditions which was affected by asphalt pavement ageing, the material quality and the circulation of the road. The usage of GER 1500 with spectral range between 280-1090 nm and acquires 512 band, and also Compact Airborne Spectrographic Imager (CASI) 550 sensor that acquires 288 bands and spectral range coverage between 400-1000 nm, were the tools that measured, analysed and processed this assessment. Their study was done based in urban areas such as Chalandri and Athens on different asphalt road conditions, various ages of asphalt pavement and circulation. The results showed how the age and quality of road materials, and the circulation are influencing the asphalt conditions. They showed how the reflectance of roads with high circulation and deterioration, increase the reflectance of the road surfaces. Furthermore, an increase of reflectance can be found on the asphalt pavements that have cracks. It was observed that they had high reflectance. In the contrary, the new road constructions had lower reflectance because of the asphalt chemistry.

Despini et. al. (2016), work was the analysis of methods of remote sensing for Urban Heat Island (UHI), by using thermal infrared spectral region in order to identify the different characteristics of the urban surfaces. Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) were the satellite with spatial resolution of 50cm that have been used for this study and also a Solar Spectrum Reflectometer V6.0 in order to measure of solar reflectance on the ground. The measurement of the reflectance of different urban surfaces such as concrete pavements, asphalt pavements, clay roof tiles, asphalt shingle dolomite, helped to create a spectral library for those surfaces in order to find the difference between their reflectance. Also, through the investigation they concluded to a correlation about 0.85 between of the two datasets.

**Table 2: Bands of the airborne sensor.**

<b>Band</b>	<b>Spectral region</b>		<b>Wavelength</b>	<b>Spatial resolution (cm)</b>
<b>1</b>	VIS	RED	0.62-0.75	50
<b>2</b>		GREEN	0.49-0.55	50
<b>3</b>		BLUE	0.43-0.47	50
<b>4</b>	NIR		0.75-1.50	50

**Source: Despini et al. 2016.**

According to Diamanti and Redman (2012), Ground Penetration Radar (GPR) is a useful method for the determination of thickness, width of cracking on asphalt pavement surfaces. For their study they used both field observations and numerical models of GPR. In both sides of wheel path used 1000MHz and 250MHz at the centre of the lane. They also used cart-based multi-channel SPIDAR system and high speed ground coupled channel road map systems. By using hands pushed carts, they collected multi frequency data of higher spatial resolution. Then, the collected data preceded with numerical methods in order to determinate the crack dimensions. The results showed that by using 250 MHz GPR, it can be more effective for the crack roughness and the waveguide effects, when 1000 MHz GPR it is better for detecting vertical pavement cracks. Finally, the results showed similar characters but with difference in between the GPR cross sections and numerical modelling results.

According to Herold and Roberts (2005), the purpose of the experiment was to investigate the effects that appeal in the pavement spectra and assess the helpfulness of imaging spectrometry for road mapping conditions. For the collection of data that were used, Analytical Spectral Devices (ASD, full range spectrometer) with spectral range from 350nm to 2400 nm, in order to create their spectral library and to compare their data with the pavement condition index (PCI) data. Furthermore, for the imaging spectrometry used HST sensor which have 227 bands from 450nm to 2450 nm and spatial resolution 0.5 m. The usage of aerial photographs in the previous years, they only mapped the distresses of asphalt such as cracks. The results of this experiment showed that according to the asphalt ageing, the newest asphalt pavements were dominated by hydrocarbon absorptions and increases in brightness. Also, the asphalt pavement damages such

as cracks decreases the brightness and accentuate hydrocarbon absorptions features. Furthermore, there are more complex when a road pavement is older and thus lower map quality. Additionally, by comparing the field spectrometry, in situ surveys and imaging spectrometry the results showed that were able to provide spectral substantiation of the asphalt pavement ageing and deteriorations. To end, it was mentioned that it was the first investigation study on the particular domain.

Herold et. al. (2008), according to the previous studies found the relationship between the road condition based on PCI and remote sensing data. On this experiment, the common practice techniques that they used by ASD full range hand held spectrometer in order to refer the new results. The data collected from the Airborne Visible/Infrared Spectrometer (AVIRIS) which has 224 bands and spectral range between 350nm to 2500 nm and spatial resolution of 4 m, but because of its low spatial resolution, the usage of HyperSpecTIR (HST) sensor and its Analysis of Variance (ANOVA) which has better reflectance (Herold et al. 2004), showed that the relationship between the signal of remote sensing and the PCI in the asphalt pavement in a road with good condition is strong but the roads that have cracks, rutting and raveling decrease the relationship between them (Herold et al. 2008). Finally, both common practices and remote sensing analysis are effective to identify roads which are in good or in very good conditions and the results are more accurate, but for poor road condition in situ observation are needed from experts (Herold et al. 2004).

Koch and Brilakis (2011), assessed the pothole detection in asphalt pavement images. The field data collection were time consuming and expensive by using methods such as the previous studies which can be separated in three main categories. The categories are, 3D laser scanning, stereo vision and vibration based using acceleration sensors. They based on the images from previous studies and by using MATLAB prototype tested 120 different images including potholes, cracks and patches. Also, they used images that were taken from the vehicles with high speed fish eye camera. After the detection of the camera an algorithm classified the defects of asphalt pavement. Finally, the results of these methods showed 86% accuracy of potholes detection.

Dumoulin et. al. (2010), worked on the active infrared thermography in order to detect and characterise the defects on asphalt pavement. For their methodology, they used a FLIR S65 infrared camera with an uncooled micro-bolometer which was the FPA detector of 320 240 sensitive elements, spectral bandwidth 7.5mm to 13mm. The samples of the asphalt pavements were heated with halogen lamps of 500W. Then the experimental thermograms obtained for 60 sec and 300 sec square heating in order to auto non-uniformity correction at the infrared camera. Furthermore, the numerical simulation took place by using FLUENT. The results of this study showed that with using both methods the defects of asphalt can be detected. Finally, as a main conclusion of this study it is possible to use uncooled infrared cameras with less thermal sensitivity to detect defects.

The relationship between the reflectance and the asphalt road conditions were mentioned in the work of Manzo et.al. (2014), for the detection of the spectral characteristic of the asphalt pavements. The asphalt pavement due to its age, the weathering and loads can appeal distresses such as raveling and polished aggregate. The exposed aggregate index (EAI) can change the spectral signature as well as these pavement distresses. This study was conducted in order to compare the asphalt pavement spectral signatures of each target with digital photos which were processed in order to get a geometric and colorimetric co-registration, by using digital cameras Nikon Coolpix S560 with assembled sensor 10.7 million pixels and 35mm lens. The conclusion of this study is that the relationship between the picture colorimetry and spectral in situ measurement is possible. The asphalt reflectance is not steady in a surface condition especially because of the exposure of aggregate on the asphalt surface. Finally, the results of this study agreed with spectral results that the exposed aggregates effects were from the near infrared (NIR) and their reflectance was identify as higher than bitumen in blue and the NIR wavelengths.

Marchetti et. al. (2008), aimed to detect sub-surface defects in the materials of the roads by using active infrared thermography. The experimental set up included asphalt samples in different shapes such as parallelepipeds and pyramids. For this assessment a FLIR S65 camera with spectral range from 7.5 $\mu$ m to 13  $\mu$ m and thermal range between 40 °C and 120 °C and also

CEDIP® camera JADE III (MWIR) with spectral range from 3.6  $\mu\text{m}$  to 5.1  $\mu\text{m}$  and optical focal of 50mm were used for image collection. Two sorts of incorporation were along these lines assessed, which warm conductivity and diffusivity (wood or air) were lower than the ones of the road surface material. Defects were detected after 60 seconds of heating the samples. Additionally, the results showed that the heating methods could identify defects of road materials. CEDIP Jade III infrared images, due to the different thermal behaviour between the binder and aggregate can be distinguished between them. Finally, the pyramidal shaped defects were not detected.

McRobbie et. al. (2010) used Highway Agency Road Research Information System scanner at the vehicle with 16 kHz in order to detect raveling on the asphalt pavement surface. HARRIS collected images with the line scan cameras and 2mm/pixel. The three cameras exhibit different grey level values and by calculating the average pixel intensity, then by change the lighting can be quantified and corresponding the curves in order to correction the images and to remove the uneven lighting. The processing methods to identify raveling used an algorithm to identify the lengths of raveling and developed the processes both of the pseudo-texture profile data and images to identify raveling. Finally, this study conclude that the investigation of the detection of raveling based on images were successfully done and imaging methods can be indentify the depth of raveling by using stereo vision.

Mei et. al. 2012 used spectrometry analysis and physical laboratory analysis in order to improve the understanding of spectral analysis of asphalt surface composition. For this experiment they used samples of asphalt pavement with two different types of aggregates such as basaltic aggregate and expanded clay granules which their different is between the physical and strength properties. The spectroradiometer Fieldspec 3 ASD with 350 – 2500 nm wavelength it was used for the results. The results which came from this experiment it is impossible to use spectroradiometric analysis in order to identify the physical characteristics of the aggregate of asphalt pavement such as lithology, porosity and water content and also, the composition between the bituminous and aggregate mixture. Finally, both laboratory and field analysis are useful tool for chemo metric analysis.

The removal bitumen on asphalt pavement can be defined by Digital Imaging Processing (DIP) and spectral analysis. The two causes of deterioration of asphalt pavement (raveling, polished asphalt) can be detected by using digital cameras with 35mm focal length. The field spectral data were collected from ASD spectroradiometer and finally, RGB pictures were taken place of this assessment for image pre-processing. The bitumen removal can increase the reflectance values. The Exposure Aggregate Index (EAI) can be measured between the data of field spectral analyses and remote sensing that means is very good tool for transportation assessment. Additionally, earlier detection of removal bitumen and the crumbling of aggregate can be present less environmental contaminations such air and soil (Mei et al. 2014a).

According to Mei et. al. 2014b, the aim of many studies is to identify the relationship between the paved surfaces and spectral data. On this study the aim was the classification of asphalt surface by analyses of field and laboratory data. Also, they used spectroradiometrical data, images of paved surfaces during field survey with different conditions and distresses and finally, remote sensing images with hyperspectral from MIVIS images (Multispectral Infrared and Visible Imaging Spectrometer) and multispectral images by using satellites such as Quickbird and IKONOS. Then they analysed MIVIS bands and the wavelength range was taken as the comparison between hyperspectral and multispectral imagery. Finally, digital photos taken by Nikon Coolpix S560 to validate asphalt pavement characteristics. The graphs of reflectance versus wavelengths classified the data by the slopes (called asphalt lines) were produced. The results of this study showed that the MIVIS, IKONOS and Quickbird data had a high accuracy. Concluding, this study, both hyperspectral and multispectral imagery can detect the removal of bitumen therefore is a good tool for the government and authorities to monitoring asphalt pavement and maintenance.

Mettas et. al. (2015) analysed three different methods of remote sensing in order to monitor the asphalt pavement deteriorations. First, by the use of the spectroradiometer SVC1024 with spectral range between 350 nm to 2500 nm, collected data of road with difference in age (new, > 10, >20 years old) and created spectral library of this study. Secondly, the data provided of the asphalt pavement were collected from different heights by UAV which has high resolution

cameras and compared with spectral library that was done. Moreover, used several satellite sensors with high spectral resolution (5m) and then by the correction of images compared the results with two other methods. The results of this study showed that the age of asphalt pavement affected to the reflectance. Additionally, when a road is in a bad condition, such as cracks etc which affect the reflectance it is difficult to monitor the roads. Also, they found that the ageing of asphalt pavement is related to the increase of the reflectance. To conclude, they referred that all their findings they agree with the past studies.

Mettas et. al. (2016), made an examination on identification spectral region in order to detect the defects of flexible pavements. The main purpose was the gap in the literature from previous studies and the aim was to cover this gap. The study focused on asphalt pavement deterioration such as cracks, patched cracking and polishing in Paphos city in Cyprus. Additionally, they used Landsat 7 ETM+ sensor which band was from 1 to 7 and because of its bands it can easily find the distinguishes between uncracked, cracked and polished asphalts pavements whilst SVC HR-1024 spectro-radiometer for field spectrometry in order to collect data and information for the different conditions of asphalt pavements (ages, Uncracked, cracked, patched cracking). The conclusion of this study mentions that they focused on a creation of spectral library for different asphalt surfaces deteriorations through satellite data. Furthermore, they found that the ageing of the asphalt pavement affected highly in the reflectance of asphalt. Moreover, the physical cracks investigated with higher reflectance than the patched cracks. Polished asphalt was identified with much higher reflectance than undamaged asphalt. An important identification of this study it was the combination of the Landsat 7 ETM+ bands which bands were the most useful for distinguish asphalt pavement of different conditions and ages.

According to Miraliakbari et. al.2014, by using infrared spectrometers, high resolution RGB camera and a laser scanner can be mapped road condition. On this study, the usage of Polytec PPS 2221 spectrometer with 256 channels, took a place in order to detect the deterioration and the condition of asphalt pavement due to its age. Moreover, by using digital single lens reflex Canon camera 5D Mark II with 21 megapixels were collected high resolution RGB images of deterioration of asphalt such as cracks. Finally, the GNNS laser scanner recorded laser point in

order to detect potholes and ruts. Finally, as conclusion indicated that the concept of road condition mapping collected by the three processes. Cause of the different ageing of asphalt the spectral information for road condition mapping was classified by spectrometer measurements and RGB images were detected the asphalt pavements cracks. The rutting of asphalt pavement identified both depths and width caused of laser scanner and its high point density.

According to Mohammadi 2012, the main purpose of his study it was to identify and mapping the material of the surfaces of roads with hyperspectral data. By using hyperspectral data the identification of surface material happens automatically. The study taken place in Baden-Wurttemberg, Germany and the images for the research area from German Aeroscope Centre (DLR) which processed corrections of radiometric, atmospheric and geometric effects. 125 bands and range between 0.4 and 2.5  $\mu\text{m}$  and has a ground sample distance of 4 m. Furthermore, a LiDAR high resolution surface model it used for this assessment. The results showed that the Spectral Angle Mapper (SAM) is useful tool for perspicacious surface materials of the roads. The main investigation of this study it was that the combination of the standard deviation and mean of spectral function can be classified asphalt, concrete and gravel. Finally, the problems that appealed on this research were the unclassified pixels and usage of higher spatial resolution of hyperspectral data that should improve the methods.

Moropoulou et. al. (2001) used infrared thermography at the airport in Athens in order to detect cracks, voids and other deterioration that might appeal at the airport pavement. For the infrared thermography Avio Tvs 2000 Mk II LW with range 8 -12  $\mu\text{m}$  was used to deflect the heat flow through the asphalt surface materials and generating dissimilarities of the temperature of the surface. Mercury Cadmium Telluride (MCT) was the equipment that was used for this study. Three different airport pavement locations were taken place on the thermo-graphic investigation (north-western taxiway, bravo taxiway and the main run way of the airport). For north-western taxiway the two yellow hot areas showed that the pavement has two defects. At the bravo taxiway the results showed that the road was in a bad condition and the image on this area showed yellow-hot colours. Further, for the main runway the results showed that the asphalt was recently replaced. As a conclusion of this study they identified deterioration due to poor work



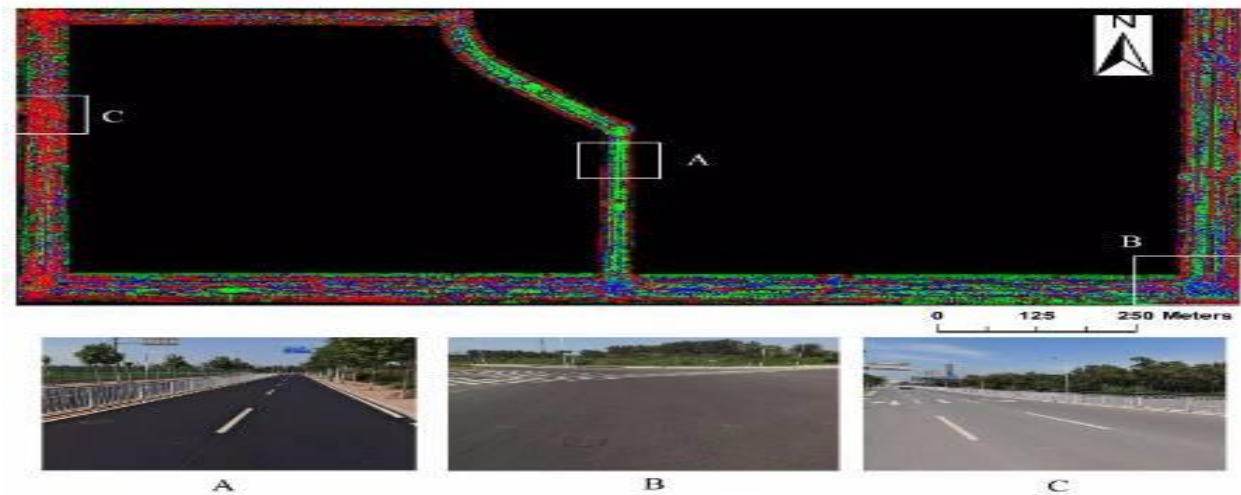
from labours and delaminating asphalt pavement. Additionally, as they mentioned the infrared thermography is better than other non-destructive techniques because it saves time, labour, machinery that are not a risk since radiation and it can be used on day and night time hours, depending upon the environmental conditions.

Noronha et. al. (2002), have studied the geometry centrelines extraction and evaluation of pavement conditions by using AVIRIS hyperspectral imagery and created a spectral library with spectral signatures of different qualities of pavements. The results of this assessment showed that there were similarities in spectral signature between the asphalt pavements and roofing materials. This research could be detecting the different types of pavements such as concrete and asphalt pavements but is difficult to detect pavement distresses such as cracks or rutting due to the low spatial resolution (4m). Also, with this study the age of the pavements could be detected. Finally, they suggested that in the future a multispectral sensor with lower spectral resolution will be helpful for pavement mapping.

Ouma and Hahn (2016), used RGB camera imagery and classification circular Radon transform in order to detect of incipient linear cracks. 72 images of deterioration asphalt pavement and a spatial resolution of 1mm were chosen for this study. By distinguishing the micro-linear and the arbitrary neighbouring pixels analysed the shapes. The 83.2% accuracy out of 72 tests images showed that this method of micro-linear distress has been detected. Finally, because of the complexity and non uniform asphalt pavements, deteriorations of pavements in gray scale imagery are not just an issue for edge detection, but needs to comprehend the neighbourhood varieties inside the crack surfaces, the causes of the textured surface of the asphalt pavements and distresses which were defined as the homogeneities showed at the asphalt surface.

Pan et al. (2016), studied about the road pavement condition mapping by using remote sensing data based on Multiple End member Spectral Mixture Analysis (MESMA). The detection of the pavement conditions due to the roads life (different ages) was the main purpose in this study. First, they used spectrometer to take field spectral measurements and then with the use of World View-2 high resolution images, they covered the on-site area. By using MESMA and RGB

images they classified as preliminary aging (green), moderately age (blue) and late aging (red). The following figure (Figure 11) shows the GPR image and the classification of the ageing of the road as green, blue and red. The main conclusion from this study was that the age of each road characterised from its own spectral feature. Using World View-2 and MESMA, found to be a useful tool, which it can be used by the authorities for road maintenance. The researchers of the study suggested that higher spectral resolution and wider band coverage would be better for this study and for future studies.



**Figure 11: RGB image for the classification of the ageing of the road (Pan et al. 2016).**

Pascucci et. al. (2008), mentioned that the remote sensing can detect deterioration of asphalt such as raveling, flushing and polishing as well as road condition mapping. They used Thermal Infrared Spectral Region to identify the distresses of asphalt pavement and can be used for atmospheric correction. Also, this method can be applied on roads, parking spaces and wide streets. The disadvantage of this method is that the usage in urban areas it's difficult. In addition, the usage of MIVIS multispectral TIR raw data is very cost effective with very good accuracy on the results of identification of all the road asphalt pavements. A future assessment aims to include field spectra analyses for the creation of spectral library and laboratories experiments for formative distresses/ ageing level of asphalt.

Radopoulou and Brilakis (2015), aimed to detect the patches of pavement surfaces with low cost remote sensing methods. They focused on previous studies that sensors were used such as laser scanners, accelerometers, imaging and video on vehicles in order to detect the different defects of asphalt pavements. In this study, video data were used acquired by the camera on car parks. The automatic detection of patches was passed to a kernel tracker in order to detect the same patches twice. The pre-processes were followed by two steps, first, the image pre-processing which deleted any unnecessary data and the second, the patch detection. The final process of this method was the image binary which focused in the darkest regions of the pavement image, which at most of the time presented the defective area. Finally this method showed the 75% accurate results, with some errors presented due to the shadows. Finally, by using this method would be easy to detect other asphalt pavement defects.

Resende et. al. (2014), aimed to monitor the condition of roads pavement surfaces by using hyperspectral images. The study used CASI-1500 sensor and Low Cost Air Monitoring System LCAMS to collect four images. Two of those images had a spatial resolution 50cm and 24 spectral bands the other two 25cm and 8 spectral bands. First, the classification of asphalt with original images was done and then the identification and classification of the asphalt distresses. The results extracted from this study it was easy to detect patches since the 25cm spatial resolution. Additionally, the detection of transversal cracks from the aerial images, during the field survey was found to have been sealed with bitumen. Finally, the usage of hyperspectral sensors carried by drones in the near future would be very useful tool for monitoring the asphalt pavement conditions.

Shahi et. al. (2015), used ASD hand-held spectro-radiometer to obtain information about the spectral reflectance of the asphalt surface and also, to create a spectral library. Furthermore, they used World View-2 satellite images cause of the high spatial resolution and for the multispectral of this satellite. The purpose it was to automatically extract road networks called road extraction index (REI), from World View-2 satellite imagery. Moreover, to determine the best bands due to the spectral data that was collected from ASD spectro-radiometer. The results of this study showed that the proposed method is 86% accurate. The blue and NIR2 bands are considered the

best band on using for the REI. Finally, some fails presented when there are trees and shadows on the study areas.

Solla et. al. (2014), used GPR and Infrared thermography in order to detect cracks of the asphalt pavements. For this experiment, four different types of asphalt concrete with 3×3 m dimensions included cracks on them were built. Data were collected by GPR field survey and an antenna with frequency of 1GHz was selected. The results show that the detection of cracks was done correctly due to 1GHz antenna. The expected hyperbolic reflections that were generated from cracks is not easily detected with cracks depths smaller than 4.0 cm. Afterwards, the usage of TH9260 model with 640×480 UFPA sensor (Uncooled Focal Plane Array) and thermal resolution of 0.06 °C at 30°C (30Hz). The thermographic images collected from 1m height above the study area, at the morning before the solar radiation influence the asphalt pavement temperature. There are two steps of correction for thermographic images. Firstly, the temperature of asphalt with contact thermometer and thermographic camera was measured and secondly, geometric correction of the images. Concluding, the GPR can detect asphalt cracks with 5.5% error and infrared thermography is a valuable tool for detection of cracks caused of different temperature between cracks and surfaces.

Yun et. al. (2010), aimed to use satellite images in order to analyse roads surfaces. ASTER and IKONOS satellite images, took place in this study. First, create a spectral library and thereafter to combine the two satellite images. The Table 3 below shows the difference between the two satellite images and also the sensors, the number of bands and the spatial resolution of each satellite sensor. In addition, eight points in the study area were selected and analysed by the satellite images that have the value of spectral reflectivity. The scope of this method it was to ensure that they can use satellite images in order to manage and monitor the asphalt pavement surfaces and to collect fundamental data. Afterwards, they analysed the images based on the location and the results showed that the points with deteriorations of asphalt pavement, had the highest value of spectral reflectivity. Finally, a verification of the data that were collected, it would be better to verify the data from field in order to get better results.

**Table 3: Satellite image data used in this study.**

<b>Satellite image</b>	<b>Sensor</b>	<b>No. Of bands</b>	<b>Spatial Resolution (m)</b>
<b>IKONOS</b>	VNIR	4	4
<b>ASTER</b>	VNIR/SWIR	3/6	15/30

**Source: Yun et al. 2010.**

### **3 Methodology**

The hypothesis of this postgraduate thesis is to explore and represent the several methods and techniques of remote sensing that are used for the asphalt pavement surface and how they can identify the asphalt surface damages for a transportation assessment. Another aim of this research is to search and assess whether those techniques and methods are better to be used, rather than previous methods that were used and how important and useful are they for the professionals on the field. A further hypothesis that was analysed and considered, is whether the remote sensing methods and techniques are financially at lower cost and if they need less time to make an assessment for the asphalt pavement. Additionally, with the destruction of the environment in the last few years, it is good to identify if those methods are more environmental friendly, rather than the previous techniques that were used, such as field observations and measurements. The methodology of how this thesis was conducted is explained in detail below.

The methodology that was followed in this study was mainly focused of the literature review. First, there was an investigation and analysis of the several types of deteriorations of the road asphalt pavements along with their causes, in order to identify the structural problems that are presented on roads. Basically, the information and details of this study were collected and analysed from two distresses manuals that deal with deteriorations of asphalt.

Furthermore, the most important chapter of this thesis was the literature review. The purpose of this thesis is the research study, at which a large number of researchers had to be analysed in order to identify the methods of remote sensing that can detect deteriorations of asphalt pavements. In addition, the studies that were selected to be examined for this research, are reviewed in Table 1, to represent the types of remote sensing methods that were used in these studies. Furthermore, the table was produced to show the authors alphabetically because it was easier to find the studies from the references list. Then, the studies' summaries that were presented, included the purpose, the equipment used, the methodology followed and the main conclusions of each study.

Moreover, in the discussion chapter, a summary of the literature review and the gap that was presented in this thesis were reported. Moreover, since the methods of remote sensing are new technologies, the researchers associated with the deterioration of asphalt pavement the last years. They have mentioned how they will attend future work. Since many of the previous studies had preliminary results, some mentioned that there will be an improvement to their methodology and equipment used.

Finally, the conclusion presents the main identification for both deteriorations and remote sensing methods while the most important part is that being extracted from the literature review after research.

### **3.1 Search Strategy**

Relevant research concerning remote sensing methods and techniques used to detect the deterioration of asphalt pavement was identified by searching. A total of 4 research databases were searched for the types of distresses of asphalt pavement and another 28 researches about remote sensing techniques and methods for the detection of the different type of deteriorations. The publications from 1993 until the present, with key journals obtained from GOOGLE Scholar, Research Gate, Science Direct and the CUT library.

### **3.2 Selection criteria**

The following step was a detailed examination of the journals. Some journals were excluded because either were not dealing with the deterioration of asphalt or were not dealing with asphalt. First, by reading the abstract of each journal and then the conclusion, understand if the journal is important and is good for using in this thesis. In other words, each journal answers the aim and the objectives of this study. Then the analytical reading for each journal in order to write a small summary including the purpose, the equipment, the methodology and the main conclusions of each journal taken place in this study. Additionally, review journals witch deal in general with

remote sensing and the distresses of asphalt pavement, studied the literature and the bibliography in order to find any journals that could be used for this study. Unfortunately, there is no access in some journals and that might affect the literature review or some of the conclusions. Finally, there are no limitations of the area of study or the methods of remote sensing and deteriorations of asphalt pavement.

### **3.3 Methodological consideration**

Most of journals have their own methodology that they used in order to present the method and the procedure. There are at least three important issues which must be kept in mind when considering the research outcomes.

There are:

1. The method of remote sensing that they used,
2. The type of deterioration of asphalt pavement,
3. The result of the studies.

First, the most researchers created their own spectral library in order to mapping the condition of asphalt pavement (age, deteriorations) and also to compare the results of the spectral library with other methods such as satellite sensors, RGB images. Additionally, other researches created algorithmic or new remote sensing programs to detect the deterioration of asphalt pavements. In other words, they provide information about the type of method remote sensing and how they used them for the studies.

Second, studies which include deterioration of asphalt pavements and analyses of the type of remote sensing that will be detected each distress. For the structural damages of asphalt many researches provide information on causes of these phenomena.

Finally, in many studies provided preliminary results. In other studies, the methods presented errors and the authors as they said would improve the methods in the near future, in order to



make the methods better to use and reduce errors thus collect better results. Additionally, the results of the studies showed if the methods work correctly.

## **4 Discussion**

An amount of studies and research were explored in order to complete the methodology of this thesis. The results of the examination are reported in detail in this section.

### **4.1 Improvement of the remote sensing techniques according to the literature review**

Remote sensing methods and techniques have been developed through the years. Also, the evolution of technology year by year gave better methods and techniques and improved the remote sensing.

This study analyses the improvement of remote sensing methods and techniques needed to use in the future, according to the authors of each journal. Some of the reasons are the preliminary results for their studies, some errors that were presented and finally, small study samples and areas.

First, many authors mentioned that their spectral library will be improved in order to collect more accurate results to reduce the errors:

- Herold et.al. (2005), stated because it was the first investigation this study was focused in a small study area and were presented problems with spectral calibration of HST caused of analysis to a VNIR. By using SWIR the spectral library results and the technique will be improved in general.
- Mei et. al. (2014a), future work is the calculation of EAI and samples analysis in the laboratory in order to create spectral library of asphalt pavement physical data.
- Mettas et. al. (2016) will provide a complete spectral library of asphalt pavement included UAVs, thermal multispectral and infrared high resolution cameras for asphalt pavement parameters.
- Pascucci et. al. (2008), states that in the future will include field spectral analyses to create spectral library with different deterioration of asphalt pavements and to provide laboratory samples for determining their deterioration/aging level

Secondly, there are some authors who will improve their methods by using better equipment.

- Diamanti and Redman (2012), in the next study it will be implementing a complete antenna system in their numerical model and will improve the waveguide effects of 250 MHz field data.
- Koch and Brilakis (2011), will be using machine to improve the accuracy of classification of pavement texture; will take more visual characteristics for the potholes shape and true optimal threshold for  $\epsilon_{\max}$  and  $r_{\max}$ .
- Pan et. al. (2016), in the future will use hyperspectral images with higher spectral resolution and wider band coverage in order to improve the results.
- Radopoulou and Brilakis (2015), will collect visual data from the road network and will use GPS devices in order to provide geospatial location of each detected deterioration of asphalt. Furthermore, an automatic method for the detection of structural damages of asphalts will be a very useful tool.
- Shahi et. al. (2015), will test the index by using different sensors and improve its ability to classify and map asphalt pavement conditions.
- Solla et. al. (2014), will be used in the future to study antenna with 2.3GHz frequency in order to detect depth crack more easily (GPR).

Thirdly, this category is based on the improvement methods that their used or by using other methods to improve their results:

- Herold et. al. (2004a), need to incorporate the dimensions in data analysis of the different urban landscapes such as roof tile, asphalt pavements. The spectral limitation in mapping urban land cover and spectral characteristic of materials by image analysis.
- Marchetti et. al. (2008), will make the test in the real pavement structure in order to investigate the different defects of the different sizes and thickness.
- McRobbie et. al. (2010), will use the imaging method that can measure the depth by using imaging method and resolve the problem to detect the raveling in full length.

Finally, the category that they will improve their results with further study or will do more analysis on their results:

- Miraliakbari et. al. (2014) will focus furtherer on the results.
- Mohammadi (2012), will continue researching in order to improve the methods and reduce the unclassified pixels.
- Le Guen et. al. (2013), in order to design new equipments for asphalt will be doing more experiments for convective mechanisms.

## **4.2 Summary of the studies**

Table 1 provides information about the remote sensing methods that the authors used in order to meet the aim of each study. It was observed that most journals deal with the spectral library. Because of the monitoring and the mapping of the road conditions there are new studies nowadays, but most researchers want to create their own spectral library, in order to understand and investigate how the spectral signatures work on different asphalt pavement conditions such as age and other deteriorations factors. Furthermore, many researchers used spectral library as in-situ method which provided more accurate results. Due to that, the acquired in-situ results were assumed as realistic data. For those researchers who utilised other remote sensing methods in order to compare the results with the spectral library such as satellites, UAVs etc. their final results were estimated values. In addition, the other remote sensing methods which measure and were taken data at a big distance from the earth's surface they needed some corrections. Moreover, the corrections included the atmospheric corrections because of the several particles such as aerosol, CO<sub>2</sub> and the reflectance find resistance until it comes to the earth's surface (Song et al. 2001). Finally, the most in-situ spectral library data was collected from spectroradiometer GER 1500, ASD full range spectroradiometer and SVC HR-1024.

Furthermore, the used remote sensing methods according to the literature were the satellites, in order to detect asphalt pavement deteriorations. Satellites due to high spectral resolutions of the cameras and sensors were non-destructive methods and tools that could take measurements and data from a great distance. The advantages of this method are, the low cost and less time consuming than from the field measurements. The disadvantage of the satellite method is that

most satellites have low spatial resolutions. Additionally, the most famous satellites that were used in order to detect and identify distresses of asphalt pavement were the Landsat, Quickbird and IKONOS.

There are more methods of remote sensing that researchers used in order to detect structural damages of asphalt pavements. The problem presented with those methods was that of the limited sources available regarding the methods above. Digital RGB, UAVs, thermal, common methods, LiDAR, GPR and infrared were some of the methods that were analysed in the literature review. Both these methods have the advantages of being not destructive methods as the satellites and spectral library were cost effective and need less time for transportation assessments. Each method used detects and identify different types of deterioration.

It should be mentioned that most studies deal with cracked asphalt pavements. Many several types of cracks such as alligator, block, transverse and longitudinal may be the most presented structural damage of the asphalt pavements (Weng 2008). In addition, the evolution of cracks will create more problems in the asphalt pavements. According to the researches, a crack can be detected and identified with remote sensing methods such as GPR, RGB images and infrared thermography. Satellite and UAVs methods are difficult to detect cracks due to their low spatial resolution.

Furthermore, many studies were conducted for the conditions of asphalt pavements. The natural and anthropogenic destruction of the asphalt pavement let the researchers to deal with these parameters. The conditions include the deterioration of asphalt pavement (anthropogenic) as well as the ageing and weathering which were natural phenomena. For this reason, the most researchers create their own spectral library. A sufficient number of journals deal with the condition of mapping the asphalt pavements.

### **4.3 Gaps of the study**

First, this postgraduate thesis studied various researches. The majority of studies in the past were focused on asphalt conditions and mapping. It is subject that identifies many information and

detail for several remote sensing methods and understands how remote sensing methods can map the condition of remote sensing.

In addition, most studies for deterioration of asphalt pavement were produced for cracks, but the majority did not refer the type of cracks. There are important parameters to know if the different types of cracks have the same or different reflectance and also, whether they can be detected by remote sensing methods.

The main gaps presented for the other types of deteriorations and the usage of remote sensing methods. There are not many studies focused on other types of deteriorations of asphalt pavements. For example, patches and potholes identified and analysed for each one of the previous studies. Additionally, the numbers of journals that deal with polishing and raveling are limited. In this study it was not identified nor analysed any remote sensing methods of some deteriorations of asphalt pavement such as rutting and bleeding.

Concluding, in the studies that have been examined in this thesis, it was clear that most researchers wanted to identify methods that could map the conditions of a road asphalt pavement in order to understand how the remote sensing works in this field. Then, most of them studied cracked areas of asphalt pavements because of the sheer amount.

#### **4.4 Professional opportunity**

Nowadays, most civil engineers follow the career of a structural engineer. This dissertation topic might open new opportunities for potential future civil engineering careers. The knowledge that will be gained from this project it will assist in learning, as well as doing in something more specialised and unique that not a lot of civil engineers practice.

In addition, another reason that led to the selection of this project is the personal interest in the remote sensing and transportation engineering domain. Moreover, remote sensing methods are

crucial, since there are methods that help professionals with time management as well as financial aspects.

Furthermore, not many civil engineers in Cyprus participate in remote sensing methods in asphalt pavement surfaces although there are huge opportunities to join a transportation company or get a job in the department of public work of Cyprus Government.

## **5 Conclusion**

This postgraduate thesis combined several studies in order to observe the usage of remote sensing methods in order to detect and identify the different types of deteriorations that were presented at the asphalt pavement surfaces. It should be mentioned that, the remote sensing method is a very useful tool for transportation infrastructure assessments. Also, year by year, the improvements and the development of new and better methods and techniques of remote sensing, give an extra advantage to government authorities and transportation companies who deal with transportation, by using these methods for monitoring and planning the deteriorations of asphalt pavements. Moreover, the financial criteria of early detection of distresses are extremely important. Therefore, the remote sensing methods will upgrade the Department of Public Works in Cyprus because the improved knowledge on these methods will help the decision making on specific situations over time. In addition, the remote sensing can reduce the risks and natural hazards causes of the continuous monitoring of asphalt pavements. Finally, using remote sensing can reduce the risk and hazards that are presented on field surveys from traffic and weather conditions.

This study presents some problems regarding the subject of remote sensing. As mentioned earlier, the new technologies of remote sensing, their techniques and more specifically the phenomenon of the detection of deteriorations of road asphalt pavements were not in the centre of attention to be further studied. Additionally, various studies have identified and analysed the conditions and crack phenomena of the asphalt pavements, but for other deteriorations, there is inadequate material after intensive research.

Based on the facts above, the literature review dealt with studies that examined mapping, the condition of the asphalt pavements and cracks in more depth. The advantages are that several types of remote sensing for these two parameters were presented. Also, as these studies shows, those remote sending methods are a useful tool to use. For example, mapping the condition of road asphalt pavements and understanding the spectral library which was the most common method used.



Spectral library is the most important method of remote sensing because the researchers studied the conditions and mapping the asphalt road pavements. Due to the age and the condition of asphalt pavements, the spectral signatures are different for each parameter; understanding and identifying the differences between the spectral signatures give many solutions to the researchers for monitoring and mapping asphalt road conditions, but also corrections and comparisons of the spectral signatures of other remote sensing methods such as satellite sensors and UAVs.

Through the whole study and the details from this research which took part on this thesis, the main conclusions are listed as follows:

- The reflectance of the cracked asphalt pavement is lower than the reflectance of the un-cracked pavement.
- Recently, asphalt pavement has low reflectance.
- The age of asphalt is a critical parameter, because of ageing of the asphalt pavement the reflectance is higher (An older asphalt pavement i.e. 10 years, has more reflectance than a newest asphalt pavement i.e. 2 years)
- Spectral library is a useful tool for transportation assessment because of understanding the condition and mapping the asphalt pavement.
- Satellite using is very familiar and widespread tool to the detection of deterioration of asphalt pavement.
- Remote sensing methods are cost effective, due to their ability to take data and information from distance.
- The time needed for the collection of the data and information is much less than the field data collection.
- Remote sensing methods are non-destructive techniques.
- Remote sensing methods such as satellites, radars and spectroradiometers work with the solar radiation and their reflectance on the surfaces which means they are environment friendly techniques.
- The remote sensing methods were presented by the researchers as very useful tools for transportation infrastructure assessments.
- The results are more accurate for mapping when the roads are in good states.
- Polished asphalts have higher reflectance than undamaged asphalt pavements.

- The circulation and the quality are also important parameters that affect conditions of the asphalts.
- A high circulation can accelerate the defects of the asphalt pavements.

Satellites need higher spatial resolution to detect the cracks. In the last few years, the dramatic improvement of this technology made easier the life of the professionals and the consumers. Remote sensing methods improve the quality of the work of a professional by using less time for field visits, and also for financial reasons they might need for a project. For example, using satellite images, from which they can map roads much faster for a project or if necessary use of continues monitoring.

Moreover, remote sensing methods can find structural damages of asphalts from the first day that they started to be used and they can get decisions quickly and effectively. The importance of remote sensing and techniques used is how useful they are for professionals who are dealing with transportation assessments since they detect and show the deterioration of the asphalt pavement surfaces.

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