SURVEY AND ANALYSIS OF LAND SATELLITE REMOTE SENSING APPLIED IN HIGHWAY TRANSPORTATIONS INFRASTRUCTURE ENGINEERING

Jingyu Wei[1], **Guoqing Zhou**[2], and **Zezhong Zheng**[2,3]
[1]School of Civil Engineering and Architecture, Nanchang University
999 Xuefu Road, Honggutan District, Nanchang, Jiangxi 330031, P. R. China
[2]Department of Civil Engineering and Technology, Old Dominion University, Norfolk, VA 23529, USA
Tel: (757) 683-6234; Fax: (757) 683-5655; E-mail: gzhou@odu.edu
[3]School of Civil Engineering, Southwest Jiaotong University, ChengDu, Sichuan, 610031, China

ABSTRACT

The U.S. Department of Transportation (U.S. DOT) initiated the Commercial Remote Sensing and Spatial Information Technology Application to Transportation program in 1999 in collaboration with the National Aeronautics and Space Administration (NASA) in accordance with Section 511 of the Transportation Equity Act for the 21st Centre. With efforts in the past several years, tremendous accomplishments have been made. For example, all transportation agencies maintain different up-to-date types of roadway inventory. These inventory elements included, e.g., 1) stopping sight distance; 2) passing sight distance; 3) side slope; 4) highway grade; and 5) contours. The collected inventory data are used for a variety of purposes, e.g., design, planning, maintenance, and rehabilitation purposes. This paper intends to make a survey and analysis for the application of remote sensing in transportation infrastructure and system engineering. Moreover, we limited the survey in the commercial land satellite' application in transportation. The survey will be divided into the following fields:

(1) Remote Sensing applied in transportation infrastructure, such as pavement construction and maintenance, and management;
(2) Remote Sensing applied in transportation planning;
(3) Remote Sensing applied in transportation safety analysis and monitoring;
(4) Remote Sensing applied in transportation operation and analysis; and
(5) Remote Sensing applied in transportation environmental analysis, such as ecosystem analysis, air pollution, etc.

With an analysis of approximate over 150 academic papers and technical reports, some problems for remote sensing applied in transportation infrastructure and system engineering has been explored, and future development and application promising are concluded.

BACKGROUND

Satellite remote sensing has been recognized as a valuable tool for viewing, analyzing, characterizing and making decisions about our environment. This is because: (1) satellite remote sensing uses sensors/detectors to acquire information about objects or phenomena from a distance, rather than *in situ* (Zhou et al., 2002); the spectral range imaged through satellite remote sensing is greater than the visible range of electromagnetic energy that our eyes only sense; (3) viewing perspectives range from regional to global scale; and (4) satellite images can form a lasting record (Zhou et al., 2003; Schowengerdt, 1997). To meet the needs of different users for remotely sensed data, there are many remote sensing systems offering a wide range of spatial, spectral and temporal parameters.

The U.S. Department of Transportation (U.S. DOT) initiated the Commercial Remote Sensing and Spatial Information Technology Application to Transportation program in 1999 in collaboration with the National Aeronautics and Space Administration (NASA) in accordance with Section 5113 of the Transportation Equity Act for the 21st Century. The program was intended to focus on unique and cost-effective application of remote sensing and spatial information technologies for achieving transportation research goals. The five (originally four) application areas within the program have been (Laramie, 2003):

1) Environmental assessment, integration and streamlining;
2) Transportation infrastructure management;
3) Traffic surveillance, monitoring and management;
4) Safety hazards and disaster assessment. So far the program has not targeted pavement construction, quality control; and

5) Highway and runway pavement construction, quality control and maintenance.

With the efforts in the past almost ten years, tremendous accomplishments have been made. This paper intends to make a survey and analysis for the applications of land satellite remote sensing in transportation infrastructure and system engineering. The survey will be divided into the following fields:

(6) Remote Sensing applied in transportation infrastructure, such as pavement construction and maintenance, and management;
(7) Remote Sensing applied in transportation planning;
(8) Remote Sensing applied in transportation safety analysis and monitoring;
(9) Remote Sensing applied in transportation operation and analysis; and
(10) Remote Sensing applied in transportation environmental analysis, such as ecosystem analysis, air pollution, etc.

REMOTE SENSING APPLIED IN TRANSPORTATION INFRASTRUCTURE

Pavement construction quality monitoring and evaluation for early scheduling of repair and maintenance are important in many areas of pavement engineering, especially in pavement management system. Remote sensing technologies using electromagnetic waves from various parts of the energy spectrum can acutely reflect the physical and chemical properties of pavement material changes, thus can be used for monitoring and evaluating pavement construction. This program has been carried out for a couple of years in cooperation with NASA and a consortium of university research centers. Many successful examples sponsored from this program can be found in the recent published papers and symposiums (References omitted!).

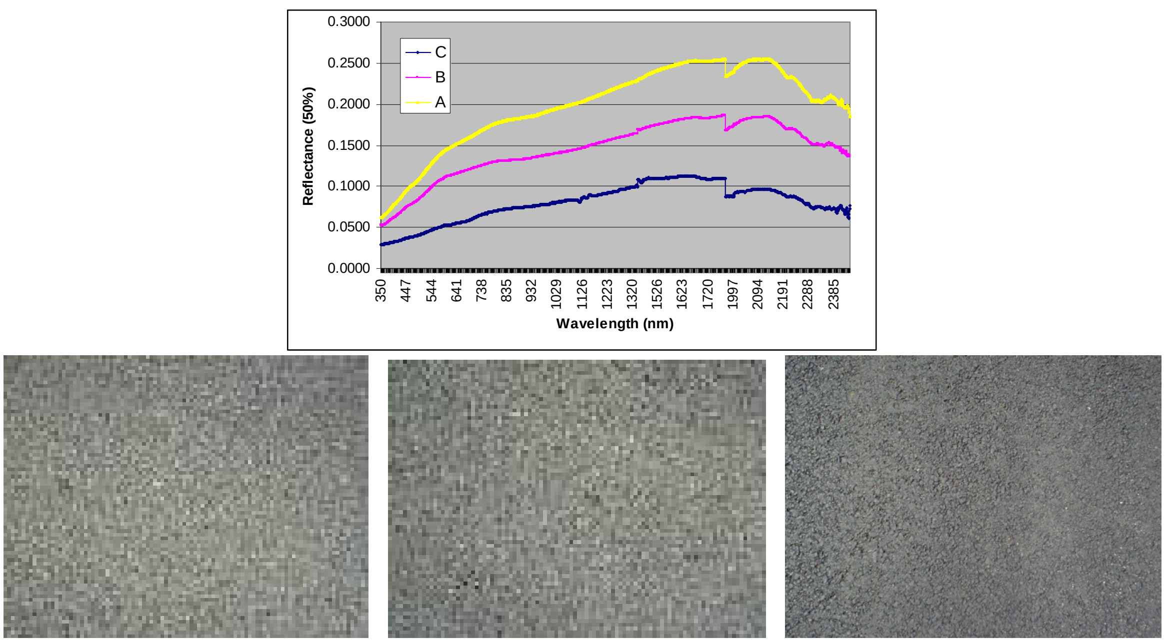
Many current researchers applied hyperspectral images for pavement mapping or high-resolution satellite imagery (e.g., IKONOS) for pavement quality management because satellite images can clearly observe/monitor the road condition, such as loss of oily components, hydrocarbon absorption, pavement condition deterioration, exposing the rocky components of the pavement, structural damages like cracking. In other words, the spectral signals for these pavement conditions can theoretically be reflected in high-resolution hyperspectral images. Lalitha (1989) used an available enhancement technique to a Landsat TM (Thematic Mapper) urban scene to ascertain which technique is effective in improving the contrast of the road features in the image. Kelley (2002) used remote sensing technology for obtaining real-time pavement specific weather information, which was used for assistance for pavement. Moriyoshi (1999) described the infrared sensing analysis of asphaltic mixture and asphaltic pavement and presented the various application of infrared sensing analysis for civil engineering. Ayalew et al. (2004) identified spatial and spectral requirements for successful large-scale road feature extraction, and further examined the benefits of using hyperspectral imaging over traditional methods of roadway maintenance and rehabilitation for pavement management applications. Spagnolini and Rampa (1999) used the Monostatic ground penetrating radar (GPR) for pavement profiling, such as layer thickness. Guo et al. (2007) developed an algorithm for suburban road segmentation in high-resolution aerial images. Many researchers, such as Beaumont (2001) have demonstrated that information acquired from the interpretation of satellite imagery can play a significant role in the planning, management and implementation of highway maintenance or rehabilitation. For example, Yoo, et al. (2005) used space-borne imagery of 1.0 meter high resolution with KOMPSAT-EOC to help road construction or repair planning. Lin et al. (2004) measured the concrete highway rough surface parameters by an X-Band scatterometer. To verify the test results, a laser profiler and a radar system were used to provide a direct measurement result. Irick and Hudson (1964) presented their research project, which contains principles and rules that can be used to design selected pavement sections and relate their behavior to similarly designed sections on AASHO Road Test. In addition, they developed the guidelines in order to provide basis for merging data of individual studies with data collected in overall program, and provide means for translation of Road Test findings to local conditions. Starks, et al. (2002) used satellite image referencing algorithms to characterize asphaltic concrete mixtures. They demonstrated from satellite imagery analysis that the corresponding mixture, the elasticity E depends on the frequency f in the range from 0.1 to 10^5 Hz. They measured the dependence of E on moderate frequencies f for different temperatures. Eckardt and White (2005) used Landsat thematic mapper to assist analysis of coarse gravel overlying a silty substrate. The silty material, known as a stone pavement, is prone to erosion.

Additionally, the other research still contain such as Keaton and Brokish (2004) used IKONOS multispectrial image to evaluate the evolving roads. Morain (2002) presented the application of Image Intelligence from Space-based and Aerial Sensors for the Critical Infrastructure Protection. He described “America's transportation systems are predicated on economic, social, and political stability. After the epiphany of September 11, and subsequent national alerts, however, all sectors of transportation, not just in the USA, but around the world have become keenly aware of the vulnerabilities inherent in such systems; and of the cascading consequences that can arise from attacks at critical nodes in any one or more of the transportation sectors." Liu et al. (2006) presented an algorithm to pavement cracking detection based on multi-scale space, since conventional human-visual and manual field pavement crack detection method are very costly, time-consuming, dangerous, labor-intensive and subjective. A robust and high-efficient parallel pavement crack detection algorithm based on multi-scale space was presented.

AN EXAMPLE: HYPERSPECTRAL IMAGERY APPLIED IN PAVEAGEMENT AGING

Spectral Properties of Asphalt Aging

With the given data, we first analyze the spectral properties of asphalt aging and road surface friction because with the increasing aging, the loss of oily components by volatility or absorption changes of composition by oxidation, and molecular structuring that influence the viscosity of the asphalt mix [15]. The results of these processes results in the different road surface friction (textures), which are exposured in spectral properties. FIGURE 1 depicts three spectral samples of road asphalt with varying ages of the pavement. Spectrum C reflects a paved road, whose surface is completely sealed with asphalt mix at an age of one year. As seen from FIGURE 1, the younger the paved road, the lower the spectral reflectance; and the minimum reflectance is near 350 nm with a linear rise towards longer wavelengths. Spectrum A represents a reflectance for an old, deteriorated road surface (see Fig. 1a). With the erosion and aging of the asphalt mix the road surface is less viscous and more prone to structural damages like cracking, resulting in high reflectance. In addition, as seen from Fig. 1, for longer wavelengths, Spectrum C exhibits some obvious absorption features in the SWIR. The low overall reflectance suppresses most of the distinct features except the most prominent ones near 1750 nm and from 2200-2500 nm. This causes the strong reflectance decrease beyond 2200 nm.



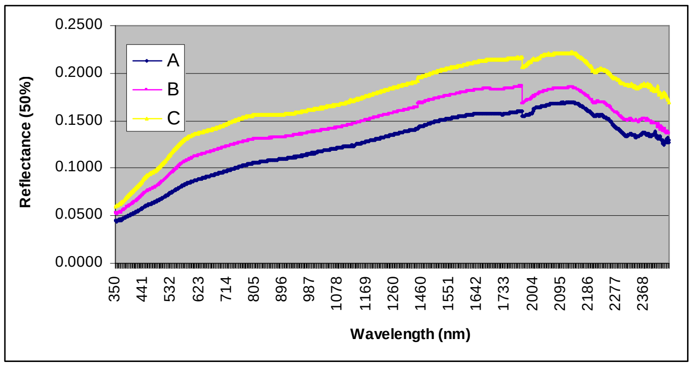
(a) (b) (c)

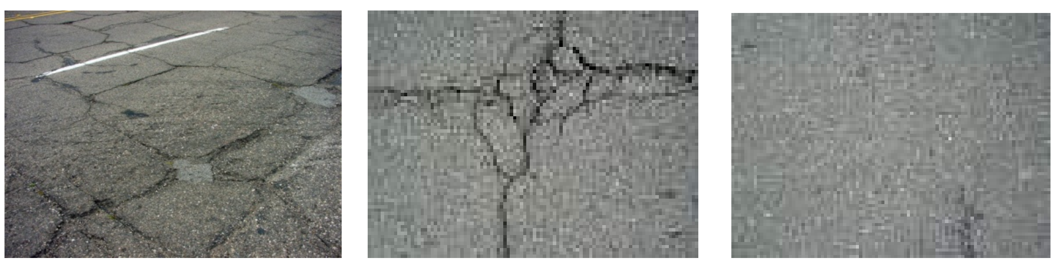
Figure 1. Spectral effects of asphalt aging and deterioration from the ground spectral measurements: (a) age greater than 10 years, (b) age less than 3 years, and (c) age is less that one year.

Spectral Properties of Typical Asphalt Road Distresses

As known, different typical asphalt road distresses cause different frictions, thus we need analyze the spectral properties of asphalt road distresses, and then further explore its relationship with the friction. FIGURE 2 shows the results of the spectral reflectance in response to structural damages or Alligator cracks at different severity. As seen from FIGURE 2, the cracking distress has significant impact to spectral reflectance in all spectrums, and it exposes deeper layers of the pavement with higher contents of the original asphalt mix that is then manifested in increased hydrocarbon absorption features. This fact highlights the contrary spectral signal between road deterioration of the pavement itself (FIGURE 1) and the severity of structural damages (FIGURE 2). The concave shape in the VIS/NIR is more obvious for brighter, noncracked road pavements.

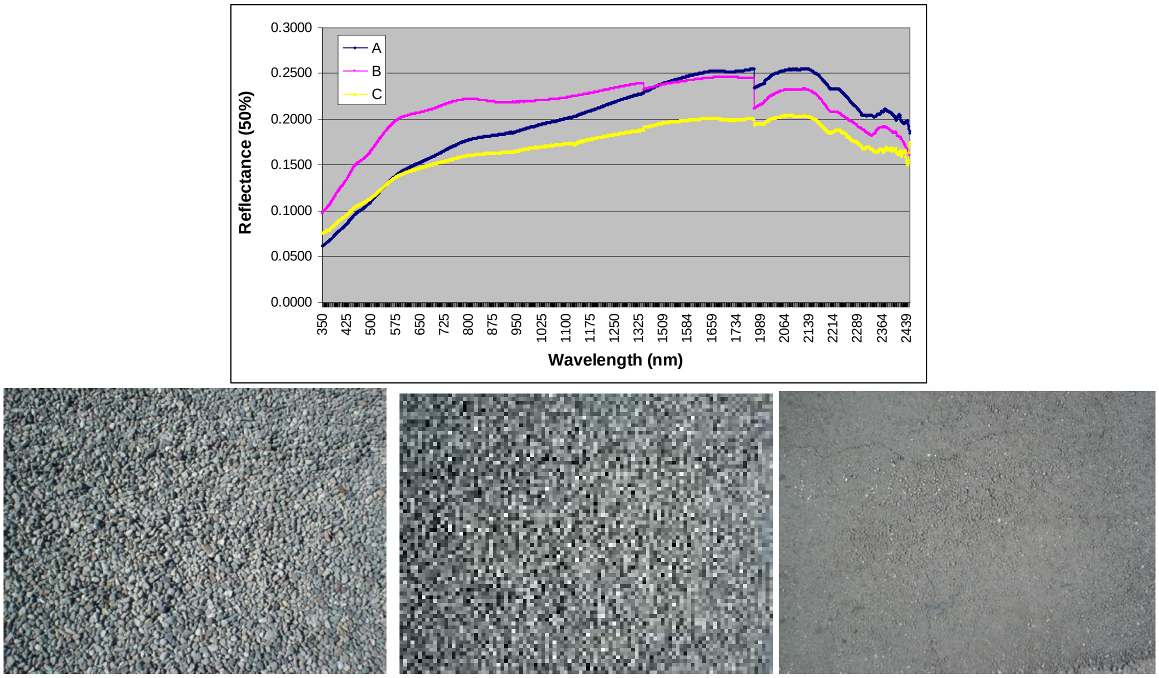
For the raveling distress, FIGURE 3 shows a comparison of spectral reflectances. FIGURE 3a exhibits larger amounts of rocky components and FIGURE 3b exhibits raveling debris (gravel) on the surface, both of them are compared to the normal pavement. As seen from Fig 3, the reflectance increases due to increasing mineral reflectance and less prominent hydrocarbon absorptions. In comparison with the pavements, spectrum C, which reflects a gravel parking lot surface, has higher reflectance in the visible and photographic near infrared due to the missing hydrocarbon absorptions. The mineral composition is reflected in more prominent features from iron oxide and other minerals like a calcite feature near 2320 nm [15].





(a) (b) (c)

Figure 2. Spectral effects of severity of structural road damages from the ground spectral measurements: (a) high severity cracking, (b) low severity cracking, and (c) no crack.

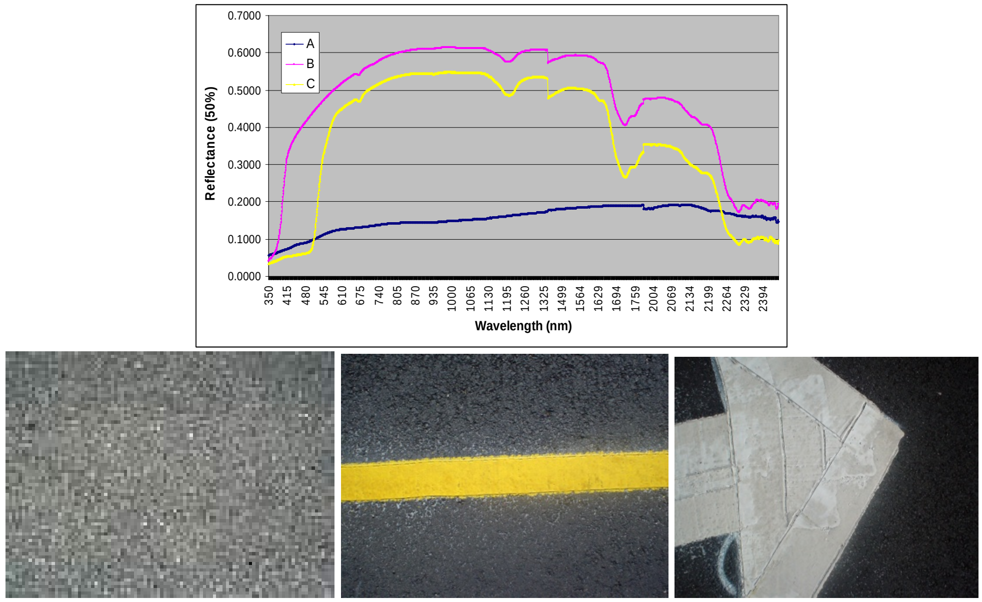


(a) (b) (c)

Figure 3. Spectral effects of raveling from the ground spectral measurements, (a) gravel pavement, (b) raveling pavement, and (c) normal pavement.

Spectral Properties of Asphalt Paint

Herold et al. [15] have demonstrated that street paint have a significant impact to pavement spectral analysis because they have highly reflective properties. For example, Spectra A and B in FIGURE 4 show reflectance values up to 60 % in the VIS/NIR region. The difference between spectrum A and B in the visible region is due to different colors since spectrum B represents yellow street paint and blue wavelengths are absorbed, and the spectrum A represents white Turn symbol. In addition, the street paint, with a typical asymmetric hydrocarbon doublet, has a strongest absorption at 1720 nm [25]. From a remote sensing perspective the presence of street paint will increase brightness of a road surface especially in the VIS/NIR and emphasize the hydrocarbon absorptions in the SWIR.



(a) (b) (c)

Figure 4. Spectral characteristics of street paint in different color versus asphalt pavement from the ground spectral measurements: (1) normal pavement, (b) yell street paint, and (c) white street paint.

Modeling the Relationship between Spectral Reflectance and Skid Resistance

In order to model the relationship between spectral reflectance and friction as exact as possible, we divided the surface road into 3 categories: new asphalt road, asphalt road with 1-3 year old, and asphalt road with over 10 year old. For each category, a polynomial equation is applied to fit the reflectance curve. The results are depicted in FIGURE 6 through FIGURE 8. For each regress analysis below, the values are in reflectance as parts of one (0.5=50 % reflectance). The spectral measurements range from 350-2450 nm (bandwith 1 nm). The major water vapor absorption bands (1340-1450 nm and 1790-1970 nm) have been deleted. No noise removal or any related modifications have been performed and every user of the library should consider that.

Category I: New Asphalt Road with Age Less Than One Year

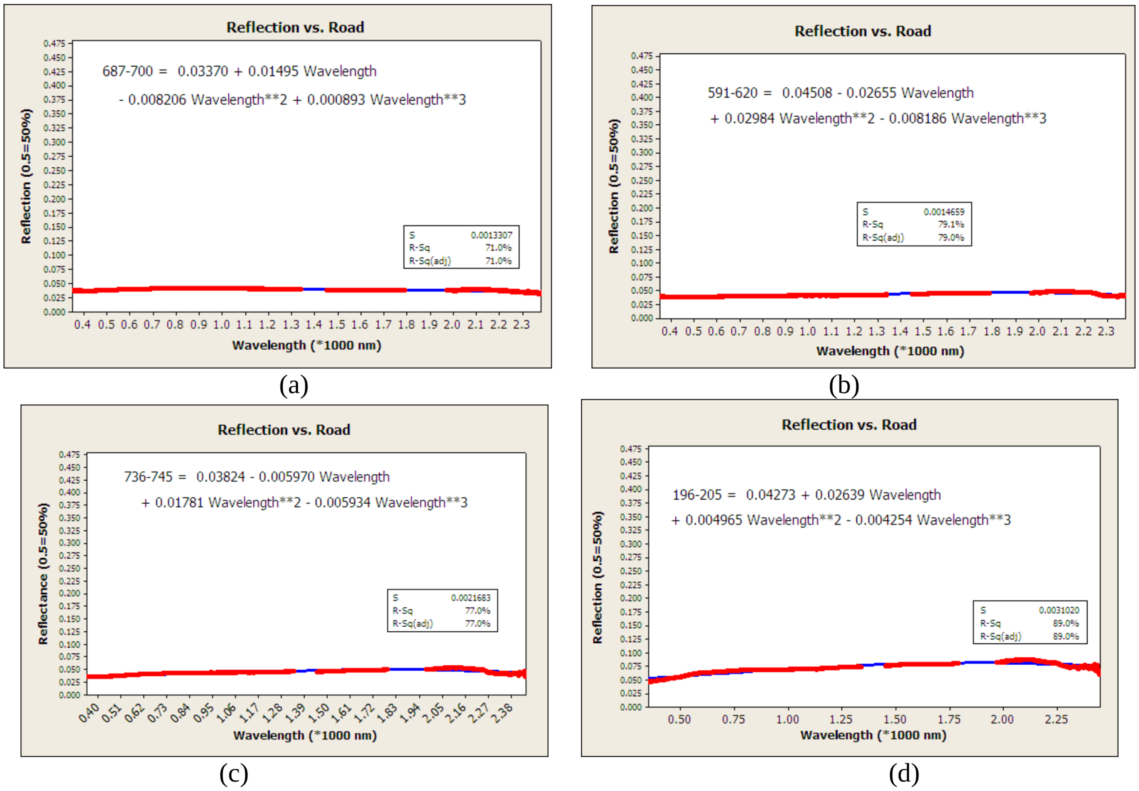
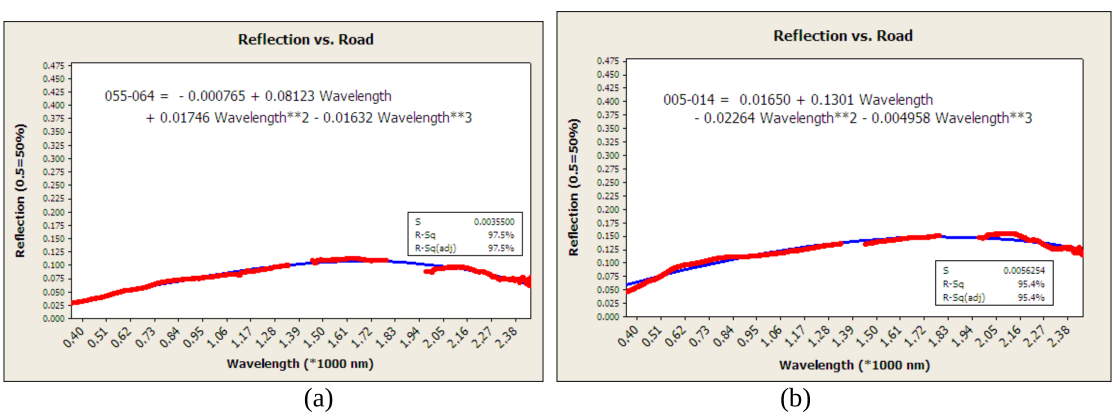


Figure 6. Spectral reflectance for type I road (data is from the ASD ground spectral measurements, and the major water vapor absorption bands are interpolated).

Category II: Asphalt Road with Age of 3 Years Old



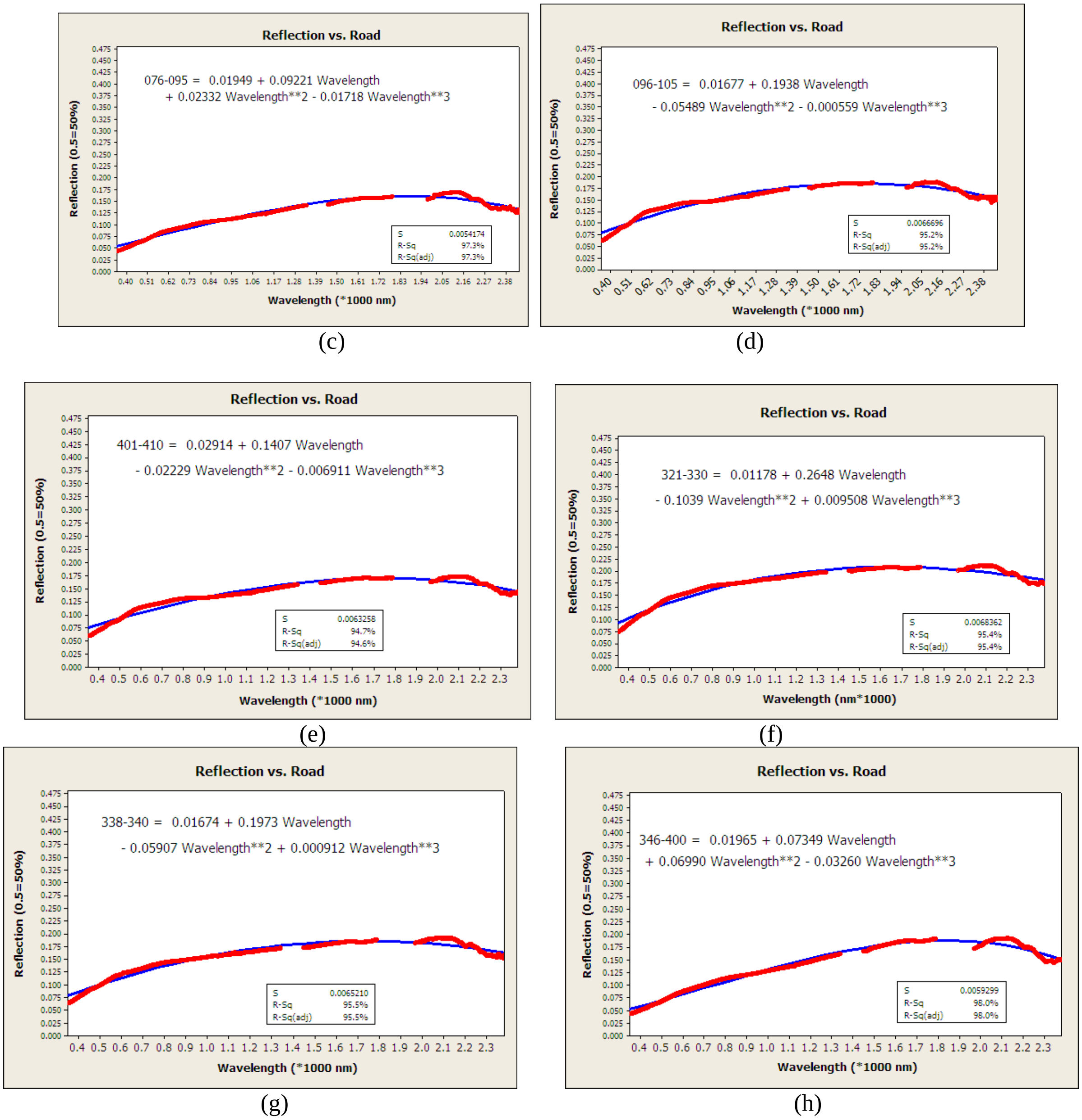
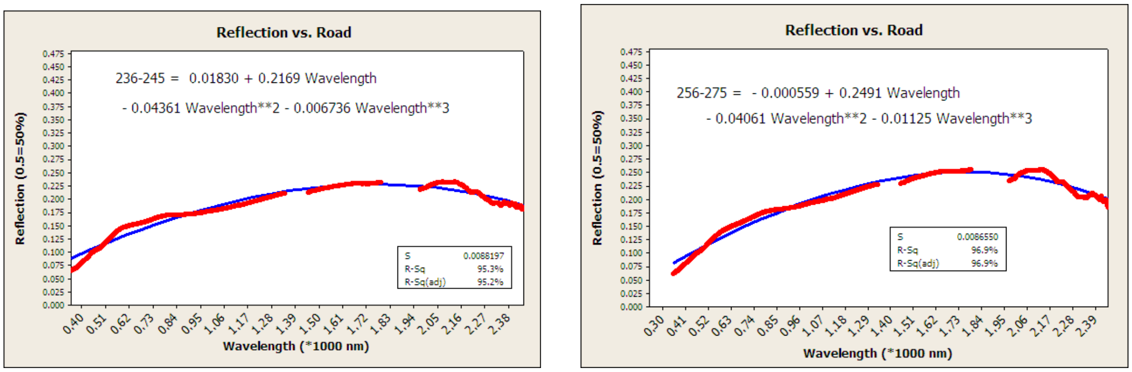


Figure 7. Spectral reflectance for type II road (data is from the ASD ground spectral measurements, and the major water vapor absorption bands are interpolated).

Category III: Asphalt Road with Age of over 10 Years Old



(a) (b)

Figure 8. Spectral reflectance for type III road (data is from the ASD ground spectral measurements, and the major water vapor absorption bands are interpolated).

Validation of Established Model

We have developed an algorithm, called *spectral reflectance curve matching,* to validate the established model. The basic idea is: The established model of describing the spectral reflectance of different type of road surface is taken as reference data, i.e., the corresponding parameters (c, X1, X2, and X3) of the model will be used as reference data. For a specific type of road, its spectral reflectance curve can be obtained, i.e., can be modeled (c', X1', X2', and X3'). We then match the corresponding coefficients of two models. If the differences of all corresponding parameters are less than a given thresholds, we will accept the model, and the corresponding skid resistance will be assigned to this type of road.

When we accept this spectral reflectance, the corresponding skidding resistance is assigned to this road. For this example, 0.56- 0.67 has been assigned to this road. This implies that this road age is about 1-3 year old. We pulled out this image and showed in FIGURE 10.

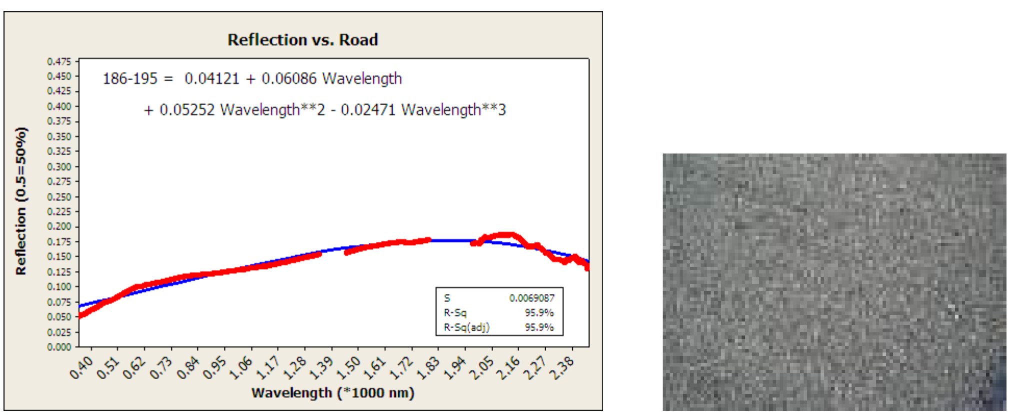


Figure 10. The recognized road associated with skid resistance at 0.56-0.67 through the spectral reflectance matching.

With the above the step, we in fact have found the AOI (are of interest) for mapping the skid resistance. We used ENVI software to map the skid resistance. The results are depicted in FIGURE 11, in which all of read points indicate that their skid resistance is about 0.56-0.67. Similarly, we also test the road at age of less than one year, associated with the skid resistance at 0.56-0.67. The results are depicted in FIGURE 12.

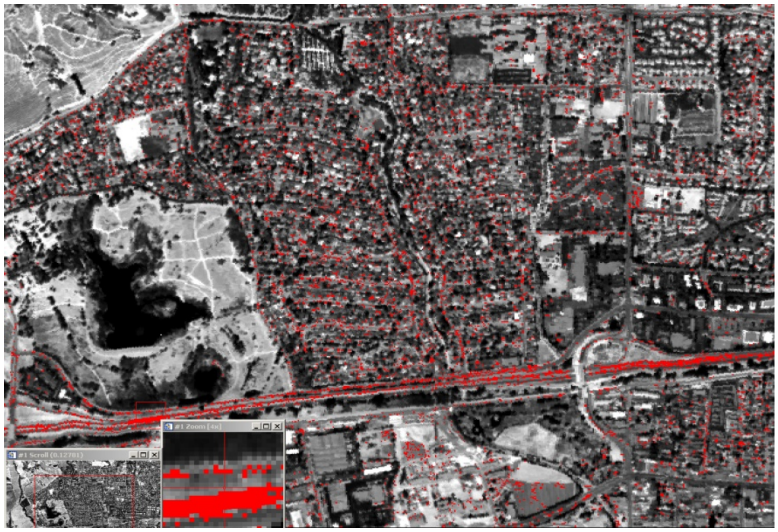


Figure 11. Mapping skid resistance at 0.56-0.67 using established model under ENVI software environment.

REMOTE SENSING APPLIED IN TRANSPORTATION SYSTEM ENGINEERING

Zhou (2008) has made a comprehensive analysis on remote sensing applied in transportation system engineering. The 4 major cartogries are analyzed. They are

1. ***Remote Sensing Applied In Transportation Planning:*** The major efforts include such as Gipps (2001), Lakshman and Reddy (2003), Kosmin (1985), Bogdanov (1999), Devereux et al. (2005), Beaumont (1978), Shirotori (1998), Souleyrette et al. (2006), Rao (1996), Lakshman (1993), Lee et al. (2002).
2. ***Remote Sensing Applied In Transportation Safety Analysis And Monitoring:*** The major efforts include such as Palubinskas et al. (2005), Dantas et al. (2000), Jeon et al. (2005), Suchandt et al. (2007) .
3. ***Remote Sensing Applied In Transportation Operation And Analysis:*** Luo et al. (2005), Bruneau (2005), Lee et al. (2003), Goel et al. (2006), Coifman (2004), Mishalani et al. (2002), Veneziano et al. (2002), Sharma et al. (2006), Lee et al. (2003), and so on.
4. ***Remote Sensing Applied In Transportation Environmental Analysis:*** The remote sensing has widely been applied in transportation environmental analysis. Tremendous accomplishments have been achieved in the past decades of years. The related literatures in the Engineering Village database have achieved several hundreds when searching with key words: transportation environmental analysis, remote sensing. A comprehensive analysis is being conducted.

CONCLUSION AND REMARK

This paper intends to make a survey and analysis of satellite remote sensing applied in transportation infrastructure and system engineering. Although hundreds of papers have been reviewed, part of their work is listed in this paper. Unfortunately, analysis of the current satellite remote sensing applied in transportation has not been described in this paper because of time. We are planning to report this part in the annual TRB meeting in 1009 if time available. This paper will analyze how the spatial resolution, spectral resolution, and temporal resolution of satellite remote sensing impact their application in transportation engineering. In summary, spatial information technologies of GIS have been widely utilized to transportation-related systems, as a part of ITS (Intelligent Transportation System); however, application of remotely sensed imagery to this field is not width and extensive in general. Many efforts still need to be investigated. For example, application of remotely sensed imagery in consideration to analysis with vector-typed digital data sets in the node-link structure can effectively used in transportation planning, but they are very large and complex task when applied in various fields.

ACKNOWLEDGAGEMENTS

We sincerely thank those authors, who contributed their work to this paper, but their papers or names may not have been listed in this paper. This paper simply collected their contributions in this field. If their papers or names are listed in this paper, please accept my apology.

REFERENCES

Individual citation has not been listed in this paper because too many papers are cited. A few descriptions in this paper are directly from some literatures, but may have not been cited BECAUSE OF both page limit and too many references.