Assessment of asphalt pavement aging condition based on GF-2 high-resolution remote sensing image

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Article

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Abstract

The aging condition of asphalt pavement is a crucial basis for traffic infrastructure evaluation. Due to the long time and high cost required to monitor and identify the aging condition of asphalt pavement, many current studies have focused on the application of satellite remote sensing methods. Based on the previous research results, we used PCI data and GF-2 high-resolution remote sensing images. The experimental results show that the DHI, RHI, and NDHI using GF-2 data can reflect the aging of asphalt pavement to varying degrees. This paper presents an entirely new asphalt pavement aging index, named the New Aging Index (NAI). It can not only perfectly identify the different aging conditions of asphalt pavements, but also has a significant distinguishing effect on the pavement interference information such as shadows and vehicles. NAI combined with GF-2 high-resolution remote sensing images can be used to assess the aging condition of asphalt pavement.

Introduction

In the actual operation process of highway pavement, due to the influence of temperature, moisture, weathering, and load factors, the strength of the pavement structure will gradually decrease, which eventually leads to the aging of the road surface and a variety of diseases (such as cracks, potholes, ruts, etc.)[1]. This greatly reduces the performance of the road surface but also brings huge economic losses and accident risk[2].

In recent years, China's highway mileage has developed rapidly, and the number of roads to be maintained has also increased steadily (Fig. 1). By the end of 2021, the total length of roads in China was 5.2807 million kilometers, an increase of 82,600 kilometers over the end of the previous year. The length of highway maintenance was 5.2516 million kilometers, accounting for 99.4% of the total highway mileage[3]. When the health condition of the road surface has problems and cannot be maintained in time, it will bring great inconvenience to people's daily life and the transportation industry, and bring great pressure to the supervision and maintenance of the road by the transportation department[4]. Therefore, the rapid investigation and detection of road conditions are of great significance for the safe and stable operation of road traffic[2]. However, different road materials, different road diseases, and different road aging degrees will bring considerable management difficulty to road supervision, management, maintenance, and renovation work[4, 5]. Therefore, there is an increasingly urgent need for macroscopic, large-scale health monitoring and management of roads.

The data source of Fig. 1 is the website of the Ministry of Transport of the People's Republic of China. The applied software is WPS Office (vision 2022) and the URL link is https://www.wps.cn.

In the early stage of highway development, the survey of road surface conditions is mainly carried out through manual measurement by road maintenance personnel[2]. However, the manual detection method is less efficient and is destructive to the road surface. With the development of computer and sensor technologies, some advanced sensors and devices such as onboard laser detectors and image
acquisition systems are used for road condition detection\cite{6-9}. These devices can obtain real-time road condition information and conduct qualitative diagnosis and quantitative evaluation analysis to provide support for scientific maintenance decisions\cite{10-12}. However, these technologies still have disadvantages such as traffic obstruction, high cost, and time consumption, and the sampling survey cannot quickly obtain the road condition information of the whole section. With the rapid development of satellite earth observation technology, especially high-resolution remote sensing satellites, satellite remote sensing technology has shown great application potential in the application of road surface condition detection because of its characteristics of macroscopic nature, present situation, and objectivity\cite{13-16}.

In recent years, the spectral characteristics of asphalt pavement and the monitoring of road health status have been carried out successively at home and abroad. Herold\cite{17,18} analyzed the variable correlation between remote sensing image information and road condition, compared the relationship between index and PCI established by hyperspectral remote sensing, and verified the feasibility of monitoring road conditions by hyperspectral remote sensing. Levinson\cite{19} found that the spectral curve of aging asphalt roads showed significant slope changes in the wavelength range of 2100 ~ 2200 nm due to silicate compound absorption and 2250 ~ 2300 nm due to hydrocarbon absorption. Liu\cite{20} analyzed converting AVIRIS and HST imaging spectral data to PCI analyzed the different spectral characteristics of different road disaster units and explored the possibility of converting spectral reflectance to PCI. Emery\cite{21} used WorldView-2 images to study the correlation of pavement reflectance values and texture features of different health conditions and verified the feasibility of high-resolution satellite images in pavement condition evaluation. Mei\cite{22,23} used the reflectivity value of different roads at 460 nm and 740 nm to draw the scatter plot, and found that these points were on the same "asphalt line", and the same level of asphalt road showed good polymerization, indicating the feasibility of multispectral and hyperspectral images in road condition monitoring. Manzo\cite{24} combined with road field spectral measurement data, conducted a preliminary study on the application of hyperspectral remote sensing based on airborne hyperspectral images such as MIVIS and AVIRIS and found that the road spectral features have corresponding changes with the change of road condition. Jin\cite{25} used the difference of asphalt pavement with different aging degrees in the wavelength range of 400 to 900 nm to propose the difference health index, ratio health index, normalized difference health index, and logarithmic health index and make a comparative analysis. Pan\cite{2} summarized the research progress of remote sensing monitoring of highway pavement quality and pointed out that the pavement condition monitoring technology based on airborne and airborne sensors still has deficiencies such as low precision and poor robustness. Cheng's\cite{4} aging assessment results based on the MAI index and WorldView-2 remote sensing images are in good agreement with the results of road field investigation, which can achieve a large-scale aging assessment.

In general, the application of remote sensing in road health monitoring is relatively few, and the use of asphalt pavement by remote sensing aging monitoring is still in the preliminary exploration stage\cite{26-29}.
On the one hand, the spectral response mechanism of asphalt pavement is still in the research stage; on the other hand, the mature method and effective quantitative evaluation model[4,30,31].

Given the above deficiencies, this study starts with the analysis of the spectral characteristics of asphalt pavement with different aging degrees. Then, the aging monitoring index of road asphalt pavement suitable for the actual situation is constructed innovatively. Finally, GF-2 high-score remote sensing images are used to verify and evaluate the proposed index, and to demonstrate the applicability of high-resolution remote sensing data in the aging condition assessment of asphalt pavement to provide technologies for the transportation department to realize a wide range of macro monitoring road conditions[32].

**Study area**

The research area is selected near the eastern section of Hunnan Middle Road in Hunnan District, Shenyang City, starting from Changqing Street in the west and Guogongzhai Street in the east, including Changqing Bridge, Xinlipu Bridge, Zhuke Street, and parts of Hunnan Expressway (Fig. 2). The roads in this area are wide. Hunnan Middle Road is a two-way eight-lane, and other pavement streets are two-way six-lane. The buildings on both sides of the road are far away, less sheltered, and have a good vision. All these are conducive to the extraction of road aging information on remote sensing images[33]. Although the aging condition of the research objects is different, most of the road surface is complete, and only a few of the sections have individual damage phenomena, such as cracks, pits, and other diseases. After the field investigation, 6 sections with different aging degrees of the asphalt pavement were selected for the actual measurement of the pavement technology (Fig. 2), which was mainly used to study the spectral characteristics of the asphalt pavement with different aging degrees.

**Data And Methods**

**GF-2 high-resolution remote sensing data acquisition and pretreatment**

The experimental data used GF-2 satellite images on November 5, 2021, including 1m panchromatic images and 4m multispectral images. The data source is the Research and Application Center of Liaoning Town and Traffic Environment of the High-Resolution Earth Observation System of Shenyang Jianzhu University. After the positive and positive correction of the multispectral data and the euchromatic data based on the ENVI 5.3 platform, the two images were fused. Then, the ArcGIS 10.2 software was used to visually extract the vector data of the roads within the study area.

**Assessment of pavement technical condition**

To facilitate the analysis of the spectral change characteristics of these aging asphalt pavements, this paper calculates the Pavement Condition Index (PCI) according to the highway technical condition assessment method stipulated in the Highway Technical Conditions Assessment Standard (JTG 5210-2018).
PCI is related to the type of road damage and the severity of the damage. The severity of damage can be described by counting the geometric characteristics of the disease, such as crack length and density, number and size of pits, length, and width of ruts, etc\textsuperscript{[34-36]}. The PCI calculation formula is as follows:

\[
\text{PCI} = 100 - a_0 \cdot DR^{a_1} \quad (1)
\]

\[
\text{DR} = 100 \times \frac{\sum_{i=1}^{i_0} w_i A_i}{A} \quad (2)
\]

In the formula, DR is the pavement damage rate (pavement distress ratio), which is the sum of various diseases and that of the pavement survey area (%); \(A_i\) is the area (\(m^2\)); \(A\) is the pavement area (the product of survey length and effective pavement width, \(m^2\)); \(w_i\) is the weight of Class I pavement disease damage, different pavement types have different values, please refer to the Highway Technical Conditions Assessment Standard (JTG 5210-2018). Model parameter \(a_0\) is 15.00 for asphalt pavement. Model parameter \(a_1\) is 0.421 for asphalt pavement. \(i\) is the pavement damage type of item \(i\) considering the degree of damage (light, medium and heavy). The \(i_0\) is the total number of damage types including the degree of damage (light, medium, heavy), asphalt pavement \(21\)\textsuperscript{[2]}.

**Spectral characteristic analysis of asphalt pavement**

The spectral change of asphalt pavement is mainly caused by the change in the pavement chemical composition and the exposure degree of rock aggregate during the road aging process (Figure 3)\textsuperscript{[25]}.

After Jin obtained the road surface spectral data from the ground measurement using FieldSpec ProFR portable earth spectral radiation meter, it was found that the new and old roads were significantly different between 400 and 900nm (Figure 4). At 400~900nm, the more serious the pavement aging, the faster the reflectivity increases, and it is not affected by the reflectivity value\textsuperscript{[25]}.

Cheng used the ASD FieldSpec spectrometer to measure the spectral reflectance data of the road surface. After analyzing the spectral curve by the guide and envelope removal, the reflectivity of the asphalt pavement within 400-680nm increases; the reflectivity of the spectral curve of the aged asphalt pavement decreases between 860nm and 970nm, while the new asphalt pavement increases (Figure 5)\textsuperscript{[4]}.

According to the above characteristics of the asphalt pavement spectral curve, combined with the wavelength coverage of GF-2, the GF-2 blue band (450~520nm), red band (630~690nm), and near-infrared band (770~890nm) in the range of 450~890nm are selected as the parameters for studying the aging index of asphalt pavement. Referring to the research results of Jin, Pan, Cheng, and Xu, a spectral index model reflecting the aging condition of asphalt pavement and suitable for GF-2 data is finally constructed\textsuperscript{[25]}.
Difference Health Index (DHI): DHI is a road health spectral index constructed based on the difference in reflectance between the near-infrared band and the blue light band. The newer the road surface, the smaller the reflectance gap between the NIR band and the blue light band; the older the road surface, the larger the gap.

\[ DHI = B4 - B1 \]

(3)

Ratio Health Index (RHI): RHI is a road health spectral index constructed based on the ratio of the reflectivity of the near-infrared band and the blue light band.

\[ RHI = \frac{B4}{B1} \]

(4)

Normalized Difference Health Index (NDHI): NDHI is a health index constructed according to the normalized vegetation index.

\[ NDHI = \frac{B4 - B1}{B4 + B1} \]

(5)

Both B4 and B1 are the reflectivities of band 4 and band 1 of GF-2 spectral data, respectively.

**Experimental Results**

**Test results of PCI**

After field measurement and calculation according to the formula, the Pavement Condition Index (PCI) and aging degree of 6 experimental subjects are shown in the table below Table 1. According to the evaluation method of highway technical conditions specified in the Standard for Evaluation of Highway Technical Condition (JTG 5210-2018), the aging condition of asphalt pavement is divided into five grades: excellent, good, average, bad, and worst.

Table 1 Pavement Condition Index (PCI) and aging determination of the subjects.
<table>
<thead>
<tr>
<th>Object name</th>
<th>Discrimination</th>
<th>PCI</th>
<th>Pavement technical condition grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changqing Bridge section 1</td>
<td>Longitudinal cracks and transverse cracks</td>
<td>88.27</td>
<td>good</td>
</tr>
<tr>
<td>Changqing Bridge section 2</td>
<td>longitudinal crack</td>
<td>96.32</td>
<td>excellent</td>
</tr>
<tr>
<td>Changqing Bridge section 3</td>
<td>Longitudinal cracks and transverse cracks</td>
<td>89.93</td>
<td>good</td>
</tr>
<tr>
<td>Hunnan Expressway section 1</td>
<td>not have</td>
<td>100</td>
<td>excellent</td>
</tr>
<tr>
<td>Hunnan Expressway Section 2</td>
<td>not have</td>
<td>100</td>
<td>excellent</td>
</tr>
<tr>
<td>Hunnan Expressway Section 3</td>
<td>not have</td>
<td>100</td>
<td>excellent</td>
</tr>
<tr>
<td>Zhuke Street section 1</td>
<td>Crack, longitudinal crack, and transverse crack</td>
<td>52.96</td>
<td>worst</td>
</tr>
<tr>
<td>Zhuke Street section 2</td>
<td>Crack, longitudinal crack, and transverse crack</td>
<td>47.59</td>
<td>worst</td>
</tr>
<tr>
<td>Zhuke Street section 3</td>
<td>Crack, longitudinal crack, and transverse crack</td>
<td>49.25</td>
<td>worst</td>
</tr>
<tr>
<td>Hunnan Middle Road section 1</td>
<td>Cracks, longitudinal cracks, transverse cracks, and rutting</td>
<td>74.01</td>
<td>average</td>
</tr>
<tr>
<td>Hunnan Middle Road section 2</td>
<td>Cracks, longitudinal cracks, transverse cracks, and rutting</td>
<td>74.46</td>
<td>average</td>
</tr>
<tr>
<td>Hunnan Middle Road section 3</td>
<td>Longitudinal cracks and transverse cracks</td>
<td>88.02</td>
<td>good</td>
</tr>
<tr>
<td>Xinlipu Bridge section 1</td>
<td>Longitudinal cracks and transverse cracks</td>
<td>81.55</td>
<td>good</td>
</tr>
<tr>
<td>Xinlipu Bridge section 2</td>
<td>Longitudinal cracks and transverse cracks</td>
<td>78.1</td>
<td>average</td>
</tr>
<tr>
<td>Xinlipu Bridge section 3</td>
<td>Longitudinal cracks and transverse cracks</td>
<td>79.5</td>
<td>average</td>
</tr>
<tr>
<td>Guogongzhai Street section 1</td>
<td>Lateral cracks and longitudinal cracks</td>
<td>84.94</td>
<td>good</td>
</tr>
<tr>
<td>Guogongzhai Street section 2</td>
<td>transversal crack</td>
<td>95.06</td>
<td>excellent</td>
</tr>
<tr>
<td>Guogongzhai Street section 3</td>
<td>transversal crack</td>
<td>90.83</td>
<td>excellent</td>
</tr>
</tbody>
</table>
Verification results of the aging index of asphalt pavement

According to the three pavement health monitoring indexes described in section 3.3, the corresponding experimental road sections (Figure 6) were selected from the GF-2 high-resolution remote sensing image to carry out the asphalt pavement aging condition extraction experiment. According to the membership function method, with the help of the Update Range tool of the eCognition, three health monitoring indexes were used to extract the aging conditions of the asphalt pavement of the experimental objects in turn. The experimental results of Guogongzhai Street and Xinlipu Bridge selected for display are shown in Figure 7.

From the comparison of the above experimental results, we can see that the three indexes can reflect the aging of asphalt pavement to different degrees, but there are some differences in extraction results and applicability (Figure 8). Through comparison and analysis with the actual measurement results of pavement aging, it can be seen that the extraction results of RHI and NDHI in the three indexes can accurately reflect the aging situation of asphalt pavement. DHI is strongly affected by external factors, and there are some differences with the actual situation of asphalt pavement aging. The extraction result of RHI shows the shadow area very clearly, but it cannot effectively show the presence of vehicles. The extraction result of NDHI can clearly show the shadow area, but cannot show the presence of vehicles. Although the extraction result of DHI can clearly show the position of vehicles, it is very insensitive to the presence of shaded areas.

Based on the data obtained from the tested samples, the univariate linear regression models between PCI and DHI, RHI, and NDHI established using IBM SPSS Statistics software are shown in the figure below. The simple linear correlation coefficients R between PCI and DHI, RHI, and NDHI are -0.41, 0.58, and 0.61, respectively (Figure 9). It can be seen that PCI is significantly correlated with RHI and NDHI, while it is weakly correlated with DHI.

In general, RHI and NDHI are relatively good aging condition monitoring indexes among the three indexes, which can meet the extraction of asphalt pavement aging conditions without interference information to a certain extent. However, for the common shadow and vehicle interference, the two indexes cannot be effectively distinguished. This makes it impossible for RHI and NDHI to combine GF-2 high-resolution image data for extensive road aging condition extraction.

Innovative results of the aging index of asphalt pavement

After a deep understanding of the aging spectral curve of asphalt pavement and summarizing a large number of experimental results, this paper proposes a new kind of aging index of asphalt pavement, namely the New Aging Index, NAI. Due to the good performance of RHI and NDHI in asphalt pavement aging monitoring, NAI combines the calculation characteristics of the two indexes. The NAI formula is as follows (NDHI in the formula is the Normalized Difference Health Index in formula (5)). The results of asphalt pavement aging conditions of Guogongzhai Street and Xinlipu Bridge extracted by this method are shown in Figure 10.
NAI=(NDHI-B)/(NDHI+B)×NDHI \hspace{1cm} (6)

Combined with the actual field survey data, after comparison and analysis with the extraction results of DHI, RHI, and NDHI, it is found that NAI can not only effectively indicate the aging condition of asphalt pavement, but also accurately identify the shadow area and the presence of vehicles on the road surface (Figure 11).

After collecting the sample points in the high-resolution remote sensing images, the NAI of each experimental section is shown in the figure below (Figure 12).

According to the simple linear correlation analysis formula, the simple linear correlation coefficient $R^2$ between PCI and NAI is 0.799. Thus, NAI and PCI are strongly correlated (Figure 13). The regression results were tested for significance, with statistics $R^2F=63.8$ and significance $\alpha \leq 0.000$. The linear relationship between the two relationships can be considered significant in statistics. Therefore, the NAI can be used to characterize the aging condition of the asphalt pavement.

Through the above comprehensive verification, it is found that the New Aging Index (NAI) can not only perfectly extract the aging situation of asphalt pavement, but also have a good distinction for the pavement interference information such as shadow and vehicles.

**Extraction results of the aging condition of the asphalt pavement**

The figure above shows the results of the road aging conditions in the study area using the New Aging Index (NAI). It can be seen from the figure that the aging condition of Zhuke Street is more serious, followed by Hunnan Middle Road. The aging condition of Guogongzhai Street has also developed significantly. The roads of Hunnan Expressway and Changqing Bridge are in good condition. These are completely consistent with the actual investigation, which shows that NAI can actually distinguish different aging conditions of the pavement, and can be used to achieve a wide range of pavement health assessment and monitoring.

Compared with the traditional PCI index of road physical parameters such as rupture, rutting, and flatness, the quantitative model from the perspective of road spectral characteristics, can be realized by remote sensing means, rapid monitoring, and evaluation, do not need a lot of human resources to field measurement evaluation, more can meet the demand of road maintenance.

**Conclusion**

Based on of fully studying the spectral characteristics of asphalt pavement with different aging conditions, this paper used GF-2 high-resolution remote sensing image to verify and compare the health monitoring index of asphalt pavement proposed by predecessors, taking the asphalt pavement of some sections of Hunnan Middle Road in Shenyang as an example. After the analysis, the extraction index of the aging degree of asphalt pavement suitable for GF-2 data is proposed. It has been proved that the New
Aging Index (NAI) has a good effect on the aging condition of asphalt pavement. The main conclusions are summarized as follows:

(1) According to previous achievements, DHI, RHI, and NDHI were proposed for GF-2 data. After experimental verification, the three kinds of indices can reflect the aging situation of asphalt pavement to varying degrees, but there are some differences in their applicability. RHI and NDHI have a high correlation with PCI, which can meet the extraction of asphalt pavement aging conditions without interference information to a certain extent.

(2) A new asphalt pavement aging index proposed in this paper, namely the New Aging Index (NAI), can not only perfectly extract the aging situation of asphalt pavement, but also have a good role in distinguishing the road interference information such as shadows and vehicles. At the same time, NAI has a significant linear relationship with PCI, and the NAI can be used to describe the aging condition of asphalt pavement.

Although some achievements have been made in this experimental study, there are still the following deficiencies: the value of the index and the degree of road aging are mainly based on empirical value, which has some subjectivity. This model is only suitable for identifying and detecting road aging, but it is not suitable for road diseases such as congestion, rutting, and cracking. The research model proposed in this paper is only applicable to asphalt pavement[4].

**Declarations**

**Acknowledgments**

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**Authors’ contributions**

DY conceived the research concept, drafted the manuscript, and managed the whole project. HW and JW collected experimental data and calculated and processed the data. ZX provided a project fund. ZH, FZ, and XW provided some materials and edited part of the paper. All authors read and approved the final manuscript.

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**Availability of data and materials**
The datasets used during the current study are available from the corresponding authors on reasonable request.

**Competing interests**

The authors declare that they have no competing interests.

**References**


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**Figures**
Figure 1

Changes of national highways in China in the past five years.

The data source of Figure 1 is the website of the Ministry of Transport of the People's Republic of China. The applied software is WPS Office (vision 2022) and the URL link is https://www.wps.cn.
Figure 2

Location map of the study area.

The source of Figure 2 is https://www.google.com. The applied software is CorelDRAW (vision 2017) and the URL link is https://www.coreldraw.com/cn.

The positions in the white boxes are the study area. a-Changqing Bridge section, b-Hunnan Expressway section, c-Zhuke Street section, d-Hunnan Middle Road section, e-Guogongzhai Street section, f-Xinlipu Bridge section
Figure 3

The aging process of asphalt pavement.

Figure 3 was modified by the author from Jin\(^{[25]}\). The applied software is CorelDRAW (vision 2017) and the URL link is https://www.coreldraw.com/cn.
Figure 4

Spectral curves of pavement with different aging degrees.

Figure 4 was modified by the author from Jin\textsuperscript{[25]}. The applied software is CorelDRAW (vision 2017) and the URL link is \url{https://www.coreldraw.com/cn}.

N-new asphalt pavement, P-preliminarily aging stage, M-moderately aging stage, H-heavily aging stage

Figure 5

Reflectivity conduction of asphalt pavement with different aging degrees.

Figure 5 was modified by the author from Cheng\textsuperscript{[4]}. The applied software is CorelDRAW (vision 2017) and the URL link is \url{https://www.coreldraw.com/cn}.
Figure 6

The corresponding position of the actually measured working road section in the remote sensing image. The source of images is the GF-2 remote sensing image. The applied software is CorelDRAW (vision 2017) and the URL link is https://www.coreldraw.com/cn.

a-Changqing Bridge section, b-Hunnan Expressway section, c-Zhuke Street section, d-Hunnan Middle Road section, e-Guogongzhai Street section, f-Xinlipu Bridge section
Extraction results of DHI (left), RHI (middle), and NDHI (right) in Guogongzhai Street. The different shades of colors in the picture represent the different aging conditions of the pavement.

The extraction results of DHI (left), RHI (middle), and NDHI (right) of Xinlipu Bridge. The different shades of colors in the picture represent the different aging conditions of the pavement.

Figure 7

Extraction results of the asphalt pavement aging condition in the corresponding road sections.

The source of images is the GF-2 remote sensing image. The applied software is eCognition Developer 64 (vision 9.0.1) and the URL link is https://www.ecognition.com.
Figure 8

The extraction results of different indexes on the shaded area and vehicles on the road of Hunan Middle Road.

The source of images is the GF-2 remote sensing image. The applied software is eCognition Developer 64 (vision 9.0.1) and the URL link is https://www.ecognition.com.

The first figure is the remote sensing image of a section of Hunnan Middle Road, which clearly shows the road under the shadow of buildings and some vehicles on the left side of the road. The second, third, and fourth figures are the results of DHI, RHI, and NDHI extraction. In the third and fourth figures, the shaded parts are divided in the middle because of the influence of urban light rail.

Figure 9

A uni-linear regression model for PCI and DHI (left), RHI (middle), and NDHI (right).

The date source is field measurement data. The applied software is IBM SPSS Statistics (vision 26) and the URL link is https://www.ibm.com/cn-zh.
Figure 10

NAI extraction results of Guogongzhai Street (left) and Xinlipu Bridge (right). The different shades of colors in the picture represent the different aging conditions of the pavement.

The source of images is the GF-2 remote sensing image. The applied software is eCognition Developer 64 (vision 9.0.1) and the URL link is https://www.ecognition.com.

Figure 11

The extraction result of NAI on the shaded area and vehicles on the road of Hunan Middle Road.

The source of images is the GF-2 remote sensing image. The applied software is eCognition Developer 64 (vision 9.0.1) and the URL link is https://www.ecognition.com.
The left figure is the remote sensing image of a section of Hunnan Middle Road, which clearly shows the road under the shadow of buildings and some vehicles on the left side of the road. The right figure is the result of NAI extraction. In the right figure, the shaded area and vehicles can be clearly displayed. The shaded parts are divided in the middle because of the influence of urban light rail.

Figure 12

The NAI in the high-resolution remote sensing images of each experimental section.

This figure is made by the author based on the field measurement data. The applied software is WPS Office (vision 2022) and the URL link is https://www.wps.cn.
Figure 13

Linearity between PCI and NAI.

The date source is field measurement data. The applied software is IBM SPSS Statistics (vision 26) and the URL link is https://www.ibm.com/cn-zh.

Figure 14

Pavement aging results of Changqing Bridge and Hunnan Expressway (left), Zhuke Street and Hunnan Middle Road (middle), Guogongzhai Street, and Xinlipu Bridge (right).

The source of images is the GF-2 remote sensing image. The applied software is eCognition Developer 64 (vision 9.0.1) and the URL link is https://www.ecognition.com