Analysis on the Applicability of High-resolution Remote Sensing Images for Highway Construction

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Abstract: This paper first analyzes and determines the scope and contents of highway engineering environmental supervision from the aspects of highway engineering composition, construction stage division, impact environmental factors and their characteristics, environmental protection requirements, etc., combines with the characteristics of high-resolution remote sensing images, proposes the construction process and supervision precision requirements for the highway engineering in which environment protection control can be carried out by using satellite remote-sensing images and UAV (unmanned aerial vehicle) remote-sensing images. Through the environmental investigation experiment of high-resolution satellite remote sensing images commonly used in typical road sections, the satellite remote-sensing images meeting the highway engineering environmental supervision requirements are selected through comparative analysis from the perspectives of spatial resolution, revisit cycle, spectral waveband characteristics, environmental supervision precision requirements and image purchase cost rationality.

1. Introduction

According to the status quo of the highway engineering environmental supervision research and practice in China and the situations of fewer quantitative supervision indicators and backward supervision means in highway engineering environmental supervision in Yunnan subtropical mountainous areas, this paper studies and establishes a highway engineering environmental supervision indicator system based on the application of high-resolution remote sensing images and the extraction and change-detection technology of highway engineering environmental supervision objects in high-resolution remote sensing images so as to improve the effectiveness of highway engineering environmental supervision work.

This paper focuses on the study of the remote-sensing image extraction method of each highway environmental supervision element, and forms the technical rules of applying high-resolution remote sensing images to engineering environmental supervision during highway construction. Based on the analysis and comparison of the performance characteristics of high-resolution remote sensing data, the advanced object-oriented remote sensing image extraction technology is adopted to research the remote sensing information extraction of various supervision indicators, so as to realize rapid extraction of environmental supervision indicators supported by high-resolution remote sensing data, finally serve the engineering environmental supervision during highway construction, and provide...
research basis for the establishment of rapid and accurate remote-sensing monitoring system for highway engineering environment. It specifically includes:

- Remote sensing application analysis of environmental supervision indicators during highway construction;
- Establishment of technical routes for extraction of environmental supervision indicator information supported by different images;
- Precision analysis on extraction of environmental supervision indicator information supported by different images;
- Selection of remote sensing images and establishment of technical routes for extraction of environmental supervision indicator information during highway construction.

2. Satellite data sources

With the growing need for environmental and resource detection and the continuous development of technology, a series of new remote-sensing technology systems have been developed faster than ever before during the last decade. In the 10 years from 1994 to 2004, up to 70 earth observation satellites were launched according to national plans. By 2020, China had launched more than 200 satellites, keeping more than 60 satellites in the sky, which is a significant progress. Hyperspectral resolution, high spatial resolution and radar remote sensing will be the main remote-sensing technology systems in the future. Since the French SPOT satellite came out with a spatial resolution of 10m, high and ultra-high spatial resolution satellite remote sensing has become an important field for some countries in the world to compete. Since 1995 and in the next few years, more than 10 ultra-high resolution remote sensing satellites or small satellites will be launched by the United States, Russia, France, Japan, Israel, India and other countries, their spatial resolutions range from 1 to 5 m, and the highest is 0.5 m, which provides a new space system and new information source for earth observation.

In addition to the full development of the remote-sensing data source acquisition technology, the processing and utilization technology of remote-sensing data has also been greatly developed with the development of modern computer technology, such as the fusion of multi-source data, the extraction of three-dimensional terrain data, the use of InSAR (Interferometric Synthetic Aperture Radar) technology, and so on.

In order to study the monitoring ability of remote sensing images with different resolutions on engineering environmental elements during highway construction and determine the applicability of each remote-sensing image in project supervision, the project team collected multi-phase and multi-source panchromatic and multi-spectral data according to the proposed project characteristics, remote-sensing image characteristics and precision requirements. It includes ALOS, QuickBird, WorldView2 and high-resolution image data sources.

| Satellite       | Sensor type       | Number of spectral wavebands | Waveband (μm)   | Spatial resolution (m) | Temporal resolution (d) | Swath width (km) |
|-----------------|-------------------|------------------------------|-----------------|------------------------|-------------------------|------------------|
| ALOS            | PRISM             | 1                            | 0.42-0.50       | 2.5                    | 60                      | 70               |
|                 | AVNIR-2           | 4                            | 0.52-0.60       | 10                     |                         |                  |
|                 |                   |                              | 0.61-0.69       |                        |                         |                  |
|                 |                   |                              | 0.76-0.89       |                        |                         |                  |
| QuickBird       | Pan (multi-spectral) | 1                           | 0.45-0.90       | 0.61                   | 1-6                     | 16.5             |
| WorldView2      | Pan (multi-spectral) | 4                           | 0.45-0.51       | 0.5                    | 5.9                     | 16.4             |
|                 |                   |                              | 0.51-0.58       |                        |                         |                  |
|                 |                   |                              | 0.63-0.69       |                        |                         |                  |
|                 |                   |                              | 0.77-0.89       |                        |                         |                  |
|                 |                   |                              | 0.86-1.04       |                        |                         |                  |
| GF-1            | Visible light     | 4                            | 0.45-0.90       | 2                      | 4                       | 60               |
3. Remote-sensing image characteristics

ALOS Land Observing Satellite

The Japanese Earth Observation Satellite Program mainly includes two series: the atmospheric and oceanic observation series and the terrestrial observation series. The Advanced Land Observing Satellite ALOS was launched on January 24, 2006, with a resolution of 2.5m in panchromatic band and a spatial resolution of 10m in multispectral band. The satellite uses the advanced land observation technology and is able to acquire high-resolution land observation data around the world.

Introduction of three ALOS sensors

PRISM: It has three independent observation cameras, which are respectively used for sub-satellite point observation, front-view and rear-view observation and used to obtain stereo images along the orbital direction, and the spatial resolution of the sub-satellite point is 2.5m. Its data are mainly used to establish a high-precision Digital Elevation Model. AVNIR-2: The AVNIR-2 sensor has a higher spatial resolution than the AVNIR carried by the ADEOS satellite, and can be used for observations in land and coastal areas, and provide land cover maps and land use classification maps for regional environmental monitoring. In order to meet the needs of disaster monitoring, AVNIR-2 has improved the directional ability of orbit, and the side-swing angle is ±44°, which can observe the changes of surface objects in time. It can be used for precise ground observation.

Table 2 AVNIR-2 sensor spectral parameters and performance characteristics

| Number of spectral wavebands | 4 |
|------------------------------|---|
| Wave length                  | Waveband 1: 0.42 to 0.50 μm  
                             | Waveband 2: 0.52 to 0.60 μm  
                             | Waveband 3: 0.61 to 0.69 μm  
                             | Waveband 4: 0.76 to 0.89 μm |
| Spatial resolution           | 10m (sub-satellite point)    |
| Swath width                  | 70km (sub-satellite point)   |
| Signal to noise ratio        | > 200                        |
| MTF                          | Wavebands 1-3: > 0.25; waveband 4: > 0.20 |
| Number of detectors          | 7000/waveband                |
| Side-swing angle             | -44° to +44°                  |

PALSAR: It uses the L-band synthetic aperture radar, it is an active microwave sensor, which is used for all-weather land observation without being affected by clouds, weather or day and night, and superior to the SAR sensor carried by the JERS-1 satellite. The sensor has high resolution, scanning synthetic aperture radar and polarization three observation modes, the high resolution mode (amplitude of 10m) is coupled with a wide area mode (amplitude of 250–350km), which enables it to obtain a wider ground swath width than the ordinary SAR. It is more suitable for the generation of the Digital Elevation Model (DEM) and also suitable for the monitoring of specific areas. It is used for all-
weather land observation.

**Landsat Land Observing Satellite**

LANDSAT is a land observing satellite system of the United States. It includes the first satellite LANDSAT 1 launched in 1972 to the latest satellite Landsat 7. Launched in 1999, LANDSAT 7 is equipped with the Enhanced Thematic Mapper Plus (ETM+) device to passively sense the solar radiation reflected and thermal radiation emitted from the surface of the earth, and has sensors in 8 wavebands, covering different wavelength ranges from infrared light to visible light. Compared with the Thematic Mapper (TM) device arranged on Landsat 4 and Landsat 5, ETM+ has a higher resolution in infrared band, so it has higher accuracy.

**Quickbird Earth Observation Satellite**

QuickBird Satellite was launched by American Digital Globe Company in Vandenberg Air Force Base on October 18, 2001, and is the first commercial satellite in the world to provide sub-meter resolution. The satellite image resolution is 0.61m. The QuickBird Satellite sensor has the industry-leading geolocation accuracy, massive satellite-borne storage, and single-scene images that are 2 to 10 times higher than other commercial high-resolution satellites of the same period. The QuickBird satellite system can capture 75 million km² of satellite image data per year, with archived data increasing at a very high rate. There are at least 2 to 3 transit orbits in China every day and archived data of about 5 million km².

Table 3 Basic parameters and characteristics of Quick Bird Satellite

| Parameter                                           | Value                                                                 |
|-----------------------------------------------------|-----------------------------------------------------------------------|
| Mass                                               | 1018 Kg (after launch)                                                |
| Sub-satellite point resolution                      | 0.61m                                                                 |
| Product resolution                                  | Panchromatic 0.61~0.72m, multi-spectral 2.44~2.88m                    |
| Product type                                        | Panchromatic, multi-spectral, panchromatic enhancement, panchromatic + multi-spectral binding, etc. |
| Imaging method                                      | Push-broom imaging                                                    |
| Sensor                                              | Panchromatic band, multi-spectral                                    |
| Resolution                                          | 0.61 (Sub-satellite point) 2.44 (sub-satellite point)                |
| Wave length                                         | 450~900nm                                                             |
| Quantized value                                     | 11 bits                                                               |
| Sub-satellite point imaging                         | Along the orbit/transverse trajectory direction (+/-25 degrees)       |
| Stereo imaging                                      | Along the orbit/transverse trajectory direction                       |
| Radiation exposure width                            | Centered on the trajectory of the upper point, 272km to the left and the right |
| Imaging mode                                        | Single scene 16.5km×16.5km                                            |
| Strip                                               | 16.5km×165km                                                          |
| Orbit height                                        | 450km                                                                 |
| Dip angle                                           | 98 degrees (synchronize the sun)                                     |
| Revisit period                                      | 1 to 6 days (70cm resolution), depending on latitude                 |

**World view Earth Observation Satellite**

WorldView-II Satellite can provide 0.5m panchromatic images and 1.8m resolution multi-spectral images. In addition to 4 industry-standard spectral bands (red, green, blue and near-infrared), the satellite-borne multispectral remote sensor also provides 4 additional spectral bands (coastal band, yellow band, infrared band and near-infrared II). A variety of spectral bands will provide users with
the ability to perform accurate change detection and mapping. Worldview Satellite responds quickly to the command, and its image turnaround time is only a few hours (the time required from issuing imaging commands to receiving images).

**GF-1**

Launched in 2013, GF-1 Satellite is the first satellite in the major special space-based systems of the national high-resolution earth observation system, and its main purpose is to break through the optical remote-sensing technology combined with high spatial-resolution, multi-spectral and high temporal-resolution, the multi-load image stitching and fusion technology, the high-precision and high-stability attitude control technology, the technology of high-reliability and low-orbit satellites with 5-8 years life, high-resolution data processing and application and other key technologies, to promote the improvement of China's satellite engineering level, and to improve the self-sufficiency rate of high-resolution data in China.

① the combination of high resolution and large swath width can be realized simultaneously on a single satellite. The imaging swath width can be more than 60km at 2m high resolution, and can be more than 800km at 16m high resolution. The GF-1 Satellite can adapt to the comprehensive needs of a variety of spatial resolutions and spectral resolutions and multi-source remote sensing data, and meet different application requirements;

② 50m image positioning accuracy without ground control points can be realized to meet users' fine application demands, and reach the highest level of similar satellites in China;

③ 2×450Mbp data transmission capacity can be realized on a small satellite to meet the demands of large data application and reach the highest scale of similar satellites;

④ It has high attitude-pointing accuracy and stability, the attitude stability is better than 5e-4°/s, and has 35° side-swing imaging capability to meet the flexible application of on-orbit remote sensing;

⑤ It can comprehensively improve the satellite service life and is the first low-orbit satellite in China that has a design and assessment life of more than 5 years;

⑥ It has the relay monitoring and control capability on domestic civil small satellites, which can realize monitoring and control and management in the foreign time period.

**GF-2**

GF-2 Satellite is the first civil optical remote-sensing satellite with a spatial resolution better than 1 meter independently developed by China, carries two 1m panchromatic and 4m multispectral high-resolution cameras, has sub-meter spatial resolution, high positioning accuracy and fast attitude maneuvering ability and other characteristics, effectively improves the satellite comprehensive observation efficiency, and reaches the international advanced level. GF-2 Satellite was successfully launched on August 19, 2014, and its first start for imaging and data transmission were made on August 21. This is China's civil land observing satellite with the highest resolution at present, and the spatial resolution of sub-satellite point is up to 0.8 meters. It marks that China's remote sensing satellite has entered the sub-meter “high-resolution era”.

① High-stability and fast attitude side-swing maneuvering control technology

GF-2 Satellite is China's first satellite equipped with a totally-domestic high precision APS star sensor, and the actuator adopts a hybrid configuration mode of control moment gyro CMG and momentum wheel to realize the rapid attitude side-swing maneuver and stability control of the satellite. Through the improvement of the single-machine algorithm of the star sensor, the optimization design of the system-level attitude determination algorithm and the control algorithm, the high-precision and high-stability attitude control is realized for the first time by relying on the totally-domestic components. The on-orbit measured data show that the satellite attitude stability can reach 1.5e-4°/s, and the attitude determination accuracy can reach 0.0025°. By designing the precise control law and adopting the attitude fast-maneuver and fast-stability control method under the constraint of “Avoiding excitation flexible vibration as much as possible”, GF-2 Satellite realizes the on-orbit side-swing maneuver of 35° within 150s and stabilizes, and is the highest level of domestic remote sensing satellites at present.
② Image high positioning-accuracy design

In order to meet the user’s quantitative application requirements, GF-2 Satellite has adopted several measures to improve the image positioning accuracy. Among them, the whole satellite high-precision timing scheme ensures that the time synchronization accuracy error is less than 50μs, so that the camera, control and GPS can work under the same time datum during imaging; various high-precision attitude measurement schemes, such as direct attitude determination with domestic high-precision star sensor and joint attitude determination with star sensors and gyroscope, as well as star sensor and camera integrated installation and high-precision temperature control, enable the satellite imaging direction to be accurately obtained; the special micro vibration isolation device suppresses the micro vibration impact to ensure the imaging pointing stability. A number of indicators related to image positioning accuracy, such as orbit measurement and attitude measurement, have reached the international advanced level through a variety of measures, and the orbit measurement accuracy has reached 10m in real time on orbit, and 0.5m off the orbit, and the attitude measurement accuracy reaches 0.003°. The preliminary evaluation of on-orbit image test shows that the positioning accuracy without control points can reach 20-35m, which is better than the 50m design indicator and reaches the international advanced level.

③ Image high-radiation quality design

GF-2 Satellite has taken several guarantee measures to improve the image radiation quality. Optimization design of the modulation transfer function MTF is carried out for the camera optical system and the imaging circuit to achieve a high MTF in the case of a small relative aperture. At Nyquist frequency, the static MTF full chromatographic band is not less than 0.12, the multi-spectral is not less than 0.2, and the on-orbit dynamic MTF is not less than 0.1. On the basis of 10 bit quantitative image sampling, the hood is first used to further improve the stray light suppression, high-precision focal plane circuit and CCD control and other measures are taken to reduce electronic noises, and the Gray code is used to reduce the system noises, so as to ensure that the image signal noise to be as low as possible, and the signal-to-noise ratio of the panchromatic band is 23-43dB and the multispectral band is 25-43dB under various solar elevation angles and surface reflection conditions, which are the leading levels of domestic satellites.

4. Applicability comparative analysis

① Spatial resolution

The selection of remote sensing images does not mean that the higher the accuracy, the better, it includes the scale effect, distance effect and economic rationality of object images. Different natural phenomena have different optimal observation distances and scales, and it is not necessarily that the closer the distance, the better, the more subtle the observation, the better. This is not to deny the systematic and high-precision field observations, but to show that appropriate distances and scales are required for effective and complete observations.

Research experience shows that, combined with existing remote-sensing data sources, ETM images, ALOS images, SPOT images and satellite radar images are better choices for vegetation features, land types, water bodies, stratigraphic lithology, large-scale collapses, landslides, debris flow and other geological disasters.

② Selection of combined wavebands

The following factors should be considered in the selection of participating combined wavebands: ① Richness of information of participating combined wavebands; ② Whether it contains the characteristic information of the target object; ③ Color saturation; ④ Brightness of color difference. The basic idea should satisfy the principle of “Maximum variance, minimum correlation”. Then, according to the spectral response curve of theoretical ground objects and the different needs of actual work, different combined wavebands are selected for the experimental interpretation of different topics, so as to obtain the best combined wavebands with easy interpretation and high intelligibility. Combined with the reflection characteristics of each waveband spectrum to soil, lithology, vegetation,
sensitivity to water and resolution of ground objects, satisfactory combined wavebands are finally selected through computer comparative analysis. Under the condition of obtaining the optimal combined wavebands, further output enhancement processing should be carried out for the selected optimal combined wavebands in order to meet the optimal effect of result images in color, clarity and contrast and visual feeling, and to avoid the failure to easily debug the image to satisfactory effects due to over large image contrast or partial information loss and other the adverse situations caused thereby.

As per the environmental supervision requirements during highway engineering construction, eligible ALOS, QuickBird, WorldView2, Landsat ETM+ and SPOT5 data are selected as alternative data, and their characteristics are compared to analyze their application effects in environmental supervision during construction of reconstruction and expansion projects.

5. Conclusion

From the perspective of the sensor and its wavebands, Landsat ETM+ data has the most wavebands and the largest wavelength range, covering from green band to mid-infrared band, but its spatial resolution is the lowest and is only 15m after panchromatic image synthesis, and its time resolution is low and is 16 days. Therefore, its swath width is large, and the price is relatively low. It is suitable for national and provincial macro-monitoring.

ALOS remote-sensing image has a narrow band coverage, with 4 bands to the near-infrared, and its spectral resolution is close to that of Landsat. The spatial resolution is as high as 2.5m, and the revisit period is short and is 2 days. The mesoscale disaster monitoring and resources are mainly used for investigation, the price is low, and the swath width is relatively medium.

SPOT5 data is similar to ALOS in band coverage and quantity, its spectral resolution is medium, the spatial resolution is 2.5m, and the revisit period is 2-3 days. However, the data is easy to obtain, its swath width is relatively large, and the price is also high.

QuickBird and WorldView2 data have a relatively low spectral resolution, a high spatial resolution to the sub-meter level and a small swath width, and its revisit period is less than 2 days. Different from other types of remote-sensing data acquired by amplitude, these two kinds of remote-sensing data have high flexibility in acquisition, but they are expensive, and the price of archived data alone is 146 yuan/km².

Based on the comprehensive comparison of the above remote-sensing data characteristics, and combined with the environmental protection supervision requirements during the construction period as well as the comprehensive costs and other factors, it is suggested that ALOS or SPOT5 data should be used for large-scale and multi-temporal change detection and analysis for more than 100km highway construction projects. For the local road sections involving environmentally sensitive areas, it is recommended to use QuickBird or WorldView2 data for change detection and analysis and regular monitoring with high-time resolution.

Table 4 Comparison of basic parameters and characteristics of several satellite data sources

| Satellite   | ALOS | QuickBird | WorldView 2 | Landsat ETM+ | SPOT5 | GF-1 | GF-2 |
|-------------|------|-----------|-------------|--------------|-------|------|------|
| Sensor type | AVNIR-2 PRISM Pan (multi-spectral) Pan (multi-spectral) ETM+ HRV | Visible light Multi-spectral Visible light Multi-spectral |
| Number of spectral wavebands | 5 | 1 | -- | 7 | 5 | 5 | 4 |
| Waveband (μm) | 0.42 - 0.50 0.52 - 0.60 0.61 - 0.69 0.76 - 0.89 | 0.45-0.51 0.51-0.58 0.63-0.69 0.77-0.89 0.86-1.04 | 0.45-0.52 0.52-0.60 0.62-0.69 0.76-0.96 1.04-1.25 2.08-3.35 | 0.45-0.52 0.52-0.59 0.63-1.04 1.55-3.33 0.45-0.52 0.52-0.59 | 0.45-0.90 0.52-0.90 0.625-0.695 0.760-1.25 | 0.45-0.52 0.52-0.59 0.63-0.69 0.77-0.89 |
| Characteristics | Spatial resolution (m) | Repetition period (d) | Revisit time (d) | Swath width (km) | Price |
|------------------|-----------------------|----------------------|-----------------|-----------------|-------|
|                  | 2.5                   | 46                   | 2               | 26              | 3550  |
|                  | 0.61                  | 1.6                  | 1.6             | 16              | 146   |
|                  | 0.5                   | 5.9                  | 1.1             | 16              | 146   |
|                  | 15m                   | 16                   | 16              | 185*185         | 4800  |
|                  | 2.5                   | 26                   | 2-3             | 60*60           | 9900  |
|                  |                       | 41                   | 4               | 60              | 3000  |
|                  |                       | 69                   | 4               | 45              | 8000  |

The main application targets are surveying and mapping, environmental observation, disaster monitoring, resource investigation and other fields to meet the mesoscale monitoring requirements.

It is a sub-meter commercial satellite and suitable for small scale and fine remote-sensing measurement and change detection.

It has large coverage and rich information and can meet the national and provincial macroscopic monitoring.

It has integrated requirements for various spectral resolutions and multi-source remote-sensing data to meet different application requirements.

It adopts the sub-meter and large swath-width imaging technology, and is easy to obtain.

Price:
- 3550 yuan/scene
- 146 yuan/km²
- 146 yuan/km²
- 4800 yuan/scene
- 9900 yuan/scene
- 3000 yuan/scene
- 8000 yuan/scene

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