Research Progress on On-Orbit Calibration of Infrared Sensors for Power Grid Fire Monitoring

Huyan Ziyu[1](✉), Wenqing Feng[2,3], Zhiqiang Zhang[1], Jing Luo[2,3], Xinyu Pi[2,3], Ouyang Yi[2,3], Lifu He[2,3], Qiming Cao[2,3], Fuzhou Duan[1], and Xiaoqin Luo[4]

[1] Capital Normal University, 105 West Third Ring Road North, Beijing, China
2210902162@cnu.edu.cn

[2] State Key Laboratory of Disaster Prevention and Reduction for Power Grid Transmission and Distribution Equipment, Changsha, China

[3] State Grid Hunan Electric Company Limited Disaster Prevention and Reduction Center, Changsha, China

[4] Beijing Zhongguancun Zhilian Safety Science Research Institute Co., Ltd., Beijing, China

Abstract. With the rapid development of China's economy and the increase in the value of industrial output, power consumption is increasing on a large scale. By the end of 2021, the domestic installed power generation capacity will be 2.38 billion kilowatts. With the continuous expansion of the scale of high-voltage and cross-regional power grids, transmission lines usually require passing through mountainous areas and agrarian areas, and the number of wildfires near the line corridor continues to increase. Compared with traditional observation methods such as unmanned aerial vehicles, ground online monitoring, and manual inspections, satellite remote sensing monitoring has a wider coverage and a shorter update cycle for large-scale data. Among them, the accurate targeting of satellite sensors is an important prerequisite and guarantee for the realization of wildfire detection, which can greatly enhance the ability to distinguish the accuracy of fires in remote sensing images. In this paper, based on the needs of power grid wildfire monitoring and the characteristics of satellite infrared sensors, by gathering, sorting, selecting and refining existing literature, the calibration methods of satellite infrared sensors are summarized and sorted, and the research is depicted in detail, progress.

Keywords: Power Grid · Wildfire Monitoring · Satellite · Infrared Calibration

1 Introduction

Wildfires refer to disasters that are difficult to control, spread and expand freely in forest land, and cause certain harm and loss to forests, forest ecosystems and humans. Due to the large scale of the transmission network and the fact that the transmission lines often pass through mountains, forests and other places in the fire-prone areas, the natural environment factors such as the aggravation of the global greenhouse effect and the

H. Yang et al. (Eds.): SmartGIFT 2022, LNICST 483, pp. 142–152, 2023.
https://doi.org/10.1007/978-3-031-31733-0_13

frequent occurrence of extreme weather and the human factors that people sacrifice to sacrifice and open up mountains and wastes due to customs Under the combined influence, the transmission lines are very vulnerable to fire hazards in forests, grasslands, and mountains, resulting in abnormal currents, trips and power outages. Because wildfires are difficult to control and are extremely harmful, it is a joint research of power grid managers and many scholars to find the fire source earlier, faster and more accurately, contain the fire in the "early stage", and reduce the economic losses caused by the fire subject [1].

Power grid security is related to people's lives. In order to ensure the safety and stability of power supply, it is necessary to conduct regular inspections of power transmission channels, master the operation of power grids and changes in power transmission channels, and timely discover and eliminate potential safety hazards in equipment and transmission lines. In the monitoring of mountain fires in power transmission lines, ground monitoring is a traditional detection method, mainly including ground patrol, watchtower monitoring, video monitoring, etc. [2, 3]. These methods have a small scope of application and high monitoring costs. The disadvantage of weak anti-interference.

However, satellite remote sensing technology has come into people's eyes due to its advantages of low observation cost, large observation range, diversified observation methods, and few restricted conditions [4]. With the advancement of space technology, the resolution of remote sensing satellite sensors has been greatly improved, and the combination of visible light band and non-visible light band has broken through the spectral range of human eye observation. Continuous and stable acquisition of information, wide observation range, many types of image information [5]. China's FY-3D/MERSI-II fire point observation products and the US's VNP14IMG fire point monitoring products based on VIIRS sensors play an important role in the world. When the satellite remote sensing sensor is observing the power grid fire, the high-precision geolocation accuracy is the basis for its application effectiveness and value, and the accurate calibration of the geometric parameters and radiation model of the remote sensing satellite imaging system is an essential key link [6]. In order to accurately identify mountain fire disasters in remote sensing image products, the radiation calibration and geometric calibration of satellite sensors are the basis and premise to ensure fire monitoring. Before the launch of remote sensing satellites, strict and comprehensive calibration and performance tests were carried out in the laboratory. However, due to factors such as vibration and acceleration during the launch process, on-orbit stress release and pollution, space environment, and detector decay, their performance will be affected. Different degrees of decay, calibration during orbital operation directly affects the quantitative application level of satellite remote sensing data. Therefore, after the satellite is launched, it is very important to give accurate and credible calibration coefficients through on-orbit radiation calibration and geometric calibration, which is very important for the application of various satellite products and is a key factor directly related to the application of satellite data.

2 On-Orbit Absolute Radiometric Calibration

When the user needs to calculate the spectral reflectance or spectral radiance of the ground object, or needs to compare the images obtained at different times and different sensors, the brightness gray value of the image must be converted into absolute radiance. This process is radiation. Target. The ultimate purpose of radiation calibration is to eliminate the error of the sensor itself and determine the accurate radiation value at the entrance of the sensor (Table 1).

Table 1. On-orbit absolute radiometric calibration methods.

lab calibration		
On-orbit absolute radiometric calibration method	On-board calibration	Based on on-board calibration equipment
		Based on stars and moon
	Based on the site calibration	reflectance-based method
		irradiance-based method
		radiance-based method
	intercalibration	

3 Progress in On-Orbit Absolute Radiometric Calibration

3.1 Lab Calibration

Lab calibration is the premise and guarantee of on-orbit radiation calibration. The sensor manufacturer needs to calibrate the sensor in the laboratory first, which is to verify whether the various indicators (response, signal-to-noise ratio, etc.) of the instrument meet the design requirements. Means, and also the initial data for the stability confirmation of these parameters during the sensor operation. At present, laboratory calibration equipment such as integrating sphere, standard lamp or solar light source or field calibration equipment is mainly used to calibrate the sensor to achieve radiation calibration [13]. The pre-launch calibration of SeaWiFs, FY series satellites and HJ satellites all use laboratory calibration [15].

3.2 On-Board Calibration

Based on on-board calibration equipment. The laboratory calibration environment is ideal, and the accuracy of the test instruments is high, so the calibration accuracy is high, and the basic parameters related to calibration can be provided. However, the satellite is affected by the impact of the launch and the radiation, collision, attenuation, etc. during operation, which makes the optical and electronic parameters of the remote sensor change, such as dark current [16], so many spaceborne remote sensors are equipped with calibration devices on the satellite to perform real-time calibration and long-term detection of the decay of the remote sensor response.

The EOS satellite is equipped with a medium-resolution imaging spectrometer MODIS [21], which adopts the calibration method based on "sun+diffuser reflector".

Images of targets such as land and ocean temperature, land surface cover, clouds, aerosols, water vapor, and fire are calibrated to an accuracy of about 2% in the solar reflectance spectrum. However, the disadvantage of the calibration method of the sun and the diffuse reflector is that the direct exposure of the diffuse reflector to the ultraviolet environment will cause serious attenuation of the di-directional reflectance of the diffuse reflector, that is, its performance becomes uncertain. And this calibration method is limited by the sun azimuth angle, which is not conducive to high-frequency calibration tasks [10].

TRUTHS by a research group led by Nigel Fox at NPL, UK. The plan establishes a radiation calibration system traceable to SI by performing absolute measurement of the 0.2–0.25 μm reflected solar radiation spectrum, thereby greatly improving the accuracy of remote sensing measurement. The laser diode is used as the monochromatic light source calibrated on the star, and the absolute low temperature radiometer is used as the traceable SI benchmark [17], which belongs to the method of "lamp+diffuse reflector".

The European Sentinel-2 satellite is equipped with a multi-spectral MSI imager, with a total of 13 multi-spectral spectra in the visible light to short-wave infrared spectrum, and push-broom imaging with a spatial resolution of 10–60 m and a width of 290 km. During absolute radiometric calibration, through the calibration shutter assembly CSM before the entrance pupil of the optical system of the remote sensor, the solar diffuse reflector and the rotating mechanism are used to switch to the calibration mode for full-aperture absolute radiometric calibration. The absolute radiometric calibration accuracy of the spectral band is about 3% [18, 19].

FY series meteorological satellite FY-3A was successfully launched on May 27, 2008. MERSI is a main instrument carried on it. It is mainly used for weather forecasting, natural disaster monitoring and global environmental change research. The design of the solar reflection band The onboard calibration accuracy is better than 5%, and it is used to monitor the relative attenuation trend of MERSI radiation response in the visible light shortwave infrared band. The onboard calibration of MERSI in the solar reflection band is mainly performed by the VOC visible infrared onboard calibrator and the SV cold sky observation. It consists of two parts and belongs to the integrating sphere method in the on-board calibration equipment.

A star- and moon-based approach. The change rate of solar radiation in the past 15 years does not exceed 0.2%, which can be regarded as a Lambertian light source with uniform and stable brightness. There is no atmosphere on the surface of the moon, and the moon is the brightest light source radiation except the sun when the sensor observes The moon's reflectivity changes less, and the stable reflection characteristics make the moon a reference radiation source for satellite sensor calibration.

MODIS [20], SeaWiFSl [21], Hyperionl [22], etc. have all carried out lunar observations. They compared the solar radiance data reflected from the observed lunar surface with the solar radiance data obtained through the diffuser to determine the solar diffuse On-orbit performance of the board. The CLARREO program in the United States has designed a lunar observation function to evaluate the stability of the visible short-wave infrared reference payload on-orbit calibration. The FY-3C medium-resolution spectral imager MERSI has added the function of observing the moon [23], and has carried out radiometric calibration in the visible and near-infrared bands, realizing the dynamic tracking and evaluation of the radiometric calibration coefficient of the MERSI solar reflection channel.

High-resolution commercial optical remote sensing satellites in Europe and the United States use the stable radiation characteristics of stars and the stable reflection characteristics of the moon to perform high-precision on-orbit calibration. In the north and south poles and the back-illuminated regions of the satellite's flight, each orbit has the opportunity to image and calibrate the stars of different magnitudes and the moon with different phase angles in the deep space. Using stellar point target calibration, it is necessary to select an appropriate magnitude. Since the point target imaging is greatly affected by discrete sampling, it is necessary to accurately estimate the sampling center. To use the moon for calibration, it is necessary to make a special radiation model for the moon. The WorldView-3 satellite, launched on August 13, 2014, has a full-color 0.31 m resolution, a visible-near-infrared multispectral resolution of 1.24 m, and a short-wave infrared multispectral resolution of 3.72 m. Using the satellite's own characteristics, the on-orbit absolute radiation calibration and relative radiation calibration are carried out with high precision and high frequency for the stars and the moon, and the accuracy of the absolute radiation calibration is better than 5% [11].

3.3 Based on the Site Calibration

The method based on on-board calibration equipment has the advantages of high calibration accuracy and is not affected by the surface and atmosphere. However, this method needs to carry on-board calibration equipment, which is difficult to achieve technically, and the cost of satellite development is high. The attenuation of the device itself will also reduce the accuracy of onboard calibration. The calibration method based on stars and moons has many limitations. First of all, it is necessary to select suitable stars and continuously observe, and build a special radiation model, and the point target imaging is greatly affected by the discrete sampling phase. Second, the satellite observation attitude requires more attention. The error in the short-wave infrared and thermal infrared bands is higher than that in the visible light band. Therefore, in the late 1970s and early 1980s, a group of scientists represented by Professor Slater of the United States proposed to use the large-scale, uniform and stable ground objects on the earth's surface to realize the on-orbit absolute radiation calibration of remote sensors [24] On-orbit field calibration is to carry out satellite-ground synchronization experiments at the ground radiation calibration field at the time of satellite transit, and use the surface and atmospheric parameters of the experimental site to realize the on-orbit radiation calibration of the sensor, which is the most widely used by remote sensing workers. Methods. There are three types of site calibration methods: reflectance-based method, irradiance-based method and radiance-based method.

The selection of the calibration site is based on the method focus of the calibration site. Since the last century, the United States has established the White Sands Calibration Test Site at the White Sands Missile Base WSMR (White Sands Missle Range) and the Edwards Air Force Base EAFB (Edwards Air Force Base). Sand Test Site) and Railroad Valley Playa Proving Ground. Subsequently, various countries have successively developed a number of radiometric calibration sites, including: the Newell test site in Canada, CNES (Centre National d'Etudes Spatiales) and INRA (Institut National de la Recherche

Agronomique) in France. The La Crau radiation correction field established near the city of Marseille in southeastern France, the radiation field established by the European Space Agency (ESA) in the Sahara Desert in Africa, and the Lake Frome radiation field established by Japan and Australia in northern Australia. The Dunhuang calibration field and the Qinghai Lake calibration field established in China have successfully achieved absolute radiation calibration of FY series satellites, HJ satellites, GF series satellites, HY series satellites and military satellites based on these two experimental sites.

Since 1987, researchers have carried out Landsat-5/TM, Landsat-7/ETM+, SPOT, MODIS, SeaWiFS, ALI, Hyperion, lkonos, ASTER, MISR and other sensors based on the White Sands calibration field in the United States. Field radiometric calibration, the on-orbit calibration coefficients of multiple sensors in different periods were obtained [25–28]. The La Crau test site based in French has completed the on-orbit calibration of sensors such as NOAA-14/AVHRR, Orbitview-2/SeaWIFS, SPOT-4/VGT, Landsat-5/TM and SPOT-2/HRV, and achieved comparative results. Good results [28, 29]. The Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia has achieved on-orbit calibration of EO-1/ALI and EO-1/Hyperion sensors based on calibration fields such as Tinga Tingana, Uardry and Lake Frome in Australia. Based on the standard results, the on-orbit radiation characteristics and application potential of the sensor were analyzed [30]. Based on the Railroad Valley Playa and Ivanpah Playa in the United States and the Tsukuba calibration field in Japan, the on-orbit field calibration of sensors such as Terra/ASTER, ADEOS/AVNIR and ADEOS/OCTS [31–33].

Every summer, the China Resources Satellite Application Center will test the four CCD sensors of HJ-1A/1B, the MUX sensor of ZY-3 01/02, the PMS sensor of ZY-3 02C, and the two PMS sensors of GF-1 at the Dunhuang calibration field every summer. Sensors, four WFV sensors of GF-1, two PMS sensors of GF-2, PAN and WFI sensors of CBERS 04, and PMS sensors of GF-4 are calibrated on-orbit, and the radiation calibration is collected through satellite-ground synchronization measurement. All the data required, and the calibration results will be published on its official website once a year for researchers to download and use.

The reflectance-based method is to measure the reflectivity factor of the ground target and atmospheric optical parameters (such as the optical thickness of the atmosphere, the water vapor content of the atmospheric column, etc.) synchronously when the satellite is over the top, and then use the atmospheric radiative transfer model to calculate the radiance value at the entrance pupil of the remote sensor [12]**, with high accuracy.** The correspondence between the radiance L at the entrance pupil and the apparent reflectance ρ at the top of the atmosphere is achieved in Eq. 1:

$$\rho = \frac{L \cdot d_{ES}^2 \cdot \pi}{E_{sun} \cdot \cos\theta_S} \tag{1}$$

where L is the apparent radiance at the top of the atmosphere, d_{ES} is the Sun-Earth distance expressed in 1AU at the time of imaging, E_{sun} is the average solar spectral radiance at a distance of 1AU outside the atmosphere, θ_S is the solar zenith angle (90°-Sun height angle).

The Mapping Satellite-1 sensor satellite uses the reflectivity-based method for on-orbit radiometric calibration, and the accuracy is better than 5% when compared with the measured reflectivity of the grassland [34].

The irradiance-based method, also known as the improved reflectance method, uses the downward diffusion and total radiance measured on the ground to determine the apparent reflectance at the height of the satellite remote sensor, and then determine the radiance at the entrance pupil of the remote sensor. This method uses an analytical approximation to calculate the reflectivity, which can greatly reduce computational time and computational complexity. The apparent reflectance can be expressed in Eq. 2 as [14]:

$$\rho^*(\theta_V, \theta_S, \varphi_V, \varphi_S) = \frac{\pi L_\lambda(\theta_V, \theta_S, \varphi_V - \varphi_S)}{E_{o\lambda}} \tag{2}$$

In the formula, $L_\lambda(\theta_V, \theta_S, \varphi_V - \varphi_S)$ is the radiance from the space measured by the satellite sensor, $E_{o\lambda}$ is the solar irradiance outside the atmosphere, $\theta_V, \varphi_V, \theta_S, \varphi_S$ represent the sensor observation and the day of the sun, respectively. Vertex and Azimuth.

The FY-1C meteorological satellite uses the irradiance-based method and uses the Dunhuang radiation correction field to perform absolute radiometric calibration on the six visible and near-infrared channels [14].

The radiance-based method uses a radiometer that has undergone strict spectrum and radiation calibration, and realizes a synchronous measurement similar to the observation geometry of a satellite remote sensor through an aviation platform. The radiance measured by the airborne radiometer is used as a known quantity to calibrate the remote sensor in flight. Finally, the error of the radiation correction coefficient is mainly based on the calibration error of the radiometer. It is only necessary to correct the atmosphere above the flight altitude, which avoids the correction error of the bottom atmosphere and is conducive to improving the accuracy. In Eq. 3, the correspondence between the image DN value and the apparent radiance L at the top of the atmosphere at the entrance pupil is achieved:

$$L = Gain * DN * \left(\frac{Abs\_factor}{\Delta\lambda}\right) + offset \tag{3}$$

In the formula, L is the apparent radiance at the top of the atmosphere, DN is the gray value of the image, Gain is the absolute scaling factor gain, Offset is the offset, and Abs_factor is the absolute scaling factor, which is related to the spectral response function of the remote sensor, imaging $\Delta\lambda$ is the effective bandwidth.

Intercalibration uses a sensor with complete calibration equipment as a reference, obtains the image pair imaged by the reference sensor and the sensor to be calibrated in the same area at the same time, performs spectral matching and other processing, and obtains the radiometric calibration coefficient of the sensor to be calibrated [9]], the accuracy of which depends on the working quality of the reference satellite [35].

The main step is to connect two satellite sensors that observe the same target at the same time and at the same angle, and they can be regarded as the same. The sensor to be calibrated can be calculated from the reflectivity of the reference satellite.

$$\rho_S = \frac{\pi \cdot L_S \cdot d^2}{E_S \cdot \cos\theta_S} \quad (4)$$

Among them, ρ is the apparent reflectivity of the sensor, *L* is the apparent radiance, d is the sun-earth distance factor, θ is the solar zenith angle, and E is the solar irradiance at the top of the atmosphere.

Chander took ETM+ as the reference sensor and the stable desert as the calibration field, realized the cross-radiation calibration of the TM sensor, and obtained the calibration attenuation relationship of the TM sensor through calculation. The scaling coefficients were revised to improve the scaling accuracy of the TM data [36]. Feng et al. chose the Dunhuang calibration field, and used Landsat-8/OLI as the reference sensor to perform cross-radiometric calibration on the four WFV sensors of GF-1; selected the BRDF product of MODIS to invert the reflectivity of the surface, and selected the gas of MODIS. The inversion of TOA reflectance of sol products has been verified, and the accuracy of cross-radiation calibration is controlled within 8% [37]. The cross-calibration method has the advantages of low calibration cost, high frequency, and can realize historical data calibration. However, the difficulty of cross-calibration is that the number of valid image pairs that can be obtained every year is very small, and it is difficult to achieve high-frequency calibration. Moreover, the accuracy of cross-calibration mainly depends on the accuracy of the reference source. In order to achieve high absolute radiation calibration accuracy, it is necessary to plan to develop very high-precision calibration satellites. The calibration is passed on to other satellites. This method is less economical.

4 Summary and Outlook

Due to the high-voltage power transmission process of the power grid, the transmission lines inevitably pass through uninhabited areas, especially in forest-rich areas, where wildfire disasters are more likely to occur, resulting in the loss of rights and interests of power grid operating companies and forest ecosystems. Based on the needs of power grid wildfire monitoring, this paper summarizes the status of satellite remote sensing methods for detecting wildfires in forests, and makes a detailed summary of the pre-orbit radiation calibration work of satellite sensors to monitor wildfires. The existing mainstream radiation calibration methods are mainly divided into The on-satellite calibration equipment method is based on the star and moon method, based on the calibration field method (which is divided into the reflectance method, the irradiance basis method and the radiance basis method based on the calibration field method), and the cross calibration method. At present, as the remote sensing sensors carried by emerging satellites have wider width, higher spatial resolution, and more sensor spectrums, their applications in fire detection and other fields are becoming more and more in-depth, and with the improvement of remote sensing image quality, popular machines Learning and deep learning algorithms can be applied to remote sensing images to further improve the accuracy of land object classification, disaster monitoring and other applications. The basis of all this is to calibrate the radiance at the entrance pupil of the satellite. Moreover, with the enhanced flexibility of the remote sensing satellite carrying platform, the joint calibration of multi-method and multi-source data can also be realized in the future.

References

1. Liu, M., et al.: Research on the risk assessment model and assessment method of transmission line mountain fire fault. Power Syst. Prot. Control **44**(06), 82–89 (2016)
2. Shen, X., Du, Y., Wang, R., Zhao, K., Qin, C.: Inclination measurement of transmission line towers based on ground-based lidar. J. Electron. Measur. Instrum. **31**(04), 516–521 (2017). https://doi.org/10.13382/j.jemi.2017.04.004
3. Zhang, Z., Zhang, C.: Transmission line wildfire monitoring scheme based on infrared detectors. Jiangsu Electr. Eng. **35**(03), 57–59+63 (2016). https://doi.org/10.19464/j.cnki.cn32-1541/tm.2016.03.015
4. Sun, M., Wang, Q., Song, Y., Chen, Y.: Satellite mountain fire monitoring and positioning of transmission lines based on image recognition technology. Autom. Technol. Appl. **38**(01), 65–69 (2019)
5. Cao, C.: Application of space remote sensing in power grid line safety inspection. Satellite Appl. (10), 22–25 (2021)
6. Man, Y., Chen, S.: Research progress on absolute radiation calibration of optical remote sensing satellites in orbit [J/OL]. China Space Science and Technology: 1–10 (2022). http://kns.cnki.net/kcms/detail/11.1859.V.20220513.2127.008.html
7. Tanaka, K., Okamura, Y., Mokuno, M., et al.: First year on-orbit calibration activities of SGLI on GCOM-C satellite. In: Earth Observing Missions and Sensors: Development, Implementation, and Characterization V, vol. 10781, pp. 101–110. SPIE (2018)
8. Palmer, J.M.: Calibration of satellite sensors in the thermal infrared. In: Infrared Technology XVIII, vol. 1762, pp. 108–117. SPIE (1993)
9. Wang, K.: Research on Jilin-1 Spectral Star Cross Calibration Method Based on Fengyun-3 Satellite. Jilin University (2022). https://doi.org/10.27162/d.cnki.gjlin.2022.000772
10. Xiong, X., Angal, A., Barnes, W.L., et al.: Updates of moderate resolution imaging spectroradiometer on-orbit calibration uncertainty assessments. J. Appl. Remote Sens. **12**(3), 034001 (2018)
11. Kuester, M., Ochoa, T.: Improvements in calibration, and validation of the absolute radiometric response of MAXAR earth-observing sensors. In: Joint Agency Commercial Imagery Evaluation (JACIE) Workshop, Reston, VA, USA (2019)
12. Dong, Y., Lv, J., Song, Q., et al.: Introduction to the principle and process of reflectivity-based radiation calibration. Sci. Technol. Innov. Appl. (24), 71–72 (2016)
13. Cui, Y.: Research on Spectral Imager Calibration Technology. Graduate School of Chinese Academy of Sciences (Xi'an Institute of Optics and Fine Mechanics) (2009)
14. Hu, X., Zhang, Y., Qiu, K.: Absolute radiometric calibration of visible and near-infrared channels of FY-1C meteorological satellite using irradiance-based method. J. Remote Sens. (06), 458–464 (2003)
15. Gao, H., Gu, X., Yu, T., Li, X., Gong, H., Li, J.: Research progress on visible and near-infrared channel radiation calibration of spaceborne optical remote sensors. Remote Sens. Inf. (04), 117–128 (2010)
16. Hu, Y.: Research on key technologies for quantitative measurement of wide-format high-resolution thermal imaging cameras. University of Chinese Academy of Sciences (Shanghai Institute of Technical Physics, Chinese Academy of Sciences) (2021). https://doi.org/10.27581/d.cnki.gksjw.2021.000030

17. Fox, N., Green, P.: Traceable radiometry underpinning terrestrial-and helio-studies (TRUTHS): an element of a space-based climate and calibration observatory. Remote Sens. **12**(15), 2400 (2020)
18. Martimort, P., Fernandez, V., Kirschner, V., et al.: Sentinel-2 MultiSpectral imager (MSI) and calibration/validation. In: 2012 IEEE International Geoscience and Remote Sensing Symposium, pp. 6999–7002. IEEE (2012)
19. Revel, C., Dick, A., Lonjou, V., et al.: Results from the Radiometric Absolute Calibration of Sentinen-2A and Sentinel-2B (2017)
20. Xiong, X., Sun, J.Q., Chiang, K., et al.: MODIS on-orbit characterization using the Moon. In: Sensors, Systems, and Next-Generation Satellites VI, vol. 4881, pp. 299–307. SPIE (2003)
21. Werij, H.G.C., Kruizinga, B., Olij, C., et al.: Calibration aspects of remote sensing spaceborne spectrometers. In: Earth Observing System, vol. 2820, pp. 126–137. SPIE (1996)
22. Barry, P., Segal, C., Pearlman, J., et al.: Hyperion data collection: performance assessment and science application. In: Proceedings of the IEEE Aerospace Conference, vol. 3, p. 3. IEEE (2002)
23. Wu, R., Zhang, P., Yang, Z., Hu, X., Ding, L., Chen, L.: Calibration, tracking and monitoring of remote sensors based on lunar reflection. J. Remote Sens. **20**(02), 278–289 (2016)
24. Holm, R.G.: The Absolute Radiometric Calibration of Space-Based Sensors. The University of Arizona (1987)
25. Slater, P.N., Biggar, S.F., Holm, R.G., et al.: Reflectance-and radiance-based methods for the in-flight absolute calibration of multispectral sensors. Remote Sens. Environ. **22**(1), 11–37 (1987)
26. Biggar, S.F., Slater, P.N., Gellman, D.I.: Uncertainties in the in-flight calibration of sensors with reference to measured ground sites in the 0.4–1.1 μm range. Remote Sens. Environ. **48**(2), 245–252 (1994)
27. Biggar, S.F., Dinguirard, M.C., Gellman, D.I., et al.: Radiometric calibration of SPOT 2 HRV: a comparison of three methods. In: Calibration of Passive Remote Observing Optical and Microwave Instrumentation, vol. 1493, pp. 155–162. SPIE (1991)
28. Thome, K.J., Arai, K., Tsuchida, S., et al.: Vicarious calibration of ASTER via the reflectance-based approach. IEEE Trans. Geosci. Remote Sens. **46**(10), 3285–3295 (2008)
29. Teillet, P.M., Fedosejevs, G., Gauthier, R.P., et al.: Radiometric calibration of multiple Earth observation sensors using airborne hyperspectral data at the Newell County rangeland test site. In: Earth Observing Systems IV, vol. 3750, pp. 470-481. SPIE (1999)
30. Barry, P., Jarecke, P.J., Pearlman, J., et al.: Radiometric calibration validation of the Hyperion instrument using ground truth at a site in Lake Frome, Australia. In: Imaging Spectrometry VII, vol. 4480, pp. 242–246. SPIE (2002)
31. Arai, K.: Atmospheric correction and vicarious calibration of ADEOS/AVNIR and OCTS. Adv. Space Res. **25**(5), 1051–1054 (2000)
32. Arai, K.: Early results from the vicarious calibration of Terra/ASTER/SWIR. Adv. Space Res. **28**(1), 77–82 (2001)
33. Arai, K.: Vicarious calibration of the solar reflection channels of radiometers onboard satellites through the field campaigns with measurements of refractive index and size distribution of aerosols. Adv. Space Res. **39**(1), 13–19 (2007)
34. Huang, H., Yi, W., Qiao, Y., Du, L.: On-orbit radiometric calibration method of “Tianhui-1” satellite. J. Remote Sens. **16**(S1), 22–27 (2012)
35. Yang, A.: Research on the VNIR band cross-radiometric calibration method and system of domestic optical satellite remote sensing data. University of Chinese Academy of Sciences (Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences) (2017)
36. Chander, G., Markham, B.L., Barsi, J.A.: Revised Landsat-5 thematic mapper radiometric calibration. IEEE Geosci. Remote Sens. Lett. **4**(3), 490–494 (2007)

37. Feng, L., Li, J., Gong, W., et al.: Radiometric cross-calibration of Gaofen-1 WFV cameras using Landsat-8 OLI images: a solution for large view angle associated problems. Remote Sens. Environ. **174**, 56–68 (2016)
38. Xu, Y.: Analysis of the application status and development trend of photogrammetry and remote sensing technology. Sci. Technol. Inf. **15**(14), 49–50 (2017)
39. Fan, G., et al.: Research and application of satellite remote sensing monitoring of fire around transmission lines. Mineral Explor. **12**(08), 1844–1851 (2021)
40. Zhang, B.: Current situation and future prospects of contemporary remote sensing technology development. Proc. Chin. Acad. Sci. **32**(07), 774–784 (2017). https://doi.org/10.16418/j.issn.1000-3045.2017.07.012
41. Lin, Y., et al.: A review of forest fire monitoring technology along transmission lines. Forestry Environ. Sci. **35**(05), 122–126 (2019)
42. Zhang, X.: Detection of land cover changes in power transmission corridors and assessment of wildfire susceptibility based on satellite remote sensing. Wuhan University (2017)
43. Pearlman, J.S., Barry, P.S., Segal, C.C., et al.: Hyperion, a space-based imaging spectrometer. IEEE Trans. Geosci. Remote Sens. **41**(6), 1160–1173 (2003)
44. Zhou, G., He, J., Zhao, H., et al.: Cross-radiometric calibration of spaceborne imaging spectrometer based on precise spectral response matching. Spectrosc. Spectral Anal. **32**(12), 3416–3421 (2012)
45. Goetz, A.F.H., Vane, G., Solomon, J.E., et al.: Imaging spectrometry for earth remote sensing. Science **228**(4704), 1147–1153 (1985)
46. Hochberg, E.J., Roberts, D.A., Dennison, P.E., et al.: Special issue on the Hyperspectral Infrared Imager (HyspIRI): emerging science in terrestrial and aquatic ecology, radiation balance and hazards. Remote Sens. Environ. **167**, 1–5 (2015)
47. Tian, C.: Research and Analysis of Gaofen-4 Cross-radiation Calibration Technology. Nanjing University of Information Technology (2020)
48. Chen, H., Li, S., Si, X., et al.: On-orbit absolute radiometric calibration of multispectral cameras based on gray-scale targets. J. Remote Sens. (S1), 28–34 (2012)
49. Helder, D., Thome, K.J., Mishra, N., et al.: Absolute radiometric calibration of Landsat using a pseudo invariant calibration site. IEEE Trans. Geosci. Remote Sens. **51**(3), 1360–1369 (2013)
50. Angal, A., Xiong, X., Wu, A., et al.: Multitemporal cross-calibration of the Terra MODIS and Landsat 7 ETM+ reflective solar bands. IEEE Trans. Geosci. Remote Sens. **51**(4), 1870–1882 (2013)
51. Shrestha, M., Hasan, M.N., Leigh, L., et al.: Extended pseudo invariant calibration sites (EPICS) for the cross-calibration of optical satellite sensors. Remote Sens. **11**(14), 1676 (2019)
52. Liu, Q., Yu, T., Gao, H.: Radiometric cross-calibration of GF-1 PMS sensor with a new BRDF model. Remote Sens. **11**(6), 707 (2019)
53. Zhang, Y.: Research on cross-calibration of multispectral cameras of ZY-3 satellite. Chang'an University (2014)
54. Li, J., Wang, R., Zhu, L., et al.: On-orbit geometric calibration of "Tianhui-1" satellite mapping camera. J. Remote Sens. (S1), 35–39 (2012)
55. Wang, M., Tian, Y., Cheng, Y.: Current status and prospect of on-orbit geometric calibration of high-resolution optical remote sensing satellites. J. Wuhan Univ. Inf. Sci. Ed. **42**(11), 1580–1588 (2017)