Estimating Egyptsat -1 Radiometric Coefficient using Cross Calibration with Spot4 and Spot5

Original Scientific Paper

Sayed Abdo
National Authority for Remote Sensing and Space Science 23
Josef Tito, New Nozha Cairo, Egypt
Sayed.abdo@narss.sci.eg

Ibrahim Ziedan
Zagazig University, Faculty of Engineering, Department of Computer and Systems Engineering
Zagazig, Egypt
ieziedan@gmail.com

Asmaa Elyamany
Zagazig University, Faculty of Engineering, Department of Computer and Systems Engineering
Zagazig, Egypt
eng.a.elyamany@gmail.com

Abstract *– The pre-processing of satellite data is a vital step in harnessing the full potential of remote sensing pictures. EgyptSat-1, Egypt's first satellite for observing the Earth from a distance, encountered a major obstacle as a considerable amount of the images it captured could not be used since the necessary radiometric coefficients were missing. This study utilises a cross-calibration methodology, taking advantage of the spectral similarity between Spot 4 and Spot 5 as reference satellites, in order to retrieve these difficult-to-obtain coefficients. The analysis demonstrates that the selection of window size in the cross-calibration process is crucial in determining the outcomes. In general, smaller window sizes tend to produce better results. However, there are certain cases when larger windows are more successful, such as in the scenario of EgyptSat-1's band 3 and its cross-calibration with Spot 5. In contrast to a previous study, the new methodology produces much diminished uncertainty factors, indicating a remarkable enhancement in accuracy. The cross-calibration results highlight the significance of selecting the appropriate window size and satellite for accurate calibration, especially for the Near-Infrared (NIR) band, which is highly responsive to these parameters. Moreover, there are differences in the computations of offset and gain between Spot 4 and Spot 5, which further highlight the intricacies involved in radiometric calibration. The results of this study lead to the determination of improved calibration coefficients for EgyptSat -1, with the specific aim of maximising the accuracy of the results and minimising any errors.*

Keywords*: information security, information system, security awareness, user behavior*

1. INTRODUCTION

It is well known that the satellites orbiting the earth are subjected to mechanical or electrical effects, as well as UV radiation. These effects can alter the way sensors on board operate, resulting in inaccurate results from satellite image processing. This is why satellite sensors must be calibrated on a regular basis. The calibration is basically the comparison of the measured instrument to an absolute reference, standard reference or a well-known accuracy this later one is called cross calibration. In cross calibration the comparison is made between the sensor to be calibrated and a well-known sensor. Egypt has lunched Egyptsat -1 since 2007, a huge amount of data has been sent to the ground station since then. the missing calibration coefficients made it hard to use those data. In 2012, cross calibration is made between Egyptsat -1 and Spot 4 to retrieve the missing radiometric calibration coefficients of Egyptsat -1 [1]. In 2016, Using simultaneously collected Landsat-8 OLI data, the Gaofen-1 WFV cameras were cross calibrated, and the findings showed that the newly calibrated reflectance exhibited a modest difference (5%) with the calibrated OLI (Operational Land Imager) reflectance for the four spectral bands over a large reflectance range [2]. In 2017, the 8 corresponding spectral bands of the Sentinel-2 MSI (MultiSpectral Instrument) cross calibrated with the well-calibrated Landsat 8 OLI as a reference and the results showed that the radiometric difference of the 7 corresponding bands are consistent to OLI within 1% or better, except on cirrus band [3]. In 2018, Landsat and Sentinel-2 cross calibration resulted in stable radiometric calibration for each instrument and consistency to ~2.5% between the instruments for all the spectral bands that the instruments have in common [4]. In 2019, the GF-1 wide coverage multi-spectral camera cross calibrated with MODIS and the results used to correct the side swing angle [5]. The findings of the calibration coefficients from the 2019 GF-1 satellite cross-calibration with MODIS and Landsat 8 showed that the suggested strategy can obtain excellent calibration accuracy, and the total calibration uncertainties of PMS using MODIS as reference sensor are less than 6% [6]. In 2019, FORMOSAT-5 satellite was both vicarious and cross-calibrated with Landsat 8, the results showed a decaying optical sensitivity, which resulted in rapid changes (6%–24% in radiometric coefficient) during the first year after [7] launch . In 2020, the GF-6/WFV is cross-calibrated with Landsat-8/OLI, Sentinel-2/MSI and Terra/MODIS, the uncertainty analysis showed that the total uncertainty is 3.35% for the blue band, 3.56% for the green band, 4.23% for the red band and 4.60% for the NIR band, all less than 5% [8]. In2020, a 4-angle BRDF normalization model was used for Cross Calibration and Validation between Landsat 8 and Sentinel 2A, the findings indicated that there was good potential for normalization in the longer wavelength bands but less promise in the blue and coastal aerosol bands. [9]. in 2021, a new cross-calibration approach using extended pseudo invariant calibration sites (EPICS) over North Africa used to evaluated the gain for Landsat 7/8 and Sentinel 2A/B, with the results showing that the sensors are calibrated within 2.5% (within less than 8% uncertainty) or better for all sensor pairs [10]. In2021, HJ-1A CCD1 and Terra MODIS data was cross calibrated on long term for gains calculation and the results are validated by the field calibration results, the gain difference between the site calibration and cross-calibration is less than 3%. The long-term cross-calibration results further indicate the attenuation rate has reached 23.51%, 21.89%, 8.11%, and 13.37%, respectively by the end of 2019 based on the cross-calibration results [11]. This study addresses the critical challenge of missing radiometric coefficients in EgyptSat-1's acquired imagery by employing a cross-calibration approach with reference to Spot 4 and Spot 5. The key contributions of this research are:

- Improved comprehension of the influence of various window widths on radiometric calibration, yielding valuable observations for enhancing the accuracy of satellite photography.
- Enhanced calibration precision, rendering Egyptsat -1 data more reliable and valuable for research and practical purposes.
- The introduction of updated calibration coefficients, specifically tailored to each band, guarantees low inaccuracies and maximizes the quality of the data.

Therefore, the rest of this paper is organized as follows, literature review of the presented problem in section 2. Detailed data descriptions are presented in Section 3. In section 4, description of the study area and region of interest. The proposed approach is illustrated in a detailed manner in Section 5. The detailed presentation of the results is presented in Section 6. Finally, the conclusion is discussed in section 7.

2. DATA DESCRIPTION

The study uses data from Egyptsat -1 while data from Spot4 and Spot 5 is used as reference. Egyptsat -1 is Egypt's first Earth remote sensing satellite. This satellite was jointly built by Egypt's National Authority for Remote Sensing and Space Sciences (NARSS) together with the Yuzhnoye Design Bureau in Ukraine and was launched on board a Dnepr rocket from the Baikonur Cosmodrome. On 23 October 2010, the National Authority for Remote Sensing and Space Sciences announced that control and communication with the satellite had been lost since July 2010 [12, 13].

SPOT-4 (Satellite pour l'Observation de la Terre) is a public Earth-imaging satellite launched in 1998 by the French National Centre for Space Studies (CNES) to provide worldwide crop monitoring for environmental research. [14], SPOT 5 was a commercial Earth-imaging satellite launched by CNES (Centre National d'Études Spatiales), the French Space Agency. Launched on 4 May 2002, it terminated operations in March 2015 due to a technical failure [15]. In this study, the first three bands' spectral range similarities were used to select a reference coefficient for cross-calibration retrieval of the missing coefficient. Table 1 lists the characteristics of the three satellites, while Table 2 lists the spectral resolutions.

Table 1. Characteristic of Egyptsat-1, Spot4 and Spot5

	Egyptsat -1	Spot4	Spot5
Lunch date	17 April 2007	24 March 1998	4 May 2002
altitude	668 Km	832 Km	832 Km
orbit	sun synchronous	sun synchronous	sun synchronous
Swath width	46 Km	120 Km	120 Km
Instrument	Push broom	Push broom	Push broom
Repeat cycle	~ 57 days	26 days	26 days
viewing capability	±35° about nadir	± 27° about nadir	± 27° about nadir

Table 2. Spectral resolutions of Egyptsat -1, Spot4 and Spot5

Bands	Description	Egyptsat -1	Res.	Spot 4	Res.	Spot5	Res.
Band1	Green	0.51-0.59	7.8 m	0.51-0.59	20 m	0.50-0.59	10m
Band 2	Red	0.61-0.68	7.8 m	0.61-0.68	20 m	0.61-0.68	10m
Band3	NIR	0.79-0.89	7.8 m	0.79-0.89	20 m	0.78-0.89	10m
Band4	Pan	0.50-0.89	7.8 m	0.61-0.68	10 m	0.48-0.71	5m
Band 5	SWIR	1.55 - 1.7	39 m	1.58 - 1.75	40 m	1.58-1.75	20m

3. STUDY AREA

The optical images selected for usage in the study area (Southern Egypt) must be cloud-free and collected on dates that are close together. The images used in this study are from the area of Aswan Egyptsat -1 Feb., 23, 2010 Spot4 Feb., 9, 2010 Spot5. Feb.,5, 2010 Fig. 1., these dates are the best that could be and the gap can be ignored as the ROI (Region Of Insert) is stable and doesn't contain much urban as well the method used uses only the homogeneous areas. The image contains water, desert and vegetation cover to consider both "bright" and "dark" target sites to allow better characterization across each sensor's dynamic range. To minimize the deference brought on by the sun's position change, the calibration target should be nearly Lambertian in nature and constant in terms of radiometric response and atmospheric conditions. Some of these qualities, such as a steady environment, radiometric response, and spatial uniformity, are present in desert sites, making them a good target for cross-calibration [16].

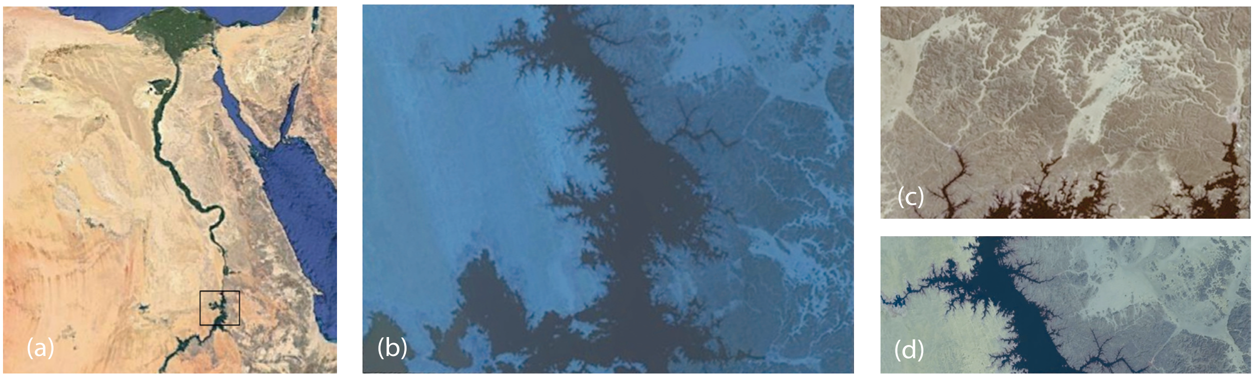

Fig. 1. (a)map of Egypt indicating the study Area ROI (b) Egyptsat -1, (c) Spot4, (d) Spot5

As the regions of interest (ROI must be in the same size and resolution and perfectly aligned together as the process uses sliding window to extract the points of interest and Calibration errors are introduced by any incorrect registration between the images acquired by the two sensors. The images used in this paper is in the DN form but registered to each other. As noticed that the resolution of the images is different so a preprocessing is a must first to proceed to the cross calibration the Egyptsat -1 is subjected to upsampling process using cubic convolution and Spot 4 MS (multispectral) bands was fused with the panchromatic band to resample the MS bands to 10 m while the Spot5 left as it is.

4. METHODS

Typically, the first stage in cross calibration is Spectral Adjustment, which eliminates the discrepancy between the spectral response of the target sensor and that of the reference sensor using spectral band adjustment factors (SBAF) [17], however the spectral response of Egyptsat -1 is unavailable that's why Spot 4 and Spot5 is chosen for the similarity in the spectral range (Table 2) Egyptsat -1's manufacturer did not provide generic calibration data, so it is considered to be missing. Consequently, Egyptsat -1 sensor calibration data is estimated using the output pixel Digital Numbers (DNs), and the missing radiometric coefficient is obtained through relative calibration relationships between the DNs of Egyptsat -1 and the source. Fig.2. shows the flow chart of the cross-calibration procedure used in this paper.

Step1: a sliding window goes over the image to extract the points of interest by selecting the center point of the window if its CV (coefficient of variation calculated by dividing the standard deviation by the mean value) of the master image (in this case the Spot image) is < 1%, as the surface in this window could be considered as homogenous. The size of the window is taken to be 15x15, 5x5 and 3x3.

Step 2: A list of matched point from the master (Spot) image and slave (Egyptsat -1) image is used to apply linear regression on the points to find the relation between the master and slave images> the list is divided to two parts 70% for the training and 30% for testing. Equation 1 shows the relation between the $DN_{Egyptsat}$ and DNS_{pot}

$$DN_{Spot} = A.DN_{Egptsat} + B \quad (1)$$

From this relation the gain and offset be determined the gain and offset of Egyptsat -1 as follows:

$$\text{Given: } L = Gain_{Spot}\, DN_{Spot} + Offset_{Spot} \quad (2)$$

From equation (1)

$$L = Gain_{spot}(A \cdot DN_{Egyptsat} + B) + Offset_{Spot} \quad (3)$$

$$L = A \cdot Gain_{Spot}\, DN_{Egyptsat} + B \cdot Gain_{Spot} + Offset_{Spot} \quad (4)$$

From that

$$Gain_{Egyptsat} = A \cdot Gain_{Spot} \quad (5)$$

$$Offest_{Egyptsat} = B \cdot Gain_{Spot} + Offset_{Spot} \quad (6)$$

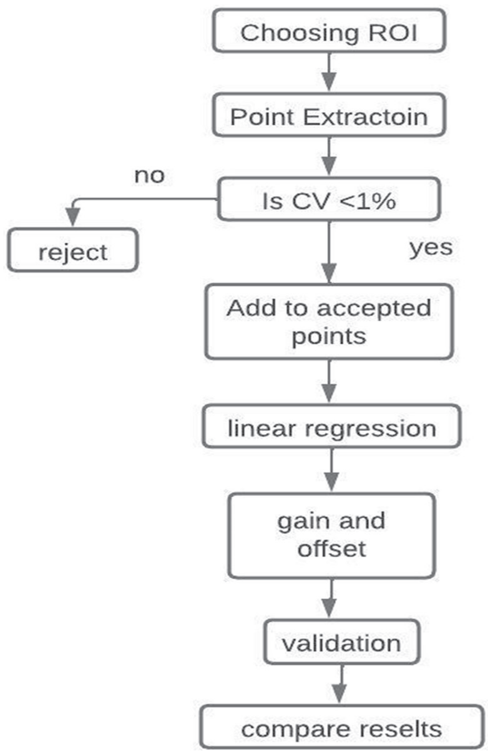

Fig. 2. The work flow of the cross-calibration process

Step 3: Using the obtained coefficients from the cross calibration with Spot 4 to retrieve Egyptsat -1 level 2A image and compare it to Spot 5 level 2A image, Likewise Using the obtained coefficients from the cross calibration with Spot 5 to retrieve Egyptsat -1 level 2A image and compare it to Spot 4 level 2A image. The compare process is done by computing the RMSE (Root Mean Square Error) and normalizing the result by dividing it by the range of the DN of the images (in this case 0-255).

5. RESULTS AND DISCUSSION

Table 3 shows the gain of Spot4 and Spot 5 from the metadata files while the offset for both satellites is 0.0.

Table 3 gain of Spot4 and Spot5

Satellite	Band1	Band2	Band3
Spot4	0.85857	0.78700	1.34100
Spot5	0.830500	0.800678	1.313315

After applying the previous algorithm and equations (5, 6) the results are shown in Tables 4 and 5, along with the uncertainty degree calculated from the normalized RMSE.

Table 4. The calibration coefficients due to cross calibration with spot 4

15x15 window			
Band	**Gain**	**Offset**	**Uncertinity**
1	2.2022	-14.0150	25.06%
2	1.3463	-6.7689	16.15%
3	1.4357	5.9256	18.7%
5x5 window			
Band	**Gain**	**Offset**	**Uncertinity**
1	2.8486	-61.6575	22.13%
2	1.5203	-25.0393	14.99%
3	1.4876	-0.1991	18.57%
3x3 window			
Band	**Gain**	**Offset**	**Uncertinity**
1	3.0921	-79.1228	21.5%
2	1.7706	-51.6968	12.91%
3	1.8168	-46.0309	14.95%

Table 5 The calibration coefficients due to cross calibration with spot 5

15x15 window			
Band	**Gain**	**Offset**	**Uncertinity**
1	2.1487	-73.4105	19.53%
2	1.4341	-57.5250	12.34%
3	0.8430	30.0816	11.9%
5x5 window			
Band	**Gain**	**Offset**	**Uncertinity**
1	2.0602	-66.7629	19.36%
2	1.3454	-48.3277	11.49%
3	0.8732	24.9954	12.25%
3x3 window			
Band	**Gain**	**Offset**	**Uncertinity**
1	2.0523	-66.1413	19.18
2	1.3215	-45.8055	11.54%
3	0.9437	15.2819	12.71%

The findings displayed were produced using an average of 400 points for the 3x3 window, while 8000 and 34,000 points, respectively, were used for the 5x5 and 15x15 windows. Figs. 3, 4 represent the scatter plot of Egyptsat -1 DN versus Spot 4 and Spot 5. plotted by MATLAB. It is evident that the points tend to form vertical lines. In order to investigate this issue, a histogram plot was drawn for Egyptsat -1 bands in Fig. 5., which reveals voids in the histogram for all three bands. This indicates that the vertical lines in Fig. 3, 4 are the result of Egyptsat -1 poor quantization. It is evident from Fig. 3, 4, that the line generated is satisfactory and fairly depicts the relationship between Egyptsat -1 points and Spot points. Spot 4 results (Table 4) shows that the uncertainty factor is decreasing with decrease of the window size, it is also noticeable that the gain fluctuates around the average with no more than 20% declines to 15% in the case of band 2 and 3, whereas the offset results are so widely dispersed from the average.

In the other hand Spot 5 results (Table 5) shows that with the decreasing of the window size the uncertainty factor decrease with the exception of band 3 (NIR) the uncertainty factor increase with decreasing the window size. By examining the findings, it can be found that the gain fluctuates around the average with no more than 6% in band 2 and 3, falling to 3% in the case of band 1,and that the offset results fluctuate by 7% in band 1, 14% in band 2, and 35% in band 3. Table 5 lists the outcomes of an earlier attempt to determine the messing coefficient of Egyptsat1 and was obtained via 13 points of cross-calibration between Egyptsat1 and Spot4 [17].

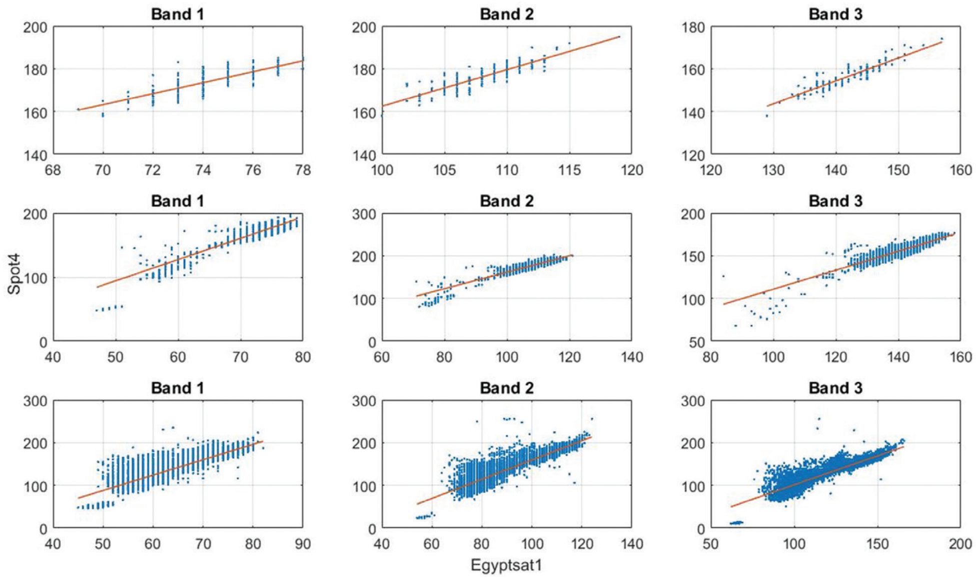

Fig. 3. Scatter plot of Spot 4 and Egyptsat -1 DN's

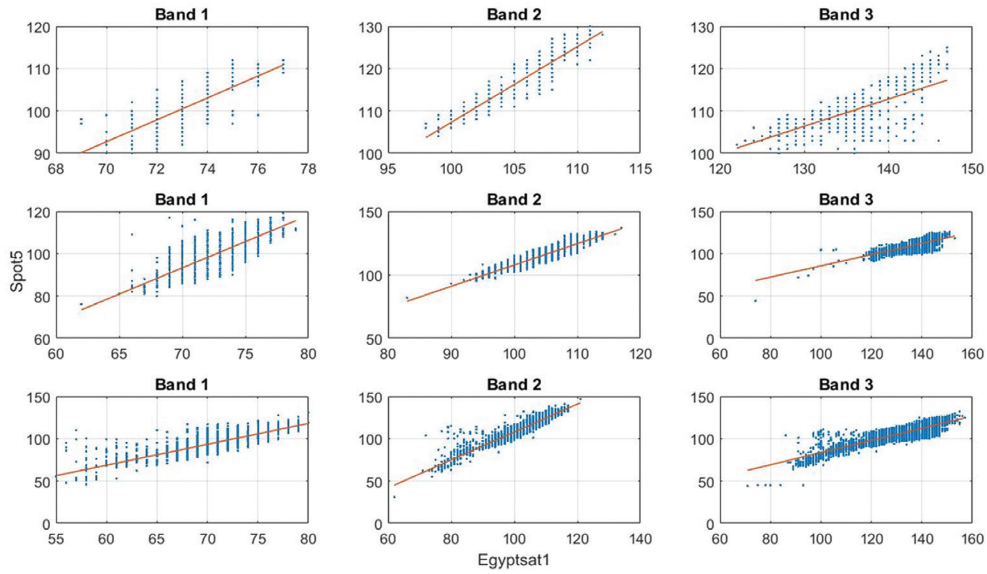

Fig. 4. Scatter plot of Spot 5 and Egyptsat -1 DN's

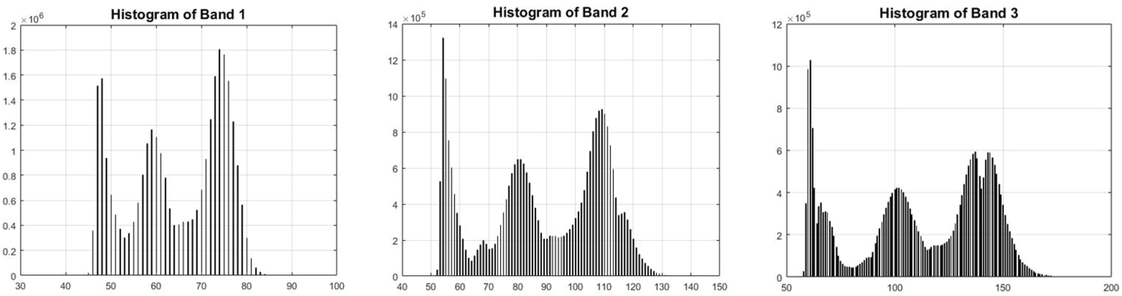

Fig. 5. A histogram for the bands of the Egyptsat -1 image in Fig. 1.(b)

It is apparent that the Spot 4 results are similar to those previously acquired in the case of gain, particularly in the window sizes of 5 and 3, while the results are very different in the case of offset.

The outcome of applying the coefficient in Table 6 to the Egyptsat-1 image to generate a level 2A image and comparing it to a level 2A image from Spot 4 is shown in Table 7.

Table 6. The finding of the prior study

Egyptsat-1	Band1	Band2	Band3
Gain [W/(m2 sr μm)]	3.032477	1.462634	1.458202
Offset [W/(m2 sr μm)]	-32.1473	-9.89971	-27.8724

Table 7. The uncertainty factor of the prior finding

Band	Uncertinty
1	38.29%
2	18.85%
3	7.06%

6. CONCLUSIONS

By stdying the cross-calibration results between Egyptsat -1 and Spot 4/5, it is evident that the smaller the window size the better the result.with except in the case of Egyptsat -1 and Spot 5 band 3 the bigger the window size the better the results

With the exception of band 3, where the earlier study's results are superior with an uncertainty factor of 7.06%, the results of the cross calibration of Egyptsat -1 with Spot 4/5 reveal that the new study has a low uncertainty factor.

The data indicate that switching from Spot4 to Spot5 and adjusting the window size has a slight impact on the gain. However, the window size in Spot 4 cross-calibration has a significant impact on the offset computation. In the case of Spot5, changing the window size from 5 to 3 has a negligible impact on the results, except for the NIR band (band 3). The NIR band is typically very sensitive to window size changes. While the offset varies between Spot4 and Spot5, band 3 varies greatly when the window is altered. In the case of the offset calculation, the results vary greatly, whereas the gain calculation yields very similar values. The uncertainty factor in the case of Spot 4 is varying from 25.06% to 21.5% in the case of band 1 while in the case of spot 5 it varies from 19.53% to 19.18% in case of band 1.

From all the previous results the calibration coefficients can be considered as follows:

Table 8. The estimated calibration coefficient of Egyptsat1

Egyptsat-1	Band1	Band2	Band3
Gain [W/(m2 sr μm)]	2.0523	1.345	1.458202
Offset [W/(m2 sr μm)]	-66.1413	-48.3277	-27.8724

These results are chosen in the light of the uncertainty factor to achieve the best results with minimum error. Band 1 coefficients are chosen from the cross calibration results with Spot5 with window size 3x3 with uncertainty of 19.18%. Band 2 calibration coefficients are chosen from the cross calibration with Spot5 with window size 5x5 with uncertainty of 11.49%.Band 3 best results obtained by applying the calibration coefficients of the prior study with uncertainty 7.06%.

7. ACKNOWLEDGMENT

The authors are grateful to the National Authority for Remote Sensing and Space Sciences (NARSS) in Egypt for supporting this study.

8. REFERENCES:

[1] A. Nasr, B. El Leithy, H. Badr, J. Centeno, "Estimation of Radiometric Calibration Coefficients of EGYPTSAT-1 Sensor", The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 39, 2012, pp. 139-143.

[2] J. Li, L. Feng, X. Pang, W. Gong, X. Zhao, "Radiometric cross calibration of gaofen-1 wfv cameras using landsat-8 oli images: A simple image-based method", Remote Sensing, Vol. 8, No. 5, 2016, p. 411.

[3] S. Li, S. Ganguly, J. L. Dungan, W. Wang, R. R. Nemani, "Sentinel-2 MSI radiometric characterization and cross-calibration with Landsat-8 OLI", Advances in Remote Sensing, Vol. 6, No. 02, 2017, p. 147.

[4] J. A. Barsi et al. "Sentinel-2A MSI and Landsat-8 OLI radiometric cross comparison over desert sites", European Journal of Remote Sensing, Vol. 51, No. 1, 2018, pp. 822-837.

[5] Y. Xie, Z. Tao, W. Shao, J. J. Qu, H. Huan, C. Tian, "Radiation Cross Calibration Based on GF-1 Side Swing Angle", Journal on Internet of Things, Vol. 1, No. 1, 2019, p. 9.

[6] Q. Liu, T. Yu, H. Gao, "Radiometric cross-calibration of GF-1 PMS sensor with a new BRDF model", Remote Sensing, Vol. 11, No. 6, 2019, p. 707.

[7] T.-H. Lin et al. "Radiometric variations of On-Orbit FORMOSAT-5 RSI from vicarious and cross-calibration measurements", Remote Sensing, Vol. 11, No. 22, 2019, p. 2634.

[8] A. Yang et al. "Radiometric cross-calibration of the wide field view camera onboard GaoFen-6 in multispectral bands", Remote Sensing, Vol. 12, No. 6, 2020, p. 1037.

[9] M. Farhad, M. Kaewmanee, L. Leigh, D. Helder, "Radiometric cross calibration and validation using 4 angle BRDF model between landsat 8 and sentinel 2A", Remote Sensing, Vol. 12, No. 5, 2020, p. 806.

[10] P. Khakurel, L. Leigh, M. Kaewmanee, C. T. Pinto, "Extended Pseudo Invariant Calibration Site-Based Trend-to-Trend Cross-Calibration of Optical Satellite Sensors", Remote Sensing, Vol. 13, No. 8, 2021, p. 1545.

[11] L. Liu, T. Shi, H. Gao, X. Zhang, Q. Han, X. Hu, "Long-term cross calibration of HJ-1A CCD1 and Terra MODIS reflective solar bands", Scientific Reports, Vol. 11, No. 1, 2021, p. 7386.

[12] Y. G. Moustafa, F. A. Farrag, A. A. Abdelhafiz, A. M. Abd Elwahed, "The Potentials of Satellite Images for Map Updating with Emphasizes on Egypt Sat-1 Images", JES. Journal of Engineering Sciences, Vol. 40, No. 4, 2012, pp. 989-1003.

[13] A. R. Elshehaby, L. G. E.-d. Taha, "Assessment of cartographic potential of EgyptSat-1 satellite image (case study in flat areas)", Applied Geomatics, Vol. 3, 2011, pp. 159-169.

[14] M. Magnusson, J. E. Fransson, "Combining airborne CARABAS-II VHF SAR data and optical SPOT-4 satellite data for estimation of forest stem volume", Canadian Journal of Remote Sensing, Vol. 30, No. 4, 2004, pp. 661-670.

[15] W. Fu, J. Ma, P. Chen, F. Chen, "Remote sensing satellites for digital earth", Manual of Digital Earth, 2020, pp. 55-123.

[16] S. Kabir, L. Leigh, D. Helder, "Vicarious methodologies to assess and improve the quality of the optical remote sensing images: A critical review", Remote Sensing, Vol. 12, No. 24, 2020, p. 4029.

[17] Q. Zhou, L. Tian, J. Li, Q. Song, W. Li, "Radiometric cross-calibration of Tiangong-2 MWI visible/NIR channels over aquatic environments using MODIS", Remote Sensing, Vol. 10, No. 11, 2018, p. 1803.