PAPER • OPEN ACCESS

Assessment of top of atmosphere reflectance generation algorithm for world view-2 high resolution images

To cite this article: M Allam *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1172** 012015

Assessment of top of atmosphere reflectance generation algorithm for world view-2 high resolution images

M Allam[1], T Mahmoud[1], A Elsharkawy[2] and B Sheta[1]

[1]Electrical Engineering, Military Technical College, Cairo, Egypt.
[2]Civil Engineering, Military Technical College, Cairo, Egypt.

E-mail: eng.ma.mo.allam@gmail.com

Abstract. Recently, there are many developments in remote sensing techniques using satellite imagery as a result of the variety of remotely sensed image sources with different spatial and spectral resolutions and from different sensors. Optical satellite products are affected by an error of payload, atmosphere (scattering and absorption), and variations relative to positions of Sun, Earth, and satellite during capturing data. Top of Atmosphere (TOA) correction is the process of removing the effects of variations relative to sensor error and positions of Sun, Earth, and satellite. In this paper, maximum benefits from high spectral and spatial resolution images are demonstrated and analyzed or compared with images from different. TOA correction algorithm, which was implemented using Python environment, is applied to high resolution images from WorldView-2 (WV-2) satellite. TOA reflectance is considered the first step in any algorithm dedicated to the change detection process. Reflectance conversion is also performed on the same images using Orfeo ToolBox (OTB), the open-source software. The performance and efficiency of the proposed algorithm are compared with that of the Orfeo ToolBox (OTB) TOA reflectance output. The achieved results show that the proposed algorithm, which is automatically performed, is faster and provides significant results for WV-2 images, and can be adapted to be applied on different optical satellite sensors.

1. Introduction

Remote sensing satellite images offer important information about earth resources and the environment used in different applications image classification, fusion, and change detection[1, 2]. The popularization of satellite images is due to availability online for visual inspection or download free for further analysis. Continuous development of optical satellite production provides a variety of satellite image products with different spectral and spatial resolutions. High spectral resolution satellite images provide dense information about different features in the image. Moreover, the high spatial resolution provides more details of earth observations. However, sometimes we have to combine data from different sensors due to restrictions of cloud coverage and low revisit time. A seamless combining of images from different sensors is not an easy or straightforward process. The combination of data from different sensors raises some worries about data compatibility. Radiometric differences at top of the atmosphere level could be one of these worries [3]. while traveling of solar spectrum electromagnetic radiation through atmosphere to satellite sensors atmosphere gases and aerosols causes absorption and scattering of radiations[4]. Atmospheric correction of impacts on optical images is a very important pre-processing step for further analysis or comparison with different sensors [5]. Achieving accurate surface reflectance becomes a mandatory step in Effective processing. TOA corrections process working on minimizing the effects of atmospheric on images and generate TOA reflectance products. TOA corrections account for variations due to acquisition time, atmospheric conditions, and positions of the Sun, Earth, and satellite. TOA correction of satellite images is very important for precise analysis and remote sensing applications. WV-2 satellite products represent a high spectral resolution image with multiple bands. The variety of spectral bands enable using of different applications such as image analysis and classify land cover according to the spectral signature of each feature[6]. WV-2 sensor provides products consists of eight multispectral bands which are useful in spectral analysis, monitoring, land-use land cover mapping, disasters, defense and intelligence, exploration, and visualization[7]. TOA reflectance conversion applied to three WV-2 images for different cities Miami, Rio De Janeiro and Brisbane captured at different times with different environments using the proposed algorithm. Orfeo Toolbox (OTB) is an open-source library for remote sensing applications and image processing initiated by the French space agency National Centre for Space Studies (CNES) [8]. The library originally targets specific images captured by satellites Pleiades and Cosmo-Skymed but also support other sensors. OTB is a rich source of variety applications available for image calibration, enhancement, ortho-rectification or pansharpening, classification, SAR processing, and much more[9]. OpticalCalibration application performs TOA calibration and supports specific sensors.

The next sections of this paper are structured as follows: Section 2 describes the area of study. Section 3 demonstrates the proposed methodology. The experimental results and discussion are illustrated in Section 4. Section 5 provides some concluding remarks, and ideas for future work in this area are also discussed.

2. Area of Study

2.1. WV-2 satellite images

WorldView-2 satellite is DigitalGlobe's third satellite in orbit launched in October. WV-2 provides a 0.46m resolution panchromatic image, and a 1.84m resolution eight-band multispectral which awards advantages compared with other DigitalGlobe's satellites as shown in figure 1[10].

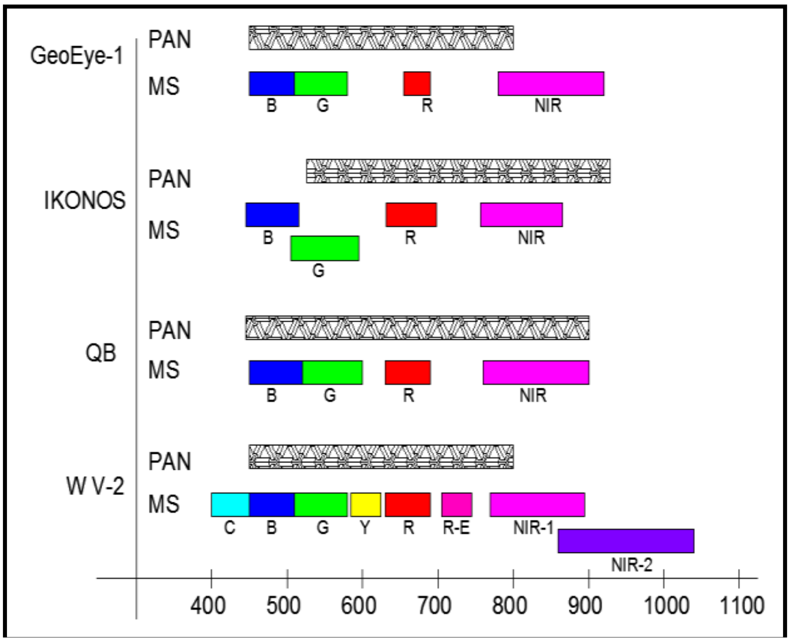


Figure 1. DigitalGlobe's satellites with different spectral bands [10].

2.2. WV-2 multispectral bands specifications

WV-2 satellite products provide eight multispectral bands six in the visible range and two in the near-infrared range figure 2 All bands have different sensitivity to features on the ground. This combination of bands improves remote sensing applications. The Coastal blue band is absorbed by healthy plants; least absorbed by water and significantly affected by atmospheric scattering. Thus, this given information makes it useful for vegetative analysis and identification, bathymetric studies, and improves atmospheric correction techniques. Yellow band measures the "yellow-ness" of particular vegetation and very useful for feature classification. The red-edge band is very useful in detecting plants. The two infrared bands partially overlapped but the second infrared band was characterized by less affection by atmospheric impact[7].

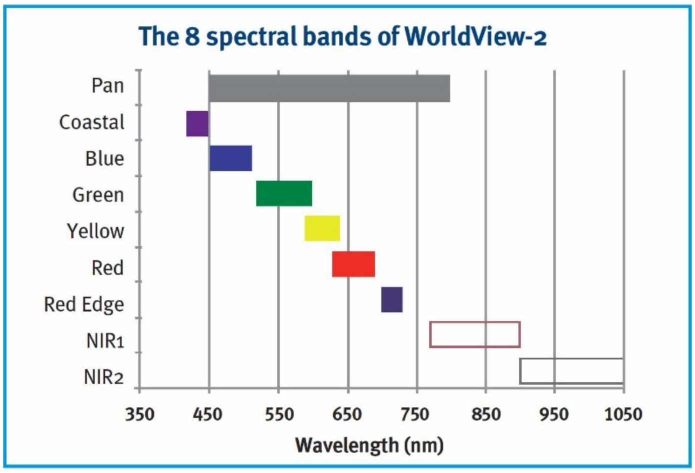


Figure 2. WV-2 image spectral bands[7].

2.3. Input data

The input data are about three WorldView-2 (WV-2) satellite images which were captured at different times of cities Miami, Rio De Janeiro, and Brisbane as shown in figure 3(a), (b), and (c), respectively. Data are downloaded from the DigitalGlobe website and captured in different environments in table 1 [10].

(a) (b) (c)

Figure 3. WV-2 satellite images: (a) Miami, (b) Rio De Janeiro, and (c) Brisbane. [10]

Table 1. Data parameters.

	Miami	Rio De Janeiro	Brisbane
Projection	UTM	UTM	UTM
Datum	WGS-84 zone 17N	WGS-84 zone 17N	WGS-84 zone 17N
Upper left corner	Lat 25° 47` 37.6841`` N Lon 80° 14` 1.9210`` W	Lat 22 ° 51` 19.6499`` S Lon 43° 13` 53.6890`` W	Lat 27 ° 26` 9.4311`` S Lon 153° 0` 31.3479 `` E
Lower left corner	Lat 25° 46` 14.6881`` N Lon 80° 11` 35.5308`` W	Lat 22 ° 63` 31.1101`` S Lon 43° 11` 28.3343 `` W	Lat 27 ° 28` 22.3549`` S Lon 153° 3` 0.4217 `` E
Size	8x(2048x1266)	8x(2048x2048)	8x(2048x2048)
Time of capturing	2010-11-12 16:08:11.809487	2011-01-25 13:11:53.815364	2011-07-13 00:19:45.597708
Sun elevation angle (deg)	44.5	63.3	35.8

3. Methodology

This research work concentrates on converting the WV-2 raw image Digital Numbers (DNs) to TOA reflectance. This conversion is performed by removing atmospheric effects from satellite images and account for variations relative to positions of Sun, Earth, and satellite. figure 4 illustrates the procedures that are utilized in the experiment. Python environment is utilized to implement the proposed TOA conversion algorithm to transform DNs to TOA reflectance which is performed in two main steps: conversion to TOA spectral radiance step followed by conversion to TOA spectral reflectance.

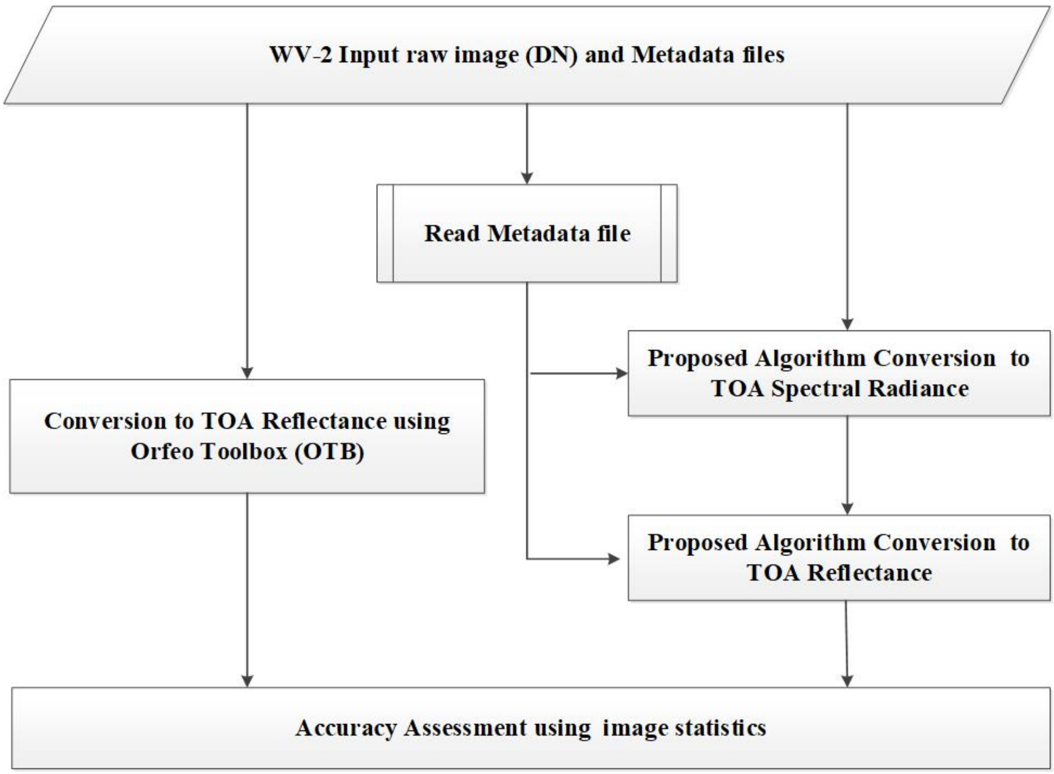


Figure 4. Research methodology.

3.1. Conversion to TOA spectral radiance

WV-2 images delivered to customers radiometrically corrected pixels. Pixel values represent the amount of spectral radiance acquired by the sensor converted to DN value [12]. Consequently, WV-2 image pixel values are particular for each sensor and could not directly compare to images from a different sensor. TOA spectral radiance of WV-2 represents the spectral radiance entering the satellite sensor. Each band of WV-2 is converted to TOA spectral radiance according to equation (1) [11].

$$\mathbf{L}_{\lambda_{\mathrm{pixel,band}}} = \frac{\mathbf{k}_{\mathrm{band}} \cdot \mathbf{q}_{\mathrm{pixel,band}}}{\Delta\lambda_{\mathrm{band}}} \tag{1}$$

Where $\mathbf{L}_{\lambda_{\mathrm{pixel,band}}}$ is the TOA spectral radiance pixels $[\mathrm{W} - \mathrm{m}^{-2} - \mathrm{sr}^{-1} - \mu\mathrm{m}^{-1}]$ (watts/unit source area* unit solid angle* unit wavelength), $\mathbf{k}_{\mathrm{band}}$ is the absolute radiometric calibration factor $[\mathrm{W} - \mathrm{m}^{-2} - \mathrm{sr}^{-1} - \mathrm{count}^{-1}]$ (watts/unit source area* unit solid angle* Digital Numbers counts) for each band, $\mathbf{q}_{\mathrm{pixel,band}}$ are WV-2 image pixels, and $\Delta\lambda_{\mathrm{band}}$ is the effective bandwidth [μm]. Both $\mathbf{k}_{\mathrm{band}}$ and $\Delta\lambda_{\mathrm{band}}$ can be found in the metadata file with the extension (*.IMD) under names absCalFactor and effectiveBandwidth, respectively.

3.2. Conversion to TOA spectral reflectance

Obtained TOA spectral radiance varies with Earth-Sun distance, solar zenith angle, topography, bi-directional reflectance distribution function (varies depending on the illumination and observation geometry), and effect of the atmosphere (absorption and scattering). So, the obtained TOA spectral radiance must be converted into reflectance before applying spectral analysis techniques or comparing it with other sensor data. For each product, some factors must be calculated: the distance from the Sun to Earth during capturing the image, the Julian Day of capturing time, and the solar zenith angle during capturing [12].

$$\mathrm{A} = \mathrm{int}\left[\frac{\mathrm{year}}{100}\right] \tag{2}$$

$$\mathrm{B} = 2 - \mathrm{A} + \mathrm{int}\left[\frac{\mathrm{A}}{4}\right] \tag{3}$$

$$\mathrm{JD} = \mathrm{int}[365.25 * (\mathrm{year} + 4716)] + \mathrm{int}[30.6001 * (\mathrm{month} + 1)] + \mathrm{day} + \frac{\mathrm{UT}}{24.0} + \mathrm{B} - 1524.5 \tag{4}$$

$$\mathrm{D} = \mathrm{JD} - 2451545.0 \tag{5}$$

$$\mathrm{g} = 357.529 + 0.98560028 * \mathrm{D} \tag{6}$$

$$\mathrm{d_{ES}} = 1.00014 - 0.01671 * \cos(\mathrm{g}) - 0.00014 * \cos(2\mathrm{g}) \tag{7}$$

The from earth to sun $\mathrm{d_{ES}}$ is calculated according to equation (7), in Astronomical Units (AU). The average solar zenith angle is calculated for the whole scene at the time of acquisition according to equation (8).

$$\theta_{\mathrm{s}} = 90.0 - \mathrm{sunEl} \tag{8}$$

Where the acquisition time and sunEl are also included in the image metadata file with the extension (*.IMD). Finally, the process of converting the radiance to reflectance is performed according to equation (9).

$$\boldsymbol{\rho}_{\lambda_{\text{pixel,band}}} = \frac{\mathbf{L}_{\text{pixel,band}} * {d_{ES}}^{2} * \pi}{\text{Esun}_{\lambda\text{band}} * \cos\theta_s} \tag{9}$$

Where $\boldsymbol{\rho}_{\lambda_{\text{pixel,band}}}$ is the TOA reflectance, $\mathbf{L}_{\text{pixel,band}}$ is the calculated TOA radiance, d_{ES} is the calculated Earth-Sun distance, θ_s is the calculated average solar zenith angle and $\text{Esun}_{\lambda\text{band}}$ is the WV-2 solar spectral irradiance.

The study uses two different programs to apply TOA reflectance on three data sets shown in figure 3.

- Conversion using open-source Orfeo Toolbox (OTB)
- Conversion using implemented python program

3.3. Orfeo ToolBox (OTB)
Orfeo Toolbox (OTB) is an open-source library/software for any remote sensing user, developer, or scientists. OTB has various functions for image processing such as Optical calibration application which permits converting pixel values from Digital Numbers (DN) to TOA reflectance figure 5 Optical calibration must be defined by satellite image and metadata files (IMD, TIL, XML, and RPC) to calculate TOA reflectance automatically [9]figure 6.

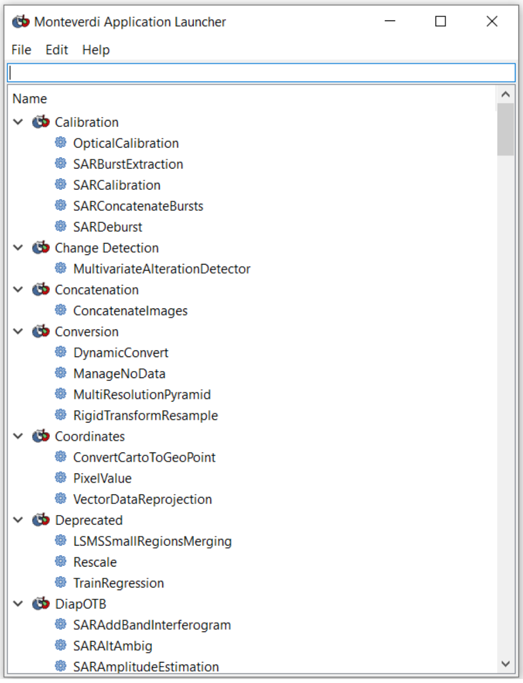


Figure 5. Orfeo ToolBox (OTB) has different applications: calibration, change detection, concatenation, conversion, Segmentation, etc…

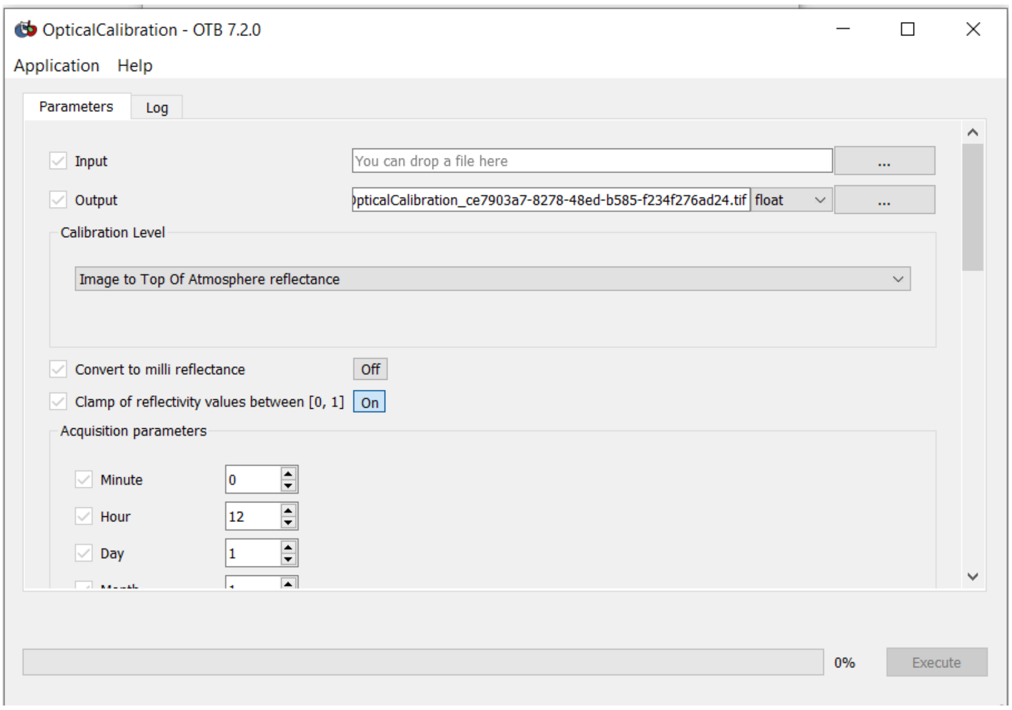


Figure 6. Optical calibration application.

3.4. Proposed algorithm

TOA reflectance conversion algorithm is implemented using high-level and general-purpose programming language Python. The implemented graphical user interface (GUI) of the proposed algorithm is designed to read the image file and attached metadata as inputs and convert the input image DN values to the TOA reflectance values in the range [0, 1] figure 7.

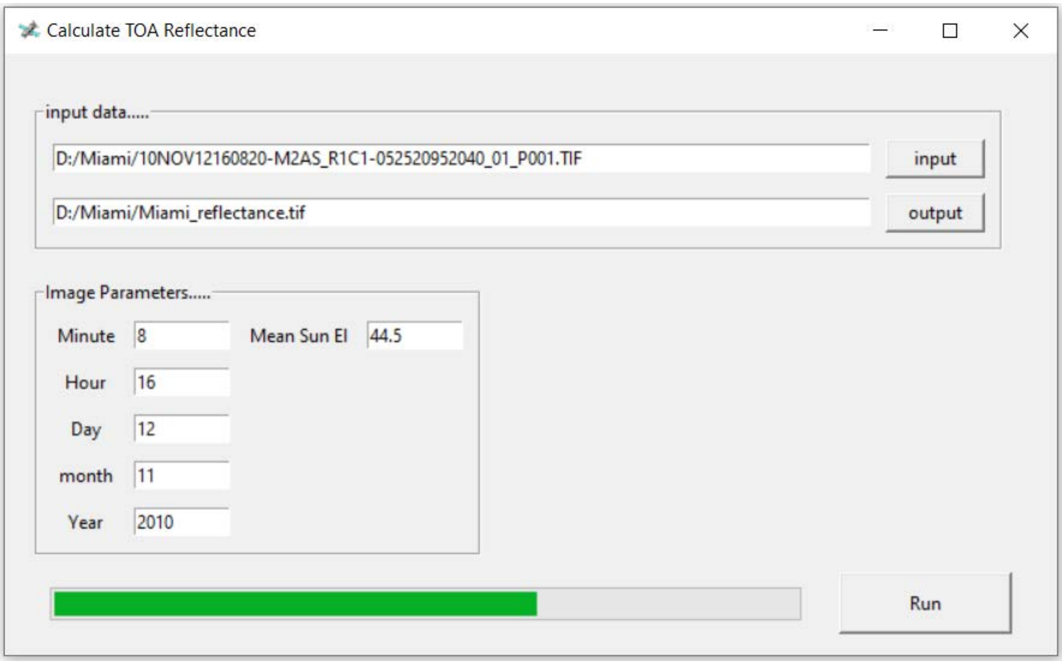
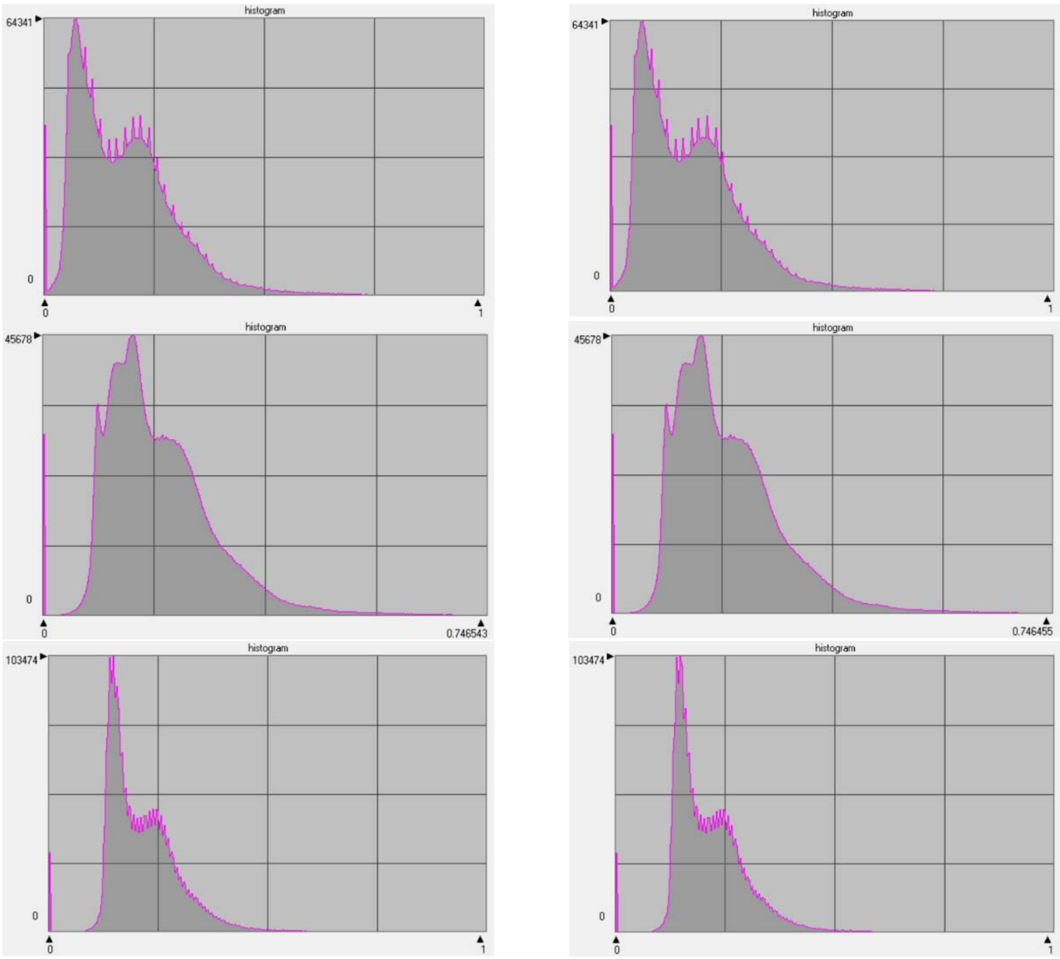


Figure 7. Proposed algorithm GUI.

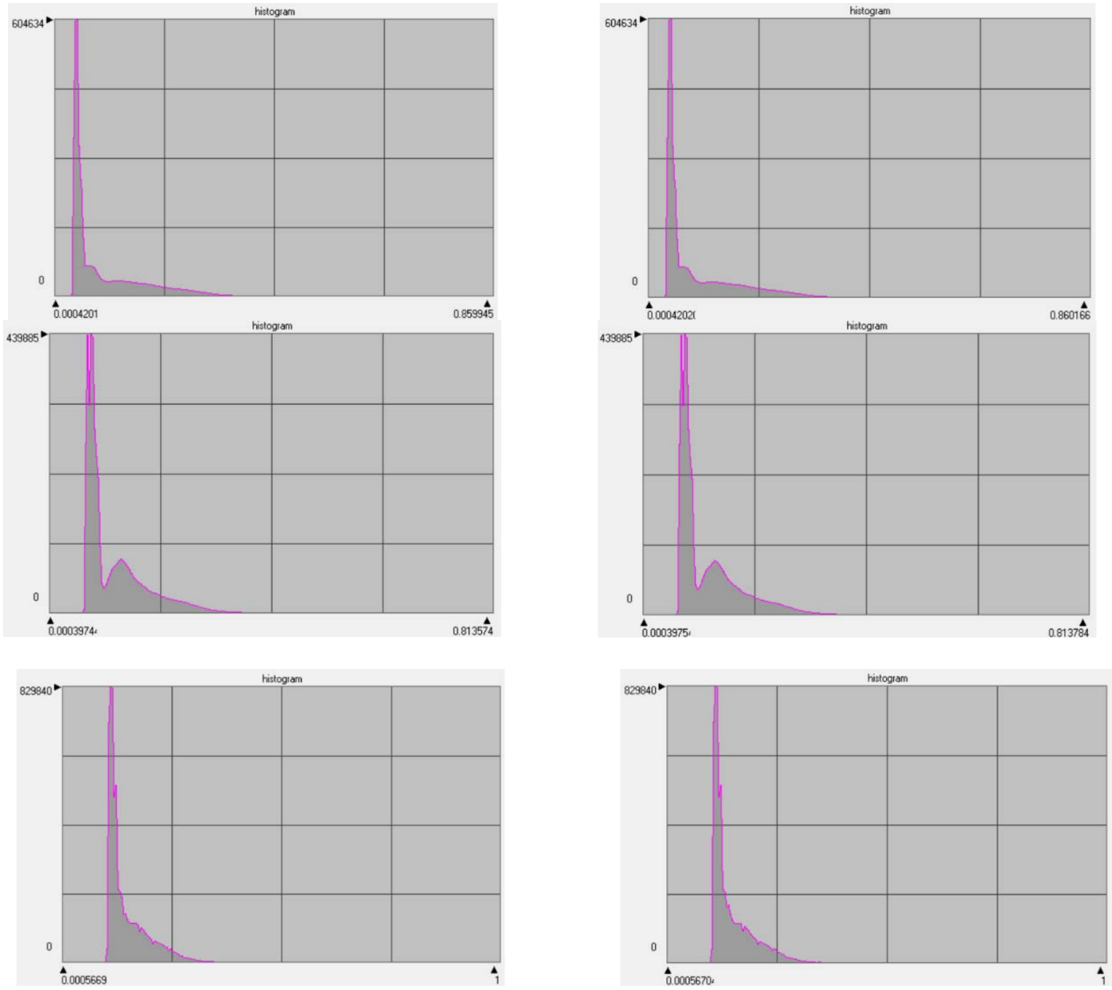
4. Results and Discussion

A histogram curve is a type of histogram that represents the distribution of pixel values as a graphical representation by plotting the frequency of each value. The histogram for a specific image enables the viewer to judge the entire distribution of the image. The histogram curve is defined by the horizontal axis (X-axis) that represents the range of minimum (darkest values) to maximum (lightest values) pixel values, DN sampled in the statistics, and vertical axis (Y-axis) of a histogram that represents the frequency of each value [13]. The histograms of output reflectance for Red, Green, and Blue bands are calculated for three WV-2 satellite images in figure 3 As samples to analyze the results, figure 8, figure 9, and figure 10 show the histogram curves of the output reflectance from the proposed algorithm and OTB for selected sample bands Red, Green, and Blue respectively. The resulted histogram curves indicate that the X-axis value and Y-axis value are approximately the same distribution.



(a) (b)

Figure 8. Histogram of TOA reflectance applied on figure 3(a): (a) using OTB, (b) using the proposed algorithm.

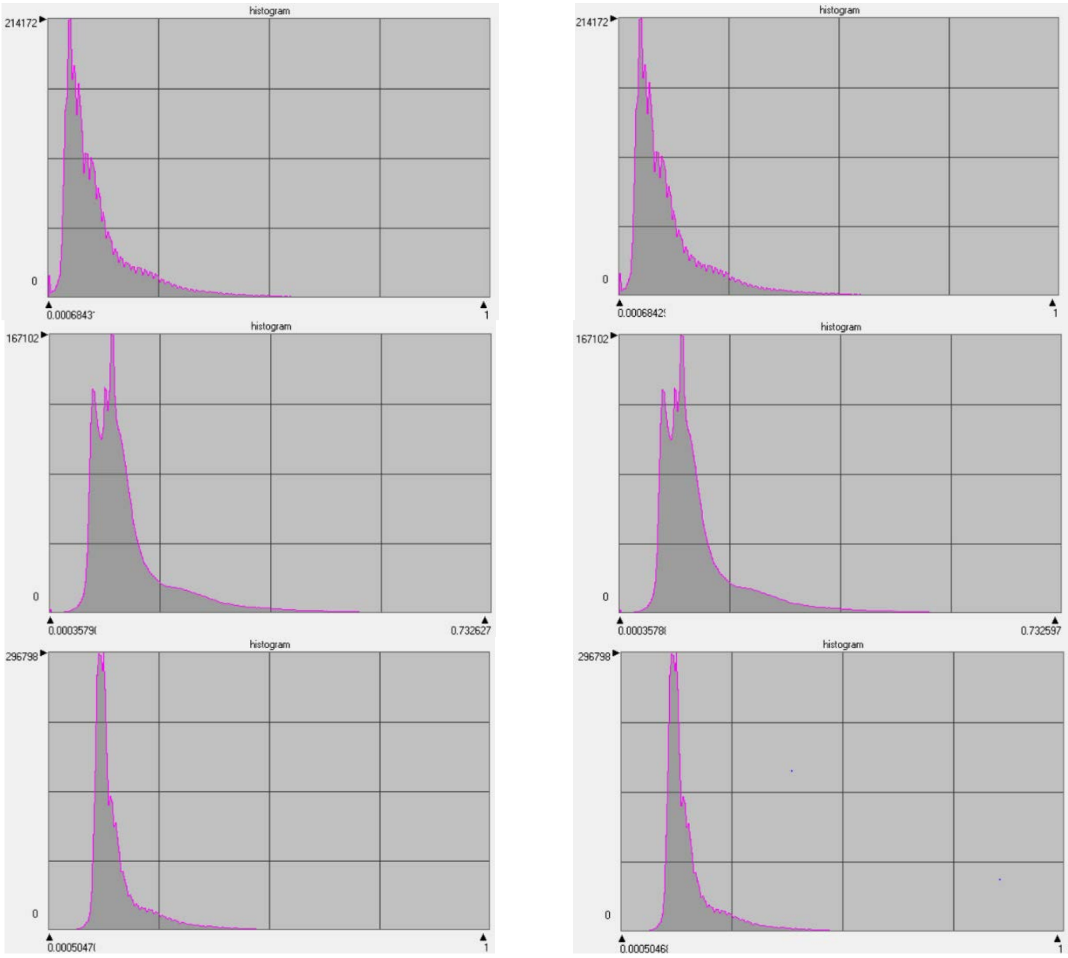


(a) (b)

Figure 9. Histogram of TOA reflectance applied on figure 3(b): (a) using OTB, (b) using the proposed algorithm.

4.1. Statistical assessment

The statistical properties of an image provide useful information, such as the total, mean and standard deviation of the pixel values. The statistical properties are calculated for the output reflectance from both software for each image data according to the minimum value seen in the column (Min), maximum value seen in the column (Max), middle value in the column (Mean), an average of the values in the column (Median), most commonly observed value in a set of data (Mode) and standard deviation (STD) calculated according to equations (10), (11), and (12) [13]. A careful study of statistical properties of generated TOA reflectance of WV-2 satellite images in figure 3, from OTB and proposed algorithm to measure the similarity, shows that they are approximately had the same statistical properties as shown in table 2.



(a) (b)

Figure 10. Histogram of TOA reflectance applied on figure 3(c): (a) using OTB, (b) using the proposed algorithm.

$$\text{Mean} = \frac{\sum p_{i,j}}{N} \tag{10}$$

$$\text{Median}(P) = \begin{cases} \dfrac{X\left[\frac{N}{2}\right] + X\left[\frac{N+1}{2}\right]}{2} & \text{if N is even} \\ X\left[\dfrac{N+1}{2}\right] & \text{if N is odd} \end{cases} \tag{11}$$

$$\text{STD} = \sqrt{\frac{\sum (p_{i,j} - \text{Mean})^2}{N}} \tag{12}$$

Where $p_{i,j}$ is the pixel value of row and column, P is the ordered list of pixel values and N is the total number of pixels.

Table 2. Statistical properties

	TOA reflectance of figure 3(a)		TOA reflectance of figure 3(b)		TOA reflectance of figure 3(c)	
	OTB	Proposed algorithm	OTB	Proposed algorithm	OTB	Proposed algorithm
Min	0	0	0.00038086	0.00038095	0.00062039	0.000623037
Max	1	1	0.77961	0.77981	1	1
Mean	0.227	0.227	0.168	0.168	0.173	0.173
Median	0.21484	0.21484	0.14953	0.14957	0.15287	0.15287
Mod	0.17969	0.17969	0.1404	0.14044	0.14506	0.14506
STD	0.063	0.063	0.039	0.039	0.052	0.052

Moreover, the processing time for any application is an important factor that must be accounted for. Therefore, the processing time for each method is calculated for each data calculated according to table 3 The achieved results indicate that the proposed algorithm implemented using Python environment is faster than that of OTB.

Table 3. Processing time.

	Image size	OTB (sec.)	The proposed algorithm (sec.)
TOA reflectance of figure 3(a)	8x(1266x2048)	1.069	0.977
TOA reflectance of figure 3(b)	8x(2048x2048)	1.465	1.329
TOA reflectance of figure 3(c)	8x(2048x2048)	2.204	1.82

5. Conclusion and Future work

In this study, TOA atmospheric correction of WV-2 images is assessed by using the proposed algorithm and OTB for study areas over cities Miami, Rio de Janeiro, and Brisbane captured at different times. The output TOA reflectance of both the proposed algorithm and OTB are then compared using image statistics to measure the accuracy of the proposed algorithm output. The statistical results show that the TOA reflectance of the proposed algorithm and OTB are approximately having the same statistical properties. The TOA reflectance conversion time of the proposed algorithm is faster than OTB by 8.6%, 9.3%, and 17.4% for WV-2 satellite images in figure 3(a), (b), and (c), respectively. The overall results provide accurate, decent capacities, fast and automated algorithm for Conversion of satellite image DN values to TOA reflectance. The proposed algorithm already supports different satellite sensors and flexible to support more satellite sensors since OTB only supports specific satellite sensors. Top of Atmosphere (TOA) correction is a very important step to remove effects results from variations relative to sensor error and positions of Sun, Earth, and satellite. TOA correction pre-process is required to either analyze or compare imagery from different sensors. In future work, the proposed algorithm can be adapted to support different satellite sensors or used as the first step in another algorithm for remote sensing image classification or change detection.

References

[1] Mani V 2020 *International Journal of Sensors and Sensor Networks* **8** 1-10
[2] Dhanaraj K and Angadi D P 2020 *GeoJournal* 1-27
[3] Sterckx S and Wolters E 2019 *Remote Sensing* **11** 1-17
[4] Doxani G, Vermote E, Roger J-C, Gascon F, Adriaensen S, Frantz D, Hagolle O, Hollstein A, Kirches G and Li F 2018 *Remote Sensing* **10** 1-18
[5] Franch B, Vermote E F, Roger J-C, Murphy E, Becker-Reshef I, Justice C, Claverie M, Nagol J, Csiszar I and Meyer D 2017 *Remote Sens (Basel)* **9** 1-14
[6] Maglione P, Parente C and Vallario A 2014 *European Journal of Remote Sensing* **47** 685-99
[7] Coffer M M, Schaeffer B A, Zimmerman R C, Hill V, Li J, Islam K A and Whitman P 2020 *Remote Sensing of Environment* **250** 112036
[8] Mclnerney D and Kempeneers P 2014 *Open source geospatial tools: applications in earth observations* (Delhi Book Store: Springer International Publishing)
[9] Lee K, Kim K, Lee S-G and Kim Y 2020 *ISPRS International Journal of Geo-Information* **9** 1-16
[10] Elsharkawy A, Elhabiby M and El-Sheimy N 2012 In: *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* pp 191-5
[11] Updike T and Comp C 2010 *Technical Note* 1-17
[12] Elhabiby M, Elsharkawy A and El-Sheimy N 2012 *International Refereed Journal of* Engineering *and Science (IRJES)* **1** 01-10
[13] Nelson S A and Khorram S 2018 *Image Processing and Data Analysis with ERDAS IMAGINE®* (Boca Raton: CRC Press)