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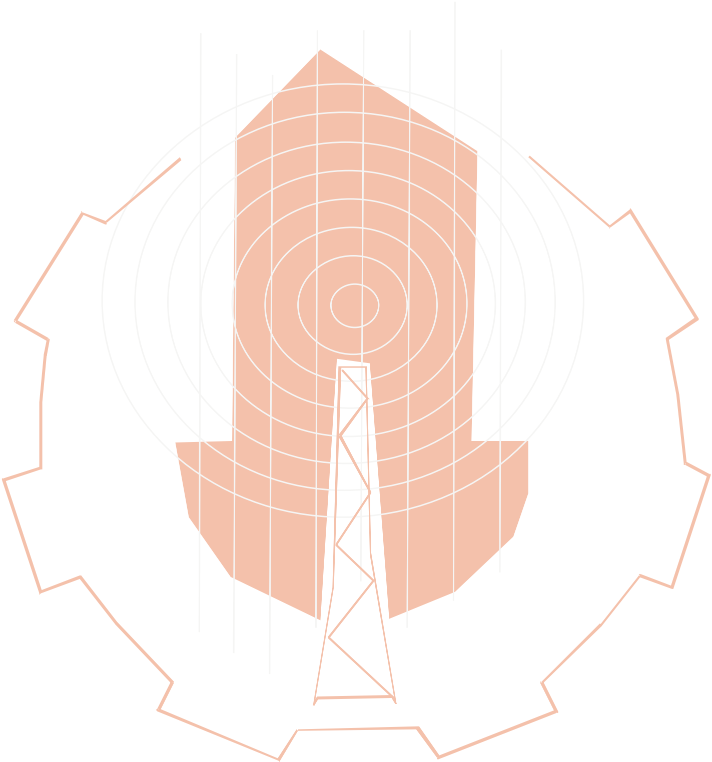

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GEO-POSITION ACCURACY OF PLEIADES HIGH RESOLUTION IMAGERY

Abdunaser Abduelmula and Mohammed Sabri Akresh

Department of Civil Engineering, Faculty of Engineering,
University of Tripoli-Libya
E-mail: Aser_gaia2013@Sapo.Pt

الملخص

التقنيات الحديثة لأجهزة الاستشعار عن بعد المحمولة على الاقمار الاصطناعية أصبحت ذات كفاءة عالية في الدقة و مع امكانية التغطية المشتركة لنفس المنطقة بأكثر من زوج من الصور وبقدرة تمييزية في نطاق نصف متر تساهم هذه التقنيات في تحديد المعلومات الجغرافية للتطبيقات الهندسية المختلفة وبدقة مكانية عالية، بالإضافة الي ان المستشعرات المتطورة للأقمار الاصطناعية، مثل الثريا "Pleiades" قد تمتعت بتقنيات حديثة يتم من خلالها تزويد المستخدم بالبيانات التي تحتوي على المعاملات الفضائية والاحداثيات الجيوديسية للصورة. حيث تساعد هذه المعاملات في ايجاد العلاقة الرياضية المباشرة بين احداثيات المواقع في الصورة والاحداثيات الارضية المقابلة لها، لغرض المعالجة والحصول على القياسات والاستخراجات السريعة.

الهدف من هذه الورقة هو تقييم الدقة الجغرافية لصور القمر الاصطناعي الثريا "صورة امامية واخري راسية "، استنادا إلى بيانات المدار "المعاملات الفضائية" والصيغ الرياضية متعددة الحدود، مع نقاط التحكم الأرضية المستقلة، وذلك من أجل التطبيق المباشر لحساب الخطأ الموقعى للإحداثيات الأفقية في صور الثريا. أظهرت النتائج أن صور القمر الاصطناعي الثريا ذات كفاءة عالية في تحديد المواقع الجغرافية "وذلك بدون الحاجة الي نقاط ضبط ارضي" وتحقيق دقة افقية مقبولة في حدود متر ونصف. بذلك يمكن الاستفادة من صور القمر الاصطناعي الثريا لتوفير الوقت والتكلفة في التطبيقات الهندسية السريعة، مثل دراسة الفيضانات والزلازل والتطبيقات الهندسية الأخرى، حينما تكون نقاط الضبط الارضي غير متوفرة او غير ممكن القيام بقياسها.

KEYWORDS: Rational Polynomial Formula; RPCs; Lat; Long; Scale; Sample; Line; Shift.

ABSTRACT

The recent development of space technology and the performance of remote sensors with spatial resolution of half meter and the new efficiency of coverage has become one of the important means to acquire high accuracy geo-position information. A geotiff space image such Pleiades has been combined with a text file containing a rational polynomials coefficienting “RPCs”. These data provide coefficients to define a Rational Functions math model which can be used to calculate sample and line image coordinates from geodetic coordinates.

The aim of this paper is to assess direct geo-position accuracy of Pleiades satellites images based on orbit data and rational polynomial formulas. Rational polynomial formulai and sensor models of Pleiades image with independent ground control points were tested in order to calculate the horizontal shift in the images space coordinates.

The results showed that the performance of Pleiades images in direct georeferencing with acceptable absolute bias error “horizontal shift in the range of three pixels” in sample and line coordinates. This means that Pleiades triplet images can be useful data sets and reduce time consumed for fast engineering applications especially

such as flooding, Earthquake and other engineering application when control points are not available or may not be possible do field surveying.

INTRODUCTION

High resolution satellite images became very important for different engineering applications in remote areas, such as flooding, earthquakes and natural disaster evaluation. This will be very important when ground control points may not available due to the acquisitions costs, logistic requirements, security or possibly prohibition, especially in many developing countries.

The resent high resolution satellite systems such Pleiads satellite has been equipped with precise positioning systems, such as dual frequency GPS receiver on-board used to determine orbital position, inernal reference units, and star trackers used to determine the position direction "rational polynomial coefficients "RPCs", allowing in sufficient direct georeferencing for many engineering applicationsens.

These RPCs contains coefficients and normalisation parameters used with rational polynomial formulas (also called rapid positional capability or and geometric analytic model), in order to make the direct georeferencing of satellite images easier for other topoghraphic extractions [1].

Satellite sensor models are different between sensor to another. However, satellite compaines decided replaced the sensor model with a common formula "Rational Polynomial Formula" composed with the rational polynomial coefficients. These coefficients are describe the object image geometry by the mathematical relations between object space coordinates (latitude, longitude) and image space coordinates (line and sample). The idea of having a common formula, in order to process satellite images of different sensors, with the same mathematical model [2,3].

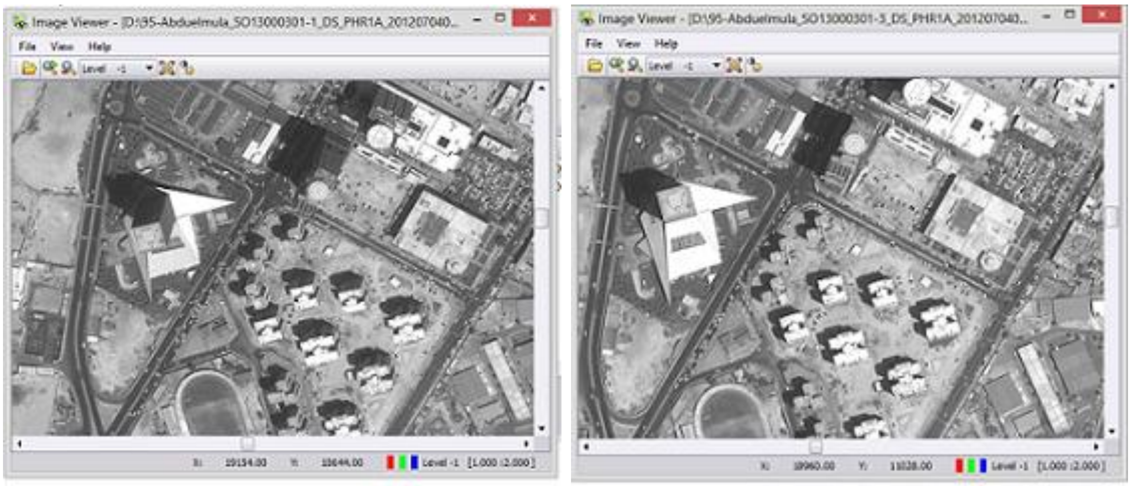
In this work, The Rational Polynomial Formulas were programmed manually in Excel, and used with PRCs coefficients and the available independent control points "ICPs", in order to calculate image space coordinates (line and sample) in the left (Forward) and right (Nadir) Pleiades images. meanwhile, PCI Geomatica "Ortho-Engine"is one of the best and most modern software in undertaking truly integrated with geo-spatial analysis of different satelliyte images. This software tool supports reading and processing of data from different satellites, such as Pleiades data, and providing algorithms allowing for manual and automatic identification of ICPs/GCPs in the images [4].

The available independent control points "ICPs" coveres Tripoli city were manually identified in the left and right of Pleiades images, and used to obtain the new image coordinates (sample and line) in left (Forward) and right (Nadir) Pleiades images. The horizontal shift in image sample "Δs" and image line "ΔL" were computed in both images, based on the difference in sample and line between calculated coordinates and measured coordinates from the image.

USED IMAGES

Pleiads stereo-pair images "left /Forward and right /Nadir" covere Tripoli area, which taken in July 2012 from specific scan mode and ground sampling distance of half meter and base to height ratio of 0.5 were used in this work.

The study area presents a normal terrain relife, with height ranging from zero to 40 m above mean sea level. Figure (1), subsets from the original Pleiades Forward and Nadir images covering approximately six square km. Both radiometric and geometric properties of used images including a sensor model rational polynomial coefficients “RPCs”.



Pleiades Forward image Pleiades Nadir image

Figure 1: subsets show the used Pleiades images covering part of Tripoli area

APPLIED MATHMATICAL FORMULAS

satellite imagery are using geometric sensor models to relate the mathematical relationship between the three-dimensional “3D” object space positions (X, Y, Z) to corresponding space position in the image (two dimensional (x, y)).

In direct georeferencing of high resolution satellite imagery, the most researchers recommend the use of the well-known vendor supplied rational polynomial coefficients of space images, and optimize geolocation accuracy through high accuracy ground control points “GCPs” [5].

In this work, the available sensor model “RPCs” for Pleiades triplet images, with rational polynomial formulas “formula -1” were manually programmed in Excel, in order to calculate the image coordinates “sample and line” based on object space coordinates. RPCs model relates the object-space (φ, λ, H) coordinates to image-space (Line, Sample) coordinates.

Given the object-space coordinates (φ, λ, H), where φ is the geodetic latitude, λ is the geodetic longitude, and height is the height above the ellipsoid, for example WGS84. Latitude, longitude, and height offsets and scale factors (LAT_OFF, LONG_OFF, HEIGHT_OFF, with LAT_SCALE, LONG_SCALE, HEIGHT_SCALE), are given for vendor in very high resolution sensors such as Pleiades, in order to normalize latitude, longitude based on the direct sensor orientation, and the relation between a ground point, given by its coordinates X, Y, Z and the image point x, y, is known as in formual-1:
RPF functional is in the form of a ratio of two cubic polynomials of object-space coordinates.

Separate rational functions “formula-1” are used to express the object-space to line and the object-space to sample coordinates relationship. This method can be applied without GCPs “so- called terrain-independent”, nevertheless the accuracy obtained are good enough for some application, when the GCPs are not available.

$$\boldsymbol{x} = F(Latitude, Longitude, Height) = \frac{Num_S(P,L,H)}{Den_S(P,L,H)} \tag{1a}$$

$$\boldsymbol{y} = F(Latitude, Longitude, Height) = \frac{Num_l(P,L,H)}{Den_l(P,L,H)} \quad (1b)$$

whereas:

$\boldsymbol{Num_{l,}(P,L,H)} = a_1 + a_2 \cdot L + a_3 \cdot P + a_4 \cdot H + a_5 \cdot L \cdot P + a_6 \cdot L \cdot H + a_7 \cdot P \cdot H + a_8 \cdot L^2 + a_9 \cdot P^2 + a_{10} \cdot H^2 + a_{11} \cdot P \cdot L \cdot H + a_{12} \cdot L^3 + a_{13} \cdot L \cdot P^2 + a_{14} \cdot L \cdot H^2 + a_{15} \cdot L^2 \cdot P + a_{16} \cdot P^3 + a_{17} \cdot P \cdot H^2 + a_{18} \cdot H \cdot L^2 + a_{19} \cdot H \cdot P^2 + a_{20} \cdot H^3$

$\boldsymbol{Den_l}$ **(P,.L,H)** $= 1 + b_2 \cdot L + b_3 \cdot P + b_4 \cdot H + b_5 \cdot L \cdot P + b_6 \cdot L \cdot H + b_7 \cdot P \cdot H + b_8 \cdot L^2 + b_9 \cdot P^2 + b_{10} \cdot H^2 + b_{11} \cdot P \cdot L \cdot H + b_{12} \cdot L^3 + b_{13} \cdot L \cdot P^2 + b_{14} \cdot L \cdot H^2 + b_{15} \cdot L^2 \cdot P + b_{16} \cdot P^3 + b_{17} \cdot P \cdot H^2 + b_{18} \cdot H \cdot L^2 + b_{19} \cdot H \cdot P^2 + b_{20} \cdot H^3$

$\boldsymbol{Num_s(P,L,H)} = c_1 + c_2 \cdot L + c_3 \cdot P + c_4 \cdot H + c_5 \cdot L \cdot P + c_6 \cdot L \cdot H + c_7 \cdot P \cdot H + c_8 \cdot L^2 + c_9 \cdot P^2 + c_{10} \cdot H^2 + c_{11} \cdot P \cdot L \cdot H + c_{12} \cdot L^3 + c_{13} \cdot L \cdot P^2 + c_{14} \cdot L \cdot H^2 + c_{15} \cdot L^2 \cdot P + c_{16} \cdot P^3 + c_{17} \cdot P \cdot H^2 + c_{18} \cdot H \cdot L^2 + a_{19} \cdot H \cdot P^2 + a_{20} \cdot H^3$

$\boldsymbol{Den_s}$ **(P,.L,H)** $= 1 + d_2 \cdot L + d_3 \cdot P + d_4 \cdot H + d_5 \cdot L \cdot P + d_6 \cdot L \cdot H + d_7 \cdot P \cdot H + d_8 \cdot L^2 + d_9 \cdot P^2 + d_{10} \cdot H^2 + d_{11} \cdot P \cdot L \cdot H + d_{12} \cdot L^3 + d_{13} \cdot L \cdot P^2 + d_{14} \cdot L \cdot H^2 + d_{15} \cdot L^2 \cdot P + d_{16} \cdot P^3 + d_{17} \cdot P \cdot H^2 + d_{18} \cdot H \cdot L^2 + d_{19} \cdot H \cdot P^2 + d_{20} \cdot H^3$

$$\boldsymbol{P} = \frac{\varphi - LAT\_OFF}{LAT\_SCALE}, \boldsymbol{L} = \frac{\lambda - LONG\_OFF}{LONG\_SCALE} \; and \; \boldsymbol{H} = \frac{H - HEIGHT\_OFF}{HEIGHT\_SCALE}$$

Formula-1. Rational polynomial formula.

x, y: normalized scene coordinates, X, Y: normalized geographic object coordinates, Height: point on ground elevation.

$Num_s(P,L,H)$: Sample/line numerator values, Den$_s$ (P,L,H):Sample denominator values.

RPF expressed with 80 coefficients (a_i,b_i, c_i and d_i, i=1,…20) presented the relation between the image and the ground coordinates, which calculated by a numerical adjustment to a grid of points with the physical model [6].

These RPF and rational coefficients were used with the available independent control points, in particular to calculate the shift in image coordinates “sample and line” based on the following formula-2a and 2b.

Table (1) shows the identification control points used in shift calculation in image sample “Δ_s” and image line “Δ_L”. Figure (2) example show the location of identified ICP in the exact location in the used stereo pair images.

Table 1: **the identification of used independent control points**

ICP ID	**ICP2**	**ICP3**	**ICP4**	**ICP5**	**ICP6**
LON	13.157789	13.182336	13.181747	13.239028	13.218752
LAT	32.879231	32.897462	32.896512	32.849305	32.827767
ICP ID	**ICP7**	**ICP8**	**ICP9**	**ICP10**	
LON	13.137311	13.239109	13.193445	13.234591	
LAT	32.839332	32.849621	32.855397	32.894444	

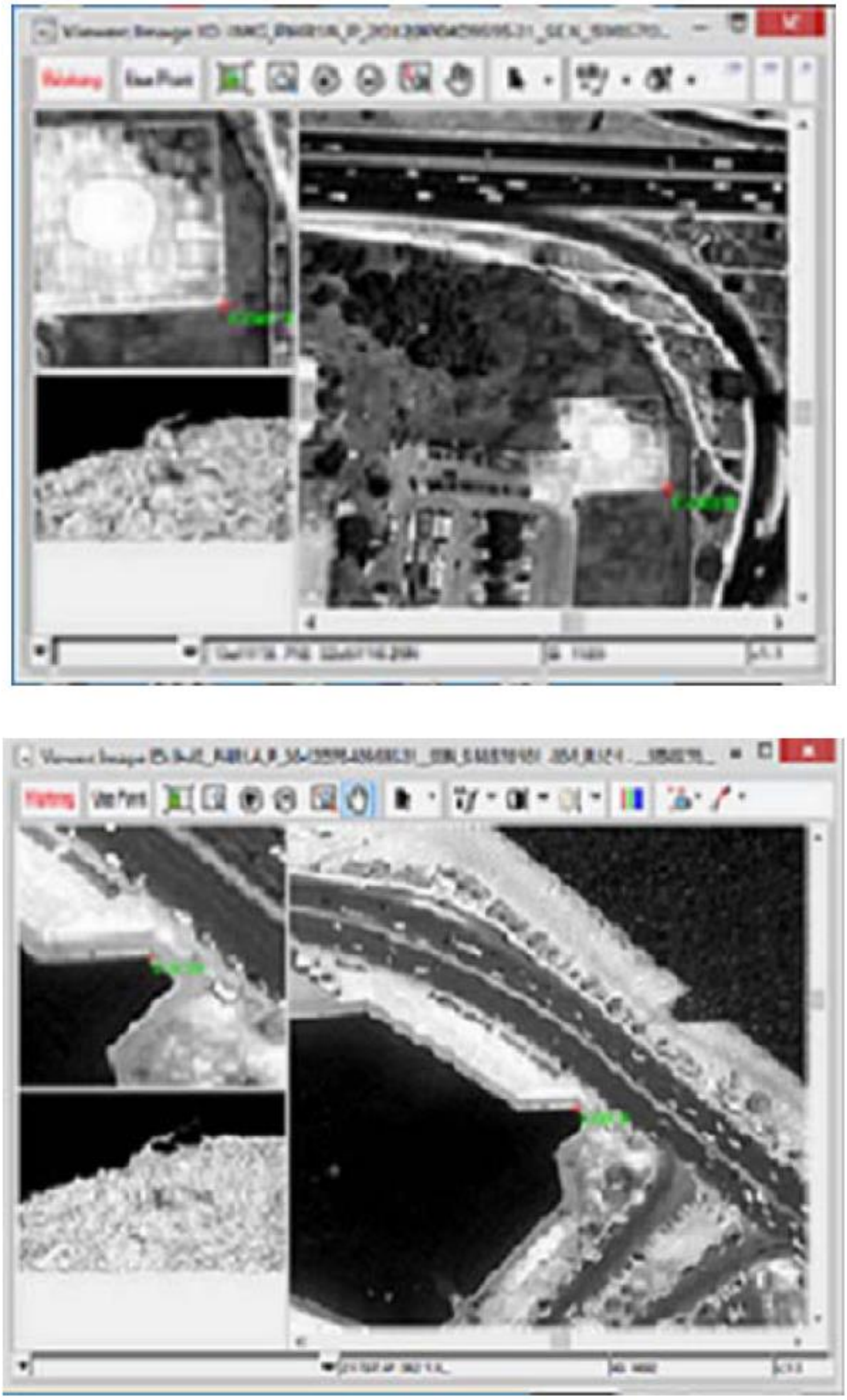


Figure 2: an example of used ICPs identified in the used images

$$\textbf{Sample} = x * SAMPLE\_SCALE + SAMPLE\_OFF \quad (2a)$$

$$\textbf{Line} = y * LINE\_SCALE + LINE\_OFF \quad (2b)$$

$\Delta \boldsymbol{S}$ = Shift difference between the computed and identified sample coordinate (3a)

ΔL = Shift difference between the computed and identified line coordinate (3b)

This difference is the bias in image sample and line. The average and root mean square error “bias“ can be calculated in pixels, and converted to distance in meters. First, in the case of Pleiades Forward image, the achieved results were RMS equal (Δ_S) = 1.24 pixels and (Δ_L) = 2.98 pixels, and for the Nadir Pleiades image: RMS equal (Δ_S) = 0.97 pixels and b_0 (Δ_L) = 1.63 pixels.

Table (2) shows the obtained shift in image coordinates “Δ_S *and* Δ_L” of Pleiades Forward image expressed in pixel units. Table (3) shows the obtained shift in image coordinates “Δ_S *and* Δ_L” of Pleiades Nadir image expressed in pixel units.

Table 2: the obtained shift “Δ_S *and* Δ_L” of Pleiades Forward image in pixel units.

Point ID	Calculated coordinates by RPFs (Pixel)		Measured Coordinates from the image (Pixel)		Shift (Pixel)	
	Sample (S)	**Line (L)**	**Sample (S)**	**Line (L)**	**ΔS**	**ΔL**
ICP7	32796.20	20434.30	32794.70	20430.50	1.50	3.80
ICP4	21631.90	10018.00	21632.50	10014.30	-0.60	3.70
ICP8	28838.10	25315.90	28836.20	25313.00	1.90	2.90
ICP3	21747.60	9806.20	21747.00	9803.60	0.60	2.60
ICP6	32778.50	20504.10	32779.20	20500.70	-0.70	3.40
ICP2	16971.40	13859.30	16972.50	13859.00	-1.10	0.30
ICP5	31909.70	10466.50	31909.70	10466.50	0.00	0.00
ICP10	12985.30	22731.00	12986.20	22729.10	-0.90	1.90
ICP9	23910.80	19158.90	23908.60	19154.30	2.20	4.60
AVERAGE					1.27	1.58
Root mean square error RMS					1.24	2.98

Table 3: the obtained shift “ΔS and ΔL” of Pleiades Nadir image in pixel units.

Point ID	Calculated coordinates by RPF (Pixel)		Measured Coordinates from the image (Pixel)		shift (Pixel)	
	Sample (S)	**Line (L)**	**Sample (S)**	**Line (L)**	**ΔS**	**ΔL**
ICP7	32279.10	19672.70	32278.70	19670.10	0.40	2.60
ICP4	21571.10	9802.10	21571.00	9800.40	0.10	1.70
ICP8	28474.10	24108.20	28473.90	24106.50	0.20	1.70
ICP3	21681.20	9608.20	21680.70	9608.60	0.50	-0.40
ICP6	32263.40	19737.20	32263.70	19735.00	-0.30	2.20
ICP2	17099.10	13270.10	17100.10	13270.70	-1.00	-0.60
ICP5	31434.10	10423.00	31434.10	10423.00	0.00	0.00
ICP10	13273.10	21393.70	13272.70	21394.20	0.40	-0.50
ICP9	23753.20	18309.90	23750.60	18307.50	2.60	2.40
AVERAGE					0.97	1.36
Root mean square error RMS					0.97	1.63

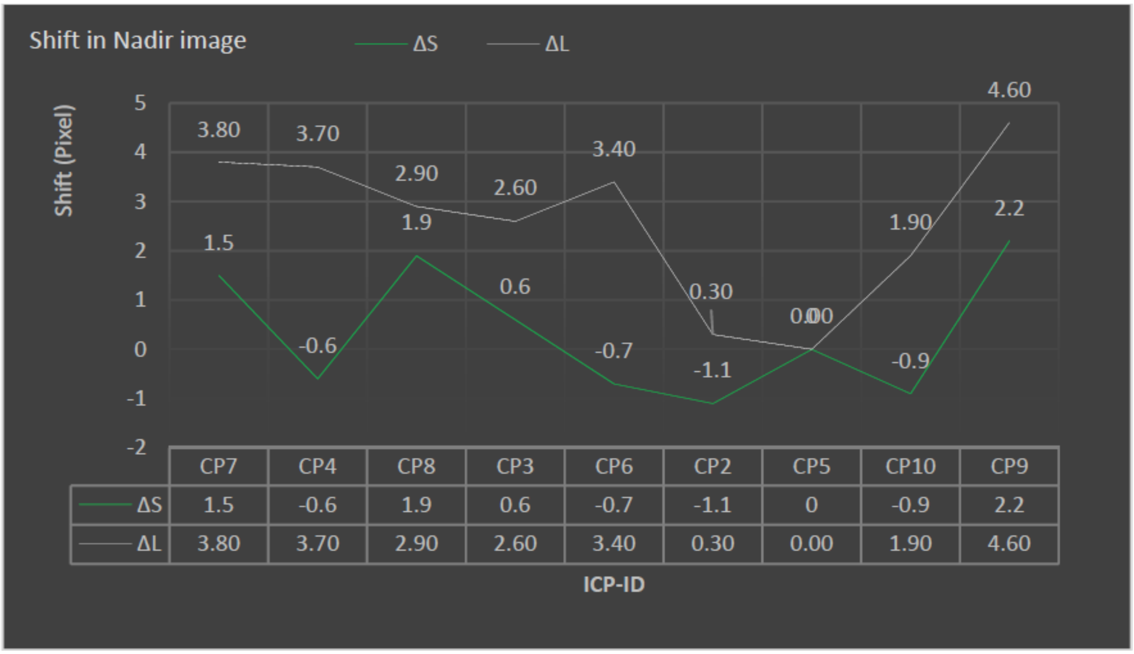
Up to now, a provided rational polynomial coefficients data enabled to perform direct georeferencing from Pleiades images with sufficient accuracy, and it represents something like three pixels of image resolution, which acceptable for some applications. The most GIS applications are not tolerating so large errors, so the same 2D transformation with GCPs are require for a corresponding terrain relief correction, and reliability and higher accuracy geometric extractions. Therefore, the user can improve the accuracy of the supplied rational function model and refining the RPCs through a few ground control points.

RESULTS ANALYSIS

RPFs and RPCs coefficients are the most common technique used to assess the bias error “Shift” in the direct orientation phase (image georeferencing) of the satellite images. In this work, well-known vendor supplied rational polynomial coefficients of space images and RPFs formulas were manually programmed in Excel and applied to Pleiades satellite images “Forward and Nadir”, in particular to calculate the horizontal shift “Δ_S and Δ_L” in both images.

The results showed that direct georeferencing of both Pleiades images without GCPs, mainly attributable to small errors in sensor attitude observations but also position and velocity, have a direct impact on geolocation since the errors are translated to shifts in object space coordinates.

The obtained results are well inside the specified accuracy of the Pleiades triplet images. This would be the best possible geolocation accuracy results after a full bias correction, and they should be attained using only a few GCPs. Figure (3) presented the obtained shift “ΔS and ΔL” of used Pleiades nadir image expressed in pixel units. Figure (4) presents the obtained shift “ΔS and ΔL” of Pleiades Forward image expressed in pixel units.



	CP7	CP4	CP8	CP3	CP6	CP2	CP5	CP10	CP9
ΔS	1.5	-0.6	1.9	0.6	-0.7	-1.1	0	-0.9	2.2
ΔL	3.80	3.70	2.90	2.60	3.40	0.30	0.00	1.90	4.60

Figure 3: the obtained shift “Δ_S *and* Δ_L” of Pleiades Nadir image expressed in pixel units

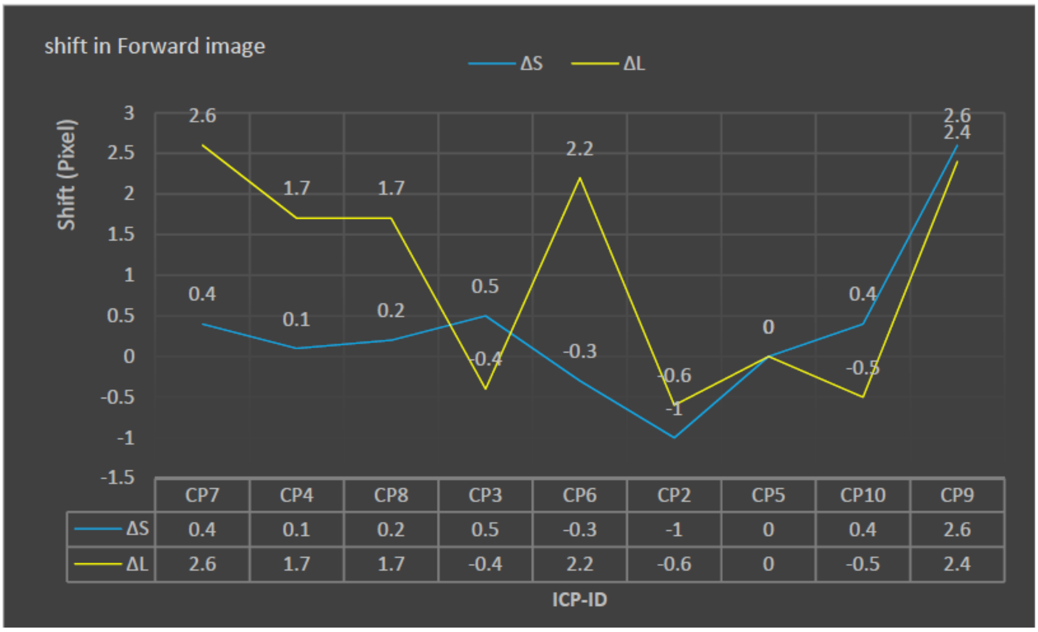


Figure 4: the obtained shift "Δ_S *and* Δ_L" of Pleiades Forward image expressed in pixel units

CONCLUSIONS

Based on to the obtained results of direct georeferenced Pleiades satellite images, when the RMS error "Shift" was less than three pixels in Forward image and dose not exceed two pixels in Nadir image.

This is indicating that the Pleiades images can be used successfully without any GCPs in some applications of remote areas, where the control point are not available or not possible to do field measurements. In addition, the minimum number of control points are enough to optimize the geolocation accuracy of Pleiades images, with planimetric accuracy of sub pixel.

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