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Geographic Accuracy Assessment of Geometric Corrections of World View-3 Satellite Images Using Polynomial Model.

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Noura Arafat, *Ashraf Sharawi* and Ayman Ragab

Abstract—**Updating large-scale maps is one of the main problems in Egypt. These maps can be either many years out of date or even non-existent. On the other hand, the recent enhancements that have been made to the spatial resolution of remote sensing imagery have more accurately enabled the modeling of the Earth's surface features at short intervals. So, if the current High-Resolution Satellite Images (HRSI) are corrected from available geo-referenced topographic maps, digital layers for different applications will be available, as well as rationalization of national budget that are spent on their updating will be offered. In the current research, high resolution satellite images of world view-3 dated 2018, have been corrected geometrically using polynomial model. This model depend on the selection of several ground control points (GCPs) on the distorted image and map them to their true locations in ground coordinates measured from geo-referenced topographic maps. The geometric corrections accuracy of resulted image had been assessed quantitatively and qualitatively. The suitable scale for producing GIS layers from HRSI was also determined. The final result of the experimental works of geometric correction of HRSI using eight ground control points was calculated (Average of RMS error of image = 0.27m), and also the result of the positioning errors using eleven check points available for accuracy quantitative assessment was calculated as (2.59m). The output suitable scale maps for layers production is 1:5000, calculated depending on planimetric allowable accuracy (RMS), taking into consideration the standards of 0.5 mm of map scale.**

I. INTRODUCTION

SATELLITE images include several geometric distortions that are inevitable aspects of the data recording step and the pattern and rotation of the Earth. An uncorrected image will, therefore, carry various

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geometry attributes to that of a map and consequently be hard to used congruently. Geometric correction is the method of improving these distortions and attaching the characteristics of a map to an image (Green, et al, 2000).

Two ways can be utilized to correct the different types of geometric distortions presented in digital image data. One is to model the nature and magnitude of the sources of distortion and use the model to establish correction formulas. This approach is valid when the types of distortions are well identified, such as that induced by Earth rotation. The second way depends on building mathematical relations between the addresses of pixels in an image and the corresponding coordinates of those points on the ground (John and Richards, 2013). The last method is the basis for current research .

The quality assessment of corrected images is necessary to be certain that the right end product is used for the right purpose because any difference at the working start would affect all the other following produce. Assessment of geometric quality of HRSI data can be performed in different ways. Check Points are quite often used for testing geometric accuracy of satellite images quantitatively. They can be derived either by using GPS or from geo-referenced map. Another way of testing is by evaluate features on image in term of its ease or difficulty to be identified, which called qualitative assessment.

The value of coordinate accuracy of corrected image that calculated and resulted from quantitative assessment, in addition to its standard from the specifications of different organizations as shown in Table-1, are used for determine the suitable scale maps produced for GIS layer. Because there is always an immediate requirement for regular map updating needed for both economic development, as well as supporting scientific inquiries, this study aims to maximize the value of ancient topographic maps using GCPs measured from them in the geometric correction of update high-resolution satellite image. In addition, it provides an accurate assessment of the corrected image to determine the right purpose for using the layers that resulted after digitization.

II. STUDY AREA

The study area is located on the western side of the River Nile, El-Ayat district, South of the Giza Governorate between latitudes 29° 35\ 24\\ and 29° 38\ 7\\ N, longitude 31° 13\ 38\\ and 31° 16\ 00\\ as shown in figure-1. It covers El-Ayat city, as well as, the part of the villages of Tahma, Bamha, Baydif, Bahbit and Kafr Shihata. The total area of the region of interest is estimated to be approximately 18.70 square Kilometer. Land cover classes of the study area are mapped from HRSI through the process of a supervised digital imaged classifications. The result of this process showed that agriculture covers about 65.8% of the region's total area, while the urban covered 31%. It means that the common activity in El-Ayat is mostly agriculture.

Table-1
Planimetric Coordinate Allowable Error According to Different Organizations for Different Map Scales

Map Scale	(1)RMS(m) of Planimetric Co. (E, N) ISPRS*	(2)RMS (m) of Planimetric Co. (E, N) NMAS **	(3)RMS (m) of planimetric Co. (E, N) NMAS**
1:1000	0.25	0.30	0.50
1:2500	0.625	0.75	1.25
1:5000	1.25	1.50	2.50
1:10,000	2.50	3.00	5.00
1:15,000	3.75	4.50	7.50
1:20,000	5.00	6.00	10.00

(1) 0.25 (1)0.25mm * map scale, (2) 0.30 mm * map scale, (3) 0.50 mm * map scale
*International Society for photogrammetry and Remote Sensing.
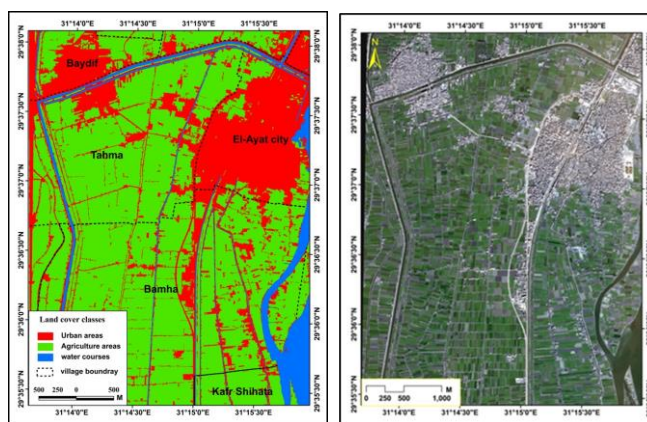**National Map Accuracy Standard, United States of American (USA).

Figure 1. land cover classes of study area (left), word view 3 image of study area to the right

III. MATERIAL

The data used in the current research are:

A- World View-3 images

It is a remote-sensing satellite mainly used to catch high-resolution images of the Earth. The spatial resolutions of images are 2.0m for Multispectral and 0.5m for panchromatic. The dimension of images is (3.74*5) km, it acquired on September 2018. Some characteristics of those images are shown in Table-2.

Table-2
characteristics of the world view-3 image used

Coordinate system		Band	Spectral Resolution (nm)	Spatial Resolution (M)
Datum	GCS_WGS 1984	1	Blue (480)	2
Projection	Transverse Mercator	2	Green (545)	2
Scale factor	0.9996	3	Red (660)	2
False Easting	500000	4	NIR (832.5)	2
False nothing	0	P	-	0.5
Central Meridian	33	-	Sun Angle Azimuth	160.80D Degrees
Latitude of Origin	0	-	Sun Angle elevation	40.40D Degrees

B-Topographic maps

Spatial layers digitized from hard copy Topographic Maps (geo-referenced Topographic Maps), scale 1:5000. Some parameters of these maps are shown in Table-3.

Table-3
Parameters of topographic maps used

Datum	Hyford 1909		
Projection	Transverse Mercator	Latitude of Origine	0
Scale factor	0.9996	False nothing	0
False Easting	500000	Central Meridian	33

IV. METHODS AND ALGORITHMS USED

A- Pan Sharpening

Pan-sharpening algorithms are used to fusing lower spatial resolution satellite image multispectral (MS) bands such as Red, Green and near-infrared, with the unique, higher spatial resolution panchromatic (P) band. The key assumption of these algorithms is using the spectral response function of a specific sensor to accurately appreciate what the panchromatic data would look like using lower spatial resolution multispectral bands. The Gram-Schmidt Pan-Sharpening has regarded one of the best usually used high-quality techniques to pan sharpen multispectral imagery. It is better than most other pan-sharpen ways in maximizing image sharpness and reducing color distortion (T. Maurer, 2013). The presence of a WorldView-3 (0.5m) panchromatic band, in synchronization with the (2m) multispectral bands, provide the possibility to create a (0.5m) multispectral pan-sharpened image, by fusing these two images, using Gram-Schmidt Pan-Sharpening tools in ENVI software a available with version 5.3, the results are shown in figures 2,3 and 4.

| Fig.2. panchromatic world view-3 image at source resolution | Fig.3. MS world view-3 image at source resolution | Fig.4 MS image pan-sharpened using gram-Schmidt pan-sharpened |

B- Image Enhancement

The cause of image enhancement is to increase the visible interpretability of an image by raising the obvious differentiation between the features. A pre-process radiometric enhancement was implemented on the new fused image resulted from the previous step by using two methods in ENVI$_{5.3\ program}$. The first is radiometric calibrations (RC) which include converting the original (raw) signal from a detector (Digital Numbers) into the required at-aperture spectral radiance in units of W/m2/sr/_m (Matthew Montanaro, et al, 2014). While, the second method is an image-based process to

cancel out the haze element caused by additive scattering from remote sensing data using dark subtractions (Chavez, 1988). In other words, it is used to wipe the effects of atmospheric dispersion from an image by subtracting a pixel value that represents a background signature from each spectral band.

C- Puncture of Ground Control Points

The selection of 19 ground points (eight control and eleven check) used in the current study was based on well-defined, sharp edges and well- distributed points on the world view-3 image and digital layers which digitized from geo-referenced topographic maps as shows in figures-5 and 6. It is determined on road intersections, bends in channel and bridges between roads. The coordinates of ground points were punctured their positions on world view-3 image (source) at UTM WGS-84 Z-36 datum as show in fig-5. While the corresponding coordinate of ground points which measured from layers (Reference) were referred to the UTM Hyford 1909, used by Military Surveying in Egypt, as show in fig-6.
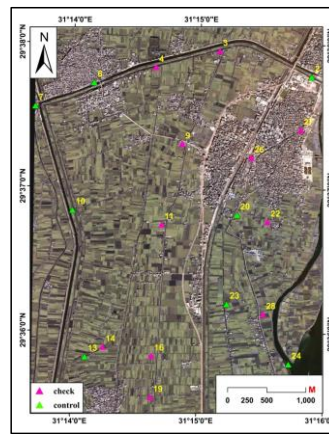

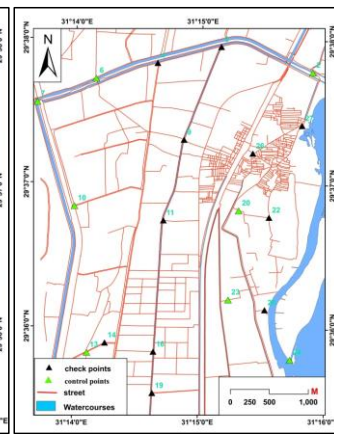Fig. 5 Distributions of ground points on an image (source)   Fig. 6 Distributions of ground points on digital layers (reference)

D- Geometric Corrections Process using Polynomial Model

Geometric correction polynomials model is considered as the most common transformation model used for geometric correction because of many pros such as simple form, moderate flexibility of shapes, well-known, understood properties and ease of computation (Tawfeik, et al, 2016). Geometric correction applies the least squares regression way, to measure the link between the reference and source x, y coordinates, which can then be used to the whole image (Green, et al, 2000), and convert source (raw) image coordinates to rectified (corrected) map coordinates. This is obtained using polynomial equations, which depends on the distortion in the imagery, number of GCPs and their locations comparative to one another. It has the shape shown in Equation (1). Complex polynomial equations may be needed to reflect the expected transformation. The degree of difficulty of the polynomial is conveyed as the order of the polynomial. Figure-7 plots the reference x coordinate versus the source x coordinate as example for a sample set of GCPs in different OP. The

polynomial functions of the 1st order with three terms in Equation (2) allow for only correcting a translation in Cartesian axes, alternation, scaling in axes and angularity. The polynomial functions of the 2nd order with 6 terms in equation (3) allow for correction, in addition to the previous parameters, torsion and convexity in both axes. While, polynomial function of the 3rd order contains ten terms in Equation (4). It provides for correction of the same distortions as the 2nd order polynomial function with others, which do not inevitably correspond to any physical reality of the image acquisition system (Zomrawi and Eisa, 2013). The number of ground control points required in mathematical conditions, three points are required for a 1st order polynomial, six for a second and ten for a third. This is because the minimal number of control points demanded to achieve a transformation of order (n) is given in Equation (5).
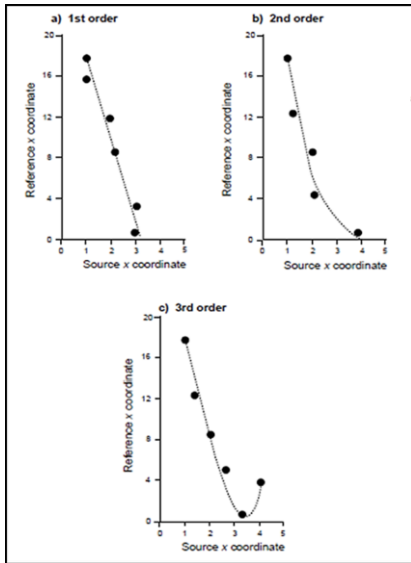
The inverse of the transformation matrix is used to re-transform the reference coordinates of the ground control points return to the source coordinate system. Unless there is an absolute match of the GCPs to the curve defined by the polynomial then some disparity will exist between the original source coordinates and the re-transformed coordinates. The distance between the GCPs initial source and retransformed coordinates is named the Root Mean Square (RMS) error (Green, et al, 2000). Figure-8 explains that RMS error have two element, the first in the x-direction (the x-residual) and the second in the y (the y-residual). Residuals are the distance between the source and re-transformed coordinates in one direction. It can be used to estimate the total RMS and RMS in the x and y directions for any group of GCPs as show in equations (6) and (7). The overall RMS also calculates to all GCPs as in Equation (8). The RMS error is a distance in meters units.
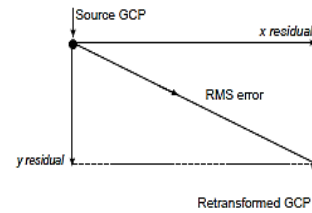

Figure 8. The relationship between residuals and the RMS

$$RMS\ (in\ X) = \sqrt{\sum_{i=1}^{n}(\Delta X_i)^2}$$

(6)

$$RMS\ (in\ Y) = \sqrt{\sum_{i=1}^{n}(\Delta Y_i)^2}$$

$$RMS\ error = \sqrt{(RMSx)^2 + (RMSy)^2} \qquad (7)$$

$$RMS\ (T) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\Delta X_i^2 + \Delta X_i^2)} \qquad (8)$$

where:
ΔXi, ΔYi = residuals of point (i) in X
and Y directions
T = total RMS error
n = number of GCPs
i = GCP number

Figure 7. Examples of transformations employing first to third-order polynomials Redrawn from (Green, et al, 2000)

$$P(x, y) = \sum_{k}^{n} a_k\, x^i y^j$$

(1)

Where
P(x, y) are source coordinates in distorted image.
(x, y) are the location of points in the reference.
a_k is the polynomial coefficients.
n is the order of the polynomial

$$P(x, y) = a_1 + a_2 x + a_3 y$$

(2)

$$P(x, y) = a_1 + a_2 x + a_3 y + a_4 x^2 + a_5 xy + a_6 y^2$$

(3)

$$P(x, y) = a_1 + a_2 x + a_3 y + a_4 x^2 + a_5 xy + a_6 y^2 + a_7 x^3 + a_8 xy^2 + a_9 yx^2 + a_{10} y^3$$

(4)

$$n = (t + 1) \times (t + 2)/2$$
$$m = (t + 1) \times (t + 2)$$

(5)

Where:
t is the order of the polynomial
n is the minimum number of GCPs
m is the number of coefficient

E-Resampling technique

After assigning a grid to the image with map coordinates, and blank (zero) data values for all pixels by using polynomial transformation model, the image grid is commonly orientated from grid coordinate of input image as shown in figure3-9. Because the geometry of the input image has been modified, it is not therefore potential to overlay images so that each pixel in the output image is matched by a single pixel in the input image. That is to say, once the geometric correction has been achieved, there is no direct link between input and output pixels. To solve this problem and allocate a data value to each pixel in the new transformed output image, the resampling process is applied as shown in figure 4-10.
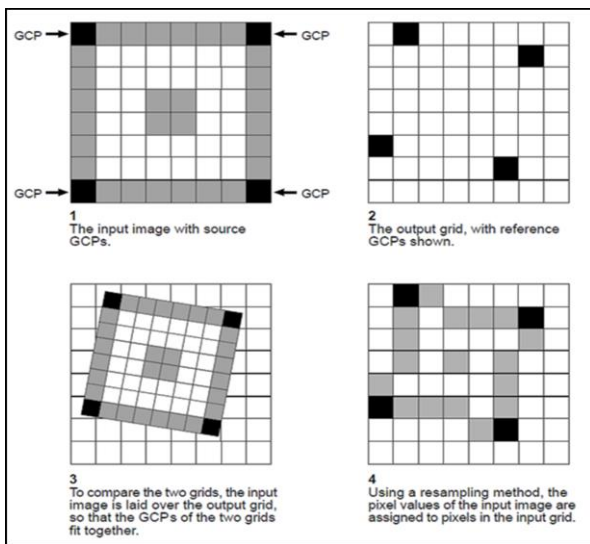
Figure 9 relationship between input and output pixel from rectification transforms the source image to resampling.
Redraw from (Green, et al, 2000)

The most common interpolations or resampling techniques are Nearest Neighbour, Bilinear Interpolation and Cubic Convolution. They are used depending on the input data and its use after the process is executed as shown in figure-10. Nearest Neighbour designate a new data value of the Picture Element (pixel) in the output corrected image from the center of nearest pixel in input image. This technique is only suitable when the new and old pixel sizes and spacings are not too diverse, and if the output image is to be classified. Bilinear Interpolation uses a weighted average of the four nearest surrounding pixels, using a linear function. This technique must be used when modifying the cell size of the data produces smoother and without stair-stepped effect. While Cubic Convolution depending on a 4x 4 grid compromising the 16 surrounding pixels using a linear function. It is recommended when the cell size of the data is being dramatically reduced.
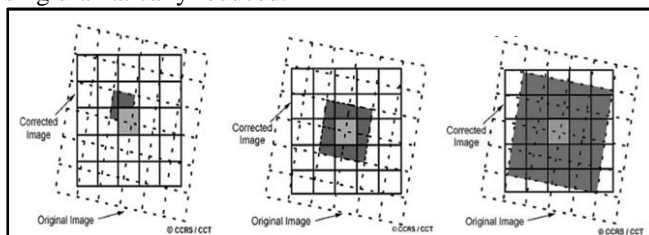
1-nearest neighp or interpolation   2-bilenear interpolation   3-cubic convolution inter

Figure 10. methods of resampling, Redrawing from (S. Santhosh Baboo and M. Renuka Devi, 2010)

In this work the bilinear interpolation was applied because it gives more spatially accurate result, smoother and less blocky image and owing to the change in the pixel size of row data using *data fusion techniques(Pan Sharpening) which are mentioned the above*.

F-Assessment of Geometric Corrections

The accuracy of world view-3 image which corrected using ground control points measured from geo-referenced topographic map, should be assess, taking into consideration the accuracy of capturing these ground points. To achieve this needed, the quantities assessment should be applied using check points, which depend on calculate the positioning errors (Linear Errors) in each check point. Linear errors can described as the variance between the measured coordinate of check points in the corrected image and the equivalent coordinate of these points in layers (reference); which is simply calculated using some statistical parameter as shown in equations (6) and (8), then calculate the suitable scale maps for produce layers depending on planimetric accuracy (RMS) as illustrate in Equation (7), taking into consideration the national map standards accuracy of 0.5 mm * map scale. The accuracy of corrected image also evaluated qualitatively. Visualization quality was assessed by determining the distinctiveness of pixels in the visual appearance of the object.

V. RESULT AND DISCUSSION

A. Results of Geometric Correction

The experimental work is applied using Earth Resources Data Analysis System (ERDAS) Imagine Software version 2015. Geometric correction by polynomial model is applied on fused Multispectral image world view-3 as the source data with coordinate (UTM WGS-84) and geo-referenced digital layers with coordinate (UTM Hyford 1909) as reference.

Table-4
RMS errors in each control point for a second order polynomial using ERDA imagine program.

GCP identifier	Source coordinates		Reference Coordinate		Residual (m)	Residual (m)	RMS errors	Contrib
	x	y	x	y	x	y		
GCP#2	332073.2	3279027	331996.4	3279059	0.017	0	0.017	0.063
GCP#6	329295.0	3278959	329217.2	3278995	-0.062	-0.165	0.176	0.652
GCP#7	328541.1	3278666	328464.7	3278699	0.071	0.343	0.35	1.295
GCP#10	329011.4	3277332	328937.9	3277362	-0.034	-0.457	0.458	1.693
GCP#13	329160.6	3275456	329090.3	3275484	-0.026	0.099	0.102	0.377
GCP#20	331117.5	3277262	331042.6	3277295	-0.072	0.043	0.084	0.311
GCP#23	330979.4	3276122	330906.0	3276153	0.178	0.349	0.392	1.45
GCP#24	331767.0	3275353	331693.3	3275381	-0.071	-0.212	0.224	0.828

Geometrically correct of HRSI involved four steps:

1. Define the position of ground control points.
2. Use the reference and source coordinates for GCPs in deriving and solve the coefficient of second-order polynomial equations, which calculate automatically by the computer and stored it in a transformation matrix.
3. Applying this equation to transform the geometry of image data from the source coordinate system to a standard Datum, and is named (Rectifications).
4. Assess the error that surplus in the image by Calculate x and y residuals for each ground control points to evaluate the RMS error as shows in table-4

Repeat work experiments showed that eight specific distribution out of nineteen points gives better results (average RMS error of image in x =0.0815, y =0.258 and total of RMS=0.27m), the used GCPs IDs are (2,6,7,10,13,20, 23 and 24). Then, applying bilinear resampling method to identify the new pixels intensity values of the rectified output image.

B. Result of Quantitative assessment

The evaluation of corrected world view-3 image quality was measured quantitatively. The RMS (Linear errors) were calculated between corrected coordinate and reference coordinate for eleven check points (CHKs), whose distribution in the corrected images is show in fig-11.
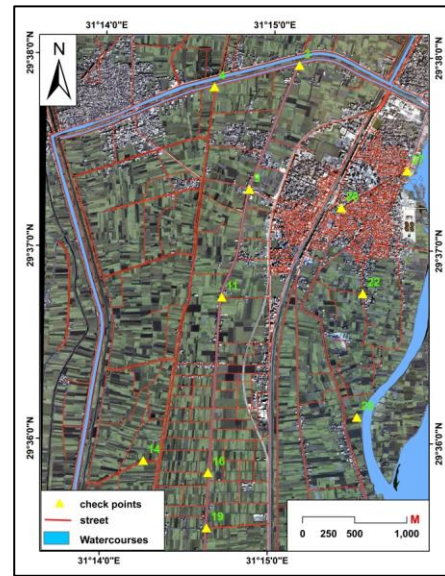

Figure 11. Distribution of checkpoints on corrected image

Table-5
Errors for each check point in a corrected image

check point identifier	Corrected coordinates		Reference coordinates		Residual (m)	Residual (m)	RMS errors (m)
	x	y	x	y	x	y	
GCP#3	330820.87	3279396.86	330823.43	3279394.35	-2.56	2.51	3.59
GCP#4	330011.40	3279193.99	330012.22	3279191.09	-0.83	2.90	3.01
GCP#9	330341.61	3278208.70	330342.4 0	3278206.24	-0.79	2.46	2.59
GCP#11	330077.23	3277174.36	330076.1	3277174.24	1.15	0.11	1.15
GCP#14	329319.25	3275608.05	329321.27	3275608.75	-2.02	-0.71	2.14
GCP#16	329946.25	3275491.16	329943.38	3275492.26	2.87	-1.10	3.1
GCP#19	329930.90	3274964.21	329928.30	3274962.68	2.60	1.53	3.01
GCP#22	331430.67	3277205.85	331430.86	3277206.48	-0.19	-0.64	0.66
GCP#26	331225.52	3278033.25	331223.86	3278029.94	1.65	3.31	3.7
GCP#27	331856.98	3278383.66	331856.72	3278381.90	0.26	1.76	1.78
GCP#28	331371.85	3276020.55	331372.83	3276022.11	-0.98	-1.56	1.84

Spatial distribution of the check points was chooses on the corrected image randomly and in multi directions to calculate the distance between reference and corrected image coordinate from all areas covered. The average of RMSx for check points was calculated from table-5 to be 1.71m, RMSy is 1.95m and the total RMS is 2.59. Moreover, a suitable scale was calculated to produce digital layers from corrected image depending on planimetric allowable accuracy (RMS) Taking into consideration the standards of 0.5 mm * map scale, as following:

Map scale from RMS:

planimetric positioning accuracy = 2.59m

Scale map = RMS/0.50mm

$\qquad$ = 2.59m/0.50mm = 5.18 *1000 = 1:5180

$\qquad$ (Theoretical Scale)

$\qquad$ = 1:5000 (practical Scale)

C. Result of Qualitative Assessment

The qualitative evaluation was applied visually by specifying some spatial feature that are distinguish by corrected image pixels as show in Figures-12 & 13. The types of features and its codification have been defined in Table-6.

Figure 12. Qualitative Assessment of feature in Agriculture Area

Figure 13. Qualitative Assessment of feature in Urban Area

Table-6
Qualitative Assessment of Different Features

landuse	Items	Description on world view2 Image
Urban	Buildings	E+
	Streets	E+
	Railway	E
	Barren area	E+
	Utility	N
Agriculture	Building	E+
	road	E+
	Railway	E
	Green area	E
	crops	N
	canal	C

E = Easily Detectable
E+ = Easily Detectable + Shadow Effect
M = Medium
D = Difficult
N = No Appearance
C = Confused

It is clear from the previous table and figures, most features in the study area are significantly more obvious and easier to identify, but accurate production of some layers is difficult due to the existence of shadow that affects their quality.

VI. CONCLUSION

Fusing the lower resolution MS image (2.0meters) with the higher resolution panchromatic image (0.50m) using Gram-Schmidt Pan-Sharpening techniques is an important process to maximizing image sharpness and reducing color distortion.

Converting digital number (DN) of world-view 3 image pixels to radiance with known unit using radiometric calibrations is a basic pre-process, applies before removing the effect of atmospheric which is important to accurately illustrate the location of GCPs when performing the geometric correction.

The obtained results show that the corrected world view-3 data from digital layers digitized from geo-referenced topographic maps using second order polynomial equation has very good efficiency. Although it is not proper for tasks which require high accuracy (better than 2.6 m), it is still reliable for use in other applications. Appropriate scale maps that can be produce from spatial layers, taking into consideration the accuracy of corrected image, is 1:5000.

The geometric correction of world view-2 image is a necessary process to remove geometric distortions from it. Produced a corrected satellite image would allow using it in multiple applications such as, digitizing the features of an image and obtained accurate estimates of its geometry characteristics, monitoring land cover changes with other images acquired at a different time (Change Detection) and integrating the image with a neighbor spatial data that has the same coordinate system (Merging).

The qualitative assessment showed that most features in the corrected image are easy to be identified, but the shadow affects the quality and accuracy of some layers. Therefore, the availability of the Digital Elevation Model (DEM) for correcting the image may reduce this effect and enhance visibility.

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Title Arabic:

التقييم الجغرافي لدقة التصحيح الهندسي للمرئية الفضائية world view-3 باستخدام النموذج متعدد الحدود

Arabic Abstract:

يعد تحديث الخريطة كبيرة المقياس من أهم المشكلات في مصر، فهي أما غير محدثة أو غير موجودة. وعلى الجانب الآخر أصبحت صور الأقمار الصناعية أعلى في دقتها المكانية الأمر الذى ساعد على نمذجة ظاهرات الأرض في وقت قياسي. ويمكن استغلال تلك الميزة عن طريق إجراء تصحيح هندسي دقيق للمرئيات الفضائية عالية الدقة من خرائط طبوغرافية مصححة الأمر الذى يتيح رقمنتها بدقة واستخدامها في التطبيقات المختلفة من ناحية وترشيد الميزانية التي ستنفق على تحديثها من ناحية أخرى. وتحاول هذه الورقة تطبيق التصحيح الهندسي لمرئية فضائية عالية الدقة world view-3 باستخدام النموذج متعدد الحدود. والذى يعتمد على اختيار عدد من نقاط التحكم الأرضية على المرئية ومقارنتها بنظيرتها المصححة من قبل، ثم تقييم النتائج كميًا ونوعيًا واستنتاج مقاييس الرسم المناسبة لإنتاج خرائط منها حسب دقة التصحيح. وانتهت النتائج التجريبية إلى أن قيمة الخطأ المحسوبة RMS عند إجراء التصحيح الهندسي باستخدام ثماني نقاط تحكم بلغت ٠,٢٧ متر. وعند تقييم دقة التصحيح السابق كميًا باستخدام ١١ نقطة أخرى بلغت قيمة الخطأ ٢,٢٩ مترا ، وهى الدقة التي يمكن من خلالها إنتاج خرائط بمقياس ١: ٥٠٠٠ مع الأخذ في الاعتبار المقاييس العالمية.