POSITIONAL ACCURACY IN ORBITAL IMAGES OF HIGH AND MEDIUM RESOLUTION: CASE STUDY WITH IMAGE SENSORS OF THE SPOT, RAPIDEYE AND RESOURCESAT SATELLITES

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Abstract

The objective of this work is to evaluate and to analyze positional accuracies, through specific sample points and tracks, of remote sensing registered images acquired by sensors on board the Spot-6, RapidEye and ResourceSat-1 satellites and having, respectively, 1.5, 5 and 24 meters of resolutions. A case study is developed in areas of the Santarém and Belterra municipalities of the Brazilian Pará state. In addition of generating reports with positional accuracy information, this paper investigates the relationship between the spatial resolutions and the positional accuracies of the different digital remote sensing image sensors. High precision reference points and tracks, continuous lines, were collected in field works in order to be compared to adjust points and tracks obtained directly by manual digitalization over each considered image. Samples of points and tracks were analyzed for different positional regions of the images and a C language program was used to perform the calculations of point and track accuracies considering metrics of Euclidean distances and error areas. Accuracy reports present statistics and deterministic error measurements, such as averages, variances, standard deviations, absolute values, areas, root mean square values, etc. Such errors were evaluated from the reference and adjust data, for points and tracks, in regions of interest of the analyzed images. In the case studies of this work it was possible to assess local and global error values, to analyze them and their relation with the different spatial resolutions of the digital images. The results showed that the image of the Spot-6 had lower value for its Root Mean Square (RMS) error, but in terms of pixels it was obtained a higher result compared to the RapidEye and Resourcesat-1 images. The presented reports enabled, also, analyses of local and global positional errors along the considered images, facilitating the achievement of the subsequent geometric corrections on the already registered images.

Key Words: Remote Sensing Image Registration, Positional Accuracy, Spot, RapidEye and ResourceSat.

INTRODUCTION

Images obtained by remote sensors have been widely used in various fields of study such as: updating cartographic maps, performing evaluation of vegetation covers, managing of urban and rural regions and for monitoring agricultural areas and the environment (Antunes and Siqueira, 2013). In many image processing applications, it is necessary to compare multiple images of the same scene acquired by different sensors or images of the same sensor but of different dates (Silva and Dutra, 2007). In the integration of spatial information acquired by different sensors, the image registration is used as a basis for several applications as, for example, analyses of land changes and covers, mosaic of images, etc. (Fedorov, 2002).

According to Weber *et al.* (1999), quality is an essential character or necessary distinction for cartographic data in order to make them useful for use. The accuracy assessment is done using trigonometric functions or known statistics (ex.: Root Mean Square (RMS) deviation, mean and standard deviation or others), and with absolute or relative values. In this sense, the accuracy is a measure of how correct is the data, resulting from observations, calculations or estimations, compared with a true, or taken as a true, value. Geometrical or positional accuracy is a measure of how the data differ spatially, in terms of absolute and relative geographical position, from that taken as the reference. For Mikhail and Ackermann (1976), cited for Monico *et al.* (2009), accuracy is presented as been the degree of proximity of the estimate related to its true value. A different and new method to evaluate positional accuracies of registered images, other than assessments by points, considers information trails, or tracks, that are vector features. Therefore, based on such tracks, it is possible to conduct evaluations, considered as quantitative validations, of positional accuracy of remote sensing registered images of different spatial resolutions (Yamada *et al.* 2015).

The satellite SPOT-6 (AIRBUS Defence & Space, launched in 2012) carries on board cameras with Panchromatic (P) and Multispectral (MS) optical sensors operating in the visible and near-infrared bands, with a spatial resolution of 1.5 and 6 meters respectively. SPOT-6 satellite images have been applied in various scientific and commercial areas, such as: monitoring of phenomena and natural resources, management of agricultural land use, support for monitoring and definition of conservation areas, updating of maps and charts, among others (Embrapa, 2013).

The spatial component of the RapidEye system is a constellation of five remote sensing satellites, identical and positioned in synchronous orbit with the sun, with equal spacing between each satellite. These satellites provide daily cover for any location on the globe, having spatial resolutions of 6.5 m and 5 m in orthoimages. Recently, the Brazilian Ministry for Environmental Monitoring (MMA) acquired RapidEye full coverage images of the Brazilian territory for apply them to general researches. These images are available for all Brazilian scientific projects from agreements signing of technical cooperation.

The Linear Imaging Self-Scanner (LISS-III) sensor, carried on board ResourceSat-1 Indian satellite (IRS-P6) that was launched in 2003, has spatial resolution of 23.5 meters, for all spectral channels, bandwidth of 141 km and temporal resolution of 24 days. Images are available at INPE catalog and are provided free of charge to any world user. This Earth Observing System is indicated for work in agriculture, land use and land cover surveys, crop monitoring, besides acting in studies of urban areas and cartography (Embrapa, 2013).

In this context, the objective of this work is to generate accuracy reports from evaluations and analyses of positional accuracy for registered images of the SPOT-6, RapidEye and

ResourceSat-1 satellite sensors. Such sensors have different spatial resolutions and their images were used to develop a case study in areas of the Santarém and Belterra municipalities of the Brazilian Pará State. These analyses allow to identify image displacement trends, local and global, using precision references of points and tracks collected in field works.

MATERIAL AND METHODS

Positional Accuracy Evaluation Concepts

Method 1: Accuracy Calculation for Points

High precision reference points were collected in field works in order to be compared to the adjust points obtained directly by manual digitalization over an image of interest. The point accuracies are evaluated using the planar coordinates of a set of *N* control points. This process aims to indicate the quality of an observed quantity or an estimated parameter (Monico *et al.* 2009).

According to Yamada *et al.* (2015), statistical parameters, such as, mean, variance σ^2, standard deviation σ and deterministic ones, as the Root Mean Square error, can be assessed from the Euclidean distance formula, *d*, as presented in equation 1, where *xr, yr* and *xa, ya* are the x and y spatial coordinates of a reference and its respectively adjust point.

$$d = \sqrt{(xr - xa)^2 + (yr - ya)^2} \quad (1)$$

Equations 2, 3, 4 and 5 presents the formulas used in this work to evaluate the mean μ, the variance σ^2, standard deviation σ and the *RMS* error considering the N control points.

$$\mu = \frac{1}{N}\sum_{i=0}^{N} d_i \quad (2)$$

$$\sigma^2 = \frac{1}{N}\sum_{i=0}^{N} (d_i - \mu)^2 \quad (3)$$

$$\sigma = \sqrt{\sigma^2} \quad (4)$$

$$RMS = \sqrt{(\sum_{i=0}^{N} d_i^2) / N)} \quad (5)$$

Method 2: Accuracy Calculation for Tracks

A different and new method to evaluate positional accuracies of registered images, other than assessments by points, considers track information, or trails. In this method, reference and adjust tracks are taken into account. A pair of a reference and its respective adjust track are used to create each polygon connecting its start and end points. The vector approach for accuracy evaluation by tracks is then performed by the area calculation of each polygon by the following algorithm:

r1=r2=0
For each point i of the polygon repeat:
*r1 = r1 + (xp[i]*yp[i+1]);*
*r2 = r2 + (yp[i]*xp[i+1]);*
area = AbsoluteValue((r2-r1)/2)

The area calculation for the tracks can also be done using raster representations. In this case, it was considered that a polygon area can be filled by pixels, with for spatial x and y resolutions rx e ry. The area of a polygon is calculated from the sum of all pixel areas that have their pixel centers inside the polygon.

In this method, the polygon areas, evaluated in vector or raster representation, are considered as errors in square meters. From the polygon areas it can be calculated several error metrics such as: minimum, maximum, total, mean, variance, standard deviation and RMS.

In order to be compared to the point errors, the area metrics can also be reported in meters when each polygon area is divided by the distance, or the length, of the reference track.

Case Study

The study area is located between the municipalities of Belterra and Santarém, in the Pará State, northern Brazil, involving part of Federal Conservation Unit, named Tapajós National Forest, near the Tapajós river and it is located between latitudes 3°26' S and 2°37' S and longitudes 55°7´ W and 54°31' W.

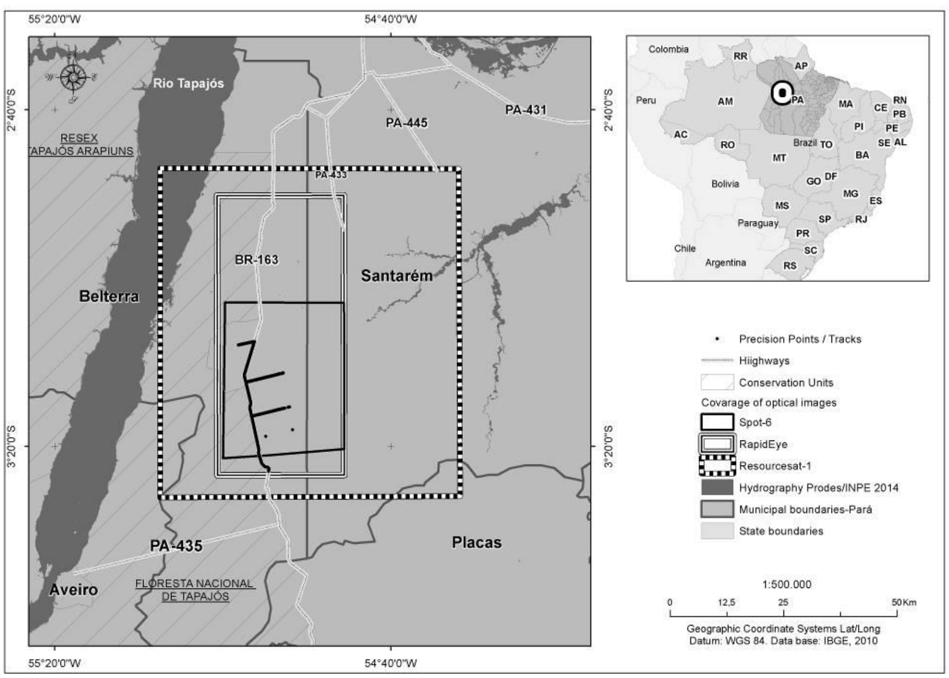

Figure 1. Location of the study area, involving the municipalities of Belterra e Santarém, in Pará State.

Material

In this study it was used three images of the following optical sensors: fused bands panchromatic and multispectral sensors of the satellite Spot-6, acquired in August 2014; color composite of bands 3, 2 and 1 of the satellite RapidEye, August 2014, and; bands 2, 3 e 4 of the sensors LISS-III of the satellite Resourcesat-1, August 2012. The images of these sensors related to the study area are illustrated in figure 2.

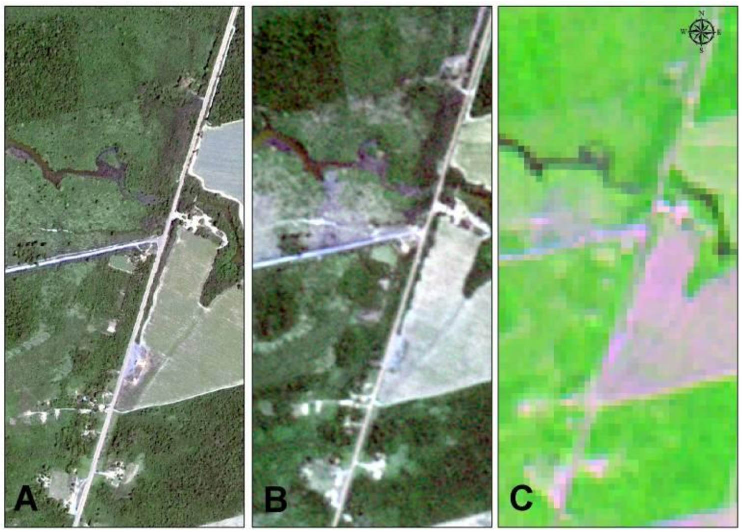

Figure 2. Illustrations of the images used in this study: A-Spot-6 (1,5m), B-RapidEye (5,0m) and C-Resourcesat-1 (23,5m).

Concerning to the registration of these images, the Spot-6 images were registered using only the Rational Polynomial Coefficients (RPC) provided with the raw image. The RapidEye and Resourcesat-1 images were registered manually by corrections based on common control points.

For the purpose of accuracy evaluation, precision points, here named reference points, were collected in the field in August, 2013 and March, 2015. The process of acquisition of these samples uses Sokkia L1 receivers, Stratus model, HP Ipaq collector considering static and kinematic positional methods (Oliveira *et al.* 2015). The coordinate system used was UTM, with datum WGS 1984 and for the 21S Zone.

In the accuracy analyses by points it was considered specific points as cross roads and points of the boundaries between different land cover classes among others. In the accuracy analyses by tracks it was used cinematic points acquired with the GPS coupled on a car as the car was coursing through parts of BR-163 highway and its access. The location of the reference points and tracks can be observed in figure 3.

To prepare the geographic database, containing the registered images and reference and adjust data it was used the ArcGIS software (Environmental Systems Research Institute, Inc. – ESRI), version 10.2. The reports with the accuracy evaluations, for points and tracks, were obtained from an ad-hoc program developed in C language, the Dev -C ++ software.

Methodology

The methodology of this work follows the below sequence:

- Input of the Spot-6, QuickBird and RapidEye images in the GIS database;
- Input of the vector references, points and tracks, information in the GIS database;
- Manual digitalization of adjust data, points and tracks, related to their references;
- Running the ad-hoc program for reporting the positional error analyses.

Manual Digitalization of the Adjust Points

After the creation of the basic GIS database, with the images and the references, the vector information of the adjust points were digitalized for each reference sample. This manual digitalization was conducted by visual inspection of each image and the reference points, displayed as background information. In this process, with the reference points superimposed on each image in the geographic database and, with the aid of field sketches, it was manually identified and stored the correct allocation of each adjust point in relation to its reference, called homologous pairs. Thus, in the points digitalization step, illustrated in figure 3 for the three images, precise adjust points were recognized and marked in the region of interest taken into account implanted junctions of roads, boundaries between different coverage classes, among other possible identification of targets in the images. For the image of the Spot-6, which has a smaller extent in the study area, were identified a total of 15 reference points with their respective adjust points and for the RapidEye was considered 20 of this points. For the ResourceSat images, despite they cover a greater territorial area, it was taken a smaller amount of precise points because these images have low spatial resolution making more difficult the target identifications.

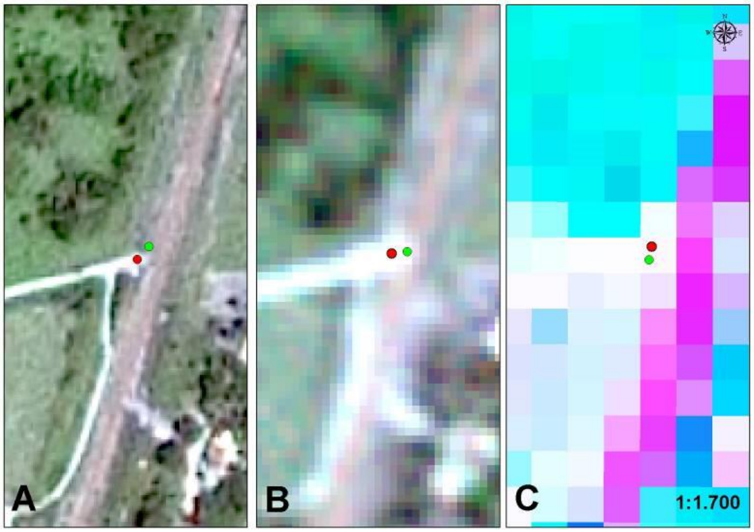

Figure 3. Homologous pairs of control points. The reference, indicated in green, and the adjust, indicated in red, overlaid on the Spot 6 (A), RapidEye (B) and ResourceSat -1/Liss (C) images.

Manual Digitalization of the Adjust Tracks

A similar approach of the digitalization of the adjust points is applied to the digitalization of the adjust tracks considering reference pathways obtained by a precise GPS carried by car. These tracks correspond to the following region features: center of the roads in some accessions, left side of the road, drive down, and right side, drive up, both in the local highway named BR-163. Figure 4 shows some examples of the allocation of the reference and respective adjust tracks, overlaid on the analyzed images, considering the center of the pathways.

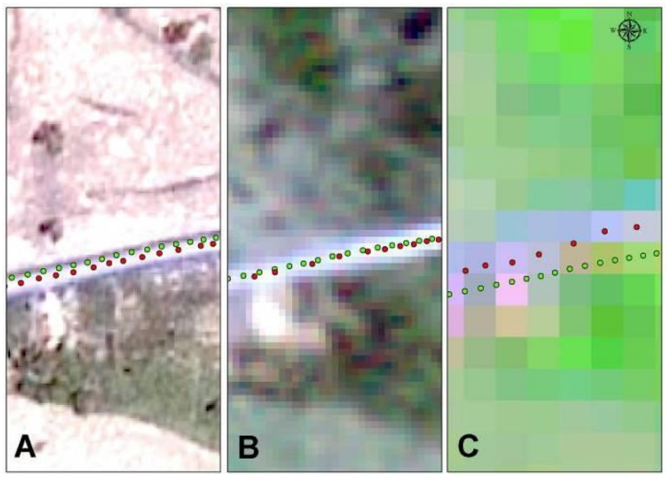

Figure 4. Reference tracks, in green, and adjust tracks, in red, overlaid on the Spot- 6 (A), RapidEye (B) and ResourceSat -1 / Liss (C) images, considering the center of the pathways.

Accuracy Evaluations and Reports

The homologous points and tracks obtained by the approaches just described were used as input data for an ad-hoc program, developed in C language, that analyses and reports accuracy metrics related to the three considered registered images. The program evaluates and reports local and global errors taken into account the reference data as the truth for the spatial locations. The program evaluates statistic and deterministic accuracy evaluation based in the metrics as presented in the methods 1 and 2 described in the Positional Accuracy Evaluation Concepts item above. The results are reported in text files that can be visualized, analyzed and edited by the user. Moreover, some reported results, as for example the local x and y displacements, can be plotted over the images as arrows that indicate the size and the direction of the local errors.

RESULTS

This section presents the results of the accuracy evaluation of registered images using points and tracks information. The results are reported in text files containing statistic and deterministic error metrics that can be used by decision makers to evaluate the positional quality of each registered image considered.

Results of Positional Accuracy for Points

Accuracy reports were generated for a set of sample points and figure 5 shows, as an example, this type of report generated for the Spot-6 image. Equivalent reports were obtained for the RapidEye and ResourceSat -1 images and their main results are summarized in table 1.

ValidaRegistroPT_V02 - **Accuracy report of spatial information by points**
Data Reference/Field: refer_spot.txt (15 pts)
Data Adjust/Image: ajuste_spot.txt

Global Information
Number of points analyzed: 15
Errors in distance
Minimum: 0.78
Maximum: 11.60
Average: 5.39
Root mean square error (RMS): 6.08
Variance: 8.46
Standard deviation: 2.91
Errors in directions X and Y
Average X: -1.69
Root mean square error (RMS): X: 3.91
Variance X: 3.65
Standard deviation X: 3.65
Average Y: 3.533118
Root mean square error (RMS): Y: 4.66
Variance Y: 9.85
Standard deviation Y: 3.14

Local Information

Name	Refer/Adjust	Xref/Xajust	Yref/Yajust	**DeltaX**	**DeltaY**	**Module**	**Direction**
	point 4	729224.00	9654246.10				
	point 4	729225.12	9654244.06	-1.12	2.04	2.33	331.32
	point 1	730742.95	9659649.61				
	point 1	730742.93	9659648.83	0.02	0.78	0.78	1.44
	point 10	732920.50	9646706.57				
	point 10	732921.47	9646701.49	-0.97	5.08	5.17	349.20
	point 11	737418.08	9647287.59				
	point 11	737427.20	9647281.94	-9.12	5.65	10.73	301.78
	point 12	728650.75	9637798.62				
	point 12	728652.97	9637791.98	-2.22	6.64	7.00	341.49
	point 13	731976.02	9638707.46				
	point 13	731977.16	9638701.64	-1.14	5.81	5.92	348.89
	point 14	729688.27	9633012.38				
	point 14	729689.32	9633014.89	-1.05	-2.52	2.73	202.65
	point 15	732378.63	9633647.82				
	point 15	732384.08	9633649.07	-5.45	-1.24	5.59	257.14
	point 2	723006.66	9656348.10				
	point 2	723008.24	9656344.88	-1.58	3.23	3.60	333.85
	point 3	725654.11	9653608.32				
	point 3	725654.78	9653602.55	-0.68	5.76	5.80	353.31
	point 5	728505.19	9651757.51				
	point 5	728508.82	9651751.85	-3.64	5.66	6.73	327.29
	point 6	732348.80	9650995.65				
	point 6	732353.46	9650994.52	-4.66	1.13	4.79	283.63
	point 7	727205.01	9647592.07				
	point 7	727197.27	9647583.42	7.74	8.64	11.60	41.84
	point 8	723615.21	9646857.70				
	point 8	723617.95	9646856.13	-2.74	1.57	3.16	299.77

Figure 5. Full report of the positional error calculation using 15 control points and the Spot- 6 image.

When analyzing the results for the Spot-6 image in table 1 it was observed that its global average error value was the lowest compared to the other two images. In terms of pixels, this global value of 5.39 m corresponds to a positional error of 3.59 pixels. The global average errors in the spatial directions X and Y, -1.69 m and 3.53 m respectively, show that the Spot-6 image has a downright global positional shift tendency.

Table 1. Global information accuracies of measures using control points to the three images.

Accuracy Analysis for Sample Points							
Satellites	**Spatial resolution (m)**	**Global values**					
		Average error (m)	**Standard deviation (m)**	**Average error (pixel)**	**Average in X (m)**	**Average in Y (m)**	**Error RMS (m)**
Spot-6	1.5	5.39	2.91	3.59	-1.69	3.53	6.08
RapidEye	5	6.13	11.80	1.23	-0.47	0.63	6.98
ResourceSat	23.5	29.05	16.87	1.24	-25.93	-4.93	33.27

Still from the table 1, it can be observed that the global average error, in meters, for the Spot-6 and the RapidEye images are similar. In this case it was expected lower average error for the Spot-6 since it has higher spatial resolution. This can be caused by the fact that the Spot-6 image was registered only by the RPCs that came along with the raw image. Considering the error average in pixels, the RapidEye has lower global average error value compared to the Spot-6 image. The global average errors in the spatial directions X and Y, -0.47 m and 0.63 m respectively, show that the RapidEye image has a downright global positional shift tendency.

The global average errors in meters for the ResourceSat-1 image are higher than for the others. This is an expected result since it has the worst spatial resolution among all. Also, this fact turns more difficult to acquire adjust control points with a good precision. However, the global average error of the ResourceSat-1 is similar to the RapidEye image when the error is evaluated in pixels. This means that their average errors in meters are proportional to their spatial resolutions. The global average errors in the spatial directions X and Y, -25.93 m and -4.93 m respectively, show that the ResourceSat image has an upright global positional shift tendency.

The text file of figure 5 also reports local errors, in the X and Y directions, related to each pair of points, reference and adjust, along with the module and direction of their deviation vectors. The module and direction error of each control point can be plotted, in form of arrows, over the images as can be seen in figure 6. Each arrow is plotted from the x and y coordinates of the adjust spatial position and the size and the direction of each arrow correspond to the module and the direction of its deviation vector. The different sizes of the arrows of the figure 6 allows to detect regions of the image with the higher, or lower, error values. Also from the directions of the arrows it can be distinguished areas of the image with specific error shift tendencies. For example, considering the Spot- 6 and RapidEye images, both contain errors with different sizes and in different directions along the image. The ResourceSat-1 image has larger positional error values concentrated in its bottom locations and the image has main tendencies to be deviated to the right since the majority of the arrows indicate errors pointing to the left direction.

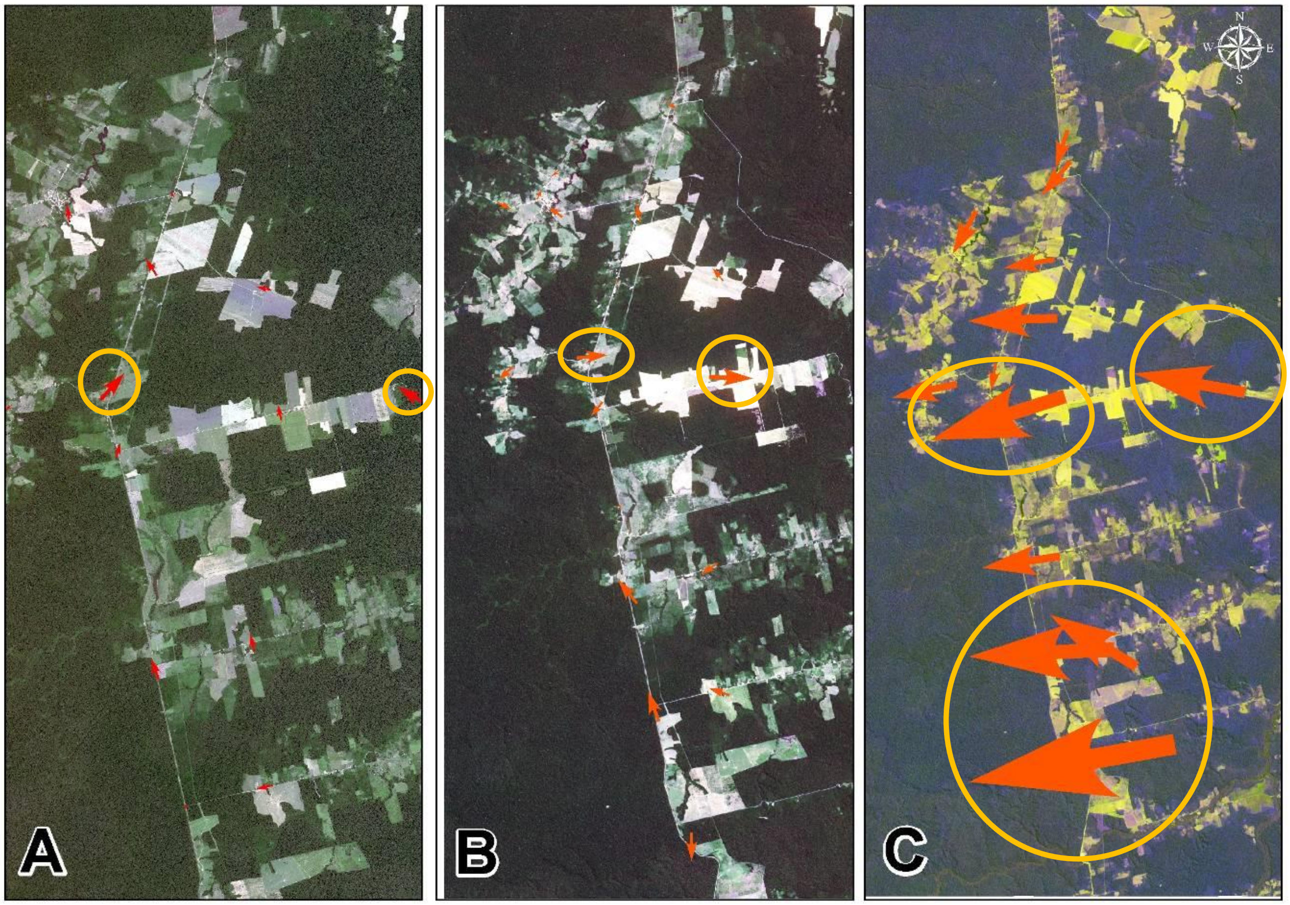

Figure 6. Arrows indicating the angular direction correction and proportion of the positional error for each set point for Spot- 6 images (A), RapidEye (B) and ResourceSat -1 (C). The orange circles indicate areas with larger errors in each image.

Results of Positional Accuracy for Tracks

As stated before, in this work it was also calculated positional accuracies of the images using line features, or tracks. Figure 9 illustrates the information reported in a text file when considering tracks for the for the Spot-6 image accuracy evaluation. Similar reports were produced for the RapidEye and the ResourceSat images. For the track error analyses each reference and its respective adjust track were connected by its initial and final points creating a polygon. The areas of the polygons were taken as error metrics, in square meters. For the purpose of comparison with the positional accuracy for points, the reports contain also relative metrics, i.e., polygon areas normalized by the lengths of their reference tracks. Table 2 summarizes main results of the positional accuracy for tracks for the three images considered.

Table 2 shows that the global average errors of the Spot-6 and RapidEye images are similar. It was expected a lower value for the Spot-6 image since it has better spatial resolution. This can be explained, as in the case of table 1, by the fact that this image was registered only with its RPCs.

This explicate also its higher value of the average error in pixels compared with the two other images.

ValidaRegistroLN_v07 - Accuracy report of spatial information for track for image Spot-6
Data Reference/Field/Track: refer.txt (0005 tracks)
Data Adjust/Image/Edited: ajuste_corr.txt (0005 tracks)

VECTOR CALCULATIONS
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Local Information

Prefix	Track	Ref/Track	Adjust/Edit	Area (m^2)	Length (m)	Relative (m)
track1	LN001	0110 pts	0071 pts	3502.38	1004.33	3.49
track2	LN002	0039 pts	0036 pts	3498.34	1760.54	1.99
track3	LN003	0026 pts	0014 pts	638.80	256.64	2.49
track4	LN004	0053 pts	0047 pts	1631.75	824.67	1.98
track5	LN005	0018 pts	0018 pts	955.14	819.80	1.17

GLOBAL information
Number of tracks: 0005

Values	Area (m^2)	Length (m)	Relative (m)
minimum:	638.80	256.64	2.49
maximum:	3502.38	1004.33	3.49
TOTAL:	10226.41	4665.98	2.19
average:	2045.28	933.20	2.19
standard deviation:	1375.87	541.28	2.54
RMS:	2386.96	1051.30	2.27

MATRIX CALCULATION resolution X= 1.500000 and Y= 1.500000
=====================
Local Information

Prefix	Track	Ref/Track	Adjust/Edit	Area (m^2)	Lengths(m)	Relative (m)
track1	LN001	0110 pts	0071 pts	3505.50	1004.33	3.49
track2	LN002	0039 pts	0036 pts	3500.75	1760.54	1.99
track3	LN003	0026 pts	0014 pts	623.25	256.64	2.43
track4	LN004	0053 pts	0047 pts	1669.50	824.67	2.02
track5	LN005	0018 pts	0018 pts	1179.00	819.80	1.44

Global Information
Number of de Tracks: 0005

Value	Area (m^2)	Lengths(m)	Relative (m)
minimum:	623.25	256.64	2.43
maximum:	3507.75	1760.54	1.99
TOTAL:	10485.00	4665.98	2.25
average:	2097.00	933.20	2.25

Figure 9. Full report for the five tracks considered in the accuracy evaluation of the Spot- 6 image.

Table 2. Global information of accuracy measures for tracks for the three images.

Accuracy Analysis for Tracks				
Satellites	**Resolution spatial (m)**	**Global Values (Vector)**		
		Average error (m)	**Standard deviation (m)**	**Average error (pixel)**
Spot-6	1.5	2.19	2.54	1.46
RapidEye	5	2.25	1.77	0.45
ResourceSat	23.5	13.31	12.53	0.56

Analogous to the accuracy point evaluations, the global average errors in meters, reported in table 2 for the ResourceSat-1 image, are higher than for the other two images. This is an expected result since it has the worst spatial resolution among all. Furthermore, this fact turns more difficult to acquire adjust control points with a good precision. Nevertheless, the global average error of the ResourceSat-1 is similar to the RapidEye image when the error is evaluated in pixels. This means that their average errors in meters are proportional to their spatial resolutions.

Finally, the results of the report of figure 9, along with of table 2, show that the use of tracks and errors based in areas of polygons, instead only control points, is an interesting alternative to evaluate the accuracy of registered images. The only problem with the track approaches is related to the areas calculations direct from the vector data. Care must be taken when the tracks intersect. In this case the calculation of the areas should avoid addition of positive with negative areas, i.e., all the areas must be considered in module.

CONCLUSION

This study explored various arrangements to evaluate and report positional errors of multi-resolution remote sensing images. It was studied images captured by sensors on board the Spot-6, RapidEye and ResourceSat-1 satellites. The register error evaluations use not only the method considering sample points but also taken into account extended tracks across the images. These two methods are illustrated with actual images and comparative analyses were performed to explore the main characteristics and advantages of each method.

Accuracy reports were produced with local and global information, for specific set of points and tracks, using reference data acquired by GPSs with high spatial resolutions. Such reports present statistic and deterministic positional errors, along the considered images, that can be used for realization of further geometric corrections, register refinements, in order to reduce their positional errors. Decision makings for environmental management activities, for example, can be better achieved when the images have more accurate geometric corrections, i. e., better quality of positional accuracy.

In the accuracy analyses of the three used images using a set of points, accuracies related to the adjust and respective reference values, it was observed that all images have the tendency to be displaced to the right, since the average values of correction in the X direction were all negatives. Considering the Y direction, the Spot-6 and RapidEye images are displaced downward while the ResourceSat-1 image in moved upward. Also for analysis by points, the report presented information of the size and direction of the local error vectors. These vectors could be plotted as arrows overlaid to the images in order to facilitate the identification of required corrections to be made by users on displacement trends in different parts of the images.

Comparing the accuracy results for the RapidEye and ResourceSat-1 images it could be observed that their global average errors were proportional to their spatial resolution values and therefore their global average errors in pixels are similar. This was expected since the worse the spatial resolution more difficult becomes the identification or determination of targets in the images. The global average error in pixels for the Spot-6 image was larger compared to the other two images because its register was accomplished using only the RPCs provided with the image. The other two images were registered with high spatial resolution control points.

In the future we intend to undertake further researches related to the issues of this article using more images with different resolutions, more accuracy metrics and different plots representing these metrics over the images.

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