



## CBERS-4 MUXCAM Sensor: A Geometric Quality Assessment

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**Resumo.** Em dezembro de 2014 Brasil e China lançaram com sucesso o satélite CBERS-4, a quarta geração dos satélites CBERS. No módulo de carga o satélite carrega a MUXCAM, uma câmera multiespectral com 20 m/pixel de resolução espacial. A MUXCAM foi construída sob responsabilidade do Brasil e é uma atualização da câmera CCD de alta resolução dos satélites CBERS-1, 2 e 2B, cujas imagens têm sido amplamente utilizadas em estudos do Pantanal, como por exemplo, no monitoramento de áreas inundáveis. Neste artigo a qualidade geométrica de uma imagem MUXCAM é analisada. A qualidade geométrica do sensor CCD pode ser medida através do cálculo da acurácia posicional e da acurácia interna das imagens adquiridas por ele. A acurácia posicional da MUXCAM resultou em ~404 m enquanto que a acurácia interna resultou em ~30 m, melhor que dois pixels. Portanto, para aplicações menos rigorosas nas quais uma grande acurácia em coordenadas não seja necessária e em que os erros possam ser negligenciados, as imagens multiespectrais adquiridas pela MUXCAM podem ser usadas sem qualquer correção geométrica.

**Palavras-chave:** Satélite CBERS-4, Acurácia posicional, Acurácia Interna.



**Abstract.** In December 2014, Brazil and China successfully launched the CBERS-4 satellite, the fourth generation of CBERS satellites. In the payload module, the satellite carries the MUXCAM, a 20 m/pixel spatial resolution multispectral camera. The MUXCAM has been built under Brazilian supervision and is an updated version of the CCD camera onboard CBERS-1, 2 and 2B, whose images have been widely used in applications such as studying flooded areas in Brazilian Pantanal. In this paper the geometric quality of the MUXCAM images is analyzed. One can measure the geometric quality of the CCD sensor by calculating the positioning and the internal accuracy of the images acquired by it. The positional accuracy for the MUXCAM resulted in ~404 m whereas the internal accuracy resulted in ~30 m, better than 2 pixels. Therefore, in coarse applications in which a high accuracy in coordinates is not mandatory, and in which such errors can be neglected, the multispectral images acquired by MUXCAM can be used without a prior geometric correction.

**Key-words:** CBERS-4 Satellite, Positioning accuracy, Internal accuracy.

## 1. Introduction

The China-Brazil Earth Resources Satellite (CBERS) Program is a partnership between Brazil and China in the space technical scientific segment to build and launch Remote Sensing satellites. The first CBERS satellite was launched in 1999 and since then the images generated by the program have been used in important areas, such as deforestation control and environmental monitoring in the Amazon Region, water resources monitoring, urban growth, soil occupation, wet land monitoring (as an example, the Brazilian Pantanal), education and several other applications (Lino et al. 2000, Epiphanyo 2013, Silva et al. 2015).

The fourth CBERS generation (CBERS-4) has been launched in December 2014 from Taiyuan Satellite Launch Center (TSLC) in Shanxi, China. In the payload module CBERS-4 has four cameras: the Panchromatic and Multispectral camera (PANMUX), the Multispectral Camera (MUXCAM), the Infrared Medium Resolution Scanner (IRSCAM) and the Wide Field Imaging Camera (WIFICAM). The PANMUX and IRSCAM have been built by China whereas the MUXCAM and WIFICAM have been built by Brazil (Boggione et al. 2014).

In this paper the geometric quality of a MUXCAM image has been analyzed. The geometric quality assessment is important to determine and validate the relationship between terrain points and their positions on CBERS-4 images for Remote Sensing applications (D'Alge et al. 2005), such as monitoring flooding areas in the Pantanal, Brazil. Several projects developed in the Brazilian Pantanal and wet areas rely on the information provided by orbital sensors, whose images are used without further corrections other than those already performed by the distribution center, which is, in the present case, the Instituto Nacional de Pesquisas Espaciais – INPE. Therefore, the scientific community should be aware of the accuracy of the data they are using in order to decide if the related errors can be neglected or if a further correction is needed for each specific case study. To do so, the positioning accuracy and the internal accuracy of a CBERS-4 MUXCAM image have been analyzed. The positioning accuracy is the average displacement between map projection coordinates that are measured on a system-corrected image and those that are measured on the Earth surface. The internal accuracy is the root mean square error of the remaining residuals after a geometric transformation is applied to tie a system-corrected image to a map projection reference system (D'Alge et al. 2005). The MUXCAM image has been provided by the Brazilian space research national institute (Instituto Nacional de Pesquisas Espaciais - INPE).

## 2. MUXCAM Images

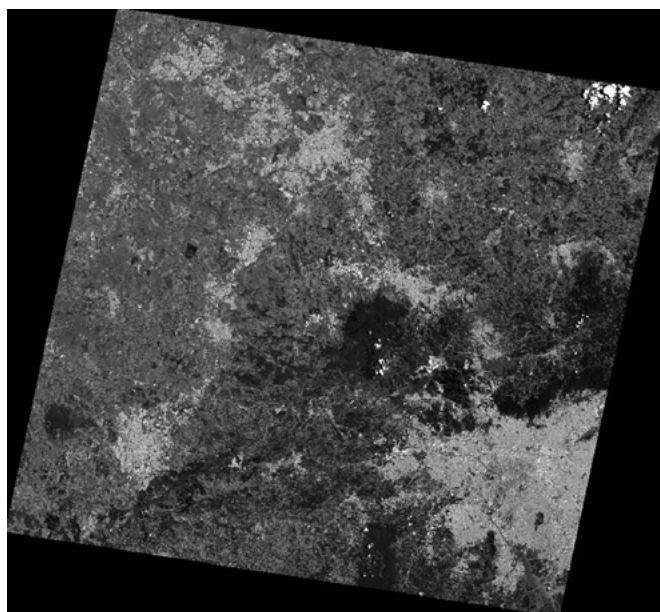
The MUXCAM camera onboard CBERS-4 uses a CCD sensor to acquire 20 m/pixel spatial resolution images in four spectral bands in a 26 days temporal resolution (Epiphanyo 2011, 2013). **Table 1** shows some parameters of the MUXCAM.



**Figure 1** shows the MUXCAM image used to perform the geometric quality assessment of the camera. The scene depicts a number of cities in São Paulo state, among them, part of the São Paulo city (the larger city in the bottom right corner), and has been taken on 01/08/2015. The CBERS-4 system-corrected image is projected in the Universal Transverse Mercator (UTM) map projection using the WGS84 geodetic reference system Ellipsoid parameters (semi-major axis  $a = 6,378,137$  m; flattening  $f \sim 1/298$ ). The scene center coordinates are 23.24041°S and 47.04819W.

**Table 1.** MUXCAM sensor parameters.

Spectral bands [ $\mu\text{m}$ ]	B1: 0.45 – 0.52 B2: 0.52 – 0.59 B3: 0.63 – 0.69 B4: 0.77 – 0.89
Spatial resolution [m]	20
Swath width [km]	120
Quantization	8 bits
Revisit [days]	26



**Figure 1.** Multispectral image used to assess the geometric quality of MUXCAM camera on-board CBERS-4 satellite.

### 3. Methodology

The geometric quality of the CBERS-4 MUXCAM image can be assessed by calculating the positioning accuracy and the internal accuracy of the scenes. In both cases, a set of Ground Control Points (GCPs) is needed. A ground control point is a position easily identified in the MUXCAM image whose corrected map coordinates are accurately known. The procedure was performed in a Geographic Information System – GIS (in this case, ESRI ArcGis), where all the data could be imported into a same reference system and a same map projection. The raster data have been modeled as regularly spaced numeric grids whereas the data points were modeled into the vector format.



### 3.1 Positioning accuracy

The displacement between the system-corrected image coordinates and their map-corrected positions is the positioning accuracy of the image. In the calculations, the system-corrected coordinates of a set of points selected from the MUXCAM image are compared to their map-corrected coordinates (GCPs coordinates), which can be obtained from GPS measurements, large-scale maps or from ortho-rectified Remote Sensing data. For each point a displacement in  $X$  and  $Y$  coordinates can be calculated as:

$$\begin{aligned}\Delta X &= X_{image} - X_{GCP} \\ \Delta Y &= Y_{image} - Y_{GCP}.\end{aligned}\quad (1)$$

Where  $(X_{image}, Y_{image})$  are the coordinates from the system-corrected image and  $(X_{GCP}, Y_{GCP})$  are the GCPs coordinates.

The resulting displacements in  $X$  and  $Y$  coordinates for a set of  $n$  points are given by:

$$\begin{aligned}\Delta \bar{X} &= \sqrt{\frac{1}{n} \sum_{i=1}^n \Delta X_i^2} \\ \Delta \bar{Y} &= \sqrt{\frac{1}{n} \sum_{i=1}^n \Delta Y_i^2}.\end{aligned}\quad (2)$$

Finally, the total Root Mean Square Error (RMSE) is the positioning accuracy, which is calculated as:

$$(\Delta \bar{X}^2 + \Delta \bar{Y}^2)^{1/2}.\quad (3)$$

### 3.2 Internal accuracy

After an image has been accurately georeferenced to a map projection system, its internal accuracy can be estimated by measuring the displacement of a set of GCPs coordinates before and after the geometric correction procedure. A geometric transformation is used to relate the system-corrected image coordinates to their georeferenced coordinates. The coordinates of a set of points manually chosen from the georeferenced image is then compared to the map-corrected coordinates of GCPs. Again, GCPs map-corrected coordinates can be obtained from GPS measurements, large-scale maps or from ortho-rectified Remote Sensing data.

The geometric transformation is usually a polynomial. The choice on the order of the polynomial depends on the amount of distortion to be corrected. The higher the order, presumably, the more significant the distortion is. One of the most used transformations for geometric correction of Remote Sensing data is the first order polynomial (or Affine transformation) given in equation 4. It accounts for 6 parameters and therefore requires at least 3 GCPs for them to be solved.

$$X_{image} = a_1 X_{GCP} + a_2 Y_{GCP} + a_3$$



$$Y_{image} = b_1 X_{GCP} + b_2 Y_{GCP} + b_3. \quad (4)$$

Where  $a_i$  and  $b_i$ ,  $i = \{1, 2, 3\}$ , are the transformation parameters.

Alternatively, a second order polynomial, such as the one shown in equation 5, can be applied. That transformation accounts for 12 parameters and therefore requires a minimum of 6 GCPs for them to be solved.

$$\begin{aligned} X_{image} &= a_1 + a_2 X_{GCP} + a_3 \cdot Y_{GCP} + a_4 X_{GCP} Y_{GCP} + a_5 X_{GCP}^2 Y_{GCP} + a_6 X_{GCP} Y_{GCP}^2 \\ Y_{image} &= b_1 + b_2 X_{GCP} + b_3 \cdot Y_{GCP} + b_4 X_{GCP} Y_{GCP} + b_5 X_{GCP}^2 Y_{GCP} + b_6 X_{GCP} Y_{GCP}^2. \end{aligned} \quad (5)$$

Where  $a_i$  and  $b_i$ ,  $i = \{1, \dots, 6\}$ , are the transformation parameters.

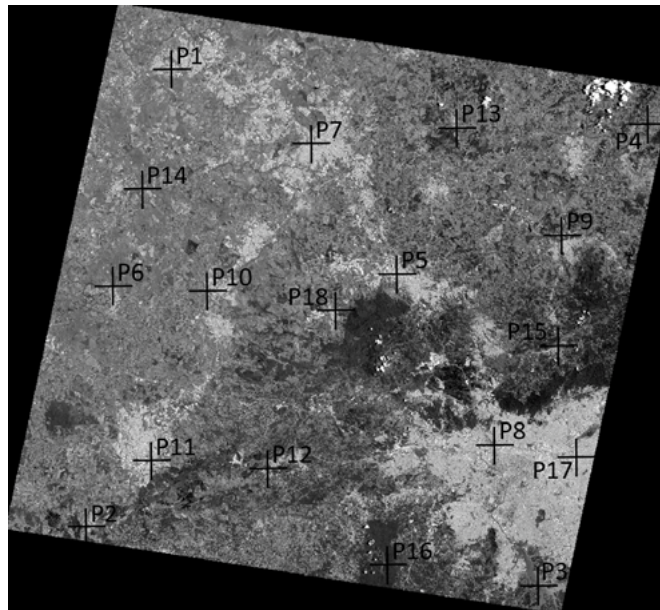
After applying a first or second order polynomial, the internal accuracy of the image can be assessed by comparing the resulting displacement between the GCPs coordinates and the transformed (georeferenced) image system-corrected coordinates. The procedure for calculating such displacement is the same as for the positioning accuracy, except that in equation 1 the displacements for  $X$  and  $Y$  are written as  $\Delta X = X_{geo} - X_{GCP}$  and  $\Delta Y = Y_{geo} - Y_{GCP}$ , with  $(X_{geo}, Y_{geo})$  being the transformed coordinates. For the sake of an unbiased analysis, the set of points used for calculating the displacements should be different from the set of points used to estimate the transformation parameters.

## 4. Results

For the positioning and internal accuracy assessment, GCPs have been manually chosen from an ortho-rectified mosaic of RapidEye images. The spatial resolution of the images is 5 m/pixel and the horizontal accuracy of the GCPs coordinates is ~6 m. The adopted geodetic reference system is the WGS84 and the projection system is the UTM.

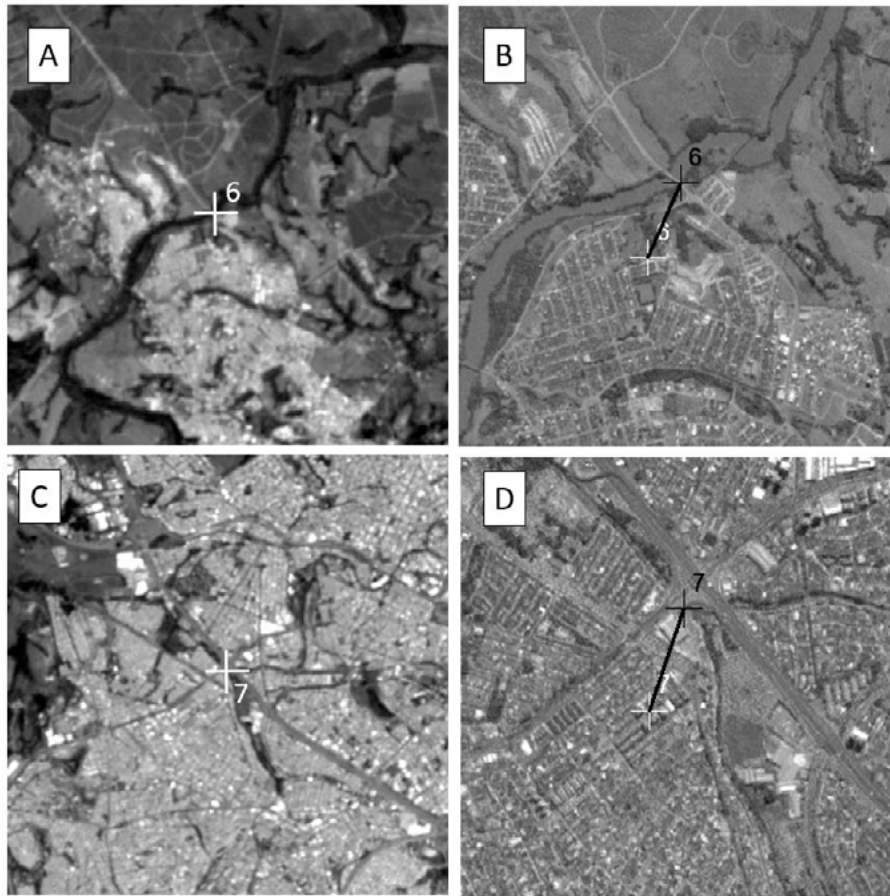
### 4.1 Assessment of the positioning accuracy

For the positioning accuracy calculations, a set of 18 GCPs ( $P_i$ ,  $i = \{1, \dots, 18\}$ ) has been selected from the RapidEye mosaic and their coordinates have been compared with the corresponding positions in the MUXCAM image. **Figure 2** shows the distribution of the GCPs over the MUXCAM image.



**Figure 2.** Distribution of the GCPs over the MUXCAM image.

The GCPs must be easily identifiable in both, the MUXCAM image and the reference mosaic. Examples of features that can be used as GCPs are crossing roads, bridges, corners, and any other feature that can be accurately pointed in the scenes. **Figure 3** shows examples of manually chosen GCPs. In **Figure 3A** one can see the ground control point 6 placed over the MUXCAM image. In Figure 3B the same control point 6 (in black) and its displacement (in white) in relation to the MUXCAM coordinates are shown over the reference mosaic. **Figure 3C** and **Figure 3D** show the same results for the GCP 7.



**Figure 3.** Manually chosen GCPs: (A) GCP 6 placed over the MUXCAM image. (B) GCP 6 (black) placed over the reference mosaic and its displacement to the MUXCAM coordinates (white). (C) GCP 7 placed over the MUXCAM image. (D) GCP 7 (black) placed over the reference mosaic and its displacement to the MUXCAM coordinates (white).

In **Table 2** the displacements between MUXCAM point coordinates and the GCPs coordinates measured from the reference mosaic are displayed. From **Table 2**, the resulting displacement in  $X$  coordinates is  $\Delta\bar{X} = 136.59$  m and for  $Y$  coordinates it is  $\Delta\bar{Y} = 380.07$  m. The total RMSE, and therefore the resulting displacement of the MUXCAM image from its expected position, is  $\sim 404$  m when considering the whole set of 18 GCPs. The assessment of the positioning accuracy of the MUXCAM is important because a number of Remote Sensing data users rely on the system-corrected coordinates of the CCD sensor onboard CBERS-4. Thus, they should be aware of the expected error when measuring such coordinates without applying any previous geometric correction to the scenes. The RMSE for CBERS-4 can be considered acceptable if compared, for example, with the CBERS-2 CCD positioning accuracy, which was  $\sim 11$  km (D'Alge et al. 2005, Devaraj and Shah 2014).

#### 4.2 Assessment of the internal accuracy

For the internal accuracy assessment, the MUXCAM image has been georeferenced by a geometric transformation used to relate its system-corrected coordinates and the GCPs map-corrected coordinates. Two transformations have been applied, a first and a second order polynomial (according to equations 4 and 5). In both cases, the same 18 GCPs used to compute the positioning accuracy have been used to estimate the transformation parameters. The RMSE



for the first order polynomial after the least square adjustment of the parameters was 39.20 m whereas the RMSE for the second order polynomial was 34.30 m. These results are similar to the ones found by Zanardi et al. (2005) when georeferencing CBERS-1 CCD images.

The displacement measurements were performed over a set of 20 GCPs that had not been used for estimating the geometric transformation parameters. These results are shown in **Table 3**.

**Table 2.** Displacements between coordinates measured in the MUXCAM image and the GCPs coordinates measured in the reference mosaic.

Point	DX [m]	DY [m]	RMSE [m]
1	-157.354875	-373.680031	405.459396
2	-159.645159	-376.336151	408.797597
3	-29.826186	-364.159737	365.379139
4	-88.737973	-435.983116	444.922134
5	-143.568341	-382.614186	408.663044
6	-150.442481	-346.764871	377.993142
7	-132.170358	-379.415972	401.777903
8	-120.508222	-421.154192	438.056029
9	-118.366158	-417.276847	433.740146
10	-141.036163	-367.564492	393.693859
11	-140.873023	-355.237020	382.149903
12	-159.215427	-392.200328	423.285541
13	-132.991399	-415.014858	435.802758
14	-152.518604	-364.638707	395.250947
15	-94.631496	-313.437827	327.411654
16	-212.769672	-335.964364	397.671959
17	-93.134184	-401.376899	412.040521
18	-136.473870	-376.186707	400.176905

**Table 3.** Displacements between coordinates measured in the georeferenced MUXCAM image and the GCPs coordinates measured in the reference mosaic.

Transformation	$\Delta\bar{X}$ [m]	$\Delta\bar{Y}$ [m]	RMSE [m]
1 <sup>st</sup> order	19.80	15.47	25.12
2 <sup>nd</sup> order	20.19	22.75	30.42

The results were similar for the polynomial transformations considered. The first order RMSE was 25.12 m whereas the second order RMSE was 30.42. The MUXCAM CCD camera spatial resolution is 20 m/pixel, thus the internal accuracy is roughly better than 2 pixels. The higher the internal accuracy, the better the MUXCAM images can be integrated with maps and geospatial data in Geographic Information Systems.

## 5. Conclusion

Brazil and China have launched the fourth generation of the CBERS program, the CBERS-4 satellite, in December 2014. Among other scientific instruments, the payload module carries the Multispectral Camera MUXCAM, produced in Brazil. In this paper the geometric quality of an image acquired by the MUXCAM CCD sensor has been assessed by comparing the image coordinates to GCPs coordinates obtained from an ortho-rectified RapidEye mosaic.

The positioning accuracy for the MUXCAM was ~404 m with a larger displacement of  $\Delta\bar{Y}$





= 380.07 m found in the NS direction. For coarse applications, the MUXCAM images can be used without any geometric correction but for those applications in which accurate positions are to be measured from the scene a geometric transformation must be applied.

After a geometric transformation has been applied, the coordinates accuracy of the MUXCAM is significantly improved. The internal accuracy has been calculated using a first and a second order polynomial function. The resulting RMSE for the first order polynomial was 25.12 m and for the second order it was 30.42 m. From the internal accuracy calculations, one can conclude that MUXCAM images can easily be integrated to other maps and spatial data in Geographical Information Systems. The results obtained for the fourth generation of CCD camera produced in Brazil onboard the CBERS-4 satellite shows a significantly improvement if compared to previous generations, such as CBERS-2, whose positioning accuracy was ~11 km.

## 6. References

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$$X_{image} = a_1 X_{GCP} + a_2 Y_{GCP} + a_3$$

$$Y_{image} = b_1 X_{GCP} + b_2 Y_{GCP} + b_3.$$

(4)







