COMPRESSION OF ORBITAL DATA USING WAVELETS TO IMPROVE CBERS SATELLITE EPHEMERIS

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ABSTRACT:

CBERS (China Brazil Earth Resources Satellite) images brought significant scientific advances in important areas, as land use mapping, urban and crops growing, deforestation and fire control monitoring, small scale update of topographic maps, and several other applications. Based on these advances, the need for improvement in these images quality is growing, mainly in CBERS ephemeris because of the significant orbital deviations what deteriorate the accuracy of image geo-referencing. But the correction of such orbital deviations is a challenge because of the difficulty in storing and distributing the large quantity of data, compatible with receiver equipments and using exclusive digital signal systems. This motivates investigations related to accurate compression of the ephemeris. In this paper a method based on multiresolution analysis (MRA) by wavelet transform (WT) for orbital deviation compression is proposed. It aims to apply the WT and find a good set of coefficients to represent a signal. The energy is often concentrated in few elements in the transformed vector. Hence only the few coefficients need to be encoded and a very effective compression may be achieved. Experiments were carried out with CBERS2B satellite and the results were very promising indicating the possibility and advantage of compressing and correcting the orbital data to the aimed accuracy. The results show that the proposed procedure diminishes the distortions provoked by orbit deviations in up to 98%, thus contributing for an improved image processing and geo-referencing. This research presents the first prospects towards the possibility of down-sizing the ephemeris representation but keeping the required accuracy to the users and minimizing computer memory recourses.

1. INTRODUCTION

The family of remote sensing satellites CBERS (China Brazil Earth Resources Satellite) brought significant scientific advances. Its data and images are used in important areas, as land use mapping, urban and crops growing, deforestation and fire control monitoring, small scale update of topographic maps, and several other applications. The use of images obtained by satellites is steadily increasing, due to the police of free distribution to Brazilian users. Based on these advances, the need for improvement in these images quality is growing. However, it has been complained by the users community that the ephemeris tagged on the image is of poor quality, and 2-lines ephemeris available through internet or computed by INPE's control center still does not deliver desired accuracy. In this sense, significant orbital deviations have been confirmed, but they are not yet corrected in the ephemeris because of the difficulty in storing and distributing the large quantity of data, compatible with receiver equipments and using exclusive digital signal systems. This motivates investigations related to accurate compression of the orbital ephemeris.

Data compression can be done, among other ways, using Fourier Transform (FT). However, wavelet transform (WT) allows a similar transform with some advantages over FT. The idea in FT or WT is to approximate a signal by linear combination of functions. In FT, by sines and cosines, and in WT, by wavelet functions. The WT is a technique very useful for numerical analysis and multidimensional discrete signal manipulation. WT gained its popularity due to its good performance being applied in several applications and areas (Pedrini and Schwartz, 2007). A potential wavelet application refers to audio, image or video data compression. As an example, they were included in the international patter JPEG 2000 (Christopoulos et al., 2000) and also in the FBI (Federal Bureau of Investigations) patter for fingerprint storage (Bradley et al., 1993). The compression used in JPEG and WT has been compared and the results using WT were extremely good (McAndrew, 2004). Even losing part of information, the result is far superior to JPEG compression standard, which is based on discrete cosine transform with a definition similar to FT. WT can be applied by implementation of a fast pyramidal algorithm allowing a signal multiresolution analysis (MRA). The great advantage of this algorithm is that, for the WT, O(N) operations are necessary. This is less than for the FT with O( N ln N) necessary operations.

In this sense, in this paper the possibility of CBERS orbital data compression by MRA using wavelets is investigated. First, the precise ephemeris is fitted to generate the corresponding 2-lines ephemeris. The fit is not perfect and presents deviations reaching around 1km or more in the along track path. The aim now is to compress data from the radial, normal, and transverse (R, N, and T) orbital deviations of CBERS satellite. The most usual way of compression is the lossy one, where a large number of coefficients are eliminated without large quality lost of the curve adjustment. The idea is to zero coefficients that not have much contribution to the signal, but considering the degree
of compression and the deterioration of the adjustment quality. This research presents the first prospects towards the possibility of down-sizing the ephemeris representation but keeping the required accuracy to the users, and minimizing computer memory recourses.

2. ORBITAL DEVIATIONS IN CBERS EPHEMERIS

CBERS Program was born from a partnership between Brazil and China in the space technical scientific segment for remote sensing. Thus, Brazil has obtained a powerful tool to monitor its huge territory by its own remote sensing satellites, looking forward to consolidate an important autonomy in this segment. CBERS has three remote sensing satellites in orbit, namely CBERS-1, -2, and -2B. The success of launches from China, in 1999, 2003, and 2007 respectively, and due to their perfect behaviour CBERS satellites had immediate effects. Indeed, both governments decided to expand the cooperation and include new satellites of the same class, CBERS-3 and 4, as a second stage of Sino Brazilian cooperation. CBERS-3 is expected to be launched in 2009, CBERS-4 in 2011. CBERS satellites were placed on a polar orbit of 98º inclination covering of 26 days, what corresponds to 373 orbits (Moraes et al., 2002). CBERS maintenance is made by Xian and INPE control centers. Among the performed operations by the control centers are trajectory monitoring and correction besides constant orbital parameters update. For orbit computations, one of most popular analytical models is the NORAD (North American Defense) model (Hoots and Roehrich, 1988). Besides the model, the exchange of orbit ephemeris is greatly facilitated by the so-known 2-line element set (2 lines of 80 ASC characters each). Such data is regularly generated by NORAD and most of ephemeris of the known orbiting objects is available through Internet (e.g. www.celestrak.com). CBERS-2 satellite has its 2-lines available in Internet. INPE's control center also generates them in a regular basis every 2 to 3 days, that is, three times a week (Kuga and Orlando, 2004). Because the ephemeris coming with the CBERS image is of poor accuracy, image processing users are using the 2-lines generated either by INPE or Internet. Using the NORAD model for ephemeris matches on the image may sometimes present poor accuracy, image processing users are using the 2-lines generated either by INPE or Internet. Using the NORAD model for ephemeris matches on the image may sometimes present errors of 1km although on the average the error is zero (Kuga, 2002; Kuga and Orlando, 2004).

Computing the differences between the precise ephemeris from INPE's control center and the orbits obtained from NORAD model, orbital deviations are generated. These orbital deviations should be corrected in CBERS ephemeris to reach the desired accuracy. However, they are not being corrected because of the impossibility in storing and distributing the large quantity of data. Even if they could be transmitted, it would be necessary an algorithm very efficient computationally to work with such data and correct it in ephemeris. In this sense, the next section presents a methodology to attend such necessity.

3. WAVELET COMPRESSION BY MULTiresolution Analysis

MRA consists of a sequence of successive closed subspaces \( V_j \) where \( V_j \subset L^1(\mathbb{R}) \) satisfy (Daubechies, 1992)

\[
\begin{align*}
\text{i. } & \cdots V_2 \subset V_1 \subset V_0 \subset V_{-1} \subset V_{-2} \subset \cdots; \\
\text{ii. } & \bigcup_{j \in \mathbb{Z}} V_j = L^1(\mathbb{R}); \\
\text{iii. } & \bigcap_{j \in \mathbb{Z}} V_j = \{0\}; \\
\text{iv. } & f \in V_j \iff f(2^j x) \in V_0; \\
\text{v. } & f \in V_0 \iff f(x - n) \in V_0, n \in \mathbb{Z}.
\end{align*}
\]

The basic MRA idea is that whenever a collection of closed subspaces satisfies (i)-(v), then there is an orthonormal wavelet basis \( \{\psi_{j,k}, j, k \in \mathbb{Z}\} \) of \( L^1(\mathbb{R}) \), \( \psi_{j,k}(t) = 2^{-j/2} \psi(2^{-j}t - k) \), \( j, k \in \mathbb{Z} \), obtained from a mother wavelet \( \psi \) such that, for all \( f \in L^1(\mathbb{R}) \) (Daubechies, 1992),

\[
P_{j-1}f = \underbrace{P_{j-1}f}_{\text{approximation}} + \sum_{k \in \mathbb{Z}} \left( f, \psi_{j,k} \right) \psi_{j,k},
\]

where \( P_j \) is an orthogonal projection into \( V_j \). Equation (1) shows the MRA idea, which is to represent the signal by approximations and details projected into subspaces, like (i) above. The approximations are the large scale that represents the low-frequency components of the signal. The details are the short scale that represents the high-frequency components.

To say that \( V_j \subset V_{j-1} \) means that passing from resolution level \( j \) to \( j-1 \), more information or details are gained (\( P_j f \to f \) when \( j \to \infty \)). Figure 1 illustrates a signal projection above the \( V_0 \) and \( V_1 \) spaces related to the simplest Daubechies wavelets of support one, also called Haar wavelet.

![Figure 1](image)

Figure 1. f signal projection above the \( V_0 \) and \( V_1 \) spaces related to the simplest Daubechies wavelets of support one, also called Haar wavelet. Source: Daubechies, 1992.

MRA is characterized by a filtering process. The original signal, \( S \), passes through two complementary filters and emerges as two signals. The approximation is then itself split into a second level approximation and detail as in Figure 2, and

\[
\begin{align*}
\text{approximation: } & S_1(t) = \sum \left( S, \phi \right) \phi(t) \\
\text{detail: } & S_2(t) = S - S_1(t)
\end{align*}
\]
so on. Thus, the orbital deviation signal is broken down into many lower resolution components (wavelet coefficients).

\[
S = A_1 + D_1 = A_2 + D_2 + D_3 = A_3 + D_3 + D_4 + D_5
\]

Figure 2. Decomposition Process Example of a signal S (Orbital Deviation) broke down into 3 lower resolution levels – MRA. Each approximation component \((A_i)\), that represents the low-frequency part, is split into another level of lower frequency approximation and a detail \((D_i)\) component representing the high-frequency part.

It is better the decomposition process be repeated until the last level, because this allows to decompose all the data and separate all details to obtain a better compression. But a question arises of how these transformed coefficients can be used to perform compression. The distribution of values for the wavelet coefficients is usually centered around zero, with very few large coefficients. This means that almost all the information is concentrated in a small fraction of the coefficients and can be efficiently compressed. In this step, the quantization of the coefficients is performed, where only the important information is kept.

To select the appropriated coefficients, usually a thresholding quantization is used. The aim is the removal (reducing to zero) the magnitude of the wavelet coefficients that have less contribution to the signal. In general, these coefficients are related to the details (high frequency of the signal). Some ways of quantization applying thresholding were discussed in Souza and Kuga (2009) and, to attend the need of the application in question, it was proposed to compress the data fixing the number of coefficients, not depending of the dataset or dataset size. As the data energy is concentrated in few elements in the transformed vector by WT, it is possible to keep a fixed number of these coefficients.

How much information can be lost or eliminated depends very much on the nature of applications. Nevertheless, the measure of a lossy compression includes a measure of the quality of reconstructed signals compared with the original ones. The RMS (Root Mean Square) can be used in this evaluation (Pedrini and Schwartz, 2007).

After the quantization process, some codification method should be chosen to perform the coefficient bit allocation. This step is not discussed in this paper, but the possibilities used in general can be found in Sayood (1998), Pu (2006), Pedrini and Schwartz (2007).

To perform the orbital deviation compression, MRA using WT was implemented in Fortran language. To perform the signal decomposition, the fast pyramidal algorithm given by Press et al. (1992) was implemented. This allows large data be compressed by MRA with minimum computer effort. The input data vector length must be power of two; otherwise the vector is completed with zeroes before its beginning and after its end.

MRA can be performed from different mother wavelets \(\psi\). There are several mother wavelets and some of them have characteristics that are more adequate for certain applications. In Souza and Kuga (2009) was verified that Coiflet mother wavelet presented very good performance among the wavelets analyzed. Thus, a Coiflet wavelet will be applied in this research.

4. EXPERIMENTS AND ANALYSES

The experiment was carried out with data of CBERS2B. From the difference between CBERS2B precise ephemeris and NORAD model it was obtained the orbital deviations or residuals for the components R, N, and T, as well as for their velocities VR, VN, and VT, with sample rate of 60s. These components are presented in Figures 1 and 2, respectively, for 3 days of data.
CBERS orbital deviations are generated every 2 or 3 days, that is, three times a week. Thus the interest is to compress the data of 2 and 3 days, consisting of 2880 and 4320 observations for each component, in case of a sample interval of 60s. These orbital deviations passed by the wavelet compression method described in section 3.

Although there are 2880 and 4320 observations, to apply the pyramidal algorithm performing a complete decomposition, it is necessary to transform the data in a power of two vector. So, the MRA was performed for a vector with $2^{13} = 8192$ positions for both cases of 2 and 3 days. To generate a border in the original vector, zeros were added in the beginning and the end of the vector.

In the quantization process, the decomposed coefficients were fixed to 25, 50, 75, 100 and 125 coefficients that have more contribution to the signal, as discussed in section 3.

The RMS of the differences between original and compressed orbital deviations for the R,N,T components are presented in Figures 5 and 6 for 2 and 3 days of data, respectively. All the results were obtained applying the Coiflet mother wavelet.

In Figure 5, the RMS of the differences between original and compressed orbital deviations for 2 complete days of data is shown.

In Figure 6, the RMS of the differences between original and compressed orbital deviations for 3 complete days of data is shown.

Comparing the results from Figures 5 and 6 for each component, the largest discrepancies after compression are related to the transverse component, as expected.

It is important to stand out that in this paper the wavelet compression was applied for 2 and 3 complete days of data without taking care with the number of complete orbits. Hence, the method showed efficiency even when it is applied for non complete orbits, what is very difficult to work in curve adjustments in general.

In Figures 5 and 6, one can verify that the RMS for the R,N,T components were of better accuracy for the largest coefficient numbers kept in the compression.

To illustrate the wavelet coefficients after MRA and quantization, Figure 7 shows part of the wavelet spectrum keeping 100 coefficients in case of data compression of 3 days.

In Figure 7, only the period that has wavelet coefficients different from zero was plotted. It is possible to see that the energy of the data is concentrated in few large coefficients. In the case plotted, there are 100 coefficients, for the other cases and for the velocity components, the behavior is similar, that is, always only the largest coefficients are kept.

In Tables 1 and 2, the mean and standard deviation of the original and after compression orbital deviations for R,N,T components and their respective velocities are presented for 2 days of data.

From Tables 1 and 2, one can verify that the accuracy of the results was very good, mainly for 75 or more coefficients. Depending on the application, the accuracy with 75 coefficients would be satisfactory. For example, the SD of 546.423m for T component was reduced for 36.434m (Table 1).
In Tables 3 and 4, the mean and standard deviation of the original and after compressed orbital deviations for R, N, T components and their respective velocities are presented for 3 days of data.

<table>
<thead>
<tr>
<th>Mean ± SD</th>
<th>R (m)</th>
<th>N (m)</th>
<th>T (m)</th>
<th>VR (m/s)</th>
<th>VN (m/s)</th>
<th>VT (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>2.359 ± 103.315</td>
<td>2.843 ± 131.844</td>
<td>5.189 ± 551.760</td>
<td>2.655 ± 57.661</td>
<td>2.606 ± 81.417</td>
<td>-0.914 ± 187.499</td>
</tr>
<tr>
<td>25 coef</td>
<td>1.760 ± 35.717</td>
<td>2.448 ± 51.566</td>
<td>4.162 ± 117.913</td>
<td>1.844 ± 24.130</td>
<td>2.848 ± 34.763</td>
<td>4.215 ± 64.137</td>
</tr>
<tr>
<td>50 coef</td>
<td>1.491 ± 16.017</td>
<td>2.871 ± 25.622</td>
<td>3.072 ± 40.531</td>
<td>75 coef</td>
<td>1.844 ± 24.130</td>
<td>2.848 ± 34.763</td>
</tr>
<tr>
<td>100 coef</td>
<td>-0.089 ± 12.433</td>
<td>2.716 ± 19.760</td>
<td>3.039 ± 27.710</td>
<td>125 coef</td>
<td>-0.089 ± 12.433</td>
<td>2.716 ± 19.760</td>
</tr>
</tbody>
</table>

Table 3. Mean and Standard Deviation (SD) of the original and after compression orbital deviations for 2 days of data

<table>
<thead>
<tr>
<th>Mean ± SD</th>
<th>VR (m/s)</th>
<th>VN (m/s)</th>
<th>VT (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>-0.006 ± 0.544</td>
<td>0.000 ± 0.016</td>
<td>0.002 ± 0.109</td>
</tr>
<tr>
<td>25 coef</td>
<td>-0.004 ± 0.121</td>
<td>0.000 ± 0.016</td>
<td>0.002 ± 0.061</td>
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<tr>
<td>50 coef</td>
<td>-0.005 ± 0.078</td>
<td>0.001 ± 0.016</td>
<td>0.002 ± 0.040</td>
</tr>
<tr>
<td>75 coef</td>
<td>-0.003 ± 0.052</td>
<td>0.000 ± 0.016</td>
<td>0.002 ± 0.028</td>
</tr>
<tr>
<td>100 coef</td>
<td>-0.003 ± 0.032</td>
<td>0.000 ± 0.016</td>
<td>0.003 ± 0.021</td>
</tr>
<tr>
<td>125 coef</td>
<td>-0.003 ± 0.023</td>
<td>0.000 ± 0.016</td>
<td>0.002 ± 0.017</td>
</tr>
</tbody>
</table>

Table 4. Mean and Standard Deviation (SD) of the original and after compression velocity orbital deviations for 2 days of data

From Tables 3 and 4, one can verify that the accuracy of the results was also very good, although the number of observations is larger than for 2 days.

The improvement factor related to the RMS of the original orbital deviations and the compressed ones are shown in Table 5 and 6 for 2 and 3 days, respectively. This improvement factor is computed by RMS<sub>Original</sub>/RMS<sub>AfterCompression</sub>.

<table>
<thead>
<tr>
<th>#Coef</th>
<th>R (m)</th>
<th>N (m)</th>
<th>T (m)</th>
<th>VR (m/s)</th>
<th>VN (m/s)</th>
<th>VT (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>6</td>
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<td>6</td>
<td>16</td>
<td>19</td>
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<td>9</td>
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<td>29</td>
<td>8</td>
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</tr>
<tr>
<td>125</td>
<td>15</td>
<td>14</td>
<td>44</td>
<td>37</td>
<td>11</td>
<td>10</td>
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Table 5. Improvement factor for 2 days of data

<table>
<thead>
<tr>
<th>#Coef</th>
<th>R (m)</th>
<th>N (m)</th>
<th>T (m)</th>
<th>VR (m/s)</th>
<th>VN (m/s)</th>
<th>VT (m/s)</th>
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<td>2</td>
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<td>5</td>
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<td>18</td>
<td>6</td>
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<tr>
<td>125</td>
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<td>7</td>
<td>20</td>
<td>24</td>
<td>9</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 6. Improvement factor for 3 days of data

This improvement factor indicates the error reduction in the determination of the orbits. Currently, these deviations are not correct due to the impossibility of sending and correcting so much data. If the compression is performed and the correction realized, it is possible to verify an improvement factor of up to 44 for the compression with 125 coefficients in transverse component (Table 5), what represents 98% of orbital deviation reduction. On the other hand, if the compression is considered for 3 days with 125 coefficients, the improvement factor of 20 reached in transverse component represents 95% of improvement in orbit determination. Hence, these results represent a great step in this research indicating the powerful possibility of orbital deviation compression by WT.

If the compression rate is compared, one can see in that very good rates were reached. While the best compression rate is the most attractive, it is necessary to evaluate the quality of the compression and choose that is more adequate for a certain application.

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