CURRENT STATUS OF LOSSLESS COMPRESSION OF ULTRASPECTRAL SOUNDER AND HYPERSPECTRAL IMAGER DATA

Bormin Huang and Hung-Lung Allen Huang

Cooperative Institute for Meteorological Satellite Studies (CIMSS)
Space Science and Engineering Center (SSEC)
University of Wisconsin-Madison

SSEC/CIMSS Satellite Data Compression Web site: http://math.ssec.wisc.edu/compression/

1St IASI International Conference, Anglet, France, 13-16 November 2007
Contemporary and future ultraspectral sounders (e.g. AIRS, IASI, GIFTS) and hyperspectral imagers (e.g. AVIRIS) provide high spectral and spatial resolutions for improved weather/climate forecast and geographic information.

Given the unprecedented volumes of three-dimensional data generated by these advanced sensors, the use of robust data compression techniques will be beneficial for data transmission and archiving.

In support of the NOAA next-generation GOES data processing, UW SSEC/CIMSS developed various 2D/3D lossless compression methods and data preprocessing schemes applied to the AVIRIS, AIRS, IASI, and GIFTS data.
Application of Principal Component Analysis to High-Resolution Infrared Measurement Compression and Retrieval

HUNG-LUNG HUANG
Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin—Madison, Madison Wisconsin

PAOLO ANTONELLI
Department of Atmospheric and Oceanic Sciences, University of Wisconsin—Madison, Madison, Wisconsin

(Manuscript received 5 February 2000, in final form 30 June 2000)

ABSTRACT

A simulation study is used to demonstrate the application of principal component analysis to both the compression of, and meteorological parameter retrieval from, high-resolution infrared spectra. The study discusses the fundamental aspects of spectral correlation, distributions, and noise; the correlation between principal components (PCs) and atmospheric-level temperature and water vapor; and how an optimal subset of PCs is selected so a good compression ratio and high retrieval accuracy are obtained.

Principal component analysis, principal component compression, and principal component regression under certain conditions are shown to provide 1) nearly full spectral information with little degradation, 2) noise reduction, 3) data compression with a compression ratio of approximately 15, and 4) tolerable loss of accuracy in temperature and water vapor retrieval. The techniques will therefore be valuable tools for data compression and the accurate retrieval of meteorological parameters from new-generation satellite instruments.

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Project Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haine, Thomas</td>
<td>Johns Hopkins University</td>
<td>Space-Based Estimates of Arctic/Sub-Arctic Exchange Using Data Assimilation and Ocean Models</td>
</tr>
<tr>
<td>Hansen, James</td>
<td>Goddard Institute for Space Studies</td>
<td>Global Climate Model Development</td>
</tr>
<tr>
<td>Huang, Hung Lung</td>
<td>University of Wisconsin-Madison</td>
<td>FPGA Re-Configurable Computation Demonstration: AIRS/MODIS Co-Registration and Cloud Characterization for Data Assimilation</td>
</tr>
<tr>
<td>Jacob, Daniel</td>
<td>Harvard University</td>
<td>Investigation of the Effects of Land Cover Change on Chemistry-Climate Interactions</td>
</tr>
</tbody>
</table>

......... 2005-2006
AIRS ULTRASPECTRAL GRATING DATA COMPRESSION

10 selected NASA AIRS digital counts granules on March 2, 2004

<table>
<thead>
<tr>
<th>Granule</th>
<th>UTC Time</th>
<th>H Difference</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>00:53:31</td>
<td>-12</td>
<td>(Pacific Ocean, Daytime)</td>
</tr>
<tr>
<td>16</td>
<td>01:35:31</td>
<td>+2</td>
<td>(Europe, Nighttime)</td>
</tr>
<tr>
<td>60</td>
<td>05:59:31</td>
<td>+7</td>
<td>(Asia, Daytime)</td>
</tr>
<tr>
<td>82</td>
<td>08:11:31</td>
<td>-5</td>
<td>(North America, Nighttime)</td>
</tr>
<tr>
<td>120</td>
<td>11:59:31</td>
<td>-10</td>
<td>(Antarctica, Nighttime)</td>
</tr>
<tr>
<td>126</td>
<td>12:35:31</td>
<td>0</td>
<td>(Africa, Daytime)</td>
</tr>
<tr>
<td>129</td>
<td>12:53:31</td>
<td>-2</td>
<td>(Arctic, Daytime)</td>
</tr>
<tr>
<td>151</td>
<td>15:05:31</td>
<td>+11</td>
<td>(Australia, Nighttime)</td>
</tr>
<tr>
<td>182</td>
<td>18:11:31</td>
<td>+8</td>
<td>(Asia, Nighttime)</td>
</tr>
<tr>
<td>193</td>
<td>19:17:31</td>
<td>-7</td>
<td>(North America, Daytime)</td>
</tr>
</tbody>
</table>

- Each granule consists of 2378 channels with 135 scan lines containing 90 cross-track footprints per scan line.
- Test data publicly available via anonymous ftp

(ftp://ftp.ssec.wisc.edu/pub/bormin/Count)
AIRS digital counts at 800.01 cm$^{-1}$ for the 10 selected granules
Bias-Adjusted Reordering (BAR) Preprocessing Scheme

- Ultraspectral sounder data features strong correlations in disjoint spectral affected by the same type of absorbing gases at various altitudes.

- The Bias-Adjusted Reordering (BAR) preprocessing scheme is used for exploring the correlation among remote disjoint channels.

- This preprocessing technique aims to improve the compression ratio of any existing scheme.
The BAR Scheme (patent application pending)

Given the $i$-th reordered vector $\tilde{V}^i$, we are seeking $V^*$ and $b^*$, the minimum norm solution of
\[
\min_{V \in S} \min_{b \in \mathbb{R}} f^i(V, b),
\]
where the cost function is
\[
f^i(V, b) = \left\| \tilde{V}^i - V - b \right\|^2 = \sum_{k=1}^{n_s} (\tilde{v}_k^i - v_k - b)^2
\]
Then the $(i+1)$-th reordered vector is simply
\[
\tilde{V}^{i+1} = V^* + b^*
\]
The optimal value of $b^*$ is obtained by
\[
\frac{\partial f^i(V, b)}{\partial b} \bigg|_{b=b^*} = 0,
\]
which yields
\[
b^* = \frac{1}{n_s} \sum_{k=1}^{n_s} (\tilde{v}_k^i - v_k) = \langle \tilde{V}^i \rangle - \langle V \rangle
\]
For lossless compression, $b^*$ is rounded to the nearest integer $[b^*]$ and the $(i+1)$-th reordered vector becomes
\[
\tilde{V}^{i+1} = V^* + [b^*]
\]
CIMSS’s Bias-Adjusted Reordering (BAR) data preprocessing scheme (Huang et al. 2004) improves the performance of existing state-of-the-art compression methods (2D CALIC, 2D JPEG-LS, 2D JPEG2000 (Part 1), 3D JPEG2000 (Part 2)).

JPEG-LS: Former ISO lossless standard
JPEG-2000: Current ISO lossless standard
CIMSS-DEVELOPED NEW LOSSLESS COMPRESSION METHODS

- Lossless PCA (Huang et al. 2004)
- Predictive Partitioned Vector Quantization (PPVQ) (Huang et al. 2004)
- Fast Precomputed Vector Quantization (FPVQ) with optimal bit allocation (Huang et al. 2005)
Comparison of CIMSS-DEVELOPED NEW LOSSLESS Performance with the EXISTING methods (AIRS Data)

Compression Ratio

Granule
5 GIFTS uplooking interferometer dataset collected on 13 Sept. 2006 by SDL, Utah State Univ. for compression study

- Each GIFTS dataset consists of
  - longwave complex interferograms, each with 1031 points;
  - 128 x 128 spatial samples (33.8 MB), and
  - midwave/shortwave complex interferograms, each with 2062 points; 128 x 128 spatial samples (67.6 MB)
Lossless Compression of GIFTS Data

- Predictive Partitioned Vector Quantization (PPVQ) scheme consists of 4 steps
  - Linear Prediction
  - Channel Partitioning
  - Faster Vector Quantization
  - Entropy Coding
Predictive Partitioned Vector Quantization (PPVQ)

- **Linear Prediction**
  - Reduce dynamic range by knowledge of previous channels

- **Channel Partitioning**
  - Group channels with same bit depths together

- **Faster Vector Quantization**
  - Unlike Linde-Buzo-Gray (LBG) algorithm, the codebook design is not done by the splitting method.

- **Entropy Coding**
  - Compress VQ indices, codebook, and VQ residual close to their optimal entropy bound
## Compression Ratio Result *(GIFTS DATA)*

<table>
<thead>
<tr>
<th>GIFTS Data No.</th>
<th>JPEG2000</th>
<th>JPEG-LS</th>
<th>3D JPEG 2000 (Part 2)</th>
<th>CCSDS- IDC 9/7 M</th>
<th>CCSDS- IDC 5/3</th>
<th>PPVQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.90</td>
<td>4.08</td>
<td>4.11</td>
<td>3.21</td>
<td>3.13</td>
<td><strong>4.71</strong></td>
</tr>
<tr>
<td>2</td>
<td>3.92</td>
<td>4.10</td>
<td>4.12</td>
<td>3.22</td>
<td>3.13</td>
<td><strong>4.74</strong></td>
</tr>
<tr>
<td>3</td>
<td>3.87</td>
<td>4.04</td>
<td>4.06</td>
<td>3.19</td>
<td>3.11</td>
<td><strong>4.49</strong></td>
</tr>
<tr>
<td>4</td>
<td>3.87</td>
<td>4.04</td>
<td>4.08</td>
<td>3.20</td>
<td>3.12</td>
<td><strong>4.67</strong></td>
</tr>
<tr>
<td>5</td>
<td>3.83</td>
<td>4.00</td>
<td>4.05</td>
<td>3.16</td>
<td>3.09</td>
<td><strong>4.62</strong></td>
</tr>
<tr>
<td>Avg CR</td>
<td>3.88</td>
<td>4.05</td>
<td>4.08</td>
<td>3.20</td>
<td>3.12</td>
<td><strong>4.65</strong></td>
</tr>
</tbody>
</table>

- PPVQ takes about several minutes to compress one huge GIFTS dataset on an AMD Opteron PC for ground data processing purposes (i.e. rebroadcast or archiving).
- The current code is written in Matlab and C/C++ mixed.
Comparison of CIMSS-DEVELOPED NEW LOSSLESS Performance with the EXISTING methods (GIFTS Data)
• NASA JPL AVIRIS hyperspectral imager has 224 bands with wavelengths from 400 to 2500 nanometers (nm)
• The following AVIRIS test dataset has been widely used in the IEEE/SPIE compression society for decades
CIMSS’s **LAIS-LUT** method (Huang et al. 2006) pushes lossless compression of the AVIRIS hyperspectral imagery data to a new high with an average compression ratio of 3.47.

<table>
<thead>
<tr>
<th>Method</th>
<th>Cuprite</th>
<th>Jasper Ridge</th>
<th>Lunar Lake</th>
<th>Moffat Field</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D-CALIC</td>
<td>2.24</td>
<td>2.04</td>
<td>2.42</td>
<td>2.39</td>
<td>2.26</td>
</tr>
<tr>
<td>LCL-3D</td>
<td>2.91</td>
<td>2.81</td>
<td>2.94</td>
<td>2.77</td>
<td>2.86</td>
</tr>
<tr>
<td>Dif. JPEG-LS</td>
<td>2.91</td>
<td>2.81</td>
<td>2.93</td>
<td>2.84</td>
<td>2.87</td>
</tr>
<tr>
<td>ASAP</td>
<td>2.97</td>
<td>2.87</td>
<td>3.10</td>
<td>3.08</td>
<td>3.00</td>
</tr>
<tr>
<td>ACAP</td>
<td>2.97</td>
<td>2.88</td>
<td>3.11</td>
<td>3.10</td>
<td>3.01</td>
</tr>
<tr>
<td>3D-CALIC</td>
<td>2.97</td>
<td>2.98</td>
<td>3.01</td>
<td>3.17</td>
<td>3.04</td>
</tr>
<tr>
<td>SLSQ</td>
<td>3.15</td>
<td>3.15</td>
<td>3.15</td>
<td>3.14</td>
<td>3.15</td>
</tr>
<tr>
<td>M-CALIC</td>
<td>3.14</td>
<td>3.06</td>
<td>3.19</td>
<td>3.27</td>
<td>3.16</td>
</tr>
<tr>
<td>SLSQ-HEU</td>
<td>3.23</td>
<td>3.22</td>
<td>3.22</td>
<td>3.20</td>
<td>3.22</td>
</tr>
<tr>
<td>LUT</td>
<td>3.44</td>
<td>3.23</td>
<td>3.40</td>
<td>3.17</td>
<td>3.31</td>
</tr>
<tr>
<td><strong>LAIS-LUT</strong></td>
<td><strong>3.58</strong></td>
<td><strong>3.42</strong></td>
<td><strong>3.53</strong></td>
<td><strong>3.36</strong></td>
<td><strong>3.47</strong></td>
</tr>
</tbody>
</table>
TOWARDS ERROR RESILIENCE IN SATELLITE “NOISY” TRANSMISSION

CIMSS’s 3D Wavelet – Reversible Variable Length Coding (3DWT-RVLC) method \((\text{Huang et al. 2005})\) yields significantly better error resilience than 3D JPEG2000.

Granule 9

Total pixels = 25600050

- **JPEG2000 Part 2**
- **3DWT+RVLC**
**DSP IMPLEMENTATION FOR REAL-TIME SATELLITE REBROADCAST**

TMS320C6416 DSP board

TMS320C6416 two-level cache-based architecture

Compression ratios of 3DWT-RVLC vs. the DSP version of 3DWT-RVLC

<table>
<thead>
<tr>
<th>Granule</th>
<th>9</th>
<th>16</th>
<th>60</th>
<th>82</th>
<th>120</th>
<th>126</th>
<th>129</th>
<th>151</th>
<th>182</th>
<th>193</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>3DWT-RVLC</td>
<td>2.53</td>
<td>2.60</td>
<td>2.40</td>
<td>2.67</td>
<td>2.52</td>
<td>2.40</td>
<td>2.70</td>
<td>2.46</td>
<td>2.41</td>
<td>2.39</td>
<td>2.51</td>
</tr>
<tr>
<td>DSP 3DWT-RVLC</td>
<td>2.37</td>
<td>2.44</td>
<td>2.28</td>
<td>2.52</td>
<td>2.37</td>
<td>2.28</td>
<td>2.52</td>
<td>2.32</td>
<td>2.27</td>
<td>2.27</td>
<td>2.36</td>
</tr>
</tbody>
</table>
TOWARD REAL-TIME SATELLITE ONBOARD COMPRESSION

- CIMSS’s fast linear-time minimum-redundancy prefix coding (Huang et al. 2007) yields a theoretically superior compression gain and faster execution time than the CCSDS’s Rice coding.

- The Rice coding is optimal only when the input data is of geometric distribution, whereas the prefix coding is optimal for any data distribution.

<table>
<thead>
<tr>
<th>AIRS Garnule No.</th>
<th>CCSDS Rice Coding CPU time (second)</th>
<th>Prefix Coding CPU time (second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>0.72</td>
<td>0.56</td>
</tr>
<tr>
<td>16</td>
<td>0.69</td>
<td>0.57</td>
</tr>
<tr>
<td>60</td>
<td>0.70</td>
<td>0.55</td>
</tr>
<tr>
<td>82</td>
<td>0.74</td>
<td>0.55</td>
</tr>
<tr>
<td>120</td>
<td>0.63</td>
<td>0.56</td>
</tr>
<tr>
<td>126</td>
<td>0.65</td>
<td>0.56</td>
</tr>
<tr>
<td>129</td>
<td>0.67</td>
<td>0.56</td>
</tr>
<tr>
<td>151</td>
<td>0.72</td>
<td>0.56</td>
</tr>
<tr>
<td>182</td>
<td>0.64</td>
<td>0.56</td>
</tr>
<tr>
<td>193</td>
<td>0.65</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Case 1

<table>
<thead>
<tr>
<th>Number</th>
<th>Fixed Frequency</th>
<th>Variable Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>101</td>
<td>'0000'</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>'001'</td>
</tr>
<tr>
<td>3</td>
<td>011</td>
<td>'0010'</td>
</tr>
<tr>
<td>2</td>
<td>010</td>
<td>'0011'</td>
</tr>
<tr>
<td>1</td>
<td>001</td>
<td>'01'</td>
</tr>
<tr>
<td>0</td>
<td>000</td>
<td>'1'</td>
</tr>
</tbody>
</table>

Total = 39

Fixed = 3*9 = 27
Prefix = 8 + 12 + 12 + 16 + 14 + 12 = 88
Rice k0 = 14 + 26 + 12 + 12 + 15 + 12 = 91
Rice k1 = 39 + 39 + 2*7 + 4*3*5 = 95
Rice k2 = 39 + 39 + 34 + 10 = 122
Rice k3 = 39 + 39 + 117

Case 2

<table>
<thead>
<tr>
<th>Number</th>
<th>Fixed Frequency</th>
<th>Variable Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>101</td>
<td>'000'</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>'001'</td>
</tr>
<tr>
<td>3</td>
<td>011</td>
<td>'0010'</td>
</tr>
<tr>
<td>2</td>
<td>010</td>
<td>'0011'</td>
</tr>
<tr>
<td>1</td>
<td>001</td>
<td>'01'</td>
</tr>
<tr>
<td>0</td>
<td>000</td>
<td>'1'</td>
</tr>
</tbody>
</table>

Total = 24

Fixed = 3*8 = 24
Prefix = 4*(2 + 2 + 3 + 3) = 64
Rice k0 = 4*(1 + 2 + 3 + 4 + 5 + 6) = 84
Rice k1 = 24 + 4*4*(1 + 2 + 3 + 4) = 72
Rice k2 = 24 + 4*4*(1 + 1 + 1 + 1 + 2) = 80
Rice k3 = 3*24 = 72
TOWARD FPGA IMPLEMENTATION OF
THE LINEAR-TIME MINIMUM-REDUNDANCE PREFIX CODING

FPGA: Field-Programmable Gate Array
Toward the VLSI design of the Fast Radiative Transfer Model: Implementation of the Exponential Function in VHDL

Bormin Huang, Jianlong Zhang, and Allen Huang
Space Science and Engineering Center
University of Wisconsin-Madison

1. In the era of hyperspectral sounders, the efficient computation of the radiative transfer model is desired.

2. The fast radiative transfer model is very suitable for the FPGA implementation to take advantage of the hardware's efficiency and parallelism, where radiances of many channels can be calculated in parallel in FPGA.

3. The success of the VLSI implementation of the fast radiative transfer model relies on the VLSI design of the exponential function for use in the transmittance calculation:

\[
R_v = \varepsilon_{rs} B_v(T_s) \tau_v(p_s) - \int_0^{p_s} B_v[T(p)] \frac{d\tau_v(p)}{dp} dp
\]

\[
+ r_{vs} \tau_v(p_s) \int_0^{p_s} B_v[T(p)] \frac{d\tau_v^*(p)}{dp} dp
\]

\[
+ R_v^{\text{sun}} \tau_v^{1+\sec^2(p_s)} r_{vs} \tau_v^{\text{sun}},
\]

with the fast transmittance model:

\[
\tau_v(p_j) = \exp\left\{ \sum_{k=1}^{j} \left[ \sum_{l_f=1}^{m_f} a_{vl_f k}^{\text{fixed}} X_{l_f k}^{\text{fixed}} \right. \right. \\
\left. \left. + \sum_{l_w=1}^{m_w} b_{vl_w k}^{\text{water}} X_{l_w k}^{\text{water}} \right. \right. \\
\left. \left. + \sum_{l_o=1}^{m_o} b_{vl_o k}^{\text{ozone}} X_{l_o k}^{\text{ozone}} \right] \right\}.
\]
4. An efficient approximate exponential function for VHDL implementation is developed by adopting Tang's algorithm with some simplifications:

\[ e^x = 2^{\text{slead}(j) + \text{strail}(j) + 1.834 \mu(r)} \]

5. Our VHDL implementation of the exponential function:
6. Numerical evaluation of the VHDL implementation of the exponential function:
(Higher accuracy is achievable, if needed, by reducing the simplifications in the exponential function.)

<table>
<thead>
<tr>
<th>Input data X</th>
<th>Matlab's exp(X)</th>
<th>Matlab simulation</th>
<th>Matlab simulation, %</th>
<th>VHDL simulation</th>
<th>VHDL simulation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td>4.4817</td>
<td>4.4973</td>
<td>0.3481%</td>
<td>4.4976</td>
<td>0.3548%</td>
</tr>
<tr>
<td>-1</td>
<td>2.7183</td>
<td>2.7217</td>
<td>0.1251%</td>
<td>2.7218</td>
<td>0.1288%</td>
</tr>
<tr>
<td>-3</td>
<td>54.598</td>
<td>54.545</td>
<td>0.0971%</td>
<td>54.552</td>
<td>0.0843%</td>
</tr>
<tr>
<td>-3</td>
<td>20.086</td>
<td>20.186</td>
<td>0.4979%</td>
<td>20.188</td>
<td>0.5078%</td>
</tr>
<tr>
<td>2</td>
<td>7.389</td>
<td>7.389</td>
<td>0%</td>
<td>7.389</td>
<td>0%</td>
</tr>
<tr>
<td>0.5</td>
<td>1.649</td>
<td>1.649</td>
<td>0%</td>
<td>1.649</td>
<td>0%</td>
</tr>
<tr>
<td>0.25</td>
<td>1.284</td>
<td>1.278</td>
<td>0.4673%</td>
<td>1.278</td>
<td>0.4673%</td>
</tr>
<tr>
<td>0.95</td>
<td>2.586</td>
<td>2.581</td>
<td>0.1933%</td>
<td>2.581</td>
<td>0.1933%</td>
</tr>
<tr>
<td>0.66</td>
<td>1.935</td>
<td>1.934</td>
<td>0.0517%</td>
<td>1.934</td>
<td>0.0517%</td>
</tr>
<tr>
<td>0.33</td>
<td>1.391</td>
<td>1.393</td>
<td>0.1438%</td>
<td>1.393</td>
<td>0.1438%</td>
</tr>
<tr>
<td>0.12</td>
<td>1.127</td>
<td>1.120</td>
<td>0.6211%</td>
<td>1.120</td>
<td>0.6211%</td>
</tr>
<tr>
<td>-0.12</td>
<td>0.8869</td>
<td>0.8871</td>
<td>0.0226%</td>
<td>0.8871</td>
<td>0.0226%</td>
</tr>
<tr>
<td>-0.25</td>
<td>0.7788</td>
<td>0.7801</td>
<td>0.1669%</td>
<td>0.7801</td>
<td>0.1669%</td>
</tr>
<tr>
<td>-0.33</td>
<td>0.7189</td>
<td>0.7178</td>
<td>0.1530%</td>
<td>0.7177</td>
<td>0.1669%</td>
</tr>
<tr>
<td>-0.66</td>
<td>0.5169</td>
<td>0.5128</td>
<td>0.7932%</td>
<td>0.5128</td>
<td>0.7932%</td>
</tr>
<tr>
<td>-0.95</td>
<td>0.3867</td>
<td>0.3869</td>
<td>0.0517%</td>
<td>0.3869</td>
<td>0.0517%</td>
</tr>
<tr>
<td>-2</td>
<td>0.1353</td>
<td>0.1346</td>
<td>0.5174%</td>
<td>0.1346</td>
<td>0.5174%</td>
</tr>
<tr>
<td>-3</td>
<td>0.0498</td>
<td>0.0497</td>
<td>0.2008%</td>
<td>0.0497</td>
<td>0.2008%</td>
</tr>
<tr>
<td>-4</td>
<td>0.0183</td>
<td>0.0184</td>
<td>0.5464%</td>
<td>0.0184</td>
<td>0.5464%</td>
</tr>
<tr>
<td>-5</td>
<td>0.0067</td>
<td>0.0067</td>
<td>0%</td>
<td>0.0067</td>
<td>0%</td>
</tr>
</tbody>
</table>

7. Execution time
For one single exponential calculation, Matlab's built-in C code takes $3.5 \times 10^{-4}$ seconds at the high-end AMD Opteron 2.4 GHz CPU, whereas the estimated Xilinx Virtex FPGA (model: x4vlx100) takes $3 \times 10^{-3}$ seconds. The FPGA is ~10x faster!

For implementation of 10 exponential calculations in parallel in one Xilinx Virtex FPGA (model x4vlx100), it is ~100x faster!!

For parallel implementation of four such FPGAs, it is ~400x faster!!

The bottom line: hardware parallelism is much more efficient than software parallelism.

7. Used resource for Xilinx Virtex FPGA x4vlx100:
- Number of Slices: 1245 out of 49152, 2%
- Number of Slice Flip Flops: 596 out of 98304, 0.61%
- Number of 4-input LUTs: 2247 out of 98304, 2%
- Number of DSP48s: 3 out of 96, 3%
SUMMARY

- This talk presents the current status of lossless compression of ultraspectral sounder and hyperspectral imager data that have been conducted since 2004 at the Cooperative Institute of Meteorological Satellite Studies (CIMSS), the University of Wisconsin-Madison.
- Besides the new algorithm development CIMSS is actively working toward the DSP/FPGA/VHDL implementation.
- So far a book chapter & more than 50 papers are published.
- Several compression schemes/methods are under consideration for patent applications.
- CIMSS is looking forward to conducting IASI compression and is in need of IASI raw data counts.
- CIMSS is also actively looking for national/international institution/industry partnership for H/W implementation and applications.
SUMMARY - continue

- New IASI initiative also includes
  - Development of a novel retrieval capability for advanced sounder
    - To develop innovative retrieval algorithms for the enhanced use of clear and cloudy IASI radiances
    - To demonstrate the ultimate IASI sounding capability that is not limited by the traditional inverse approaches.
Acknowledgement

This work is prepared in support of National Oceanic & Atmospheric Administration (NOAA) GOES-R data compression research under grant NA07EC0676.

NOAA co-leads are Roger Heymann of NOAA NESDIS OSD and Tim Schmit of NOAA NESDIS STAR.

Congratulations to Roger Heymann and Tim Schmit for receiving the 2006 NOAA Bronze medal. Their medal citation is "For reducing costs and increasing satellite earth science global data distribution and archiving through world-leading R&D in data compression."
Useful Links
For references, datasets, publications, & software

CIMSS Satellite Data Compression Web site:
http://math.ssec.wisc.edu/compression/

CCSDS Web site:
Per CCSDS’s request, CIMSS sent in 20+
published papers for their posting at the
CCSDS web site: http://www.ccsds.org/
Reference

Satellite Data Compression Team
Cooperative Institute for Meteorological Satellite Studies
Space Science and Engineering Center
University of Wisconsin-Madison

Book Chapter


Selected Publications (since 2004)


47. B. Huang, A. Ahuja, and H.-L. Huang. "Optimal compression of high spectral resolution satellite data via adaptive vector quantization with linear prediction," Journal of Atmospheric and Oceanic Technology (accepted with minor revisions).

http://math.ssec.wisc.edu/compression/
Satellite Data Compression, Communication, and Processing Conference
Satellite Data Compression, Communication, and Processing IV (OP404)

Part of the SPIE International Symposium on Optical Engineering + Applications
10-14 August 2008 • San Diego Convention Center • San Diego, CA, USA

Conference Chairs: Bormin Huang, Univ. of Wisconsin-Madison; Roger W. Heymann, National Oceanic and Atmospheric Administration; Joan Serra-Sagrista, Univ. Autonoma de Barcelona (Spain)

Conference Co-chairs: Aaron B. Kiely, Jet Propulsion Lab.; Shen-En Qian, Canadian Space Agency (Canada)

Program Committee: Gary E. Bingham, Utah State Univ.; Shila Ghosh, B.P. Poddar Institute of Management & Technology (India); Irina Gladkova, City College/CUNY; Shuxu Guo, Jilin Univ. (China); Allen H. Huang, Univ. of Wisconsin; Matthew A. Klimesh, Jet Propulsion Lab.; Yunsong Li, Xidian Univ. (China); Jarno Mielikainen, Univ. of Kuopio (Finland); Pichet Maungnoul, King Mongkut’s Institute of Technology Ladrkrabang (Thailand); Donald P. Olsen, The Aerospace Corp.; Jeffrey J. Puschel, Raytheon Space and Airborne Systems; Ana M. C. Ruedin, Univ. de Buenos Aires (Argentina); Timothy J. Schmit, National Oceanic and Atmospheric Administration; Carole Thibaud, Ctr. National d’Etudes Spatiales (France); Shih-Chieh Wei, National Univ. (Taiwan)

With the advances in contemporary and future active and passive sensor technology with high spectral and spatial resolutions, more powerful airborne and spaceborne instruments are being developed for remote sensing of the atmosphere, oceans, lands of Earth and other planets. Their finer resolution and faster scanning result in significant data volume increases. These increases present challenges to data transmission and archiving; particularly for satellites with limited access to a growing congested radio frequency (RF) spectrum. Data compression techniques provide reduced data volume for effective data transfer within the limited satellite RF spectrum, while reducing the cost of data transfer radio frequency (RF) spectrum. Satellite data communications techniques facilitate data transmission in the wireless error-prone channels.

This conference provides an interdisciplinary forum for exchanging the latest research results and views on the current work in the areas of satellite data compression and communication. The advances in satellite data compression have been influenced by the progress and knowledge in generic 2D and 3D image and video coding techniques. Research in these areas is also welcome in hope to inspire the scientists in satellite data compression. This conference also extends its interests to data processing techniques to reduce, improve or extract the noisy data via onboard pre-processing or on-site post-processing. Topics of interest include but are not limited to:

Data Compression

Ultra-spectral, hyperspectral and multispectral data compression, generic 2D image and 3D video coding, lossless, near-lossless, and lossy compression, computationally efficient compression, error-resilient compression, applications of compression to geophysical product retrieval, compression-based anomaly quantization, wavelet compression, multiwavelet compression, fractal compression, restricted radio frequency (RF) spectrum, data compression techniques provide reduced data volume for effective data transfer within the limited satellite RF spectrum, while reducing the cost of data transfer radio frequency (RF) spectrum.

Data Communication

Channel coding, source coding, advanced modulations, error-correction coding, restricted radio frequency (RF) spectrum, telemetry systems, telecommand systems, space link protocol, link analysis, transmission techniques, multiple access, satellite networks, multibeam satellites, communication payload, wireless communication, applications of Europe’s DVB satellite standard, application of CCSDS modulation by space agencies, controlling out-of-band emissions. All of these issues relate to how much data can be transmitted.

Data Processing

Filter design, digital filters, data reduction, sampling and quantization, data archiving, data indexing, image registration, image restoration, image interpolation, data recovery, image restoration, desrting, bowtie correction, data calibration, data correction, data enhancement, noise filtering, analog and digital signal processing, statistical signal processing, adaptive signal processing, geometric transformation, image stabilization, color correction, brightness and contrast adjustment, data representation and transforms, super-resolution, multi-resolution processing and wavelets, motion-based motion analysis & tracking, feature extraction, morphological image processing, neural networks, fuzzy processing, data format, content-