ADPCM Image Compression Techniques for Remote Sensing Applications

Ashok Kumar*, Rajiv Kumaran, Sandip Paul, Sanjeev Mehta
Scientist/Engineer, Space Applications Centre, Indian Space Research Organization, Jodhpur Tekra, Ahmedabad, India-380015
*Email: ashokkumar@sac.isro.gov.in

Abstract—ISRO’s remote sensing continuity mission Resourcesat-II provided better radiometric performance as compared to Resourcesat-I. However, this improvement required implementation of onboard image compression techniques to maintain same transmission interface. In LISS-4 payload, prediction based DPCM technique with 10:7 compression ratio was implemented. Based on received data from this payload, some ringing artifacts were reported at high contrast targets, which degrade image quality significantly. However occurrences of such instances were very few. For future missions, efforts are made to develop an improved low complex image compression technique with better radiometry and lesser artifacts. Adaptive DPCM (ADPCM) technique provides better radiometric performance. This technique has been implemented onboard by other space agencies with their own proprietary algorithm. To maintain existing 10:7 compression ratio, novel ADPCM techniques with adaptive quantizers are developed. Developed ADPCM techniques are unique w.r.t. predictor and encoding. Developed techniques improve RMSE from 1.3 to 10 times depending on image contrast. Ringing artifacts are reduced to 1% from 38% with previous technique. Developed techniques are of low complexity and can be implemented in low end FPGA.

Table 1. Usage of DPCM technique onboard

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Compression Algorithm</th>
<th>Compression Ratio</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPOT I/II/III/IV (CNES1986/90/93/98)</td>
<td>Fixed Rate DPCM</td>
<td>8:6</td>
<td>1.33</td>
</tr>
<tr>
<td>Resourcesat-II (ISRO 2011)</td>
<td>10:7</td>
<td>1.41</td>
<td>FPGA</td>
</tr>
<tr>
<td>LANDSAT-7 (M7)</td>
<td>ADPCM</td>
<td>8:1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>IKONOS (US GeoEye1999)</td>
<td>ADPCM Kodak</td>
<td>11:2.5</td>
<td>4.4</td>
</tr>
<tr>
<td>QuickBird (US DigitalGlobe 2001)</td>
<td>11:4</td>
<td>2.75</td>
<td>4.3</td>
</tr>
<tr>
<td>WorldView-1 (US DigitalGlobe2007)</td>
<td>Different Predictive (ADPCM)</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>

In Resourcesat-2 (ISRO-2011) LISS-4 payload, DPCM technique was used with compression ratio of 10:7 [2]. This availability of 10-bit radiometric data leads to better image quality as compared to Resourcesat-1 (7-bit digitization) [3, 4]. Fig. 1 shows few onboard images (False Color image after fusion of multi-spectral data).

**I. INTRODUCTION**

Due to recent advancement in sensor technology, ISRO’s future remote sensing systems will have better spatial, radiometric, and spectral resolution. This improvement leads to higher data volume. Image compression is usually employed to meet transmission capability in space missions [1]. Compression ratio is usually decided by trade-off studies between available satellite resources and image quality requirement from user community.

DPCM, a prediction based image data compression techniques, has been used in many missions. Table-1 provides usage summary for DPCM and its adaptive part ADPCM [1].

Fig. 1. Resourcesat-2 LISS-4 images

Fig. 2 shows typical histogram of an LISS-4 image (12000X12000). Kindly observe the non-linear axis.
Implemented DPCM technique has quantizer dynamic range of 270 pixel difference counts, which was derived based on analysis of various payload images. But, difference count up to 600 was observed due to higher system MTF performance, which indicates that ringing artifacts are expected at high contrast locations [3]. Higher dynamic range of quantizer may force radiometric degradation at lower contrast locations. Existing technique also causes error propagation in recovery of 25% pixels [3].

Issue of ringing artifacts at high contrast and radiometric degradation at low contrast can be resolved by multiple quantizers with selective application per group [4]. Quantizer with small step size should be applied for low contrast groups. This ensures better radiometric performance considering higher probability of such instances (75-98%) in remote sensing images. Quantizer with bigger step size should be applied for high contrast groups. This ensures lesser ringing artifacts.

Implementation of multiple quantizers leads to adaptive DPCM (ADPCM) compression technique. Proprietary ADPCM algorithms had been implemented in LANDSAT, IKONOS and Quickbird missions [1]. For LISS-4 compression ratio of 10:7, custom ADPCM techniques with adaptive quantization are developed. This paper provides details of existing DPCM technique and newly developed ADPCM techniques with simulation results. Section II provides details of existing DPCM technique in LISS-4 payload. Section-III provides details of newly developed ADPCM techniques ADPCM-4P & ADPCM-5P. RMSE & Ringing artifacts results are shown in section IV & V respectively.

II. EXISTING DPCM TECHNIQUE IN LISS-4 PAYLOAD

Block diagram of existing DPCM encoder/decoder [2-4] is shown in Fig. 3. DPCM is implemented in a group of pixels. In a single group, at least one pixel is transmitted in its original form (lossless). For remaining pixels, residue with predictor is quantized and transmitted [5].
Input Difference Value (IDV) i.e. the DPCM residue P1-P3 or similar is quantized through LUT and 6-bit (including one sign bit) Encoded LUT value (ELV) is generated. One of the pixels is sent without processing. Hence 25% data will be recovered losslessly.

Existing DPCM technique is developed with quantizer dynamic range of 270 IDV only, which was derived based on analysis of various payload images. But, IDV up to 600 count is possible due to higher system MTF performance, which indicates that ringing artifacts are expected at high contrast locations [3]. Dynamic range of existing LUT can be increased through bigger quantization step sizes, but this will degrade radiometric performance. Another issue with existing DPCM technique is error propagation i.e. error in recovery of P5 pixel affects P7 pixel’s recovery.

The issue of dynamic range coverage and radiometric performance can be resolved by multiple quantizers. Quantizers will be applied selectively as per input contrast per group. Quantizer with small step size will be applied at low contrast location; this will ensure better radiometric performance considering higher probability of such instances (60-90%). Quantizer with bigger step size will be applied at high contrast location. This will cover input dynamic range and reduce ringing artifacts. Requirement of multiple quantizers leads to Adaptive DPCM (ADPCM) technique, which is discussed in next section.

III. DEVELOPMENT OF ADPCM TECHNIQUES FOR LISS-4 PAYLOAD DATA CONFIGURATION

Because of lower complexity, ADPCM with adaptive quantizer is considered for development [5]. In single ADPCM group, one pixel is transmitted in original form (lossless) [5]. For remaining pixels, residue i.e. difference with predictor is quantized by look up table (LUT). Fig. 5 shows block diagram of ADPCM technique.

For low contrast group, lossless LUT (LUT-DR-31) is applied. This means IDV values are transmitted without any losses. For high contrast group, lossy piecewise linear LUT (LUT-DR-600) is applied. LUT-DR-600 will cover full input dynamic range and helps in avoiding ringing artifacts. Fig. 6 shows details of both these LUTs. Proposed LUTs commensurate with expected IDV histogram, shown in Fig. 7. Kindly observe non-linear axis in plot.

![Fig. 5. ADPCM block diagram](image)

![Fig. 6. Proposed ADPCM’s Quantizer Details](image)
One of the main advantages of this technique is zero error propagation. However, this leads to poor prediction because reference pixel can be one of the four pixels. If it is P1 or P7, then poor correlation may increase residues and then quantization errors. Requirement of pixel sorting slightly increases hardware implementation complexity.

B. Development of ADPCM-5P technique

Algorithm of proposed ADPCM-5P technique for an odd pixel group is shown in Table 4. A group of 5 adjacent pixels is processed at a time. Details of required quantizers are already mentioned in Fig. 6.

Table 4. Algorithm of Proposed ADPCM-5P

<table>
<thead>
<tr>
<th>Odd Pixels</th>
<th>P1 (10-bit)</th>
<th>P3 (10-bit)</th>
<th>P5 (10-bit)</th>
<th>P7 (10-bit)</th>
<th>P9 (10-bit)</th>
<th>SEL LUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPCM Operation</td>
<td>P1-P3 (6-bit)</td>
<td>P3-P5 (6-bit)</td>
<td>REF= P5 (10-bit)</td>
<td>P5-P7 (6-bit)</td>
<td>P7-P9 (6-bit)</td>
<td>S (1-bit)</td>
</tr>
</tbody>
</table>

This technique provides better pixel correlation (or better prediction) than ADPCM-4P. However, error in recovery of P3 & P7 pixel propagates in recovery of P1 & P9 pixels respectively. This error propagation can be avoided by calculating the errors before encoding as shown in equation (1) and (2).

\[
\Delta E_{P3} = DLV(ELV(IDV_{P1,P3})) - IDV_{P1,P3} \quad (1)
\]

\[
\Delta E_{P7} = DLV(ELV(IDV_{P7,P9})) - IDV_{P7,P9} \quad (2)
\]

Rather than quantizing P1-P3 & P7-P9 data, P1-P3+\Delta E_{P3} & P7-P9-\Delta E_{P7} will be quantized respectively. This technique is termed as ADPCM-5P-NEP (no error propagation).

IV. RMSE SIMULATION RESULTS

Four different 10-bit image-sets covering various contrast ranges are used for simulation purpose. These are shown in Fig. 8. Table 5 shows image parameters [6]. Image 1 & 2 can be treated as low contrast images. Image 4 is of very high contrast image. Fig. 9 shows histogram of simulation image-sets.

\[
RMSE = \sqrt{\frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I_{REF}(i,j) - I_{recovered}(i,j)]^2} \quad (3)
\]

where \([m n]\) is image size. \(I_{REF}\) is considered reference image-set for simulation purpose, while \(I_{recovered}\) is decompressed image.

\[
Entropy(\text{bits/pixel}) = \log_2 \left( \sum_{i=0}^{1023} i.p(i) \right) \quad (4)
\]

\[
\text{Line Complexity} = \frac{1}{m(n-1)} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} |I_{REF}(i,j+1) - I_{recovered}(i,j)| \quad (5)
\]

Line complexity is computed from across track odd pixel data.

![Fig. 8. Image-sets used for simulation](image-url)

![Fig. 9. Histogram of simulation image-sets](image-url)
Simulation results are shown in Fig. 10. Due to lossless quantizer, proposed ADPCM techniques achieve much better radiometric performance for low contrast images. Proper dynamic range coverage of quantizer helps in achieving better RMSE performance for very high contrast images. Peak error performance is shown in Fig. 11. These results are verified with the recovered pixel statistics from ADPCM-5P & ADPCM-4P. This is shown in Fig. 12 & 13. For image-1 & 2, lossless encoding of >99% pixels leads to RMSE error of <0.15 LSB. Kindly note that Existing DPCM technique recovers fixed 25% pixels as lossless.

$$\text{Ringing Artifacts (RA\%)} = \frac{P_n (P_{n-1} + P_{n+1})}{2} \times 100$$

(6)

Simulation dataset (8X8 pixel matrix) with maximum contrast is developed as per LISS-4 system MTF [3]. Fig. 15 shows simulation results (color mapped). In uniform along track and across track regions, ringing artifacts are computed by using Equation 6. Proposed ADPCM techniques reduce ringing artifacts to <1.5%.

In recovered image 1 to 4 [Fig. 8], no visual ringing artifacts were observed. For visual analysis, some artificial high intensity objects were inserted in image-4. Recovered images are shown in Fig. 16. It can be concluded that ADPCM reduces ringing artifacts significantly.
From above analysis, it can be noted that ringing artifacts cannot be eliminated fully, as these arise because of quantization. Artifact pattern and its extent depend on encoding technique and quantization table. Other space agencies have also reported DPCM noise in recovered image. Fig. 17 shows noise due to ADPCM compression, reported for IKONOS PAN images [7, 8].

VI. CONCLUSION

The proposed novel ADPCM techniques shows better image reproducibility compared to existing DPCM technique. New ADPCM techniques maintain the compression ratio of 10:7 and achieve significant radiometric improvement on low as well as high contrast images compared to existing DPCM technique. Developed ADPCM techniques produce RMSE of 10 counts compared to 41 counts for very high contrast image. These produces RMSE of 0.04 counts compared to 0.48 counts with low contrast images. Ringing artifacts are reduced to 0.5% compared to 38.2%. Algorithm of both techniques has low complexity.

ACKNOWLEDGMENT

We gratefully acknowledge the constant encouragement and guidance received from Shri Arup Roy Chowdhury – GD-SEG, Shri R M Parmar-DD-SRA, Shri DRM Samudraiah- Prof. Satish Dhawan Scientist, Shri Saji A Kuriakose–DD-SEDA and Shri A. S. Kiran Kumar-Director SAC. We are thankful to our colleagues of Payload Checkout Electronics Group for providing the images.

REFERENCES


Authors’ Profiles

Ashok Kumar, male, is a Scientist/Engineer at Space application Centre (ISRO). He completed his BE degree (Electronics and communication) from University of Rajasthan in 2007. He is currently involved in advance research and development activities for future electro-optical payloads at Sensor Front End Electronics Division (Sensor Development Area). His research interest includes VLSI design, image processing, computation photography etc. He has been awarded “ISRO team excellence award-2009” for “Miniaturized camera electronics development. He has published 9 papers in various international/national conferences and peer reviewed journals. Contact:
4396, SFED/SEG/SEDA, Space Applications Centre, Jodhpur Tekra, Ahmedabad-380015
Phone- 91-79-26914396
Email: ashokkumar@sac.isro.gov.in

Rajiv Kumaran, male, is a Scientist/Engineer at Space application Centre (ISRO). He passed his BE (E&C) from GEC, Modasa. He joined Space Applications Center (SAC) in April 2000. Presently he is working on design and development of electronics for IRS payloads.