Image Compression Technique with Higher Compression Ratio

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Abstract

Future high resolution instruments planned by ISRO for space remote sensing will have higher data rates as a result of planned improvements in resolution and dynamic range. Limited transmission capability mandates higher compression ratio for such missions. Differential Pulse Code Modulation (DPCM) is prediction based image compression technique (10:7) successfully used in Resourcesat-2 mission. An effort has been made to develop low complex image compression techniques with higher compression ratio while maintaining similar/better radiometric performance. Adaptive DPCM (ADPCM) is another prediction based image compression technique, which has been used by other space agencies with proprietary algorithms. Custom ADPCM techniques with multiple quantizers are developed with compression ratio of 10:6 and 10:5. Developed low complex ADPCM techniques are unique w.r.t. predictor selection. Developed techniques are evaluated for both low and high contrast images.

***Keywords:** DPCM, RMSE, Dynamic Range, Compression*

INTRODUCTION

In remote sensing payloads, parameters like spatial resolution, radiometric resolution, spectral bands and swath determine the data volume to be down linked. Present and future remote sensing payloads demand improvements of these parameters. Satellite power and transmission bandwidth limit real time data-rate transmission. Data compression is usually employed to meet transmission capacity. Various onboard data compression techniques have been used in space missions [1].

Data compression can be lossless or lossy. Lossy methods provide higher compression but have some implications on scientific information (performance in terms of RMSE). Trade-off studies among satellite resources, application and available technology decide the compression ratio.

Differential Pulse Code Modulation (DPCM) is one of the prediction based data compression techniques. It was first used in SPOT-1 (CNES-1986) mission with 1.33:1 compression ratio [2]. In Resourcesat-2 (ISRO-2011) LISS-4 payload, DPCM was used to provide higher radiometric resolution (10 bit) data w.r.t. Resourcesat-1 after compressing it to existing 7-bit data interface [3, 4]. Figure 1 shows one of the onboard images.

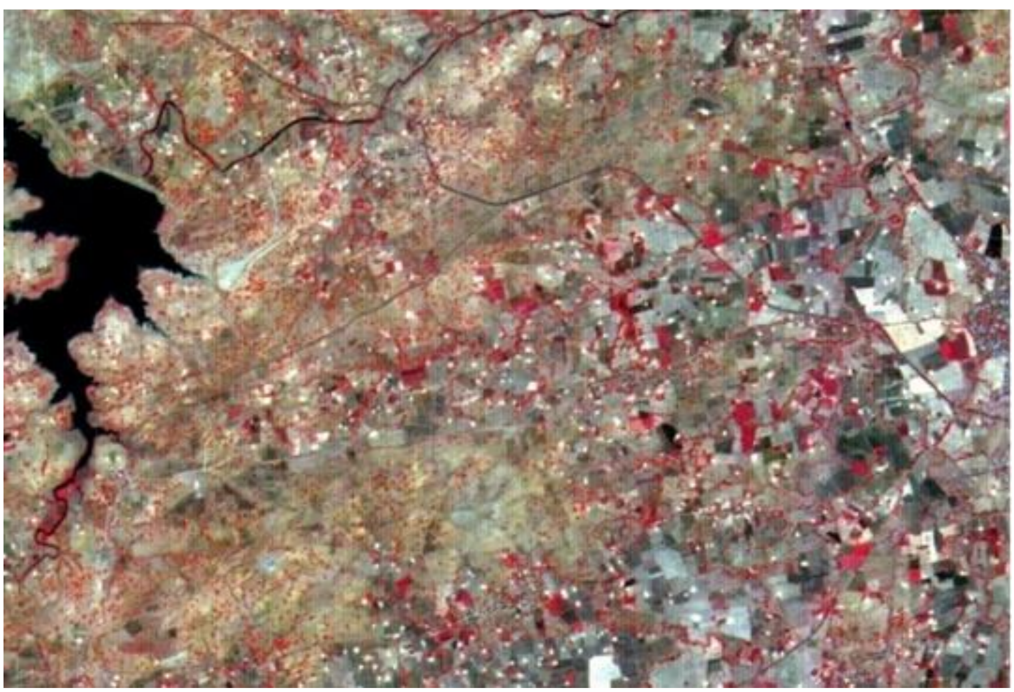


Figure 1

Adaptive DPCM (ADPCM) provides better radiometric performance than DPCM [1].

With proprietary algorithm, its variants have been implemented in LANDSAT, IKONOS, Worldview and Quickbird missions with compression ratio as high as 2.5 and 4 [1]. To meet required compression ratios, custom ADPCM techniques with adaptive quantization are explored and developed. Quantizer of proposed technique meets required dynamic range.

This paper provides details of existing DPCM technique, newly developed ADPCM techniques and simulation results. ADPCM techniques are developed with pixel group size of 3X3. Their performance is compared with existing DPCM technique.

Quantization error refers to error due to quantizer (i.e. LUT) mapping and not because of Analog to Digital Converter (ADC).

2. EXISTING DPCM TECHNIQUE

Block diagram of existing DPCM encoder/decoder is shown in Figure-2. DPCM is implemented in a group of pixels. In a single group, at least one pixel is transmitted in its original form (lossless) [3]. For remaining pixels, residue with predictor is quantized and transmitted.

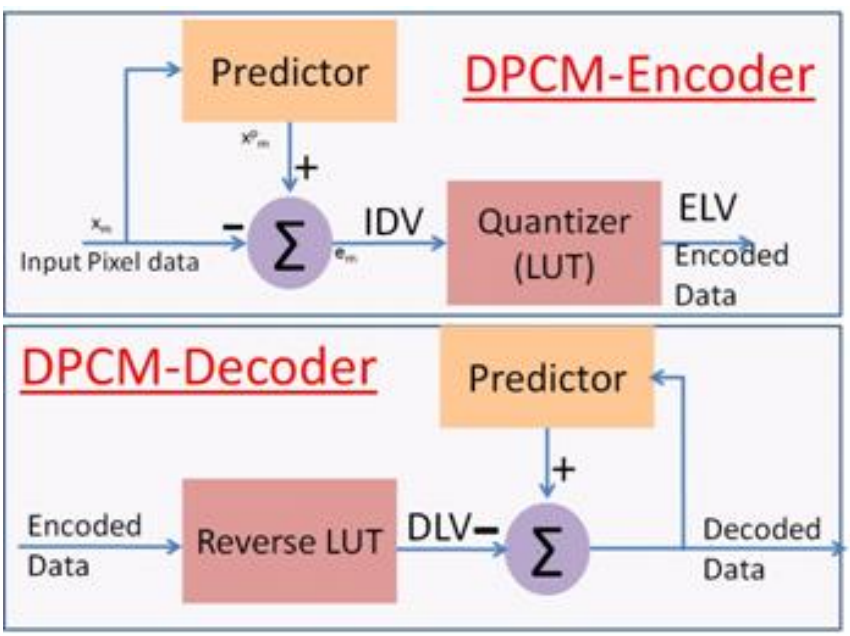


Figure.2 DPCM block diagram

Algorithm of existing DPCM technique is shown in Table-1. DPCM technique is applied separately on odd and even ports to eliminate effect of port level gain/offset variation. A group of 4 adjacent pixels e.g. P1, P3, P5 & P7 for odd port is processed at a time.

Hence, real time data compression is carried out on ADC output data directly with no external memory. For P1, P5 & P7 pixels, the 6-bit difference value (residue) will be transmitted. This difference value will occupy >6 bits, hence a piecewise linear quantization table (LUT: Look up Table) is prepared to retain the information at low differences (vegetation) at the expense of some loss at higher differences (cloud & snow) as shown in Figure-3 [5].

Table 1: Algorithm of Existing DPCM Technique

Odd pixels	*P1 (10-bit)*	*P3 (10-bit)*	*P5 (10-bit)*	*P7 (10-bit)*
DPCM operation	P1 – P3	Ref Pixel	P3 – P5	P5 – P7
Output bits after LUT mapping & adding sign bit	6-bit	Reference pixel is sent in original form (10-bit)	6 –bit	6 –bit
After repacking transmitted data	Bit-2 of reference pixel & above 6-bits (7-bits)	LSB 7-bits of ref pixel (7-bits)	Bit-1 of reference pixel & above 6-bits (7-bits)	Bit-0 of reference pixel & above 6-bits (7-bits)
Even pixels	*P2 (10-bit)*	*P4 (10-bit)*	*P6 (10-bit)*	*P8 (10-bit)*
DPCM operation	P2 – P4	P4 – P6	Ref Pixel	P6 – P8
Output bits after LUT mapping & adding sign bit	6-bit	6 –bit	Reference pixel is sent in original form (10-bit)	6 –bit
After repacking transmitted data	Bit-2 of reference pixel & above 6-bits (7-bits)	Bit-1 of reference pixel & above 6-bits (7-bits)	LSB 7-bits of ref pixel (7-bits)	Bit-0 of reference pixel & above 6-bits (7-bits)

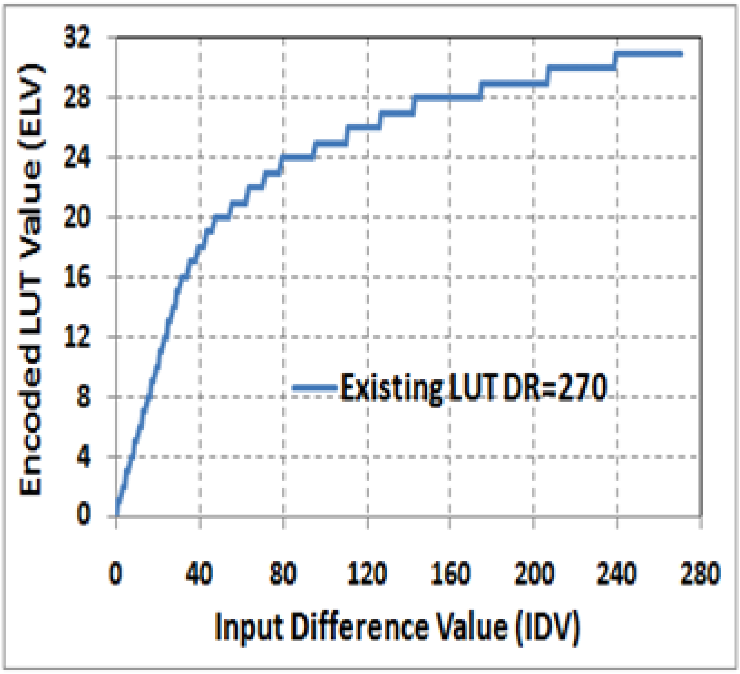


Figure.3 Existing DPCM's Quantizers (LUT) Details.

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 listlessly. Decoded LUT values (DLV) are available on ground while decoding.

Existing DPCM technique is developed with quantizer dynamic range of 270 IDV only [5], 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 [5]. Dynamic range of existing LUT can be increased through bigger 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 quantizes. Quantizes 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 quantizes leads to Adaptive DPCM (ADPCM) technique, which is discussed in next section.

3. DEVELOPMENT OF ADPCM TECHNIQUES

ADPCM can be adaptive in terms of predictor or quantizer or both [6]. Block diagram of proposed ADPCM encoder/decoder with adaptive quantization is shown in figure-4. ADPCM is implemented in a group of pixels. In a single group, at least one pixel is transmitted in original form (lossless) [3, 5]. For remaining pixels, residue with predictor is quantized and transmitted.

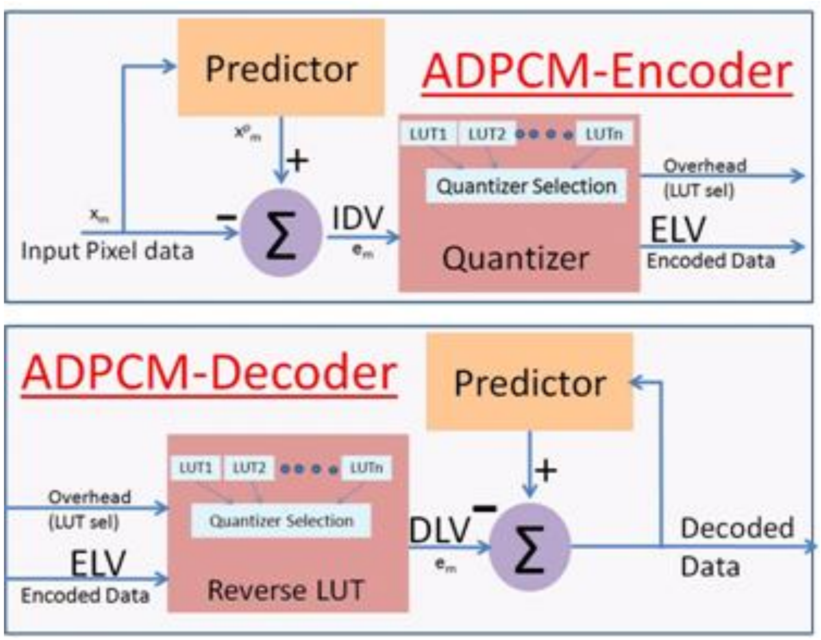


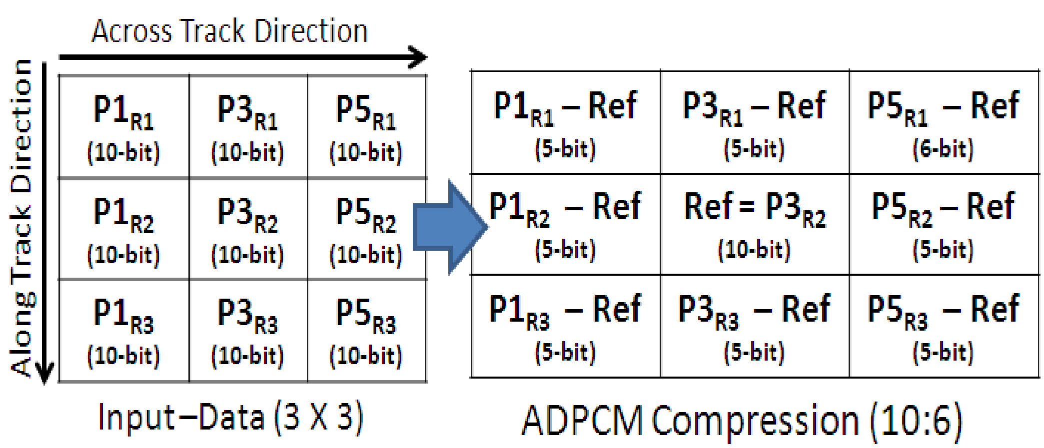
Figure. 4 ADPCM block diagram

Group size selection is one of the major design considerations. Smaller group size causes lesser prediction error and poorer compression ratio. However, bigger group size causes more prediction error and better compression ratio. Existing DPCM technique uses pixel group size of 4. To achieve higher compression ratio, group size needs to be increased. Existing DPCM technique utilizes only across track data because of non-availability of external memory. With uses of along track data also, group size can be increased with similar prediction error. ADPCM techniques are studied and developed with pixel group size 3X3. Details are given next.

3.1 Development of ADPCM (10:6) technique

ADPCM technique requires compression of 9-pixel 90-bit data to 54-bit. One reference pixel will occupy full 10-bits. Mapped eight IDV values occupy 48-bits (6-bit quantizer, which includes one sign bit). This produces 58 output bits. Hence, to achieve higher compression ratio, number of quantization levels in LUT are reduced to 16 from earlier 32. Eight quantizes are used to cover IDV dynamic range. This requires transmission of 3 LUT-sel bits. So out of 54 bits, 53 bits (10 + 5X8 +3) have been utilized. Algorithm of proposed ADPCM technique for odd pixel group is shown in Table-2.

Table 2: Algorithm of Proposed ADPCM (10:6)



For low contrast group, lossless LUT (LUT-DR-15) is applied. This means IDV values are transmitted loss lessly. For high contrast group, lossy LUTs are applied. Higher dynamic range of LUT produces more quantization error. LUT is kept same for one group which consists of 8 IDVs. For LUT selection, RMSE error per group with each LUT is computed. LUT with minimum RMSE is selected for final implementation. One of the main advantages of this technique is zero error propagation, as predictor is same for all encoded pixels [5]. Quantizes dynamic range is 908 IDVs compared to requirement of 600 IDVs. The only issue is higher hardware complexity. Prediction can be further improved if reference pixels of nearest groups are averaged first to estimate the predictor. This averaging reduces the ADPCM residue at high contrast locations. Lesser residue leads to lesser quantization error. However, this generates different predictors for each of 8 processed pixels. This technique can be termed as ADPCM-RA (Reference Averaging). Details are shown in Figure-6. It should be noted that still there is no error propagation in recovery, as same predictor is available at ground during decompression.

3.2 Development of ADPCM (10:5) technique

This technique is similar to ADPCM-RA (10:6) except quantizers. Here, quantization levels are reduced to 8 only. Details of algorithm are shown in Figure-5

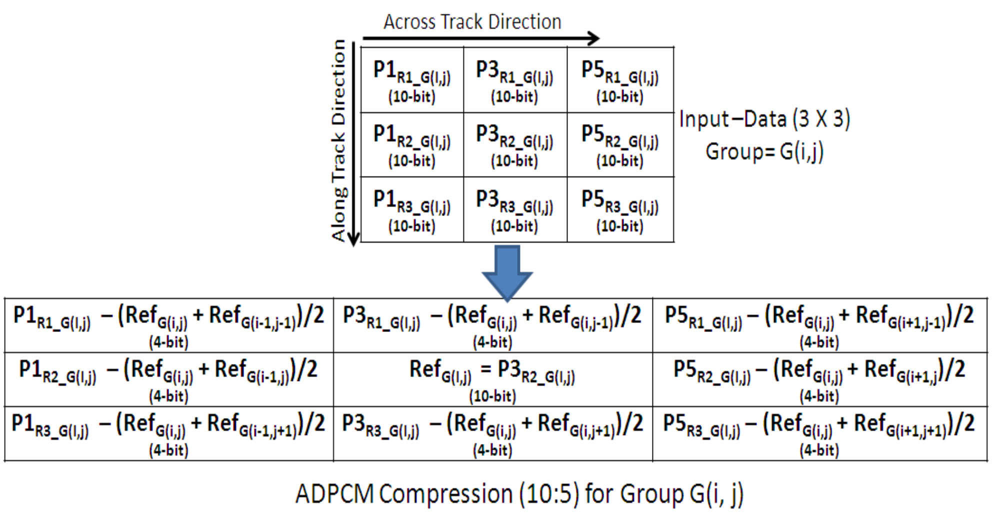


Figure 5

Line complexity is computed from across track odd pixel data.

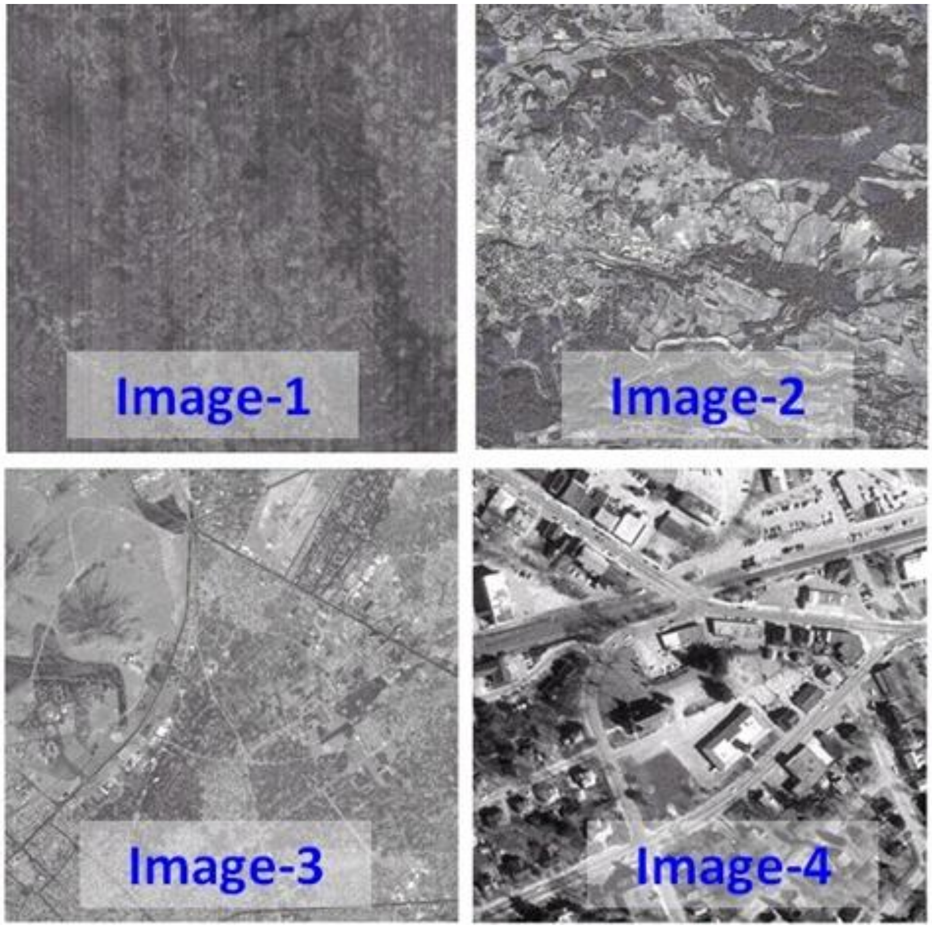


Figure 6 Image-sets used for simulation

Table 3: Simulation Image-sets parameters

	Mean	Std. dev	Max IDV	IDV Entropy	Line Complexity
Image1 (1000X1000)	97.4	11.9	71	3.4	8.1
Image2 (3000X3000)	60.1	12.4	182	2.5	4.3
Image3 (3000X3000)	184.6	32.5	799	3.9	13
Image4 (360X360)	553.5	221.1	794	6.5	95.8

Summary of simulation results with these images are shown in Figure-7. ADPCM (10:6) provide much better performance than existing DPCM (10:7) technique. ADPCM-RA provides further improvement.

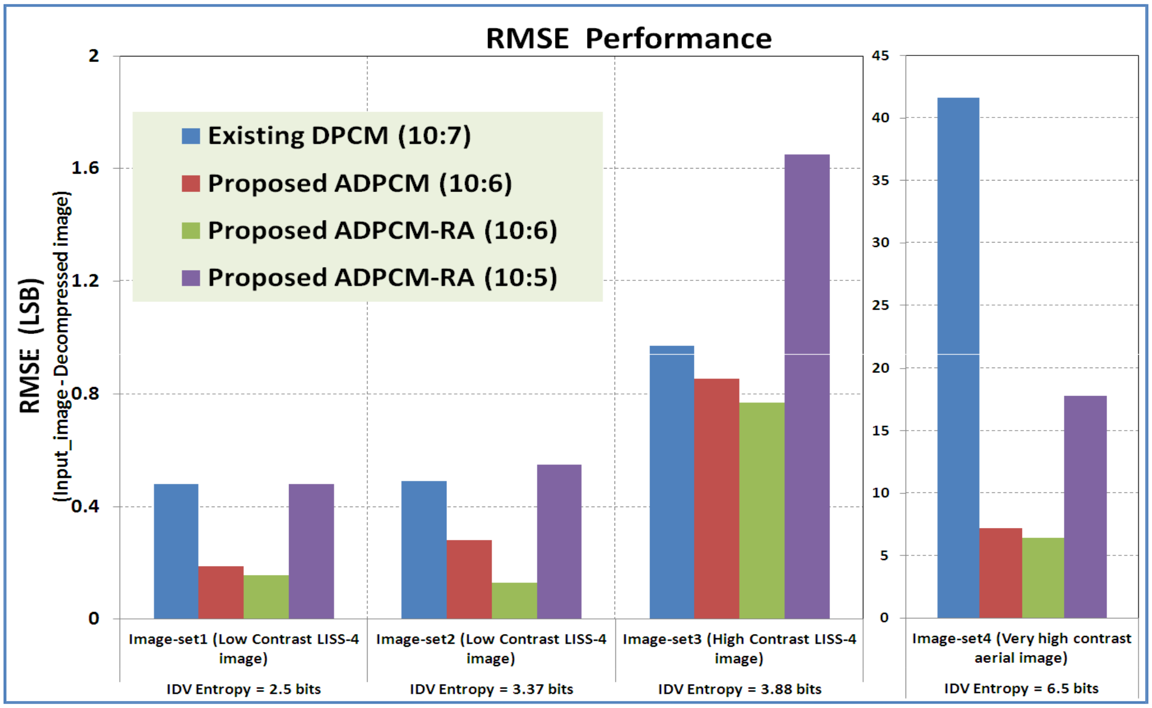


Figure 7

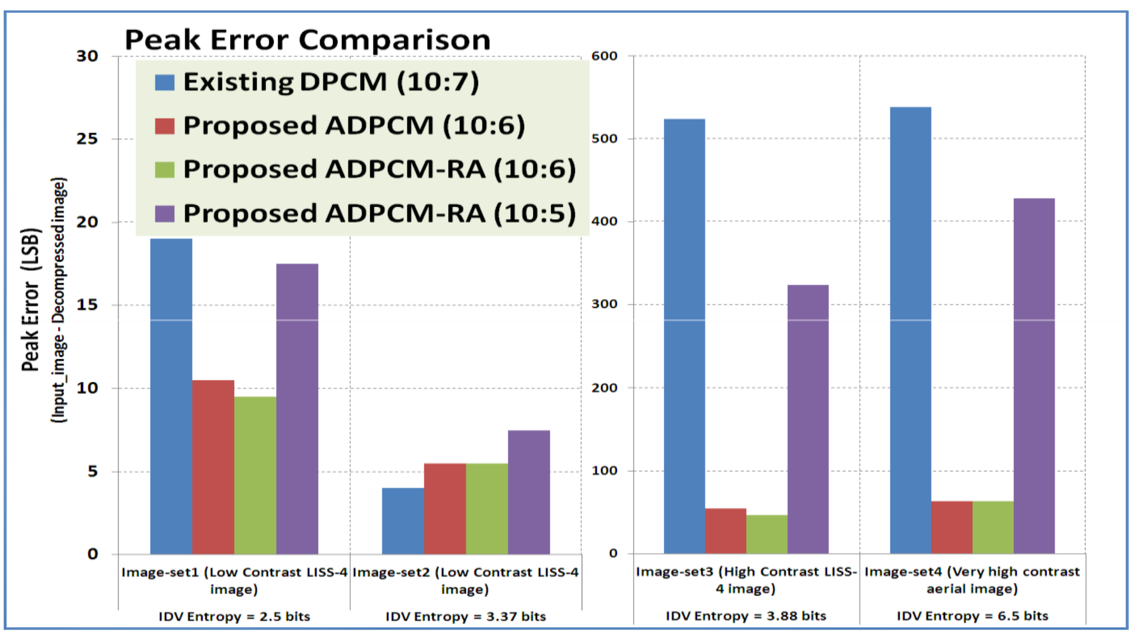


Figure 8

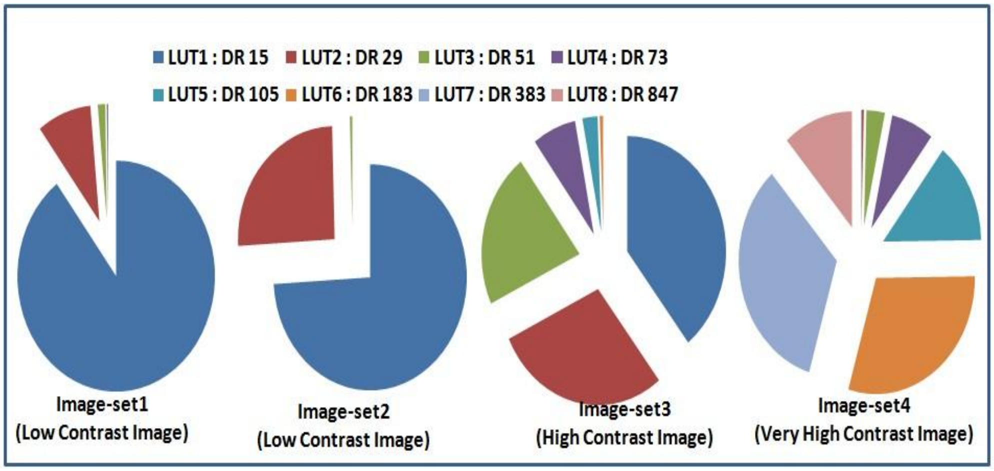


Fig. 12 Recovered data Statistics with ADPCM (10:6)

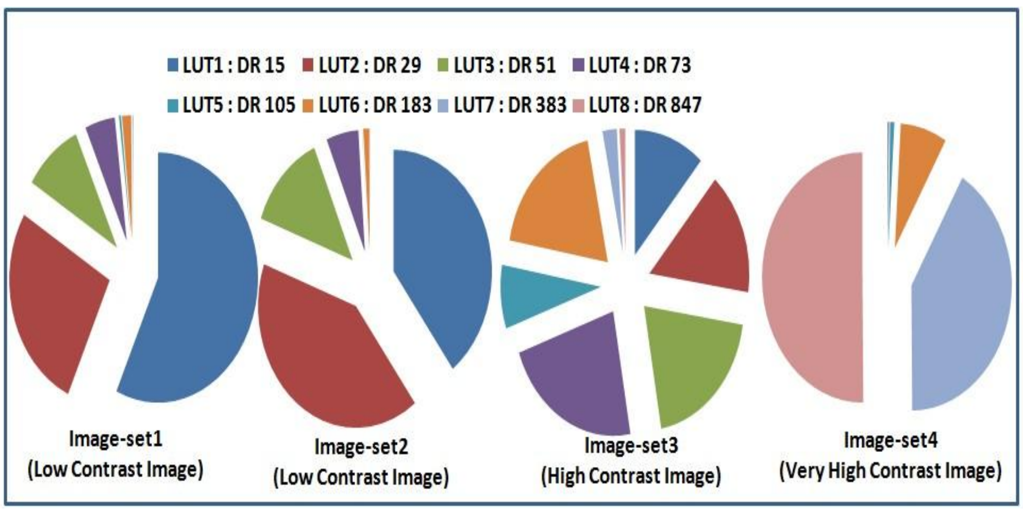


Fig. 13 Recovered data Statistics with ADPCM-RA (10:5)

CONCLUSION

The proposed ADPCM techniques provide higher compression ratio and considerable improvement in radiometric performance at low as well as high contrast image-sets compared to existing DPCM technique. Newly developed ADPCM (10:6) techniques provide RMSE of 7 counts compared to 41 counts for very high contrast image. It also provides RMSE of 0.20 counts compared to 0.48 counts with low contrast images. Proposed ADPCM (10:5) technique provides also provide significant improvement in radiometric performance. Proposed technique provides up to 40% higher compression ratio. Both techniques are a low complex solution and can be implemented in FPGA.

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