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New Prediction Technique For Lossless Compression of Multispectral Satellite Images

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Abstract
In this paper, we present a new image prediction scheme for multispectral images. One of the most recently used algorithms for spatial prediction is the Median Adaptive Predictor (MAP), which has been presented in recent lossless image compression algorithms such as LOCO-I. The spectral information among the bands includes redundant information. Removing such redundancy will lead to compression ratio improvement. The Linear Prediction is useful tool in determining the relationships among the spectral bands but at high cost of computational processing power. The proposed algorithm gives a simplified on-line locally-adaptive linear prediction scheme. The results obtained from simulation on LANDSAT-7 multispectral image are encouraging. New merits of measuring the performance of the prediction are given.

Keywords: *satellite image compression, linear prediction, loco-I, MED, LANDSAT-7.*

1. Introduction
Image prediction is the first step in any lossless image compression. The role of the image prediction is to remove the redundancy found in both spatial and spectral domains. The Median Adaptive Predictor (MAP) [1] (sometimes called Median Edge Detector MED) is one of the non-linear fast high-performance predictors and it was adopted to be the base of the LOCO-I (Low Complexity Lossless Compression for images) [2]. LOCO-I has been standardized and labeled as JPEG-LS (JPEG lossless)[3]. LOCO-I is the state-of-art continuous-tone still images compression technique where MAP is considered to give the best performance/low-complexity predictor among other non-linear predictors such as *Differential Adaptive Run Coding* (DARC), *Gradient Adaptive Predictor* (GAP), *Activity Level Classification Model* (ALCM) and *Continuous-tone Lossless Coding with Edge Analysis and Range Amplitude Detection* (CLARA). MAP is found to gain most out of these predictors if it is aided with feedback system [4]. The spatial prediction step by using the MAP is applied for still images, to remove the spatial redundancy. However, to remove the redundancy from the spectral domain, a further step should be taken. A motion estimation vector, optimal three-dimensional (3-D) linear prediction, and context-based Golomb Rice entropy coding were used in [5] and gave better gain compared to 3-D extension of the JPEG-LS [6].

Another method was presented to exploit the correlation among temporal/spectral bands in [7]. The method suggested a linear prediction relationship between pixels in one band and their relevant pixels in the other bands. In [8] the spectral deltas were used besides the prediction errors controlled by the correlation of some regions. A linear prediction step was used extensively to obtain a spatial decorrelation through three possible neighborhood contexts in [9]. A further step was provided then to extend the linear prediction to combine the spectral bands into one linear prediction. Using a linear prediction in both spatial and spectral domains requires a lot of computation and two-scan procedures for transmission. Such a computation cost was considered as extremely high, thus researches in [10] and [11] aimed to reduce the computations, and to find on-line linear prediction algorithms.

The need for lossless image compression of satellite images has been extremely increased due to the growth of different spectral bands including bands outside the visible spectrum up to 200 bands in a recent technology [12], which are taken by SPOT satellites, in addition to the increment in resolution of taken images. A huge amount of data in addition to bandwidth constraints have implied the need for on-board image compression system that may take more than one pass to complete the downloading of the acquired images [13].

Satellite images contain typically much less redundancy information than conventional natural images. It is therefore not an easy task to achieve a high compression ratio for these images. For the natural images, a good compression ratio can be achieved through (ADPCM) or (VQ), which cannot be in the satellite images [14].

The algorithm developed in this research is compared in terms of a computational complexity and prediction improvement against the ordinary linear prediction algorithm. The compression ratio was supplied as another performance evaluation.

This paper is organized as follows. In Section II, the background of MED predictor is given. In section III, the linear prediction as well as and its application to multispectral images are explained. The proposed algorithm is explained in Section IV. Section V demonstrates experiments and simulation(s) for the proposed algorithm. The conclusion is drawn in section VI.

2. The MED Predictor

The MED predictor is a fast edge-detector non-linear predictor. It was first introduced in [15] to remove the spatial redundancy (to decorrelate). In this work, we assume raster scanning of image $I(x,y)$ (from top to down and from left to right) as given in figure (1).

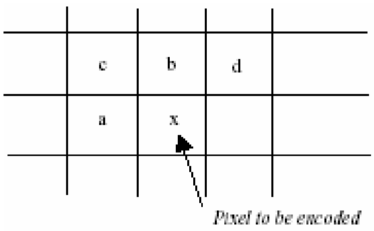

Figure 1. MED predictive pattern

The formula of the MED predictor is given in equation (1).

$$p_x = \begin{cases} Min(R_a , R_b) & if \ R_c \geq Max(R_a , R_b) \\ Max(R_a , R_b) & if \ R_c \leq Min(R_a , R_b) \\ R_a + R_b - R_c & otherwise \end{cases} \quad (1)$$

The MED will result in a new image of $\hat{I}(x,y)$ with predicted pixel values. Those pixels are spatially uncorrelated. After applying the prediction step, the predicted image is subtracted from the original image and this subtracted image is encoded and transmitted. We refer to this resultant difference image with the error image.

3. The Linear Prediction

In this research it is assumed there are two images, one is the reference image and the other is sensed image named respectively, I_{ref} , and I_{sen} , which might be taken whether in different time (multitemporal) or in spectral order (multispectral). The predicted sensed image is $\hat{I}_{sen}$. The predicted image is considered to have a linear relationship with the reference image as stated in equation (2).

$$\hat{I}_{sen} = a_0 + a_1 I_{ref} \quad (2)$$

In equation (3), J is proposed as an objective function. The goal of this objective function is to minimize the average summation of squared error, resulted from the prediction process.

$$J = \overline{\sum_{All\ Pixels} \left(I_{sen} - \hat{I}_{sen}\right)^2} \quad (3)$$

By differentiating J to the constants a_0 and a_1 , we can obtain their values by solving the following system of matrix.

$$\begin{bmatrix} C_s \\ C_{sr} \end{bmatrix} = \begin{bmatrix} a_0 & a_1 \end{bmatrix} * \begin{bmatrix} 1 & C_r \\ C_r & C_{rr} \end{bmatrix} \quad (4)$$

where $C_{xy} = \overline{\sum_{All\ pixels} I_x I_y}$ which represents the correlation coefficient between images I_x , I_y , and $C_x = \overline{\sum I_x}$ refers to the average values of image I_x , *r* refers to the reference and *s* to the sensed images.

4. The Proposed Algorithm

This research aims to minimize the sensed spatial errors resulted from the MED predictor through utilizing the reference band errors. It is expected that the errors resulted in both reference and sensed bands have a similar behavior, hence the sensed errors can be drawn from the reference band errors. In order to determine a_0 and a_1 Equation (4) is going to be used through replacing every I_x with E_x , where E_x represents the error band.

Multiple simplifications have been made to reduce the computing of the correlation coefficients found in equation (4), as they are elaborated in next paragraphs:

- Simplified Linear Prediction (SLP): From equation (4) it is found that four correlation coefficients should be computed. Considering the spatial prediction errors as a random variable with zero mean. From equation (4) it can be inferred that C_r and C_s are considered zero. The elimination will reduce the calculation of the correlation coefficients to its half as well as the addition operations. Hence, only a_1 should be evaluated since a_0 has been considered to be zero.

$$a_1 = \frac{C_{SR}}{C_{RR}} \quad (5)$$

- On-Line Simplified Linear Prediction (OSLP): Compressing the image, assuming SLP, requires two-scan procedures; one for calculating a_1 and the other is for coding. However, by considering any pixel in the middle of the image, the only required knowledge to be known is the history occurred before the pixel being coded and the relationships between errors in both sensed and reference bands. That would result in the availability of calculating a_1 on the fly. By using two accumulators to hold updated values for both of C_{SR} and C_{RR}; a_1 can be determined on-line. The on-line computation will reduce the two-scan procedures provided in SLP as well as the time to start compression and the memory resources.

- Dynamic On-Line Simplified Linear Prediction (DOSLP): To consider the local changes of the image, the two accumulators C_{SR} and C_{RR} would be computed adaptively by taking the local changes into a consideration. A dynamic strategy was taken to reflect the local changes of the area into the computation of a_1. This strategy is expressed in the equation (6).

$$\begin{aligned} & if\ ((a_{1(new)} - a_{1(old)}) <= \theta_1 * a_{1(old)}) \\ & \qquad C_{SR} = \theta_2 * C_{SR} \\ & \qquad C_{RR} = \theta_2 * C_{RR} \qquad (6) \\ & end \end{aligned}$$

where θ_1 is chosen to be a small value (.05) and θ_2 to be a value close to unity (e.g. .95). θ_1 is a chosen threshold value which represents the minimum allowed change in a_1. Any lower change than θ_1 will enforce the algorithm to update C_{SR} and C_{RR}. θ_2 represents the forgetting factor, its nearly unity value is chosen to continuously reduce C_{SR} and C_{RR}.The more the progress of scanning new pixels, the more of past pixels information will be added into the two accumulators C_{SR} and C_{RR}. To eliminate this effect, it is proposed to reduce their values gradually by θ_2 whenever saturation occurs in a_1 by amount of θ_1.

5. Simulation and Results

An experimental test was made on taken multispectral image (900 * 900) for Egypt in 1990 as shown in figure (2). The image was taken by LANDSAT-7 and composed of 7 bands. The sixth band represents the infrared band, therefore it does not represent a realistic structure of the taken image and it has been avoided.

The algorithms described before were applied, and two merits were taken to evaluate the performance of the algorithms. The first one is the error energy reduction (EER).

$$ERR = (\sum E_{sen}^2 - \sum \hat{E}_{sen}^2) / \sum E_{sen}^2 \quad (7)$$

Table 1: *Error Energy Reduction* ***(ERR) in%*** *due to using one reference band*

Ref. band	***Sense band***	***LP***	***SLP***	***OSLP***	***DOSLP***
3	1	45.504	45.504	43.951	45.053
3	2	65.613	65.671	65.640	64.914
3	7	51.366	51.366	51.483	54.29
7	5	65.171	64.843	64.992	66.041
5	4	13.175	13.153	13.063	13.527

And the other merit is absolute error reduction (AER)

$$AER = (\sum ABS(E_{sen}) - \sum ABS(\hat{E}_{sen})) / \sum ABS(E_{sen}) \quad (8)$$

Results obtained by applying the linear prediction algorithm are shown in Table 1 and 2, by taking into consideration the best order of bands that would give the best results. It is shown that the DOSLP gives the best results without an excessive calculation needed for the LP.

It is clear from those tables that the simplifications in this research have achieved the same performance of the LP with a slight difference for much less computational complexity and memory resources.

Table 2 *Absolute Error Reduction* ***(AER) in%*** *due to using one reference band*

Ref. band	***Sense band***	***LP***	***SLP***	***OSLP***	***DOSLP***
3	1	19.437	19.437	17.584	19.053
3	2	33.275	33.355	33.31	33.516
3	7	18.582	18.582	18.416	22.401
7	5	28.926	28.418	28.486	30.606
5	4	6.7196	6.7056	6.7675	7.1286

By applying the provided algorithms as a step to JPEG-LS system, the compression ratios evaluation is given in Table 3. The results are compared to the JPEG-LS in 2D. From Table 3, it is found that the performance of the OSLP has accomplished very comparable results as ordinary JPEG-LS with the LP prediction step.

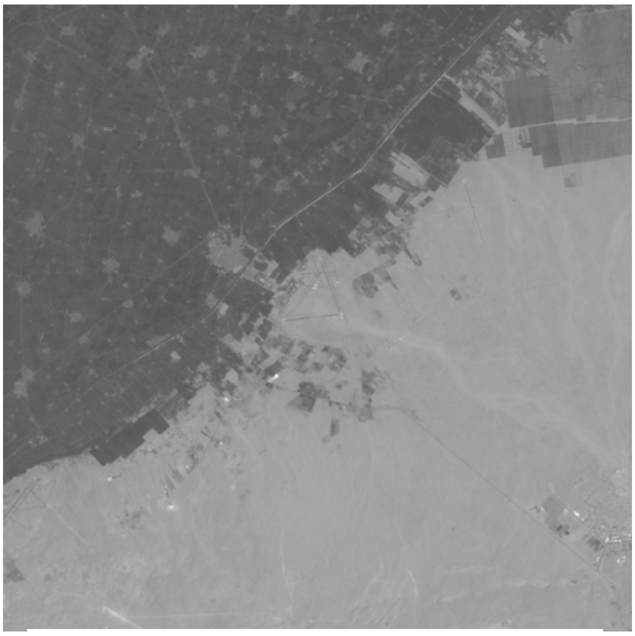

Figure 2: Egypt multispectral image in 1990

Table 3: *Compression Ratio due to using one reference band*

Ref. band	Sense band	JPEG-LS 2D	LP	SLP	OSLP	DOSLP
3	1	2.468	2.644	2.644	2.608	2.634
3	2	2.904	3.326	3.33	3.326	3.336
3	7	2.242	2.301	2.301	2.296	2.366
7	5	1.92	2.055	2.048	2.048	2.08
5	4	2.133	2.178	2.178	2.18	2.178

6. Conclusion

The enthusiasm for lossless satellite image compression is highly demanded currently due to the excessive amount of data to be transmitted to earth and the short available bandwidth. A new proposed algorithm has been conducted for compressing of satellite multispectral images. The new algorithm gives a significant compression ratio improvement over using plain JPEG-LS. The algorithm has modified the prediction part of JPEG-LS through the ordinary linear prediction process but with reduction in storage requirements and starting time needed to begin transmission.

The algorithm provided in this research aims to eliminate spectral redundancy. A reduction in mathematical computations has been reached to 50% compared with the linear prediction. A fast on-line processing with only one scan process has been provided which implies reduction in off-line calculations and memory resources. The algorithm aims also to optimize the performance through the dependency on the local activity of the pixels. More research should be conducted to determine how to include more than one band for linear prediction as well as the multitemporal images.

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