Coding of SAR Raw Data

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Abstract

The raw data rate of a SAR (Synthetic Aperture Radar) system is in the order of hundreds Mbit/s up to 1 Gbit/s. Due to restricted transmission channel and storage capacity efficient coding schemes for data compression are mandatory. The methods presented here are based on **reversible** transforms of the SAR raw data. Once, the transforms have been performed, coding techniques are applied to the generated data. On the one hand transform coding techniques along with entropy coding of the transform coefficients are considered and on the other hand the LBG vector quantiser, [4], has been applied.

The proposed techniques have been verified on real airborne SAR raw data acquired by the German sensor DoSAR.

1 Introduction

Due to the very poor correlation of SAR raw data it is not useful to apply redundancy reduction techniques directly. Possible compression ratios which have been reported in this case are in the order of 1.15-1.2 [2]. Higher compression ratios in the order of 4-5 have been achieved with lossy coding by applying vector quantisation techniques as reported in [5] and [3].

In this paper methods for coding of SAR raw data are presented which are based upon suitable **reversible** transforms T and T' of the complex raw data. T' is a slightly modified version of the **reversible** transform T, which has been derived from a conventional SAR processing scheme based on migration techniques [6]. By means of T new data can be generated whose statistics are similar to those of complex focused data. In particular, the redundancy and correlation of the transformed data are increased. Contrary to the SAR raw data the transformed data can be efficiently coded by entropy and transform coding methods. A detailed description of T as well as an encoder consisting of a 1D-DCT and Huffman coding is given in [1].

In the new approach presented here the 1D-DCT coding is substituted by the 1D-DFT coding. As will be seen later a substantial reduction of the computational efforts could be achieved compared to former work, [1]. In addition the so-called Linde-Buzo-Gray vector quantisation algoritm has been applied to transformed data to achieve higher compression ratios, [4].

2 Coding of SAR Raw Data

2.1 Reversible Transform of SAR Raw Data

A block diagram of the proposed technique along with an encoder is shown in Fig. 1. The azimuth and range directions are denoted by x and z, respectively. t is the travelling time of the reflections from ground. The left part of Fig. 1 describes the subsequent steps to perform T'. In order to emphasize the differences, on the right side the implementation of T is shown.

The input signal to the system shown in Fig. 1 is the demodulated complex SAR raw data $s(x, 0, t)$.The range transform, denoted by T_R, is a modified range compression. The modification consists in an adjustment of the reference chirp spectrum in order to guarantee the reversibility of T_R without computational losses. The length N_R of the DFT in range within T_R is given by the number of acquired range samples (e.g. $N_R = 2048$ for the data considered here). The azimuth transform T'_A is carried out blockwise by a multiplication of the range transformed data $d(x, 0, t)$ with exponential terms in the 1D respectively 2D Fourier domain. In Fig. 1 these exponential terms are denoted by $H_1(k_x, t)$ and $H_2(k_x, k'_z)$.

To generate the data $d(k_x, z', -t_0)$ transform T'_A is performed in azimuth not on the whole synthetic aperture length, but on so-called subapertures of length N_A. The DFT-length in range N_{RA} within T'_A can also be varied. In this way the processing can be done very quickly depending on chosen block sizes $N_A \times N_{RA}$.

The data $d(x, z', -t_0)$ generated by means of T exhibit a close relationship to the complex singlelook SAR data generated by a conventional SAR processor. On the other hand the data $d(k_x, z', -t_0)$ at the output of T' is the azimuth spectrum of $d(x, z', -t_0)$ which corresponds to the Doppler spectrum of complex singlelook data.

The transforms T and T' and their inverse transforms T^{-1} and T'^{-1}, respectively, are indeed reversible and numerically well conditioned. Calculating the inverses all multiplications have to be substituted by the corresponding divisions. Due to the exponential terms contained in $P_M^*(\omega)$, $H_1(k_x, t)$ and $H_2(k_x, k_z')$ this results mainly in the same multiplications with reversed sign of the exponent, [1].

2.2 DFT Coding

Due to the increased redundancy and correlation in $d(x, z', -t_0)$ entropy coding can be applied in a more efficient way compared to the direct entropy coding of SAR raw data. While in [1] the Discrete Cosine Transform is used to code the data, in this approach the encoding is carried out in the 1D Fourier domain along the azimuth axis, see Fig. 1. The coefficients are marked by $d(k_x, z', -t_0)$ (t_0 is the time at which the chirp pulse is reflected by an object on ground).

In comparison with T the number of processing steps of T' is reduced by the second IDFT. A supplementary block to perform the transform coding is omitted. Due to the shift of the encoder in the processing chain the computational efforts are drastically reduced. The generated N_A complex coefficients are quantised and coded by a Huffman Coder (HC). Due to the flat power density spectrum of the data in range only 1D transform coding in azimuth is performed. The lack of correlation in range can be explained by the white spectrum of the transmitted chirp pulse.

In a first approach the lengths of the DFT's were chosen to $N_A = 256$ and $N_{RA} = 2048$. In comparison the 1D-DCT length as presented in [1] was chosen to $N_{ADCT} = 32$. Due to similar statistics of real and imaginary parts of the DFT-coefficients only one Huffman code for each complex coefficient is generated.

After coding and decoding at different rates the inverse transform T'^{-1} is performed to reconstruct the SAR raw data. To verify the achieved result the reconstructed SAR raw data are finally processed by a conventional SAR processor and compared to an image which has been processed directly from the original SAR raw data.

2.3 Vector Quantisation

Instead of performing the DCT with subsequent HC, see Fig. 1, the algorithm by Linde, Buzo and Gray

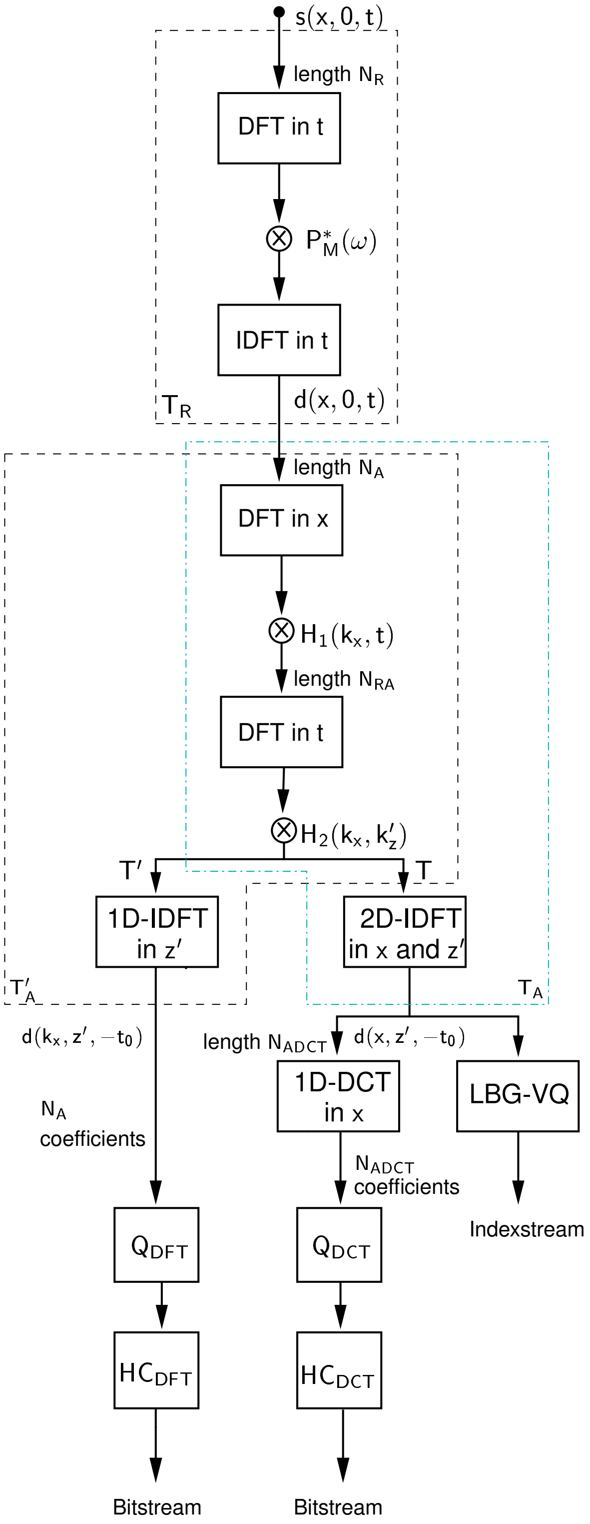

Figure 1: Compression System for SAR Raw Data (left T' with DFT and Huffman Coding , right T alternatively with DCT and Huffman Coding or with LBG-VQ).

(LBG-VQ), [4], has been tested on the data $d(x, z', -t_0)$ transformed by T. Vectors of $4 \times 1, 8 \times 1, 16 \times 1, 2 \times 2$ and 4×2 samples (azimuth $\times$ range) have been generated. The codebook size has been chosen to $N = 256$. Better performance of the LBG-VQ is achieved if more samples are taken in azimuth to build up the vectors. This supports the previous result that transform coding only provides an additional coding gain in azimuth due to absence of correlation in range. To examine the influence of coding at different rates the same procedure as mentioned in 2.2 is carried out, i.e. decoding, inverse transform T^{-1} and SAR image generation.

3 Results

The quantisation of the SAR raw data used in our experiments is 8 bit/sample for the I and Q components, respectively. Experiments with DFT length $N_A = 256$ and codebook length $N = 256$ at different data rates have been done.

To measure the quality of the reconstructed SAR raw data the signal-to-noise ratio (SNR) has been calculated according to

$$SNR = 10 \log_{10} \frac{\sum_k |X_k|^2}{\sum_k (|X_k - Y_k|)^2} \text{ in } dB,$$

where X are the original SAR raw data (reference) and Y are the reconstructed raw data (reconstruction). In a similar way a SNR for processed SAR images can be calculated. In this case the reference X is a SAR image which is processed directly from the original SAR raw data and the reconstruction Y is processed from the coded/decoded raw data. In Tab. 1 and Tab. 2 the measured SNR values for SAR raw data and SAR image data are listed for different data rates. The achieved

Rate	DFT $N_A = 256$	
	SNR (Raw Data)	SNR (SAR Image)
$\frac{bit}{sample}$	dB	dB
1.1	5.0	9.3
1.9	17.5	23.3
2.7	19.2	26.5
3.5	23.9	29.0

Table 1: DFT Coding: SNR in dB of Reconstructed SAR Raw Data and Image Data.

SNR values of the reconstructed SAR raw data have to be compared to the maximum SNR of an 8 bit quantiser fed with Gaussian distributed input, which is approximately $40dB$. The SNR values of the image data are in both cases significantly better than the SNR's of the raw data. This can be explained by the fact that the coding is not performed on SAR raw data, but on data which have similar statistics to these of focused complex data.

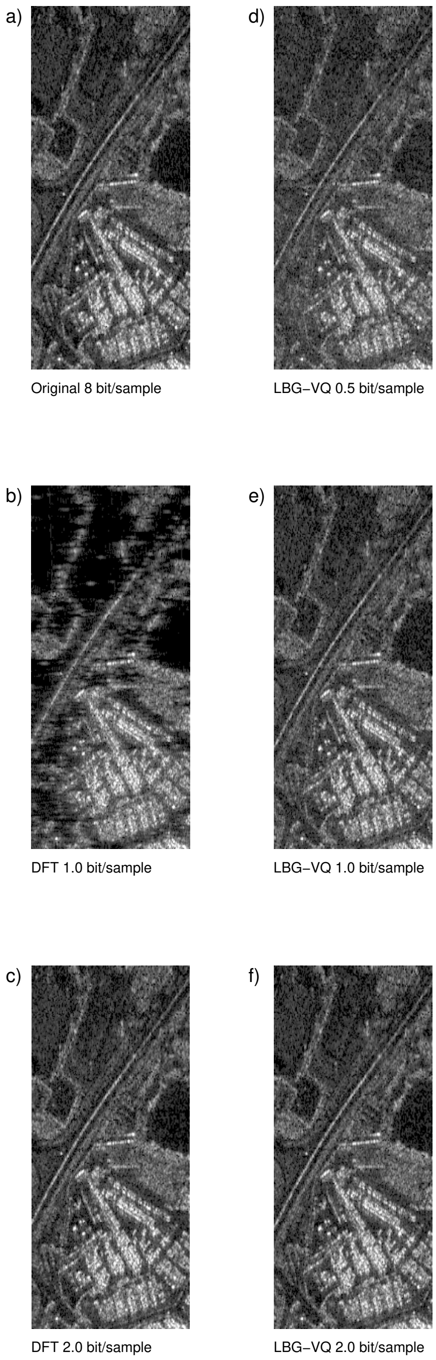

Figure 2: SAR Images Processed: (a) from Original SAR Raw Data, (b) DFT $N_A = 1 \times 256$, rate=$1 bit/sample$, (c) DFT $N_A = 1 \times 256$, rate=$2 bit/sample$, (d) LBG-VQ 1×16, rate=$0.5 bit/sample$, (e) LBG-VQ 1×8, rate=$1 bit/sample$, (f) LBG-VQ 1×4, rate=$2 bit/sample$.

Rate	LBG-VQ Codebook Size $N = 256$	
	SNR (Raw Data)	SNR (SAR Image)
$\frac{bit}{sample}$	dB	dB
0.5	5.2	11.5
1	8.8	16.1
2	13.6	22.6
4	20.5	25.6

Table 2: LBG-VQ: SNR in dB of Reconstructed SAR Raw Data and Image Data.

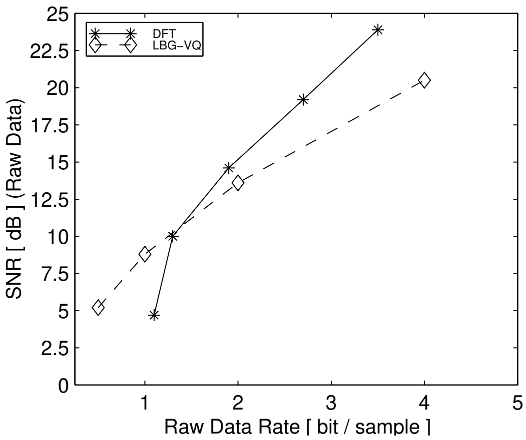

Figure 3: SNR of Raw Data versus Raw Data Rate.

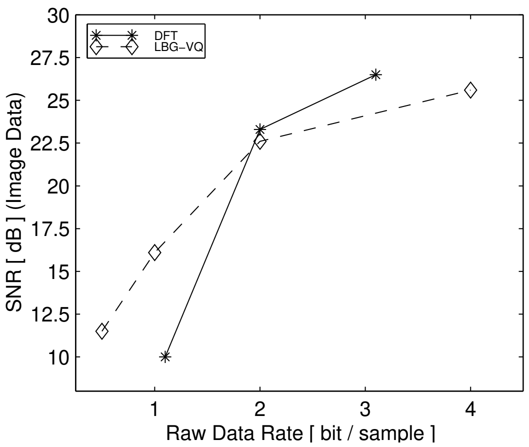

Figure 4: SNR of SAR Image Data versus Raw Data Rate.

Fig. 2 shows processed SAR images at different raw data rates. In 2 a) the reference image is shown.

4 Conclusions

A new coding technique for SAR raw data has been presented. This technique is based upon a reversible transform of SAR raw data. Due to quantisation distortion the compression ratio is limited to about 6 in case of DFT coding with Huffman coding. Higher compression ratios lead to SAR images with significantly degraded image quality, as shown, e.g., in Fig. 2 b).

Satisfactory processing results with compression ratios up to 16 have been presented in case of LBG-VQ. With higher compression a noticeable loss of contrast is observed. Compared with results obtained with VQ algorithms applied direct to SAR raw data, e.g. [3], higher compression ratios and significantly better quality are achieved.

For an accurate interpretation of the losses introduced by coding, experiments with photo interpreters could be very useful.

In a forthcoming experiment the vector quantisation will be applied directly to the data $d(k_x, z', -t_0)$ in the Fourier domain. In this way we expect the same performance of the LBG-VQ at much lower computational costs.

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6 Literature

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