Coding of SAR Image Data for Data Compression

Ulrike Pestel-Schiller
Institut für Informationsverarbeitung, Leibniz Universität Hannover, pestel@tnt.uni-hannover.de, Germany

Abstract

A JPEG1988 coding system extended by Speckle adaptive quantization and improved entropy coding is compared against the standard coding systems JPEG1988, JPEG2000, MPEG4-AVC and HEVC with regard to their coding efficiency related to SAR images. A Speckle adaptive quantization is presented that exploits the masking potential of the Speckle noise to achieve additional data compression. For coding that does not impair the interpretation of the SAR images, JPEG1988 requires a data rate of 1.0 bit/pixel which is slightly better than JPEG2000. JPEG1988 extended by improved entropy coding reduces the data rate to 0.81 bit/pixel and with additional Speckle adaptive quantization to 0.63 bit/pixel. Using intra mode, H.264/MPEG-4 AVC requires a data rate of 0.75 bit/pixel and HEVC a data rate of 0.66 bit/pixel.

1 Introduction

Efficient transmission of SAR data from an airborne platform to a receiving ground station requires an onboard processing of SAR raw data to SAR image data and data compression of the SAR image data [1]. Onboard raw data to image data processing requires a well-working autofocussing of the SAR data, an example of which is presented in [2]. The compression has to preserve an image quality that does not impair the image interpretation. Early approaches of SAR image data compression are described in [1], [3].
In this paper, the standard coding systems JPEG1988 [4], JPEG2000 [5], H.264/MPEG-4 AVC [6], HEVC [7] are compared with regard to their coding efficiency.
To achieve a higher coding efficiency, also an JPEG1988 coding system extended by a Speckle adaptive quantization and an improved entropy coding [8] is investigated.
An experimental setup appropriate for SAR image coding is used for the assessment of the coding efficiency of the presented coding systems. Evaluations by professional interpreters are carried out to find the minimum bit rate not affecting the interpretation.
The paper is organized as follows: Chapter 2 presents the experimental setup for the assessment of SAR images. The investigated coding systems are described in Chapter 3. Chapter 4 presents in detail the Speckle Adaptive Quantisation (SAQ). Results of the assessment of the coding systems are presented and discussed in Chapter 5.

2 Experimental Setup for Assessment of SAR Images

For finding the minimum bit rate of a coding system not affecting the interpretation, the interpreter has to identify special targets which are used to measure the capability of the interpretation. An interpreter evaluates SAR images on a monitor with a non-linear relationship between signal and light intensity. Therefore, the SAR image data s shown in **Figure 1** is γ-corrected to compensate the distortion of the monitor resulting in the reference image data s_{ref} by

$$s_{ref} = \sqrt{s}. \tag{1}$$

The γ-corrected SAR image data s_{ref} is the input signal of the coding system. While the image data s has an amplitude resolution of 16 bit per sample, 8 bit per sample are sufficient for the reference image s_{ref}.

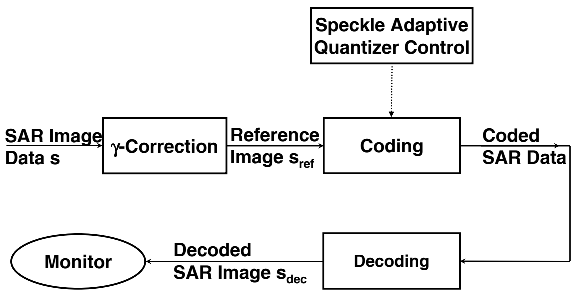

Figure 1: Block Diagram of the Experimental Setup

The coding system consists of coding and decoding. The quantization can be controlled from outside. The decoded SAR image s_{dec} is assessed for evaluating the coding systems. The assessment is realized by professional interpreters and by a technical quality criterion.
The minimum data rate that does not impair the capability of interpretation specifies the Interpretation Impact Threshold (IIT). This threshold is determinded for each coding system and defines the required data rate.
Two methods are applied for the assessment, one with professional interpreters, the other using a technical quality criterion. For an assessment of a coding system the interpreter has to identify special objects. SAR images coded at different data rates are evaluated and by increas-

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ing the data rate the Interpretation Impact Threshold can be determined.
For assessment by a technical quality criterion the 'Peak Signal to Noise Ratio' (PSNR) as defined in Eq. (2) is used.

$$PSNR = 10log\frac{255^2}{(s_{ref} - s_{dec})^2} \quad (2)$$

The PSNR weights the square of the amplitude range relative to the square of the coding error. For coding systems which induce a similar type of coding error, the PSNR over the data rate is an additional reasonable technical quality criterion.

3 Investigated Coding Systems

Two standard still image coding systems are investigated, the JPEG1988 [4] and the JPEG2000 [5]. JPEG1988 consists of a 8x8 Discrete Cosinus Transform (DCT), followed by a quantization which exploits the Modulation Transfer Function (MTF) of the human eye and is terminated by a Huffman-based entropy coding. JPEG2000 is a wavelet-based coding system using a special bitplane coding called EBCOT.
In addition JPEG1988 extended by arithmetic entropy coding [8], called JAE, and additional Speckle adaptive quantization (SAQ), called JAE+SAQ, is investigated. An overview of the investigated still image coding systems is shown in **Table 1**.

Coding System	Transform	Entropy Coding
JPEG1988	DCT 8x8	Huffman
JPEG2000	Wavelet	EBCOT
JAE	DCT 8x8	Arithmetic
JAE+SAQ	DCT 8x8	Arithmetic

Table 1: Investigated Still Image Coding Systems

Two standard video coding systems are investigated, the H.264/MPEG-4 AVC [6] and the HEVC [7]. For SAR image coding only the intra mode is used. **Table 2** shows an overview of the investigated video coding systems.

Coding System	Transform	Entropy Coding
MPEG-4 AVC	Integer 8x8, 4x4	CAVLC, CABAC
HEVC	Integer 32x32, 16x16 8x8, 4x4	CABAC

Table 2: Investigated Video Coding Systems

Both coding standards use transform coding and work block oriented with different transform block sizes of 4x4 or 8x8 in H.264/MPEG-4 AVC respectively 4x4, 8x8, 16x16 or 32x32 in HEVC.

4 Speckle Adaptive Quantisation

SAR images are known to contain speckle noise, which is inherent to the SAR generation process [9]. In the following, an approach is presented that exploits the presence of speckle noise as a means to achieve additional data compression. Generally, noise components in images can mask quantization noise, in the sense that the quantization noise is not perceived as a deterioration of image quality.
Specifically for SAR images, the strength of the Speckle noise $\sigma^2_{Speckle}$ is known to be proportional to the squared local signal average m_s^2 by [9]

$$\sigma^2_{Speckle_s} = \frac{4-\pi}{\pi} m_s^2. \quad (3)$$

According to Eq. (3), speckle noise increases with the local signal average ${m_s}^2$ allowing locally a more coarsely quantization and bit rate reduction.
In this approach, the additional quantization noise $\sigma^2_{q_s}$ of the Speckle adaptive quantization error is assumed to be proportional to the speckle noise with respect to a factor α as

$$\sigma^2_{q_s} = \alpha\frac{4-\pi}{\pi} m_s^2 \quad (4)$$

which has to be determined by measurements of the interpreters.
The γ-correction yields

$$m_{ref} = \sqrt{m_s}. \quad (5)$$

where m_{ref} is the local signal average of s_{ref} and corresponds to the local average brightness. By locally adapting the quantizer stepsize, additional quantization errors are introduced which are just small enough to be masked by the speckle noise of the SAR image. In a coding system that performs quantization of the DCT coefficients blockwise in the frequency domain, the locally adaptive quantization is also realized on a block-by-block basis.
Thus, the quantizer stepsize is varied from block to block controlled by the local signal average m_{ref}.
In the following the functional relationship between the quantizer step size δ_{SAQ} of the coding system and the local signal average m_{ref} is derived.
In a DCT block the quantized DC coeffizient corresponds to the local signal average m_{ref} of the reference image signal s_{ref}

$$DC = m_{ref} \quad (6)$$

which is scaled to 8 bit for control.
Using local linearization at m_{ref} the quantization noise $\sigma^2_{q_{ref}}$ corresponds to

$$\sigma_{q_{ref}} = \frac{dm_{ref}}{dm_s}\sigma_{q_s} = \frac{1}{2\sqrt{m_s}}\sigma_{q_s} \quad (7)$$

yielding to Speckle noise

$$\sigma^2_{q_{ref}} = \frac{1}{4m_s}\sigma^2_{q_s}. \quad (8)$$

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and with Eqs. (4) and (5) to

$$\sigma^2_{q_{ref}} = \alpha \frac{4-\pi}{4\pi} m^2_{ref}. \quad (9)$$

The quantization of standard coding systems exploits the MTF of the human eye which means that it is frequency dependent and causes a quantization noise $\sigma^2_{q_{cod}}$. The Speckle Adaptive Quantization (SAQ) exploits the masking of the Speckle noise which depends on the local mean and causes a quantization noise $\sigma^2_{q_{ref}}$. Thus, the variance $\sigma^2_{q_{SAQ}}$ of the total quantization noise can be written as

$$\sigma^2_{q_{SAQ}} = \sigma^2_{q_{cod}} + \sigma^2_{q_{ref}}. \quad (10)$$

Assuming fine quantization [10], the quantizer step size δ_{SAQ} can be approximated by

$$\delta^2_{SAQ} = 12\sigma^2_{q_{SAQ}}. \quad (11)$$

Eqq. (10) and (11) then result in

$$\delta_{SAQ} = \sqrt{12}\sqrt{\sigma^2_{q_{cod}} + \sigma^2_{q_{ref}}} \quad (12)$$

or using Eq. (9)

$$\delta_{SAQ} = \sqrt{12}\sigma_{q_{cod}} \sqrt{1 + \alpha \frac{4-\pi}{4\pi\sigma^2_{q_{cod}}} m^2_{ref}}. \quad (13)$$

With $\alpha = 0$, Eq. (9) simplifies to $\delta_{SAQ} = \sqrt{12}\sigma_{q_{cod}}$ which means that the quantizer stepsize corresponds to that of the standard coding system given by

$$\delta_{cod} = \sqrt{12}\sigma_{q_{cod}} \quad (14)$$

and Eq. (13) can be written as

$$\delta_{SAQ} = \delta_{cod} \sqrt{1 + \alpha \frac{3(4-\pi)}{\pi\delta^2_{cod}} m_{ref}{}^2}. \quad (15)$$

Figure 2 shows the functional relationship of Eq. (15) for some values of α

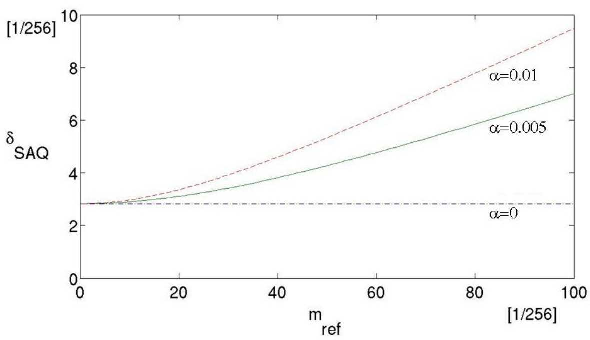

Figure 2: Quantiser Stepsize δ_{SAQ} over m_{ref}

With $\alpha > 0$, the quantizer stepsize increases with the local average brightness m_{ref}. This enlargement of the quantizer stepsize results in an additional quantization error. Measurements showed that with $\alpha = 0.005$ the quantization error is just masked by the Speckle noise.

5 Results

The SAR test image data used, shows a German town with surrounding landscape with a mean of 3940.

The evaluation of JPEG1988 and JPEG2000 was carried out by interpreters. As a result of the evaluation, JPEG1988 is slightly better than JPEG2000 at the Interpretation Impact Threshold. At this threshold the data rate is 1.0 bit/pixel respective bit/pel, the PSNR is 26.8 dB.

The DCT based coding systems JPEG1988, H.264/MPEG-4 AVC and HEVC use similar quantizations which generate similar quantization errors. For comparing these coding systems, the PSNR is a reliable technical quality criterion. By comparing the coding systems at the same PSNR the coding efficiency can be jugded from the data rate.

The data rate of JPEG1988 can be reduced to 0.81 bit/pel by applying the arithmetic coding using JAE which is a reduction of 19%. With H.264/MPEG-4 AVC a further data reduction to 0.75 bit pel can be achieved at the same PSNR. HEVC requires only a data rate of 0.66 bit/pel.

The quantization error of the JAE+SAQ coding system is different. Therefore the PSNR is not an appropriate technical quality criterion. Evaluations at the visibility threshold confirmed by interpreters were carried out resulting in a required data rate of 0.63 bit/pel. The minimum bit rates at the Interpretation Impact Threshold are shown in **Figure 3**.

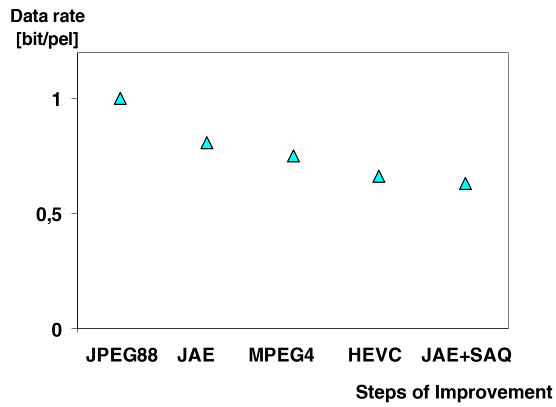

Figure 3: Required Data Rates for Coding of SAR Images with various Coding Standards

The progress in standardization from JPEG1988 to HEVC results in a data rate reduction of 34%. Using the JAE+SAQ coding system, the data rate can be reduced by 37% relative to that of JPEG1988.

6 Conclusion

The standard coding systems JPEG1988, JPEG2000, MPEG4-AVC and HEVC, the JPEG1988 coding system

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with advanced entropy (JAE) coding and the JAE coding system with additional Speckle adaptive quantization (JAE+SAQ) are compared with respect to the minimum bit rate required for SAR image coding. The progress in standardization from JPEG1988 to HEVC results in a data rate reduction of 34%. Using the JAE+SAQ coding system, the data rate can be reduced by 37% relative to that of JPEG1988. Worth mentioning that the hardware complexity of JAE+SAQ is much less complex compared to HEVC by achieving a comparable data reduction.

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